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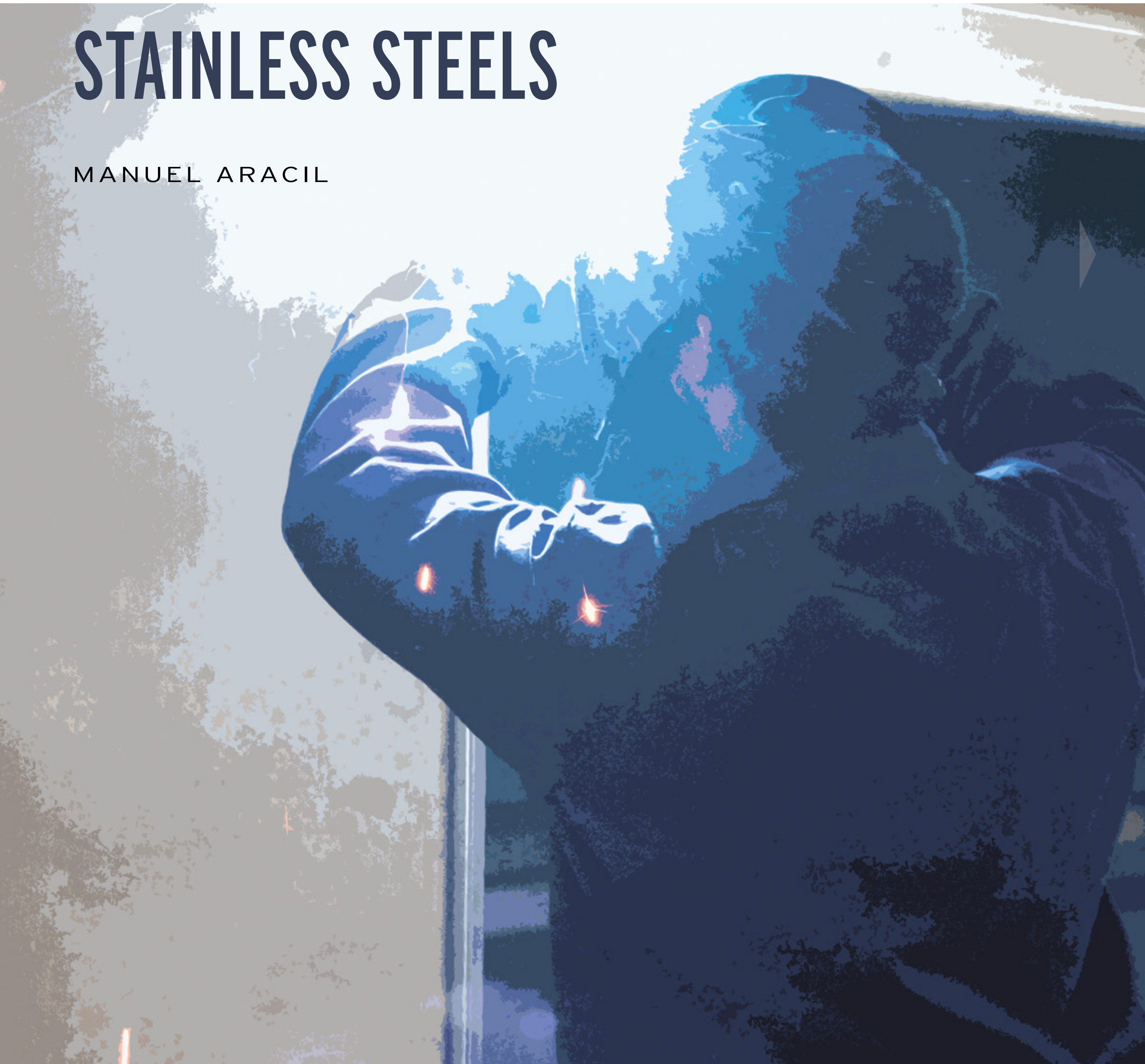
WELDING AND CUTTING OF STAINLESS STEELS

MANUEL ARACIL



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- To promote creativity, dissemination, employment and updating of stainless steels.
- To organize visits, conferences, courses and exhibitions promoting stainless steel applications.
- To communicate all technical news and to assist interested companies.
- To contact other similar organizations abroad and specifically the organizations in the European Union.
- The creation of a documentation centre, both technical and statistical.
- The publication of brochures, magazines or any edition of interest, which contributes to the development of the stainless steels market.

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Editorial

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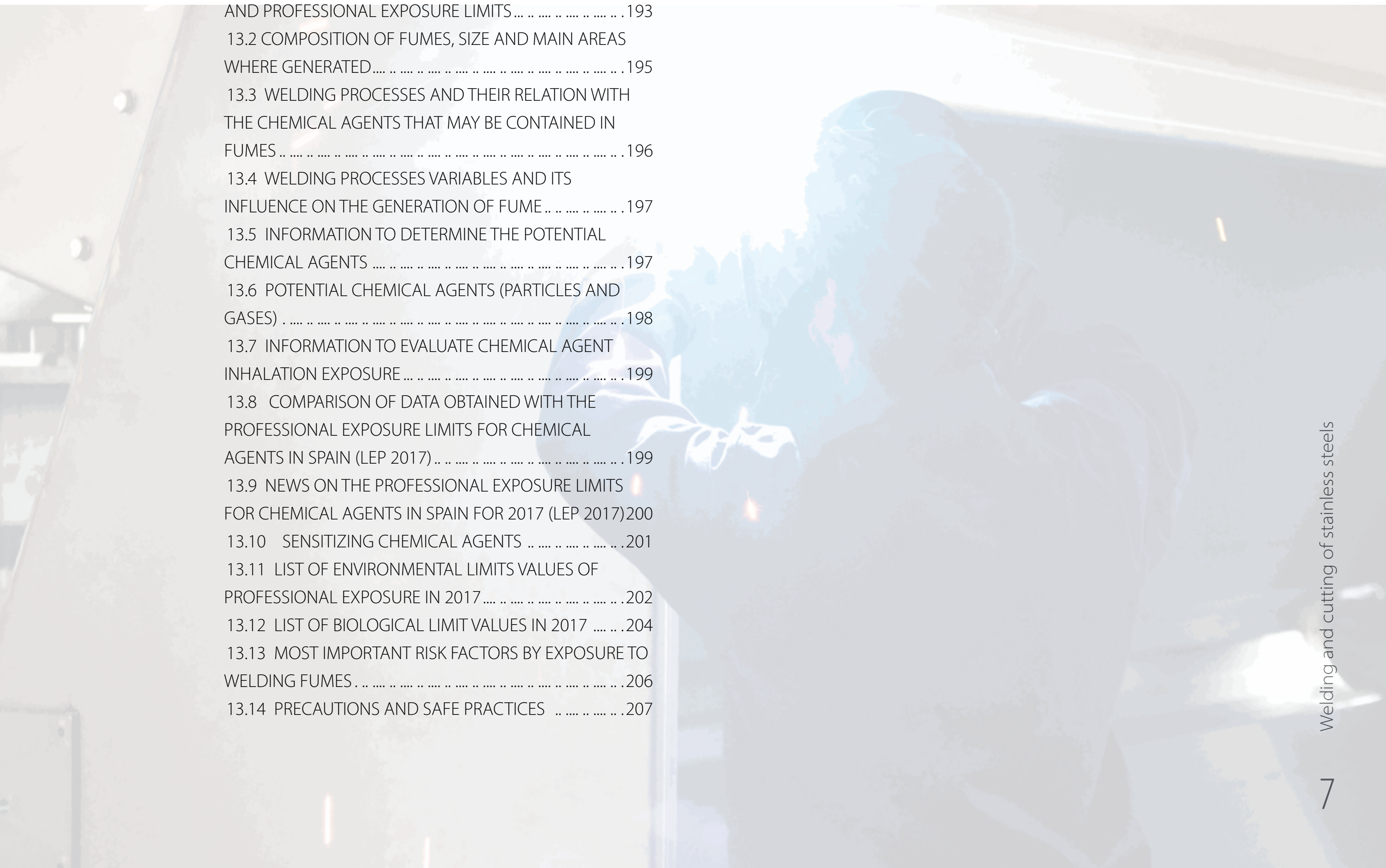
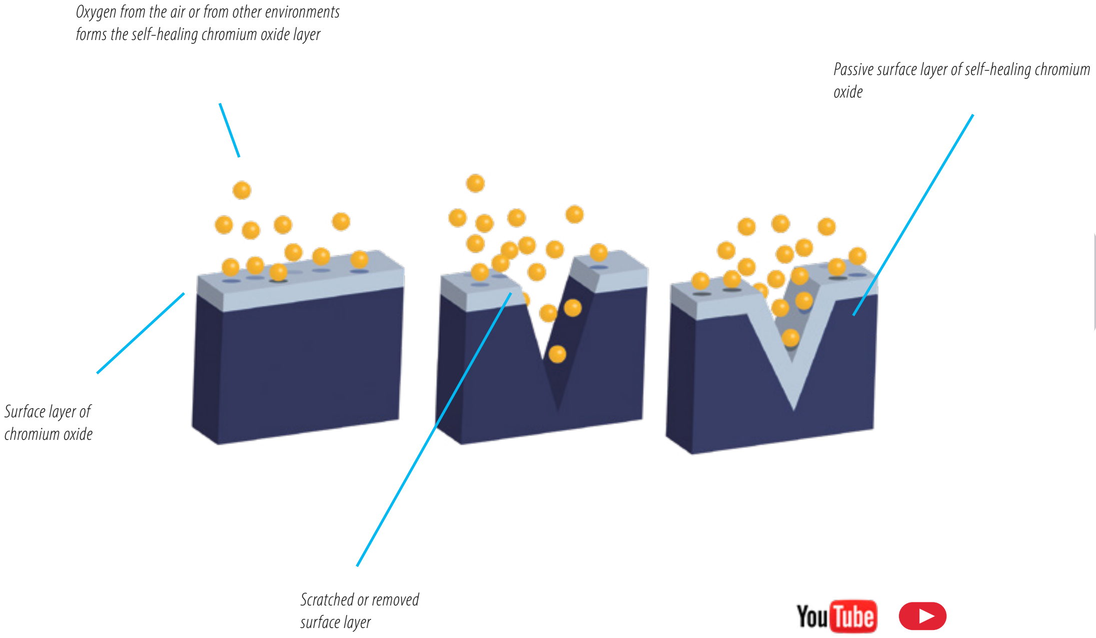


1 Welding and cutting of stainless steel

The main purpose of this manual is to summarize the main characteristics of the different types of stainless steels and to facilitate the selection of the welding and cutting processes.

In a simple way, it could be said that stainless steel is an alloy of iron and chromium with content of chromium (Cr) higher than 10.5% and of carbon (C) lower than 1.2%. With these minimum contents of chromium and carbon, a stable and self-healing chromium oxide surface layer may already be formed, providing corrosion resistance.



In the event this layer is scratched or removed, only with the presence of oxygen from the air and enough time or with another oxidizing environment, it would form again. The rest of elements added to the stainless steel help to improve the behaviour of the steel in specific applications.

The most usual classification of stainless steels, according to their physical and chemical properties, which allow differentiating the general characteristics of their behaviour to welding and cutting are:

- Austenitic.
- Austenitic- ferritic (Duplex).
- Ferritic.
- Martensitic.

1.1 INFLUENCE OF THE MAIN ELEMENTS OF STAINLESS STEEL

The metallurgical structure, the physical, chemical and mechanical properties of steel and its corrosion resistance will depend on its chemical composition. The influence of the main chemical elements which form stainless steels are:

Chromium (Cr)

It is the element that at levels higher than 10.5% makes steel stainless. The level of chromium may increase to 20-28% for applications in environments where higher resistance to corrosion is necessary.

It is an alphagenic element which favours the formation of ferrite.

Nickel (Ni)

Like the rest of the gammagenic elements present in the composition of a stainless steel, it forms and stabilizes austenite. The most common austenitic type, AISI 304, has 8% Ni, combined with 18% Cr, to form austenite. In order to maintain an austenitic structure in a stainless steel, the higher its Cr and Mo content, or other alphagenic elements favourable to the formation of ferrite, the higher the content of Ni should be, or other gammagenic elements, which favour austenite.

Due to its austenite stabilizing and formation effect, it allows austenitic stainless steels to maintain their good mechanical properties

Nickel improves the corrosion resistance of reducing acids and increases corrosion resistance under stresses higher than 20%. It also reduces the hardening speed by deformation and cold work.

Carbon (C)

It is a strong austenite former. In austenitic steels, it is used in applications where mechanical strength to high temperatures is required.

In addition to the above mentioned advantages, carbon is used in low quantities to avoid a decrease in corrosion resistance by the formation of carbides.

Molybdenum (Mo)

This element improves the resistance to pitting and interstitial corrosion in chloride media. Its content ranges from 2% in AISI 316 steels up to 8%.

Ferrite former, its weldability should be taken in consideration since it may form phases that affect corrosion resistance at high temperatures.

Nitrogen (N)

Being strong austenite former, N stabilizes and delays the formation of secondary phases and the formation of carbides, which may damage the mechanical properties and corrosion resistance of steel.

Its content may be up to 0.6% in high alloy austenitic steels in applications where the resistance to pitting and interstitial corrosion in the presence of chlorides is necessary.

In MIG / MAG and TIG welding of austenitic and duplex steel, N is included in the protection and backing gases, to maintain or increase its content in the molten pool and to improve the welding behaviour.

Manganese (Mn)

Also in stainless steels, as in all types of steel, manganese is used as deoxidizing element.

As an alloying element its function is to stabilize the austenite. This function is also important in welding.

Mn increases the solubility of nitrogen in stainless steel; therefore it is added in high alloy austenitic steels to allow high nitrogen content and to improve corrosion resistance.

It inhibits hot cracking by forming manganese sulphide.

Niobium (Nb)

Strong carbide-former, it is added in austenitic steels stabilized as AISI 347-EN 1.4550 and also in ferritic steels stabilized as AISI 430Nb-EN 1.4511, to combine with carbon, leaving chromium free and to reduce the potential intergranular corrosion by the formation of carbides, and its consequent decrease in chromium, if poor technique is used in welding or in heat treatment.

They constitute an alternative to low carbon austenitic steels. Nb is ferrite former and improves the toughness of the welded joint but worsens weldability.

Titanium (Ti)

Its behaviour is similar to Nb. Strong carbide-former, it is added in stabilized austenitic steels such as AISI 321-EN 1.4541 or AISI 316Ti-EN 1.4571 and also in stabilized ferritic steels such as AISI 430Ti-EN 1.4510. They constitute an alternative to low carbon austenitic steels. Ti refines grain better and does not complicate weldability.

Welding of stabilized with Ti steels as AISI 321 and AISI 316Ti, should be accomplished with the corresponding (stabilized with Nb) consumables as AISI 347 and AISI 318, respectively. This is because Ti should not be used as stabilizer in the consumable because it "burns" in the electric arc. It is ferrite former.

Copper (Cu)

It is added to high-alloy austenitic stainless steels to improve the corrosion resistance of stainless steel in reducing acid media such as sulphuric acid, phosphoric acid and the corresponding mixtures.

Cu reduces the hardening speed by deformation in austenitic steel and is an austenite former.

Silicon (Si)

Like manganese, it is used as deoxidizer. Si influences weldability, corrosion resistance and the polishing process and It is ferrite former.

Sulphur (S)

It increases machining easiness, causes hot cracking during welding and makes hot working difficult.

Phosphorus (P)

It makes hot working difficult when forging and rolling mill operations.

P increases machining easiness and promotes hot cracking during welding

Summary of elements that promote the formation of ferrite and austenite:

FERRITIC FORMERS	AUSTENITE FORMERS
Iron	Nickel
Chrome	Nitrogen
Molybdenum	Carbon
Silicon	Manganese
Niobium	Copper
Aluminium	Cobalt
Titanium	
Tungsten	

1.2 PHYSICAL PROPERTIES OF STAINLESS STEELS

Heat produced by welding will affect the welded piece depending on its physical properties. Deformations and residual stresses will depend on their conductivity and coefficient of thermal expansion. Table 1 summarizes the main physical properties to be taken in consideration in welding.

Properties	Units	Austenitic	Austenitic-ferritic (duplex)	Ferritic	Martensitic	Carbon Steel
Density	t/m^3	8.0	8.0	7.8	7.8	7.8
Coefficient of Thermal Expansion (0-538ºC)	10^{-6}m/m/ºC	17-19	14	11-12	11.6-12	11.7
Thermal conductivity	W/(m.K)	16.2	17	24-26	28.7	51

Table 1. Main physical properties to be taken in consideration in welding.

1.3 WELDING OF AUSTENITIC STAINLESS STEELS

When manufacturing stainless steel equipment or structures, it is necessary to make welded joints. Initially, one of the main options is an austenitic stainless steel of the 300 series, although it is necessary to later evaluate if the rest of the design conditions may be complied with.

The types of austenitic steels are as follows:

1.3.1 Chrome-Nickel / 300 series

Chrome – Nickel, standard austenitic steels or 300 series for its AISI classification (American Iron and Steel Institute).

The most used ones are as follows:

AISI	EN	UNS
304	1.4301	S30400
304L	1.4307	S30403
316	1.4401	S31600
316L	1.4404	S31603
347	1.4550	S34700
321	1.4541	S32100
309	1.4828	S30900
309S	1.4833	S30908
310S	1.4845	S31008
314	1.4841	S31400

Fig. 1 - Austenitic stainless steel micro structure with austenite grains free of precipitates.

Main characteristics of the austenitic stainless steels of the 300 series

- Good corrosion resistance in general.
- Good mechanical properties.
- Good weldability, ease and known cutting, machining, folding and drawing processes. All these make them the first option for many applications.
- Excellent toughness at low temperature, lower than gas liquefaction temperatures, with applications for those temperatures.
- In general, they are not magnetic, although some types may be slightly magnetic after cold work.
- They do not harden by heat treatment or by welding during the heating and cooling cycle.
- In welding preparation, it should be taken in consideration that thermal expansion coefficient is 50% higher than carbon steel, ferritic and martensitic stainless and approximately 30% higher than duplex ones and thermal conductivity is much lower, 30% of carbon steel and 60% of ferritic or martensitic steel.

1.3.2 Chrome-Manganese-low Ni / 200 series

The cost of these steels is lower than that of austenitic, but care should be taken when used in corrosion applications for which they are not appropriate, especially when replacing the 300 series. The most commonly used are the following:

AISI	EN	UNS	Chemical composition		
			Cr	Ni	Mn
201	1.4372	20100	16-18	3.5-5.5	5.5-7.5
202	1.4373	20200	17-19	4-6	7.5-10
205	-	20500	16.5-18	1-1.75	14-15.5

Main characteristics of chromium-manganese steels with low nickel 200 series content

Taking as reference the 200 series, AISI 201 (1.4372–20100) and comparing with the 300 series, with AISI 304 (1.4301–S30400), we have:

- Lower and more stable cost due to its lower nickel content.
- Higher hardness.
- Lower corrosion resistance.
- Lower sheet metal forming.
- Lower weldability.
- Mechanical properties with higher tensile and yield strength and lower elongation.
- Both are not magnetic, so simple magnet test may not be used to differentiate the two types, as it may be done with a ferritic or martensitic steel series 400.

1.3.3 Chromium-Nickel-Molybdenum- Nitrogen

They are high alloy stainless steels. These steels have been developed from standard austenitic steels, mainly with additions of elements such as Mo and N, in higher quantities, to adapt to new applications, where higher corrosion resistance than the 300 series steel is needed.

EN	UNS	Chemical composition			
		Cr	Ni	Mo	N
1.4539	N08904	20	25	4.3	-
1.4547	S31254	20	18	6.1	0.20
1.4529	N08926	20	25	6.5	0.20
1.4565	S34565	24	17	4.5	0.45
1.4652	S32654	24	22	7.3	0.50

Main characteristics of high alloy austenitic stainless steels

- Better corrosion resistance than austenitic Cr-Ni steels (300 series) and in some cases, better mechanical properties.
- Better resistance than 300 series to pitting and interstitial corrosion.
- Good resistance to various types of stress corrosion cracking.
- Very good ductility.
- Good weldability.

Table 2 shows the recommended filler metals for welding the most used austenitic stainless steels.

1.3.4 Applicable welding and cutting processes

All arc welding processes, GTAW, GMAW, PAW, SMAW, FCAW, SAW and with resistance and laser are used.

Brazing and Soldering soft welding are possible with the limitations of these processes.

Plasma (PAC) and Laser (LBC) processes are used for cutting.

On pages 84-87, 1.10 WELDING PROCESS SELECTION GUIDE, important features of each process are included for a quick review.

On pages 88-167, more detailed information is included regarding each process.

1.3.5 Consumables

The different consumables for arc welding procedures should comply with:

Coated Electrodes (SMAW):
UNE ISO 3581/SFA 5.4

Solid rod for manual TIG welding (GTAW):
UNE EN ISO 14343/SFA 5.9

Solid wires for MIG/MAG (GMAW)
or semi- or fully automated TIG welding:
UNE EN ISO 14343/SFA 5.9

Tubular wires for
MIG/MAG welding (FCAW):
UNE EN ISO 17633/SFA 5.22

Solid wire for submerged
arc welding (SAW):
UNE EN ISO 14343/SFA 5.9

Flux[2] for submerged
arc welding (SAW):
UNE EN ISO 14174

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[2] Author's note Appendix 3, page 258.

Table 2. Filler materials for welding austenitic stainless steels.

BASE METAL	FILLER MATERIALS			
STAINLESS STEEL	WELDING PROCEDURE	TRADE NAME	EN	AWS/ASME
Chromium-Nickel filler materials resistant to corrosion with low carbon content				
No. 1.4301-304	Electrode (SMAW)	NIPPON INOX 502	UNE EN ISO 3581 E 19 9 L R 32	SFA 5.4 E 308L-17
	Electrode (SMAW)	NIPPON INOX B-308L	UNE EN ISO 3581 E 19 9 L B 22	SFA 5.4 E 308L-15
No. 1.4307-304L	TIG (GTAW)	NIPPON T-308L	UNE EN ISO 14343 W 19 9 L	SFA 5.9 ER 308L
	MIG/MAG (GMAW)	NIPPON M-308L	UNE EN ISO 14343 G 19 9 L Si	SFA 5.9 ER 308LSi
	MIG/MAG (FCAW)	NIPPON FG-308S	UNE EN ISO 17633 T 19 9 L R M3	SFA 5.22 E 308LTO-4
	Submerged arc (SAW)	NIPPON UM-308L	UNE EN ISO 14343 S 19 9 L	SFA 5.9 ER 308L
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	
Stabilized chromium-nickel fillers resistant to corrosion				
No. 1.4541-321	Electrode (SMAW)	NIPPON INOX 507	UNE EN ISO 3581 E 19 9 Nb R 32	SFA 5.4 E 347-17
	TIG (GTAW)	NIPPON T-347	UNE EN ISO 14343 W 19 9 Nb	SFA 5.9 ER 347
No. 1.4550-347	MIG/MAG (GMAW)	NIPPON M-347	UNE EN ISO 14343 G 19 9 Nb Si	SFA 5.9 ER 347Si
	MIG/MAG (FCAW)	NIPPON FG-347S	UNE EN ISO 17633 T19 9 Nb L R M 3	SFA 5.22 E 347TO-4
	Submerged arc (SAW)	NIPPON UM-347	UNE EN ISO 14343 S 19 9 Nb	SFA 5.9 ER 347
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	
Chromium-Nickel-Molybdenum filler materials resistant to corrosion with low carbon content				
No. 1.4401-316	Electrode (SMAW)	NIPPON INOX 510	UNE EN ISO 3581 E 19 12 3 L R 32	SAF 5.4 E 316-17
	Electrode (SMAW)	NIPPON INOX B-316L	UNE EN ISO 3581 E 19 12 3 L B 22	SFA 5.4 E 316L-15
	TIG (GTAW)	NIPPON T-316L	UNE EN ISO 14343 W 19 12 3 L	SFA 5.9 ER 316L
No. 1.4404-316L	MIG/MAG (GMAW)	NIPPON M-316L	UNE EN ISO 14343 G 19 12 3 L Si	SFA 5.9 ER 316L Si
	MIG/MAG (FCAW)	NIPPON FG-316S	UNE EN ISO 17633 T 19 12 3 L R M 3	SFA 5.22 E 316LTO-4
	Submerged arc (SAW)	NIPPON UM-316L	UNE EN ISO 14343 S 19 12 3 L	SFA 5.9 ER 316L
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	
Stabilized Chromium-Nickel-Molybdenum fillers resistant to corrosion				
No. 1.4576-318	Electrode (SMAW)	NIPPON INOX 514	UNE EN ISO 3581 E 19 12 3 Nb R 32	SFA 5.4 E 318L-17
	TIG (GTAW)	NIPPON T-318	UNE EN ISO 14343 W 19 12 3 Nb	SFA 5.9 ER 318
	MIG/MAG (GMAW)	NIPPON M-318	UNE EN ISO 14343 G 19 12 3 Nb	SFA 5.9 ER 318Si
	MIG/MAG (FCAW)	NIPPON FG-318S	UNE EN ISO 17633 T 19 12 3 Nb L R M 3	SFA 5.22 E 318TO-4
	Submerged arc (SAW)	NIPPON UM-318	EN ISO 14343 S 19 12 3 Nb	SFA 5.9 ER 318
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	
Filler materials for welding high temperature resistant steels				
No. 1.4332-309L	Electrode (SMAW)	NIPPON INOX 73	UNE EN ISO 3581 E 23 12 LR 32	SFA 5.4 E 309L-17
No. 1.4833-309S	TIG (GTAW)	NIPPON T-309L	UNE EN ISO 14343 W 23 12 L	SFA 5.9 ER 309
	MIG/MAG (GMAW)	NIPPON M-309L	UNE EN ISO 14343 G 23 12 L	SFA 5.9 ER 309
	MIG/MAG (FCAW)	NIPPON FG-309	UNE EN ISO 17633 T 23 12 L R C 3	SFA 5.22 E309TO-3
	Submerged arc (SAW)	NIPPON UM-309L	UNE EN ISO 14343 S 23 12 L	SFA 5.9 ER 309
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	

Table 2. Filler materials for welding austenitic stainless steels.

BASE METAL	FILLER MATERIALS			
STAINLESS STEEL	WELDING PROCEDURE	TRADE NAME	EN	AWS/ASME
Filler materials for welding steels resistant to high temperatures. Refractory				
No. 1.4841-314	Electrode (SMAW)	NIPPON INOX 46	UNE EN ISO 3581 E25 20 R32	SFA 5.4 E 310-17
No. 1.4845-310S	TIG (GTAW)	NIPPON T-310	UNE EN ISO 14343 W 25 20	SFA 5.9 ER 310
	MIG/MAG (GMAW)	NIPPON M-310	UNE EN ISO 14343 G 25 20	SFA 5.9 ER 310
	MIG/MAG (FCAW)	NIPPON FG-310	UNE EN ISO 17633 T 25 20 P C 1	SFA 5.22 E 310TO-3
	Submerged arc (SAW)	NIPPON UM-310	UNE EN ISO 14343 S 25 20	SFA 5.9 ER 310
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA FB 2 DC	
Fillers for high alloy austenitic stainless steels welding				
No. 1.4539-904 L	Electrode (SMAW)	NIPPON INOX R-385	UNE EN ISO 3581 E 20 25 5 Cu N L R 12	SFA 5.4 E 385-16
	Electrode (SMAW)	NIPPON INOX B-385	UNE EN ISO 3581 E 20 25 5 Cu L B 12	SFA 5.4 E 385-15
	TIG (GTAW)	NIPPON T-385	UNE EN ISO 14343 W 20 25 5 Cu L	SFA 5.9 ER 385
	MIG/MAG (GMAW)	NIPPON M-385	UNE EN ISO 14343 G 20 25 5 Cu L	SFA 5.9 ER 385
	MIG/MAG (FCAW)	NIPPON FG-385	UNE EN ISO 17633 T Z 20 25 5 Cu L P M 1	SFA 5.22 E 385T1-4
	Submerged arc (SAW)	NIPPON UM-385	UNE EN ISO 14343 S 20 25 Cu L	SFA 5.9 ER 385
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA AF 2 Cr DC	
No. 1.4547-254 SMO	Electrode (SMAW)	NIPPON NI 209	UNE EN ISO 14172 E Ni Cr 22 Mo 9	SFA 5.11 E NiCrMo-3
	TIG (GTAW)	NIPPON T-209	UNE EN ISO 18274 S NiCr22Mo9Nb	SFA 5.14 ERNiCrMo-3
	MIG/MAG (GMAW)	NIPPON M-209	UNE EN ISO 18274 S NiCr22Mo9Nb	SFA 5.14 ERNiCrMo-3
	MIG/MAG (FCAW)	NIPPON FG-209	UNE EN ISO 12153 T Ni 6625 P M21 2	SFA 5.34 ERNiCrMo-3T1-4
	Submerged arc (SAW)	NIPPON UM-209	UNE EN ISO 18274 S NiCr22Mo9Nb	SFA 5.14 ERNiCrMo-3
			UNE EN ISO 14174 SA AF 2 Cr DC	
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380		
No. 1.4652-654 SMO	Electrode (SMAW)	NIPPON INOX 4652	UNE EN ISO 14172 E Ni Cr 25 Mo16	SFA 5.11:ENiCrMo-13
	TIG (GTAW)	NIPPON T-4652	UNE EN ISO 18274 S Ni Cr 25 Mo 16	SFA 5.14 ERNiCrMo-13
	MIG/MAG (GMAW)	NIPPON M-4652	UNE EN ISO18274 S Ni Cr 25 Mo 16	SFA 5.14 ERNiCrMo-13
	Submerged arc (SAW)	NIPPON UM-4652	UNE EN ISO18274 S Ni Cr 25 Mo 16	SFA 5.14 ERNiCrMo-13
	Submerged arc Flux (SAW)	NIPPON flux um 380	UNE EN ISO 14174 SA AF 2 Cr DC	
No. 1.4529	Electrode (SMAW)	NIPPON INOX 4529	UNE EN ISO 14172 E NiCr22Mo9Nb	SFA 5.11 E NiCrMo-3
	TIG (GTAW)	NIPPON T-4529	UNE EN ISO 18274 S NiCr22Mo9Nb	SFA 5.14 ERNiCrMo-3
	MIG/MAG (GMAW)	NIPPON M-4529	UNE EN ISO 18274 S NiCr22Mo9Nb	SFA 5.14 ERNiCrMo-3
	MIG/MAG (FCAW)	NIPPON FG-4529	UNE EN ISO 12153 T Ni 6625 P M21 2	SFA 5.34 ERNiCrMo-3T1-4
	Submerged arc welding (SAW)	NIPPON UM-4529	UNE EN ISO 18274 S NiCr22Mo9Nb	
	Submerged arc Flux (SAW)	NIPPON FLUX UM 380	UNE EN ISO 14174 SA AF 2 Cr DC	

1.3.6 Precautions to take welding austenitic stainless steels

Good weldability of austenitic steels has been mentioned. However, due to poor practice during welding, it is necessary to consider that depending on the type of steel, there are some areas of the welded joint that are subjected to a certain temperature interval during excessive welding time. The properties of such steel and the behaviour in service of the assembly may be affected.

There are differences between standard austenitic steels of the 300 series and high alloy austenitic steels.

Welding of standard stainless steels. 300 Series

304	304L	316	316L
347	321	309	310

A

DECREASE OF CORROSION RESISTANCE, BY FORMATION OF CHROMIUM CARBIDE

Depending on the steel, chromium and carbon will combine within a temperature range of 425 and 870°C and will precipitate in the grain boundaries as chromium carbides (Cr23C6), leaving an area with low chromium around each grain.

These areas are known as "sensitized" and in a corrosive environment may cause intergranular corrosion. (Fig. 2)

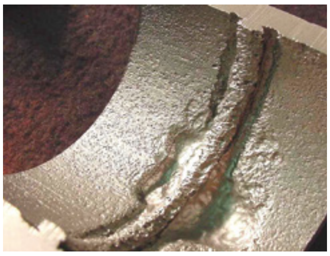

Fig. 2 - Stainless 304 pipe with intergranular corrosion in the heat affected zone

Even if the weld bead was not exposed long enough at temperatures between 425 and 870°C, it may be the case that the adjacent areas have been exposed, and are therefore "sensitized". The degree of sensitization will depend on the C content of the stainless steel, the temperature at which it has been exposed and the time. (Fig. 3)

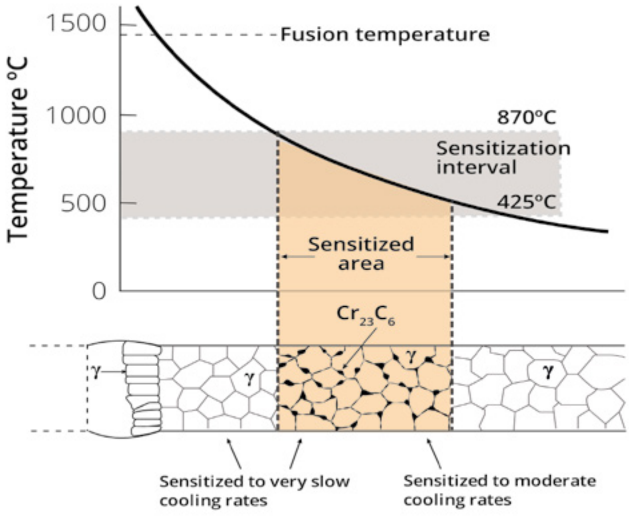

Fig. 3 - Heat affected zone by welding into temperature range of 425-870ºC.

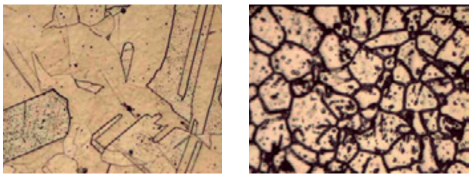

Fig. 3.1 - Stainless steel micro structures without sensitization (left) and sensitized (right), metallographically attacked with oxalic acid to reveal the existence of the phenomenon.

The precautions which may be taken to avoid the formation of chromium carbides are as follows:

1 To maintain low carbon content (0.03 max in the "L" grades).

Fig. 4 shows that for a carbon content of 0.02%, it would take 10 hours for precipitation of carbides to happen in 18/8. This time is significantly reduced if the carbon content is higher.

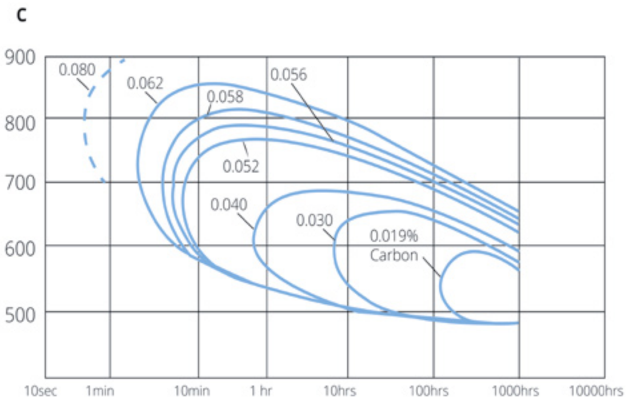

Fig. 4 - Time/Temperature graph of susceptibility to intergranular corrosion of 18/8 with different carbon contents.

2 Stabilising carbon with titanium or niobium. Both elements have high affinity for carbon and compete with chromium, previously forming the corresponding carbides TiC and NbC, which precipitate at temperatures higher than chromium carbide ($Cr_{23}C_6$) temperatures. In this way, the C content in solution is decreased and sensitization is avoided.

The most usual stabilised stainless steels are type 321 (minimum added titanium 4x%C) and 347 (minimum added niobium 10x%C) and are used for long periods of time at high temperatures and in corrosive media or when low carbon steel is not suitable.

3 To prevent sensitization, which in corrosive media may cause intergranular corrosion, heat treatment is needed, depending on the type of stainless steel, if it is stabilized or not, and logically, if the dimensions of the welded component allow it:

Unstabilised steels:

It is necessary to give a solubilisation tempering or hyper tempering at 1050°C, above the sensitization temperature range, which completely solubilises the chromium carbides.

The cooling should be fast enough to prevent the chromium carbides from precipitating again. The higher the steel C percentage, the higher the cooling rate will be. A lower temperature, such as the temperature of a stress relief at 870ºC, would not restore corrosion resistance; on the contrary, it may favour the precipitation of chromium carbides. After treatment, corrosion resistance must be restored by pickling the oxide formed during the high temperature heat treatment. In practice, this heat treatment is not widely used, because stainless steels which are usually welded, have a low C content <0.03% and use good cleaning and welding execution practices.

Stabilised steels:

These stabilised steels may be subject to a characteristic type of intergranular corrosion, called "knife blade" - ("Knife line attack" - "KLA"), in a narrow area and close to the weld, closer than the area of sensitization of an unstabilised steel. This is formed when the heat input from the weld is reached in an area close to the melting area, a temperature in the order of 1425ºC, which is high enough to dissolve the titanium or niobium carbides, leaving carbon free, steel behaving as unstabilised.

If subsequently, there are other heat inputs from other welds with multi-passes or from a stress relief, where temperatures between 425 and 870°C are reached, then, the formation of chromium carbides faster than carbides of titanium or niobium is possible. This area will become sensitised and susceptible to the intergranular corrosion type, specific to the above mentioned stabilised stainless steels, of "knife blade" ("knife line attack").

In order to eliminate this intergranular corrosion susceptibility, it should be subject to stabilisation heat treatment, at temperature of 1065ºC, to dissolve chromium carbides and to form titanium or niobium carbides. The rapid cooling process, after this treatment, is not essential, since there is no carbon to form chromium carbides because it is fixed in the form of carbide stabilising elements.

B

CRACKING

Under high degree of restraint[1] conditions, in some occasions hot cracking appears in the weld bead.

Often, these hot cracks are not visible, but a bending test will reveal their presence as tiny cracks of no more than 1.6 mm in length, randomly distributed in the weld. It was observed that if the weld contained small percentages of ferrite, between 2 and 5%, the resulting weld was without cracking.

With the use of the Schaeffler diagram (Fig. 5) a balance of chemical elements may be made to obtain deposits with adequate amounts of ferrite.

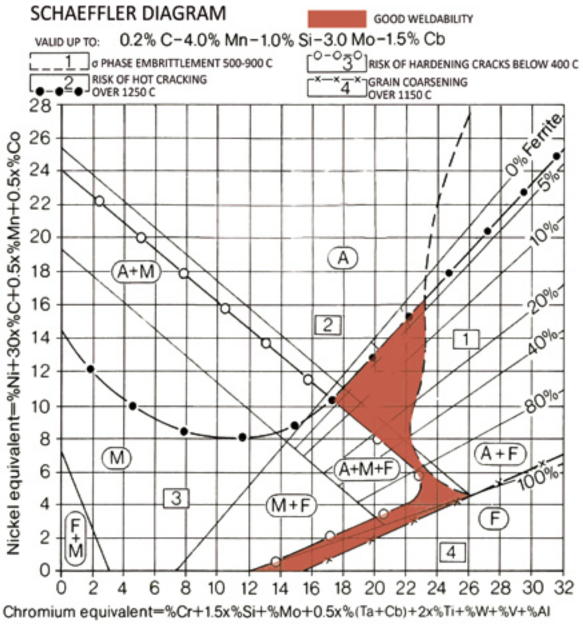

Fig. 5 - Schaeffler diagram.

Delong diagram (Fig. 6) takes in consideration N content for the equivalent Ni calculation.

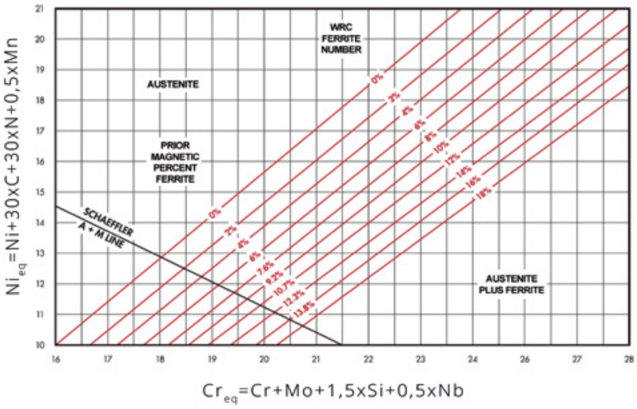

Fig. 6 - Delong diagram.

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[1] Author's note Appendix 3, page 258.

C

FRAGILIZATION. SIGMA PHASE FORMATION

A small amount of ferrite benefits welding to prevent cracking, usually in the order of 5%. If the ferrite content is increased above the 12% range it may be detrimental to corrosion resistance and properties at high temperatures.

If the welded component has service temperature, between 550 and 900ºC, or stress relief heat treatment should be necessary within this range, the sigma phase may be formed with 45% Cr and 55% Fe composition. At 730ºC the sigma phase will form quickly, but at lower temperatures it will take long time intervals. (Fig. 7)

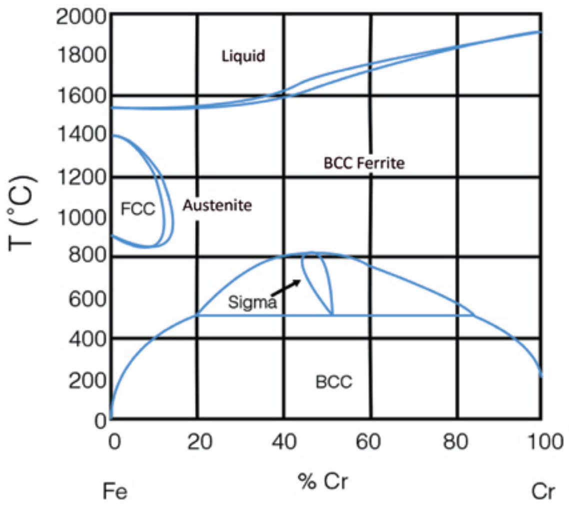

Fig. 7 - Cr-Fe diagram.

One way to eliminate the negative effect of this phase is to dissolve it by heating to 1100ºC and restoring the austenite. However, for practical reasons, this solution is not possible in most cases.

D

STRESS CORROSION

For this type of corrosion, the existence of stress which may be produced by the welding itself, must coincide with the presence of a medium containing chlorides or strongly alkaline solutions.

As precaution, it may be more economical, to substitute austenitic stainless steel with duplex steel which may be more appropriate for this type of corrosion, but in case this is not possible, some actions should be taken:

- In the project phase, eliminate residual stresses or those generated by external efforts.
- Use appropriate stainless steels, as the types with molybdenum as AISI 316.
- Give stress relief treatment, with two options:

1. Use low temperature, between (315-425ºC) for 4 hours per inch and followed by slow cooling. This temperature range is applicable to steels 304, 304L, 316 and 316L and stabilised steels 321 and 347 because they are below the sensitization temperature. This low temperature range may not be applicable, depending on the degree of residual stresses, because it is not sufficient to completely eliminate residual stresses.
2. Use higher temperature, between (425-925ºC). For example 870ºC, which would be within the sensitization range and the time should be taken in consideration, 1 hour, would be enough. This temperature is not appropriate for steels 304 and 316 because they could be sensitised and chromium carbides could be formed. If it is necessary to use this temperature, low-carbon stainless steels 304L or 316L or stabilised ones 321 and 347 should be used.

The potential stress relief should take in consideration the risk of steel sensitization when deciding temperature and time.

Welding of high alloy austenitic stainless steels

		Cr	Ni	Mo	N
1.4539	N08904	20	25	4.3	-
1.4547	S31254	20	18	6.1	0.20
1.4529	N08926	20	25	6.5	0.20
1.4565	S34565	24	17	4.5	0.45
1.4562	S32654	24	22	7.3	0.50

DECREASE OF CORROSION RESISTANCE BY FORMATION OF INTERMETALLIC PHASES

High alloy austenitic steels, with high chromium and molybdenum content, have a low carbon content which decreases the chromium carbide formation rate and therefore its sensitization; in general, intergranular corrosion is not a problem, but other intermetallic chi and sigma phases may be formed due to the high content of Cr and Mo, which decrease corrosion resistance. In order to avoid this, you have to:

- Use welding parameters which introduce a heat input minimizing the time that the welded joint is within the steel critical temperature range, around 1090ºC.
- Cool the joint to limit the time the joint is within the critical temperature range.
- Limit thickness.
- Try to avoid multipass.
- Control the inter pass temperature to a limit of 100ºC.

A

INTERMETALLIC PHASE FORMATION

The formation of chi and sigma intermetallic phases will depend on the chromium and molybdenum content. These may be formed in a short period of time, which does not happen in the less alloyed standard austenitic, such as AISI 304 and AISI 316. In an AISI 316 steel with its typical composition of 2% Mo and % C higher than 0.03%, chromium carbides may be formed in 5 minutes, but it would take more than 80 hours for chi and sigma phases to be formed (Fig. 8). In contrast, in an alloy with a similar content of chromium and nickel, but with 5% Mo, the chi and carbide phases' formation occurs in a short period of time. (Fig. 9)

The addition of nitrogen may help to delay the formation of carbides and phases for the same steel, if the content of N increases to 0.145%, then the time of chromium carbides formation and the chi phase increases up to 10 minutes, so welding could be done without any problem. (Fig. 10)

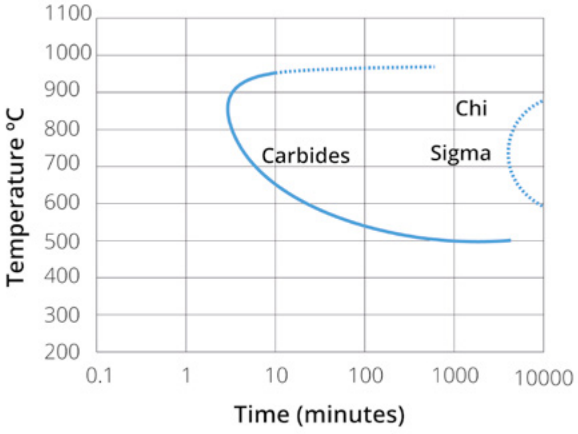

Fig. 8 - TTT diagram for AISI 316 steel. The formation of chromium carbides could take 5 minutes, but the formation of sigma and chi phases has a very high formation time.

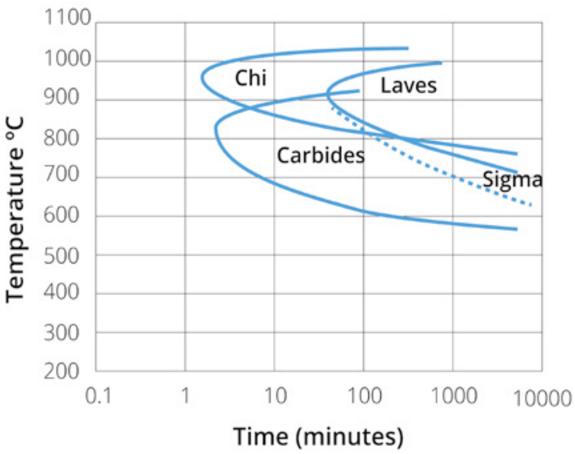

Fig. 9 - TTT diagram for steel 0.05% C-17% Cr-13% Ni-5% Mo. In this steel with a higher Mo content of 5% the formation of sigma and chi phases has a shorter formation time.

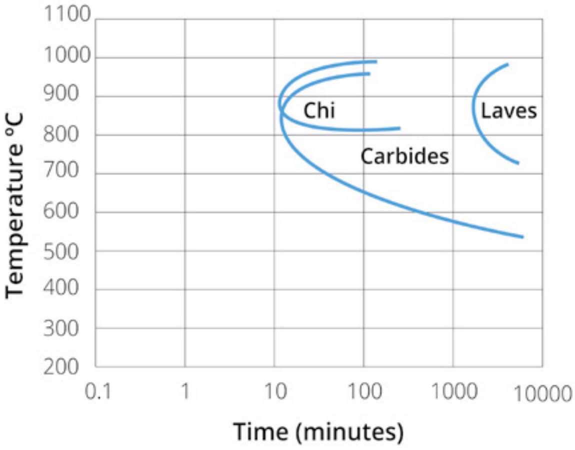

Fig. 10 - TTT diagram for steel 0.05% C-17% Cr-13% Ni-5% Mo, after the addition of 0.145% N. The formation of chi phase and chromium carbides is delayed until an order of 10 minutes, so there is enough time for welding.

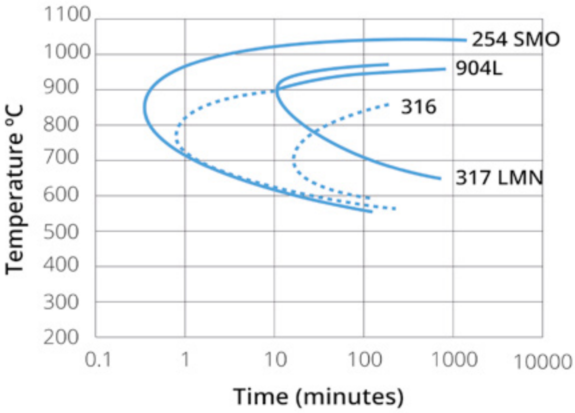

Fig. 11 - TTT diagram for different steels. When Cr and Mo increase to very high values, the addition of nitrogen is not enough to delay the formation of intermetallic phases.

When Cr and Mo increase to very high levels, as in most high alloy austenitic steels, intermetallic phases form in shorter periods of time. In the case of some alloys, increasing the additions of N to high contents of 0.20-0.50% help to delay times in the order of 10 minutes which allow welding, but in the case of other alloys this delay in the formation of intermetallic phases is not achieved.

In Figure 11 this effect in the TTT curves of various steels may be seen:

317LMN (1.4439) S31726 (Cr=17%, Ni=14%, Mo=4.5%, N=0.15%) forming secondary phases with approximately the same time of 316, in the order of or more than 10 minutes, which should be sufficient for cooling after welding.

254 SMO (1.4547) S31254 (Cr=20%, Ni=18%, Mo=6%, N=0.20%), begins to suffer precipitation in 30 seconds.

904L (1.4539) N08904 (20% Cr, 25% Ni, 4.55% Mo, with no addition of N), suffers the formation of intermetallic phases in less than 1 minute.

For these last two alloys and for similar alloys thickness limitations should be established in heat input or quick cooling to avoid the formation of secondary phases.

B

CRACKING

These alloys, being fully austenitic, are more sensitive to hot cracking; this will increase under conditions of high degree of restraint[1].

This cracking may be minimized, using low welding heat inputs and by welding with stringer beads.

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[1] Author's note Appendix 3, page 258.

1.3.7 Welding cleaning

As in the welding of all stainless steels, cleaning is essential in all areas which are going to be subjected to heat.

Grease, paint, oil, moisture will affect welding and will decrease the corrosion resistance and mechanical properties of the welded joint.

If it is not cleaned with a suitable product and in a systematic way before welding, the qualification of the welding procedure may be of no use.

You may get more information about stainless steel cleaning in the bibliography or in Cedinox (www.cedinox.es).

1.3.8 Dissimilar steel welding

Although the general information on dissimilar steels welding, when one of the steels is stainless, is included in 1.7 DISSIMILAR STEELS WELDING, when one of the metals to be joined is austenitic stainless steel it is advisable to take the following in consideration:

- Standard austenitic stainless steels may be joined to other high alloy austenitic steels, to duplex stainless steels, to carbon and low alloy steels. Mechanical properties and corrosion resistance of the welded metal must be superior to that of the base metal with inferior properties.
- When welding an austenitic stainless steel to another stainless steel or duplex, with different molybdenum contents, the selected consumable must have appropriate molybdenum content so that, taking in consideration the dilution of the welded metal, it has an equal or superior content to the metals to be joined.
- When welding with duplex stainless steel, in case nickel-based consumables such as ENiCrMo-3 are used, the possible reaction of the niobium and titanium contained in this alloy, with the nitrogen content in the duplex, must be taken in consideration. When the austenitic steel is stabilized with titanium, the reaction with the nitrogen of the duplex must be also considered.
- When welding stainless steel to carbon or low alloy steel, the formation of martensite should be avoided, due to its low ductility and possible cracking problems. It is likewise advisable to have a minimum ferrite content of 5% in the welding metal to have good resistance to hot cracking. The most appropriate consumables are E307, E309L, E309MoL and E312, depending on the ferrite content, corrosion resistance and the coefficient of thermal expansion required in the welding metal.

1.3.9 Possible effects, due to poor welding practice on the mechanical properties and corrosion resistance of an austenitic stainless steel

Austenitic steels are the most used ones when it is necessary to join by welding. If during the manufacturing process, a poor welding practice is used, it may decrease steel properties which decrease its mechanical properties and corrosion resistance.

Table 3 includes the possible effects produced by welding, thermal, stresses and discolouration, which depending on the type of steel, may cause a type of corrosion.

Effects	Stainless steel AISI types / Types of corrosion			
	304 - 316	304L - 316L	321 - 347 - 316Ti	High Mo(*)
Thermal	Intergranular corrosion		Intergranular corrosion on knife line attack(1)	Pitting and interstitial corrosion
Stresses	Cracking by stress corrosion			
Lack of cleanliness	Pitting and interstitial corrosion			
First arc strike and protrusion	Interstitial corrosion			
Surface oxidation discolouration	Interstitial corrosion			

Table 3. Possible effects produced by poor welding practice.

(*) Austenitic high alloy steels with high Mo.

(1) Knife line attack: "deterioration in welds resulting from intergranular corrosion occurring in a very narrow band adjacent to the weld in stabilized steels. Niobium carbide dissolves when the metal is heated to a very high temperature (T>1230ºC) and remains in solution when rapidly cooled. If the metal is heated to the precipitation zone of chromium carbides, the niobium carbide remains in solution and the alloy behaves as if it were not stabilised. It happens in the metal which is immediately adjacent to the weld and that has been sufficiently heated. "(Corrosion, Mechanical Engineering, University of Alicante)

1.3.10 Equivalences between USA, JAPAN AND EUROPE standards for austenitic steels

USA - JAPAN			EUROPE	
AISI	JIS	UNS	EN / DIN	EN / DIN
201	SUS 201	S 201 00	1.4372 (EN)	X12CrMnNiN17-7-5
	QMS 5			
202	SUS 202	S 202 00		
		S 209 10		
		S 215 00		
		S 245 65		
219				X4CrNiMn21-9-6
301	SUS 301	S 301 00	1.4310 (EN)	X10CrNi18-8
301 L			1.4318 (EN)	X2CrMoM18-7
302	SUS 302	S 302 00	1.4319	X10CrNi18-9
303	SUS 303	S 303 00	1.4305 (EN)	X8CrNiS18-9
	SUS 303 Cu			
	SUS 303 HS2			
	SUS 303 HS3			
303 Se	SUS 303 Se	S 303 23		X10CrNiS18-9
304	SUS 304	S 304 00	1.4301 (EN)	X6CrNi18-10
304 Cu	SUS XM 7	S 304 30		
304 L	SUS 304 L	S 304 03	1.4306 (EN)	X2CrNi19-11
304 L	SUS 304 L	S 304 03	1.4307 (EN)	X2CrNi18-9
	SUS 304 ELC			
304 H	SUS 304 H	S 304 09	1.4948	X8CrNi19-10
	SUS 304 Cu1			
	SUS 304 Cu2			
		S 304 15	1.4891	
		S 304 15	1.4818	
304 N	SUS 304 N1	S 304 51		X5CrNiN18-10
	SUS 304 N2			
304 LN	SUS 304 LN	S 304 53	1.4311 (EN)	X2CrNiN18-10
	SUS 304 MF			
305	SUS 305	S 305 00	1.4303 (EN)	X8CrNi18-12
	SUS 305 J1			
F 46		S 306 00	1.4361 (EN)	X1CrNiSi18-15-4
		S 306 15		
308				
309		S 309 00	1.4828	X15CrNi23-13
309		S 309 00	1.4849	
309 S	SUS 309 S	S 309 08	1.4828	X15CrNiSi20-12
309 S	SUS 309 S	S 309 08	1.4833	X6CrNi22-13

USA - JAPAN			EUROPE	
AISI	JIS	UNS	EN / DIN	EN / DIN
309 S	SUS 309 S	S 309 08	1.4833	X12CrNi23-13
309 H		S 309 09	1.4833	
309 Cb		S 309 40		
309 HCb		S 309 41		
310			1.4841	X15CrNiSi25-20
310			1.4845	X12CrNi25-20
	SUS 310 ELC			
310 L			1.4335 (EN)	X1CrNi25-21
310 L			1.4466 (EN)	X1CrNiMoN25-22-2
310 S	SUS 310 S	S 310 08	1.4842	X6CrNi25-20
310 S	SUS 310 S	S 310 08	1.4845	X8CrNi25-21
310 H		S 310 09	1.4845	
310 Cb		S 310 40		
310 HCb		S 310 41		
310 HCbN		S 310 42		
310 SCB				
		S 310 50	1.4465	X1CrNiMoN25-25-2
		S 310 50	1.4466 (EN)	X1CrNiMoN25-22-2
F 44		S 312 54	1.4547 (EN)	X1CrNiMoCuN20-18-7
314	SUS 314	S 314 00	1.4841	X15CrNiSi25-20
316	SUS 316	S 316 00	1.4401 (EN)	X5CrNiMo17-12-2
316	SUS 316	S 316 00	1.4436 (EN)	X3CrNiMo17-13-3
316 Cb		S 316 40	1.4580 (EN)	X6CrNiMoNb17-12-2
316 F	SUS 316 F	S 316 20	1.4427	X6CrNiMoS18-11
316 L	SUS 316 L	S 316 03	1.4404 (EN)	X2CrNiMo17-12-2
316 L	SUS 316 L	S 316 03	1.4406	X2CrNiMoN17-11-2
316 L	SUS 316 L	S 316 03	1.4432 (EN)	X2CrNiMo17-12-3
316 L	SUS 316 L	S 316 03	1.4435 (EN)	X2CrNiMo18-14-3
316 L	SUS 316 L	S 316 03	1.4441	X6CrNiMo17-11
316 H	SUS 316 H	S 319 09	1.4919	X6CrNiMo17-12
	SUS 316 J1			
	SUS 316 J1L			
316 N	SUS 316 N	S 316 51	1.4406 (EN)	X2CrNiMoN17-11-2
316 LS			1.4436 (EN)	X3CrNiMo17-13-3
316 LS			1.4435 (EN)	X2CrNiMo18-14-3
316 LN	SUS 316 LN	S 316 53	1.4406	X2CrNiMoN17-11-2
316 LN	SUS 316 LN	S 316 53	1.4429 (EN)	X2CrNiMoN17-13-3
316 LN	SUS 316 LN	S 316 53	1.3952	X2CrNiMoN18-14-3
316 LN	SUS 316 LN	S 316 53	1.4910	
316 S				
316 Ti	SUS 316 Ti	S 316 35	1.4571 (EN)	XCrNiMoTi17-12-2
316 Ti	SUS 316 Ti	S 316 35	1.4573	X10CrNiMoTi17-13-3

USA - JAPAN			EUROPE	
AISI	JIS	UNS	EN / DIN	EN / DIN
317	SUS 317	S 317 00		
	SUS 317 J1			
317 L	SUS 317 L	S 317 03	1.4438 (EN)	X2CrNiMo18-15-4
317 L		S 317 03	1.4434 (EN)	X2CrNiMoN18-12-4
317 LM		S 317 25		
317 LN		S 317 53	1.4439 (EN)	X2CrNiMoN17-13-5
317 LMN		S 317 26	1.4439 (EN)	X2CrNiMoN17-13-5
F 48		S 317 26	1.4439 (EN)	X2CrNiMoN17-13-5
318				
319				
319 L				
321	SUS 321	S 321 00	1.4541 (EN)	X6CrNiTi18-10
321	SUS 321	S 321 00	1.4878	X12CrNiTi18-9
321 H	SUS 321 H	S 321 09	1.4878	X12CrNiTi18-9
321 H	SUS 321 H	S 321 09	1.4941	X7CrNiTi18-11
		S 326 15		
		S 326 54		
327			1.4821	
		S 327 50		
		S 328 03		
333				
		S 332 28		
347	SUS 347	S 347 00	1.4550 (EN)	X6CrNiNb18-10
347 H	SUS 347 H	S 347 09	1.4961	X6CrNiNb18-12
347 HFG				
348		S 348 00	1.4878	
348 H		S 348 09		
		S 353 15	1.4835	
926			1.4529 (EN)	X1NiCrMoCuN25-20-7
21-6-9		S 219 04		
22-13-5		S 209 10	1.3964	X2CrNiMnMoNNb21-16-5-3
16-8-2H				
XM-10		S 219 00		
XM-11		S 219 04		
XM-15		S 381 00		
	SUS XM 15J1			
XM-17		S 216 00		
XM-18		S 216 03		
XM-19		S 219 10	1.3964	X2CrNiMnMoNNb21-16-5-3
XM-19	SUS XM 19	S 209 10	1.3974	X2CrNiMnMoNNb23-17-6-3
XM-21		S 304 52		

USA - JAPAN			EUROPE	
AISI	JIS	UNS	EN / DIN	EN / DIN
XM-29		S 240 00		
XM-31		S 214 00		
			1.4371 (EN)	X2CrMnNiN17-7-5
			1.4373 (EN)	X12CrMnNiN18-9-5
			1.4537 (EN)	X1CrNiMoCuN25-25-5
			1.4577	X5CrNiMoTi25-25
			1.4848	GX40CrNiSi25-20
				X6CrNiCu18-10-4
Alloy 286		S 662 86	1.4980	X5NiCrTi16-15
			1.4961	X8CrNiNb16-3
			1.4981	X8CrNiMoNb16-16
			1.4988	X8CrNiMoVNb16-13

1.4 AUSTENITIC-FERRITIC (DUPLEX) STAINLESS STEELS WELDING

The mixed structure (duplex) of these steels has an approximately equal content of ferrite and austenite.

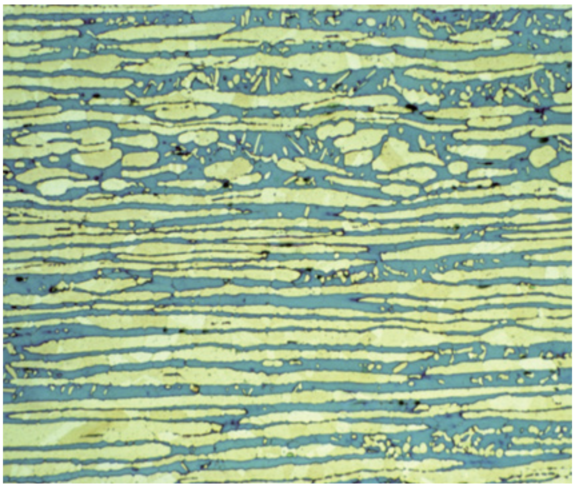


Fig. 12 - Example duplex stainless structure EN 1.4462 – Type 2205 - UNS S32205.

In order to make this structure stable, an adequate balance of the four basic chemical elements such as chromium, nickel, molybdenum and nitrogen is necessary. It is considered that from 30% of ferrite and 70% of austenite, the properties that characterize these steels may be achieved.

Interval of elements:

C ≤ 0.03%

Cr = 21% - 26%

Ni = 3.5% - 8%

Mo ≤ 4.5%

N ≤ 0.35%

These steels improve austenitic steels stress corrosion resistance and have higher mechanical properties. By selecting the most appropriate duplex steel the needs to improve service life may be achieved and cost may be reduced in places where there are stress corrosion problems in the presence of chlorides and good mechanical properties are likewise necessary.

1.4.1 Main characteristics of duplex stainless steels

- High stress corrosion resistance.
- Good mechanical properties compared to austenitic steels that may allow a reduction in thickness and, therefore, in costs.
- Lower heat expansion coefficient than austenitic steels, which favours its use in complicated forms.
- Higher heat conductivity than austenitic steels.
- Low nickel content, which makes it competitive in terms of costs.
- It is magnetic due to the ferrite content.
- Weldability is lower than austenitic steels, but without problems by hot cracking.

1.4.2 Types of austenitic-ferritic (duplex) stainless steels

Duplex steels are classified into 4 groups depending on their corrosion resistance:

Lean duplex: with low content of Mo or without Mo (0.10% - 0.80%) and low content in Ni (1.35% - 5.5%). They have high mechanical properties and due to their low cost they constitute an alternative to the most usual austenitic stainless steels like AISI 304L and AISI 316L.

Examples: 1.4482 / (2001) / S32001 or 1.4162 / (2101) / S32101 or 1.4362 / (2304) / S32304

Standard duplex: they are the most used ones, with an average content of alloy of 22% chromium, 5% Ni and 3% Mo.

Duplex S32205 has had successive developments, increasing the content of N and Mo to improve its weldability and corrosion resistance.

Examples: 1.4462 / (2205) / S32205

Super duplex: they have a PREN>40. The S32550 and S31260 steels have both 25% chromium and average contents of Ni of 5.5% and 6.5%, Mo of 3.4% and 3% and N of 0.17% and 0.20%, respectively.

Steel S32750 has also 25% chromium, but higher contents of Mo and N, allowing it to be suitable for extreme corrosion service conditions, such as applications where high voltages coexist in the presence of chlorides, such as those existing in the seawater.

Examples: 1.4507 / (2550) / S32550, DP3 - S31260; 1.4410 / (2507) / S32750.

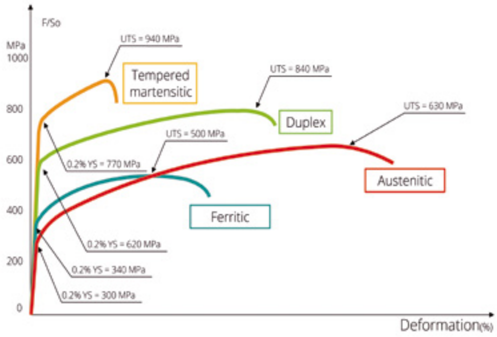
Hyper duplex: they have a PREN>48. High alloy steel, with high contents of Cr, Mo and N. Suitable for applications where high corrosion resistance is required under stresses in the presence of chlorides at higher temperatures or longer service life, combined with good mechanical properties. Especially suitable in aggressive environments by hydrochloric acid.

Examples: 1.4658 / S32707 or S33207

Table 4, shows the properties of austenoferritic steels compared to other stainless steels and the improvements which may be obtained, with the appropriate selection of the most appropriate type of duplex stainless.

STAINLESS STEEL		Corrosion resistance	Mechanical properties	Elongation	Weldability
Ferritic		HIGH	MEDIA	AVERAGE	LOW
Austenitic		EXCELLENT	MEDIA	VERY HIGH	GOOD+
Duplex	Lean duplex	EXCELLENT	HIGH	ALTO	MEDIUM
	Standard	EXCELLENT++	HIGH	ALTO	MEDIUM
	Super	EXCELLENT+++	HIGH	ALTO	MEDIUM
	Hyper	EXCELLENT++++	HIGH	ALTO	MEDIUM

+ Good austenitic weldability.
++ Improved corrosion resistance of lean duplex steels.
+++ Improved resistance to stress corrosion cracking.
++++ Increased resistance to pitting and stress corrosion in the presence of H2S and chlorides at high temperature or longer service life.



1 Megapascal (MPa) = 10.197 Kgf/cm²
1 Megapascal (MPa) = 1 N/mm²

1.4.3 Applicable welding and cutting processes

All arc welding processes, GTAW, GMAW, PAW, SMAW, FCAW, SAW and with resistance and laser are used. Brazing and Soldering are possible with the limitations of these processes.

In the cutting process, plasma (PAC) and laser (LBC) processes are used.

On pages 84-87, 1.10 WELDING PROCESS SELECTION GUIDE, the important characteristics of each process are included for a quick review. On pages 88-167, more detailed information on each process is included.

1.4.4 Consumables

The different consumables for arc welding procedures must be in accordance with:

Coated electrodes (SMAW):
UNE ISO 3581/SFA 5.4

Solid rod for TIG welding (GTAW:
UNE EN ISO 14343/SFA 5.9

Solid wires for MIG/MAG welding (GMAW):
UNE EN ISO 14343/SFA 5.9

Tubular wires for MIG/MAG welding (FCAW):
UNE EN ISO 17633/SFA 5.22

Solid wire for submerged arc welding (SAW):
UNE EN ISO 14343/SFA 5.9

Flux2 for submerged arc welding (SAW):
UNE EN ISO 14174

As coated electrodes, for both austenitic and duplex steels, rutiles electrodes are used for standard applications, but when higher quality welds and better mechanical properties are required, basic electrodes should be used.

Tubular wires offer the possibility to select for welding in all positions or specifically for flat or vertical. In order to obtain the weldability offered by the manufacturer, it is advisable to follow the instructions regarding to the shielding gas used and its flow.

For submerged arc welding, it is advisable to know the flux[2] information of the manufacturer to know the behaviour of the different elements and if any leaks should be expected from any of them or if the behaviour is neutral.

To select filler materials the following should be taken in consideration:

1 Chemical composition similar to the metal to be welded. If rapid cooling occurs due to welding, large amounts of ferrite may be obtained. It is used when the welded part will be subjected to solubilisation annealing after welding.

2 Over-alloy chemical composition. It is used when the welded piece will not have a post weld heat treatment. In general, these consumables incorporate higher nickel content, which favours the formation of austenite. This compensates the ferrite formed by rapid cooling caused by welding.

On the next page Table 5 shows the recommended filler metals of the most widely used duplex.

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[2] Author's note Appendix 3, page 258.

Table 5. Filler materials for duplex stainless steel welding

BASE MATERIAL	FILLER MATERIAL			
STAINLESS STEEL	**WELDING Procedure**	**FILLER MATERIAL**	**EN**	**AWS/ASME**
No. 1.4482	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) MIG/MAG (FCAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2307 NIPPON INOX R-2209 NIPPON T-2307 NIPPON T-2209 NIPPON M-2307 NIPPON M-2209 NIPPON FG-2307 NIPPON FG-2209 NIPPON UM-2307 NIPPON UM-2209 FLUX 805	EN ISO 3581-A: E 23 7 N L R EN ISO 3581-A: E 22 9 3 N L R 3 2 EN ISO 14343-A W 23 7 N L EN ISO 14343-A W 22 9 3 N L EN ISO 14343-A: G 23 7 N L EN ISO 14343-A: G 22 9 3 N L EN ISO 17633-A: T 23 7 N L R EN ISO 17633-A: T 22 9 3 N L R EN ISO 14343-A: S 23 7 N L EN ISO 14343-A: S 22 3 9 N L EN ISO 14174: SA AF 2 Cr DC	SFA 5.4 E2307-17 SFA 5.4 E2209-17 SFA 5.9 ER2307 SFA 5.9 ER2209 SFA 5.9 ER2307 SFA 5.9 ER2209 SFA 5.22 E2307T0-4 SFA 5.22 E2209T0-4 SFA 5.9 ER2307 SFA 5.9 ER2209
No. 1.4162	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) MIG/MAG (FCAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2307 NIPPON INOX R-2209 NIPPON T-2307 NIPPON T-2209 NIPPON M-2307 NIPPON M-2209 NIPPON FG-2307 NIPPON FG-2209 NIPPON UM-2307 NIPPON UM-2209 FLUX 805	EN ISO 3581-A: E 23 7 N L R EN ISO 3581-A: E 22 9 3 N L R 3 2 EN ISO 14343-A W 23 7 N L EN ISO 14343-A W 22 9 3 N L EN ISO 14343-A: G 23 7 N L EN ISO 14343-A: G 22 9 3 N L EN ISO 17633-A: T 23 7 N L R EN ISO 17633-A: T 22 9 3 N L R EN ISO 14343-A: S 23 7 N L EN ISO 14343-A: S 22 3 9 N L EN ISO 14174: SA AF 2 Cr DC	SFA 5.4 E2307-17 SFA 5.4 E2209-17 SFA 5.9 ER2307 SFA 5.9 ER2209 SFA 5.9 ER2307 SFA 5.9 ER2209 SFA 5.22 E2307T0-4 SFA 5.22 E2209T0-4 SFA 5.9 ER2307 SFA 5.9 ER2209
No. 1.4662	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged Arc (SAW) Flux Submerged Arc (SAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2209 NIPPON T-2209 NIPPON M-2209 NIPPON FG-2209 NIPPON UM-2209 FLUX 805 FLUX 10.95	EN ISO 3581-A: E 22 9 3 N L R EN ISO 14343-A: W 22 9 3 N L EN ISO 14343-A: G 22 9 3 N L EN ISO 17633-A: T 22 9 3 N L R EN ISO 14343-A: S 22 9 3 N L EN ISO 14174: SA AF 2 Cr DC EN ISO 14174:S A AF 2 56 44 Ni DC	SFA 5.4 E2209-17 SFA 5.9 ER2209 SFA 5.9 ER2209 SFA 5.22 E2209T0-4 SFA 5.9 ER2209
No. 1.4362	Electrode (SMAW) TIG (GTAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged Arc (SAW) Flux Submerged Arc (SAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2307 NIPPON T-2307 NIPPON T-2209 NIPPON M-2307 NIPPON FG-2209 NIPPON UM-2209 FLUX 805 FLUX 10.95	EN ISO 3581-A: E 23 7 N L R EN ISO 14343-A: W 23 7 N L EN ISO 14343-A: W 22 9 3 N L EN ISO 14343-A: G 23 7 N L EN ISO 17633-A: T 22 9 3 N L R EN ISO 14343-A: S 22 9 3 N L EN ISO 14174: SA AF 2 Cr DC EN ISO 14174:S A AF 2 56 44 Ni DC	SFA 5.4 E2307-17 SFA 5.9 ER2307 SFA 5.9 ER2209 SFA 5.9 ER2307 SFA 5.22 E2209T0-4 SFA 5.9 ER2209
No. 1.4462	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged Arc (SAW) Flux Submerged Arc (SAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2209 NIPPON INOX B-2209 NIPPON T-2209 NIPPON M-2209 NIPPON FG-2309 NIPPON UM-2209 FLUX 805 FLUX 431	EN ISO 3581-A: E 22 9 3 N L R 3 2 EN ISO 3581-A: E 22 9 3 N L B EN ISO 14343-A: W 22 9 3 N L EN ISO 14343-A: G 22 9 3 N L EN ISO 17633-A: T 22 9 3 N L R EN ISO 14343-A: S 22 9 3 N L EN ISO 14174: SA AF 2 Cr DC EN ISO 14174: SA FB 2 DC	SAF 5.4 E 2209-17 SFA 5.4 E 2209-15 SFA 5.9 ER 2209 SFA 5.9 ER 2209 SFA 5.22 E2209T0-4 SFA 5.9 ER 2209
No. 1.4410	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged Arc (SAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2594 NIPPON T-2594 NIPPON M-2594 NIPPON FG-2594 NIPPON UM-2594 FLUX 805	EN ISO 3581-A: E 25 9 4 N L R EN ISO 14343-A W 25 9 4 N L EN ISO 14343-A: G 25 9 4 N L EN ISO 17633-A: T 25 9 4 N L P EN ISO 14343-A S 25 9 4 N L EN ISO 14174: SA AF 2 Cr DC	SFA 5.4 E2594-16 SFA 5.9 ER2594 SFA 5.9 ER2594 SFA 5.22 E2594TO-3 SFA 5.9 ER2594
No. 1.4501	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged Arc (SAW) Flux Submerged Arc (SAW)	NIPPON INOX R-2594 NIPPON T-2594 NIPPON M-2594 NIPPON FG-2594 NIPPON UM-2594 FLUX 805	EN ISO 3581-A: E 25 9 4 N L R EN ISO 14343-A: W 25 9 4 N L EN ISO 14343-A: G 25 9 4 N L EN ISO 17633-A: T 25 9 4 N L P EN ISO 14343-A: S 25 9 4 N L EN ISO 14174: SA AF 2 Cr DC	SFA 5.4 E2594 SFA 5.9 ER2594 SFA 5.9 ER2594 S SFA 5.22 E2594TO-3 SFA 5.9 ER 2594

1.4.5 Precautions to be taken in duplex steels welding

The latest improved compositions of this type of steels allow obtaining an adequate structure in the heat affected zone; however, it is advisable to limit the heat input.

In general neither preheating nor post-heating is needed, but it is advisable to take the following precautions:

1. Grain growth in the heat affected zone which is above 1100ºC. We seek to avoid this by using steels with higher austenite content, according to the application.

2. Precipitation of chromium carbides in the heat affected zone. It will depend on the carbon content.

3. Sigma phase formation, at a temperature which will depend mainly on chromium content and which will be formed if cooling at a temperature of 900ºC is carried out slowly (more than 2 or 3 minutes).

A

BALANCE OF FERRITE AND AUSTENITE IN THE WELD

Duplex steels leave the factory with a balanced content of 40-50% ferrite and austenite.

It is considered that the benefits that duplex steels may provide, in terms of mechanical properties, toughness, corrosion resistance and stress corrosion resistance in the presence of chlorides, may be obtained with at least 25% ferrite and austenite balance. The ferrite in the weld is usually in the range of 25% to 70% (35-100FN) Ferrite content in compliance with ISO 8249).

Sometimes, manufacturer's ferrite- austenite balance is altered for different reasons.

When ferrite content in welding specifications is higher than 40%, there may be cracking when thickness is high and there is a high degree of restraint[1], due to the low ductility and low elongation of the ferrite phase. These cracking problems may be solved with a tight consumable composition to get a higher content of austenite and improve toughness.

In the case of fast arc starts (small repairs made with TIG), there is fast cooling and tend to have a higher ferrite content of 60%, which will have low toughness and low corrosion resistance.

When welding is autogenous, that is to say without filler weld consumables (for example in laser welding, resistance welding, thin thickness TIG welding) as there is no dilution with consumable which may help to obtain an adequate balance of ferrite-austenite, depending on the cooling rate, a negative micro structure may be obtained affecting the weld properties.

For a given consumable and considering dilution with the metal to be welded, ferrite content in the joint may be predicted, but there may be other variables affecting cooling rate and thus the expected ferrite content. These variables are welding procedure, heat input, preheating, interpass temperature, joint and mass thickness that can increase the cooling speed. The higher the cooling rate, the higher the ferrite content.

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[1] Author's note Appendix 3, page 258.

B
PREHEATING

As a general rule, preheating of duplex stainless steel is not recommended because it delays the cooling of the weld and the heat affected zone.

Preheating should not be a part of an approval of a procedure unless there is a specific justification.

Preheating may be beneficial when used to remove moisture from the joint. In this case, the steel should be heated evenly and only at approximately 95°C and after the weld preparation has been cleaned.

Preheating may likewise be beneficial in exceptional cases where there is a risk of high ferrite content formation in the heat affected zone, due to fast cooling, such as welding a thin sheet to a sheet or a thin-walled tube, or any joint with a very low heat and where cooling is fast.

The welding of high thickness and with high degree of restraint[1] could require a preheating of 100°C to avoid cracking.

C
HEAT INPUT AND INTERPASS TEMPERATURE

Duplex steels may tolerate higher heat inputs than austenitic steels. To ensure that optimal properties are obtained for duplex steels, heat should be maintained between:

- Lean duplex: 0.5-2.5 kJ/mm
- Standard duplex: 0.5-2.5 kJ/mm, normally between 1.75 or 2.0 kJ/mm
- Super duplex: 0.2-1.5 kJ/mm, normally between 1.5 or 1.75 kJ/mm
- Hyper duplex: 0.2-1.0 kJ/mm

With correct heat input and cooling, the structure of a duplex weld resists hot cracking much better than that of an austenitic steel weld. Duplex stainless steels have a higher thermal conductivity and a lower coefficient of thermal expansion than that of austenitic stainless steels, so such high stresses are not created due to heating by welding.

Therefore, while the degree of restraint[1] is not severe and stresses are low, hot cracking does not usually constitute a problem for duplex steels. To avoid problems in the heat affected zone, the welding procedure should allow fast cooling (although not extremely fast) of this area. The initial temperature of the piece to be welded is important because the mass of the piece itself should provide the correct cooling of the heat affected zone. Normally, the maximum temperature between passes is limited to:

- Lean duplex: 250ºC
- Standard duplex: between 150-250ºC
- Super duplex: between 100-150ºC
- Hyper duplex:100ºC

This limitation should be included in the welding procedure and during manufacture and ensured it is not exceeded. It must be taken in consideration that the thickness and mass of the coupon used for the qualification of the welding procedure may affect the cooling rate and the interpass temperature. If, during manufacturing, the interpass temperature is higher, cooling rate will decrease and the time and temperature in the heat affected zone will increase.

Table 6 shows a comparative summary of austenitic and duplex steels, with the limitations of heat input and interpass temperature.

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[1] Author's note Appendix 3, page 258.

Table 6. Comparison between austenitic and hardness duplex (metal and consumables), heat input and temperature between passes

METAL	METAL HARDNESS		CONSUMABLE MIG/MAG/GMAW	METAL HARDNESS PURE WELDING	T between passes (ºC) (*)	Heat input (KJ/mm) (**)
	HB	HRC				
AUSTENITIC						
304L-1.4307 (S30403)	201		UNE EN ISO 14343 G 19 9 L Si / SFA 5.9 ER 308LSi	160	150	2.0
316L-1.4404 (S31603)	217		UNE EN ISO 14343 G 19 12 3 L Si / SFA 5.9 ER 316L Si	160	150	1.5
321- 1.4541 (S32100)	217		UNE EN ISO 14343 G 19 9 Nb Si/ SFA 5.9 ER 347Si	225	150	1.5
347- 1.4550 (S34700)	201		UNE EN ISO 14343 G 19 9 Nb Si / SFA 5.9 ER 347Si	225	150	1.5
DUPLEX						
LEAN DUPLEX						
1.4482-2001 (S32001) 1.4162-2101 (S32101)		≤30	EN ISO 14343 G23 7 N L/SFA 5.9 (ER2307)	230	250	3.0
			EN ISO 14343 G 22 9 3 N L/SFA 5.9 ER2209	240	250	0.5-2.5
1.4362-2304 (S32304)		≤30	EN ISO 14343 G 23 7 N L /SFA 5.9 (ER2307)	230	250	<2.5
			UNE EN ISO 14343 G 22 9 3 N L /SFA 5.9 ER2209	240	250	0.5-2.5
STANDARD DUPLEX						
1.4462-(2205) (S32205)		≤31	UNE EN ISO 14343 G 22 9 3 N L /SFA 5.9 ER2209	240	150-250	0.5-2.5
SUPER DUPLEX						
1.4410-2507 (S32750)		≤32	UNE EN ISO 14343 G 25 9 4 N L /SFA 5.9 ER2594	298	150	0.2-1.5
1.4507-2550 (S32550)		≤32	UNE EN ISO 14343 G 25 9 4 N L /SFA 5.9 ER2594	298	150	0.2-1.5
HYPER DUPLEX						
1.4658 2707 (S32707)		≤34	27 9 5 L	≤350	100	0.2-1.0
3207 (S33207)		≤36	32 7 3.5	≤33 HRC		

(*)The temperature data between passes is indicative and due to the influence it has on the thermal cycle of the heat affected zone, it should be controlled together with the heat input.

(**)The appropriate heat input is determined by several factors, but surely the most important one is thickness. The recommended values should be adapted according to thickness, mass of the piece, tools that may generate heat and the like.

D
POST WELD HEAT TREATMENT

Carrying out a stress relief after duplex steel welding, is neither necessary nor useful, and could even be harmful, because the heat treatment can precipitate intermetallic phases between 700-1000ºC or at 475ºC formation of alpha prima (α'), with loss of toughness and corrosion resistance. Post weld heat treatment higher than 315°C, may negatively affect the toughness and corrosion resistance of duplex steels.

Any post weld heat treatment should include complete solubilisation annealing, followed by water tempering. The full solubilisation annealing should be considered after autogenous welding (without consumable), since the micro structure will be highly ferritic if a high alloy filler metal is not used.

If a complete solubilisation annealing and post welding tempering is to be used, for example in the manufacture of an accessory, this heat treatment should be considered as part of the welding procedure.

Post weld heat treatment may eliminate problems associated with excess ferrite and intermetallic phases and the manufacturing process may tolerate some of these undesirable conditions as an intermediate state before final annealing.

E
HARDNESS

The standard hardnesses for duplex steels are:

- Lean duplex: ≤30 HRC
- Standard duplex: ≤31 HRC
- Super duplex: ≤32 HRC
- Hyper duplex: 34-36 HRC

Duplex steels are alloys of high mechanical strength which may only be produced with certain hardness.

Hardness limits are established mainly to avoid cracking under stresses and tests have been carried out which have shown that super duplex steels resist cracking under stresses with hardness up to 36 HRC.

Table 6 shows a comparative summary of the hardnesses of the austenitic and duplex steels and of the consumables most used in their welding.

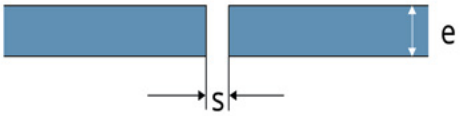
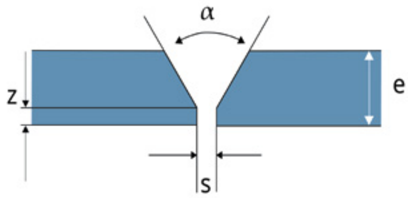
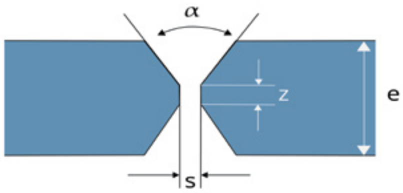
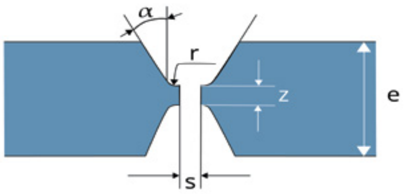
F
JOINT DESIGN

Duplex steels require a joint preparation (Fig. 13), with a design allowing good penetration and avoiding places without consumable input in the welding. In comparison with standard austenitic steel, with the same parameters, welder would observe a lower penetration and lower bath fluidity; in order to compensate this and to facilitate penetration the angle should be about 10º bigger, the root face smaller and the root opening higher.

It is better to mechanize than to grind for joint preparation and to provide uniformity in thickness and edge separation. In the case of grinding use, it is necessary to guarantee a uniform edge separation in order to perform a correct fusion and penetration.

In the case of austenitic stainless steel, an experienced welder may overcome the deficiencies in joint preparation with torch handling. In the case of duplex stainless steel, this handling may cause excessive joint heating and may reach a harmful temperature that may cause results outside the qualified procedure.

Fig.13 - Types of joint used for duplex steels.

TYPE OF JOINT	Process	Thickness e (mm)	Root opening s (mm)	Root face z (mm)	Angle Bisel α (º)
	GTAW	3-5	1-3	-	-
	GMAW	3-6		-	-
	SMAW	3-4		-	-
	GTAW	>3	0-2	-	-
	GMAW			-	-
	SMAW			-	-
	SMAW	4-15	1-3	1-2	55-65
	GTAW	3-8			60-70
	GMAW	5-12			
	SAW	9-12	0	5	80
	SMAW	3-15	2-3	1-2	60-70
	GTAW	2.5-8			
	GMAW	3-12			
	SAW	4-12			70-80
	SMAW	>10	1.5-3	1-3	55-65
	GMAW				60-70
	SAW		0	3-5	90
	SMAW	>25	1-3	1-3	10-15
	GMAW				
	SAW		0	3-5	
	SMAW	12-60	1-2	2-3	
	GTAW	>8		1-2	
	GMAW	>12		2-3	
	SAW	>10		1-3	

1.4.6 Difference between welding of austenitic and duplex steels

The austenitic one has hot cracking problems and to correct this the composition of the consumable is adjusted to obtain a welding ferrite percentage, normally less than 10%. In case this is not possible, considering it is a high alloy austenitic, which should be welded with Ni-base consumable, obtaining a totally austenitic metal in the weld, then, it is necessary to weld with low heat inputs to avoid cracking.

Duplex stainless steels do not have hot cracking problems due to its ferrite content.

The problem for these steels is not in the welding, it is generated in the HAZ (Heat Affected Zone) with a loss of corrosion resistance, toughness or post welding cracking. In order to eliminate this problem, the procedure should be carried out in such a way as to minimize the total time in which duplex steel is at the temperature that may cause problems, rather than the heat input in each pass.

Duplex steel weldability is much more sensitive than austenitic steel to small changes in chemical composition, preparation of joint edges or the cutting and welding process. The chemical composition and the metallurgical state of the duplex steel used for production should be of the same quality and as similar as possible to that used for the welding procedure to be correct.

1.4.7 Welding cleaning

As all stainless steels welding, cleaning is essential in all areas that are going to be subjected to heat.

Grease, paint, oil, moisture, will affect the weld and will decrease corrosion resistance and the mechanical properties of the welded joint.

If it is not cleaned with a suitable product and systematically before welding, the quality of the welding process may not be of any use.

1.4.8 Welding of dissimilar steels with duplex steels

The general information on the joint of dissimilar steels when one of the steels is stainless may be seen in section 1.7.

Table 7 includes a summary of the most used consumables with denomination EN / ISO and AWS, for dissimilar steels joints, when at least one of the metals is duplex steel.

General guidelines to be taken into consideration:

- The consumables used for the joint of duplex stainless steels to other duplex steels are usually duplex stainless steels as well.
- For duplex stainless steel to austenitic steel welding, an austenitic consumable with molybdenum is used as AISI 309LMo.
- AISI 309LMo or AISI 309L is used to join a duplex stainless steel to a carbon steel or a low alloy steel. Considering austenitic stainless steel has less mechanical strength than duplex steel, joints made with an austenitic consumable may not have the strength of duplex steel.
- Depending on the requirements, when welding duplex with high alloy austenitic stainless steels, nickel-based consumables are used.

For duplex stainless steels welding nickel-based consumables are not normally used, but in case they are used, they should be free of niobium. This is suggested based on the low results that have been obtained using the ERNiCrMo-3 (nickel base alloy 625) consumable and that is possibly due to the reaction of the consumable Nb with the N of the base metal duplex.

Table 7. Most used consumables for welding to dissimilar steels with EN / ISO and AWS denomination.

	S32001 (1.4482) S32101 (1.4162)		S32304 (1.4362)		S32205 (1.4462)		S32750 (1.4410) S32760 (1.4501)		S32707 (1.2707) 2707	
	EN/ISO	AWS	EN/ISO	AWS	EN/ISO	AWS	EN/ISO	AWS	EN/ISO	AWS
S32001 (1.4482) S32101 (1.4162)	ER23 7NL	ER2307	ER23 7NL	ER2307	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER27 9 5 NL	ER2707
S32304 (1.4362)	ER23 7NL	ER2307	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209		
S32205 (1.4462)	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER25 9 4 NL	ER2594		
S32750 (1.4410) S32760 (1.4501)	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER25 9 4 NL	ER2594	ER25 9 4 NL	ER2594		
S32707	ER27 9 5 NL	ER2707	ER27 9 5 NL	ER2707	ER27 9 5 NL	ER2707	ER27 9 5 NL	ER2707		
304	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209		
316	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209	ER22 9 3 NL	ER2209		
CARBON STEEL	ER23 12 L	ER309L	ER23 12 L	ER309L	ER23 12 L	ER309L	ER23 12 L	ER309L		

1.4.9 Equivalences between USA, JAPAN and EUROPE standards for austenitic-ferritic steels (duplex)

USA - JAPAN			EUROPE	
AISI	JIS	UNS	EN / DIN	EN / DIN
2205	QS 2205	S 318 03	1.4462 (EN)	X2CrNiMoN22-5-3
2205		S 322 05		
2304		S 323 04	1.4462 (EN)	X2CrNiMoN22-5-3
2506		S 312 60		
2507		S 327 50	1.4410 (EN)	X2CrNiMoN25-7-4
2550		S 325 50	1.4460	
2550	QSA 2505	S 325 50	1.4507 (EN)	X2CrNiMoCuN25-6-3
F 50		S 312 00	1.4460	X3CrNiMoN27-5-2
F 51	QS 2205	S 318 03	1.4462 (EN)	X2CrNiMoN22-5-3
F 51		S 322 05		
F 52		S 329 50		
F 53		S 327 50	1.4410 (EN)	X2CrNiMoN25-7-4
F 54		S 327 40		
F 55		S 327 60	1.4501 (EN)	X2CrNiMoCuWN25-7-4
		S 312 54		
	QS 1905	S 315 00	1.4417	X2CrNiMoSi19-5
		S 317 60		
329	SUS 329 J1	S 329 00		
	SUS 329 J2L			
4462				
			1.4362 (EN)	X2CrNiN23-4
		S 392 74		

1.5 FERRITIC STAINLESS STEELS WELDING

These steels compete with austenitic and duplex stainless steels, aluminized steels, galvanized, primed or painted and aluminium, due to the following:

- Cost advantage due to its composition, with or without Ni content.
- Physical properties, low expansion coefficient and high thermal conductivity, which facilitates its use in boiler making.
- Good resistance to stress corrosion cracking, better than austenitic.
- Ease to recycle compared to other alternatives.

For the above mentioned advantages, ferritic steels are present in high consumption applications such as the automobile, appliance manufacturing, sinks, hot water tanks, solar energy applications and the like.

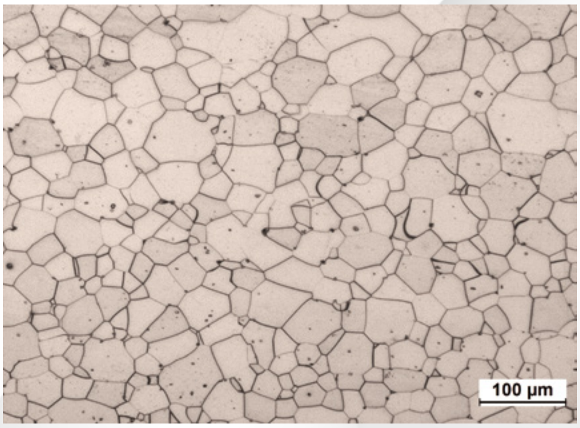


Fig. 14 - Ferritic stainless steel micro structure.

1.5.1 Main characteristics of ferritic stainless steels

- Fe-Cr alloy with Cr> 10% content and does not require the presence of nickel like austenitic stainless steels.
- Ferritic micro structure at room temperature.
- Low toughness, as a consequence of a body-centered cubic structure, with ductile-brittle transition temperature, at relatively high temperature, between 20 and 80°C, below that toughness is very low.
- Do not harden by heat treatment.
- Always magnetic.
- Corrosion resistance, based on its Cr content, which is 10-30%, lower than austenitic steels, but they have better stress corrosion resistance and in sulphurous gases media, where austenitics should not be used due to the presence of Ni.
- Currently used ferritic steels have low carbon content, among other reasons, to improve weldability, but there are alloys with higher content, to improve strength to high temperatures (800-1150ºC).
- Low to medium weldability depending on the type.
- With little or no nickel content which helps to be competitive in costs and in price stability.
- Molybdenum is added in some of these steels, to improve corrosion resistance.
- Titanium and niobium are added because they are strong carbide formers, which fix carbon, preventing formation of chromium carbides, sensitization, intergranular corrosion and improving weldability.
- Compared to austenitic steels they have the advantage of producing less distortions during welding or heat treatments, considering they have:
  - Thermal expansion coefficient similar to carbon steel's and 50% less than austenitic stainless steel's.
  - Thermal conductivity, half of that of carbon steel, but much higher than austenitic steels'.

1.5.2 Types of ferritic steels

Keys which allow their classification into five groups are:

- Composition, especially content of the fundamental elements Cr and C.
- Possible formation of martensite during heating and cooling by welding.
- Continuous improvements made in its production, to enhance corrosion resistance, toughness and to facilitate its use in manufacturing, especially in its weldability such as:
  - Reduction of interstitial elements (C + N).
  - Addition of Mo.
  - Addition of stabilizers Ti and Nb.

Group I

Low chromium content - Cr=10-14%

1.4003 - S40977:		
Cr = 10.5-12.5 %	C = 0.03%	N<0.030%
409 - 1.4512 - S40900:		
Cr = 10.5-12.5%	C = 0.03% max with Ti	

This group has the lowest Cr content of all stainless steels; likewise, it has low C and N contents. It may be an economical solution for applications in low corrosive media replacing galvanized steel, aluminized or painted carbon steel.

As may be seen in Fig 15 due to the low Cr content, when these steels are heated by welding, fall in the area (δ+γ) with a dual structure, the majority being ferrite but with an austenite content, which prevents grain growth which would only have a ferritic structure and which during the welding cooling thermal cycle is turned into martensite. As the C content of these steels is low, the martensite formed will be relatively soft and ductile.

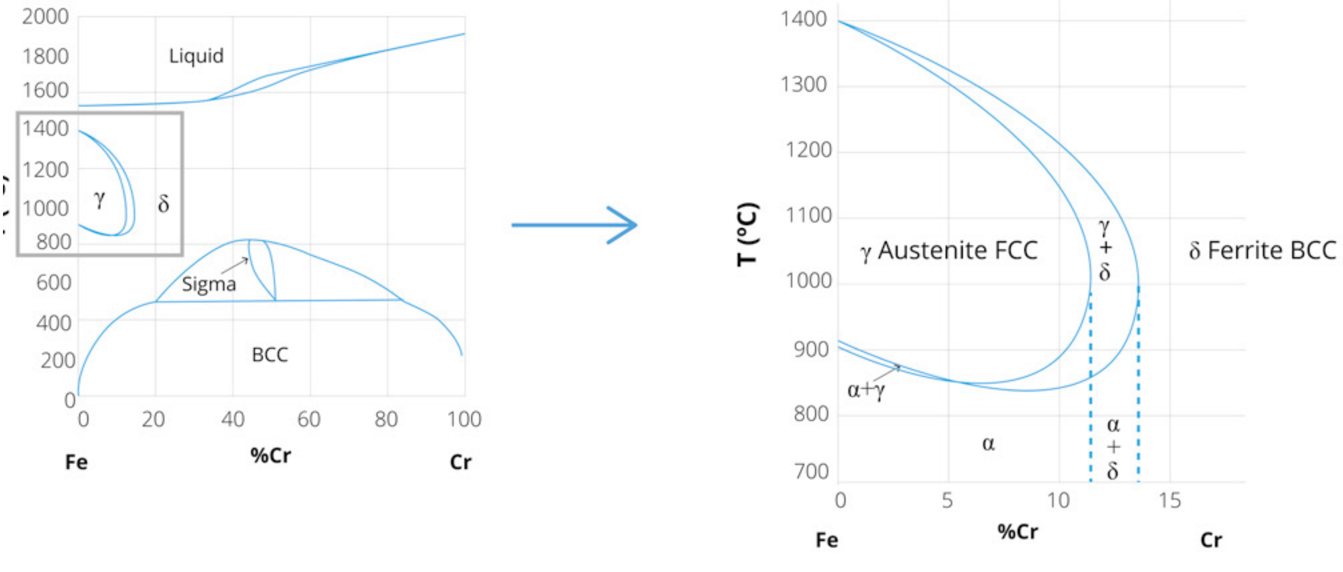


Fig. 15 - Cr-Fe diagram and enlargement of the austenite area.

Type 1.4003 has, during heating by welding, a ferritic-austenitic micro structure which helps it improve its weldability against steels that are totally ferritic and be competitively positioned against carbon and coated steels, where a moderate corrosion resistance is needed.

The ferritic-austenitic structure, during heating by welding, will limit the grain growth that would only have a ferritic micro structure. During post welding cooling if austenite has low carbon content, it will form martensite with better toughness. The amount of martensite will depend on the chemical composition, the heat input of the weld and thickness. It is advisable to weld with austenitic consumables 308L and 309L, to have greater welding ductility.

Type 409-1.4512 is stabilised with Ti and has low contents of C and N, so it will have a low tendency to sensitisation. Weldability is good and the only limitation is the possible grain growth in the area affected by heat, so the heat input of the welding should be kept as low as possible.

For thin thickness, there is usually no preheating or post welding treatment. If necessary, preheating is between 150-250ºC, but the grain growth and the heat treatment between 760-815°C should be taken into account.

The same ferritic type 409 or an austenitic type as 308L may be used as consumables, to have greater welding ductility.

Group II

Average chromium content - Cr=14-18%

430 - 1.4016 (S43000)		
Cr = 16-18 %	C=0.12% max.	N<0.030%

The main representative of this group is **steel 430**, which belongs to the first generation of ferritic steels, with average Cr content and high C content. To improve tenacity, today the C content is usually C<0.08%.

Martensite formation during welding. With the values of Cr and (C + N) and without stabilising elements, this steel is ferritic at room temperature, but during welding, at high temperatures, according to the Fe-Cr equilibrium diagram it will have two phases, ferrite-austenite. The maximum austenite level will be at temperatures of 1100ºC.

During fast cooling from high temperature to room temperature, the ferrite-austenite micro structure will turn into ferrite-martensite. If the martensite has a high carbon content, it will be brittle and these steels should not be put into service without getting treatment to improve brittleness.

Other problems that this steel may have are grain growth, sensitization, formation of carbides and chromium nitrides and embrittlement when subjected for long periods of time to temperature ranges between 400 and 550ºC (reversible embrittlement of 475ºC) and between 600 and 800ºC (irreversible embrittlement due to sigma phase formation). The embrittlement due to steel permanence during long periods of time within these intervals, is not usually caused by welding, rather by an incorrect heat treatment or by the service temperature.

Post weld heat treatment between 790-815ºC reduces fragility and improves corrosion resistance of the affected area, although there will be no refining in the grain. To minimize grain growth, as for all ferritic steels, it is necessary to weld with the lowest possible heat input which is compatible with obtaining good penetration.

For large thickness, preheating between 150-200ºC may reduce the cooling speed, martensite formation and brittleness, although it may help grain growth.

The suitable consumables are the same type of ferritic alloy 430 and austenitic 308L and 309L to have higher welding ductility.

Group III

Average chromium content - Cr=14-18%, low carbon content - C<0.05%, titanium and niobium

441 - 1.4509 - S43940:			
Cr = 17.5-18.5%	C<0.030%	Ti, Nb	
430Ti - 1.4510 - S43035:			
Cr = 16.0-18.0%	C<0.050%	Ti	
439 - 1.4510 - S43035:			
Cr = 16.0-18.0%	C<0.050%	Ti	
430Nb - 1.4511:			
Cr = 16.0-18.0%	C<0.050%	Nb	
430Ti - 1.4520:			
Cr = 16.0-18.0%	C<0.025%	N<0.015	Ti

These steels are a variation of group II, improving their weldability, have a lower C content and are stabilised. During cooling and solidification, Ti and Nb fix the C and N forming stable compounds of carbides and nitrides that precipitate, leaving the ferritic structure with a lower content of C and N. These steels will have better intergranular corrosion resistance, better toughness, ductility and weldability.

As the current manufacturing procedures allow the reduction of elements C and N, it will be possible to optimize the quantity and type of stabilizing elements, in order to improve properties of pitting corrosion resistance or high temperature strength. It is likewise possible to facilitate the surface finish that allows the use of Nb against Ti; this should be also taken in consideration when selecting the consumable.

Suitable consumables are the same type of ferritic alloy and austenitic 308L and 309L to have higher ductility of the weld.

Steel 441, due to its Cr content and keeping the sum of interstitial elements (C+N) low, is ferritic at all temperatures and is stabilized with Ti and Nb. Keeping the addition of interstitial elements (C+N) <0.08% and the stabilisation it has better mechanical properties and corrosion resistance than 430.

Stabilization with Ti as well as Nb reduces sensitization and martensite formation and favours weldability.

As with all ferritic steels, during welding the heat input should be kept as low as possible, in order to limit grain growth in the heat affected area.

The suitable consumables are similar to ferritic **430Nb**; stabilization with Ti is not used as consumable for the loss of this element which takes place in the electric arc, and the austenitic as 308L and 309L that improve the ductility of the weld.

Group IV

High chromium content - Cr=16-20%, molybdenum - Mo>0.5% and any Ti and Nb

434 - 1.4113 - S43400:					
Cr=16-18%	C<0.08%	Mo=0.9-1.40%			
436 - 1.4513 - S43600:					
Cr=16-18%	C=0.025%	Mo=0.8-1.40%	N<0.020	Ti	
444 - 1.4521 - S44400:					
Cr=17.5-19.5%	C=0.025%	Mo=1.80-2.50%	N<0.030	Ti	Nb

These steels are alloyed with Mo, have an average Cr content of 17-19% and good corrosion resistance, better than 304. Due to the content of ferrite forming elements, (Cr and Mo), they have a totally ferritic micro structure with low tendency to martensite formation. In general, they are stabilized with Ti and Nb so they will also have good resistance to sensitization and intergranular corrosion.

Like most ferritic steels, during welding, there may be grain growth in the heat affected area, which may adversely affect the mechanical properties in that area, so heat input should be limited to the minimum possible and should not be subjected to dynamic loads in the condition "as welded".

Applications where welding is required, are limited to maximum thickness of 3.0 mm.

The proper austenitic consumable should have Mo as the 316L or 309LMo.

Type 444 is an example within this group, with average values of Cr, stabilized with Ti and Nb, low content of interstitial elements (C+N) and with Mo to improve corrosion resistance.

During welding, the interstitial elements should be kept low and this should be taken in consideration when selecting the consumable and the shielding gas.

Grain growth should likewise be limited using low heat input.

Although for embrittlement due to the formation of secondary phases, a long time within the temperature ranges is needed (which is usually given more in the case of heat treatment or with service conditions than with welding) it is necessary to be careful with the interval of temperatures between 400 and 550ºC by embrittlement at 475ºC, due to Mo content, which may favour the formation of sigma phase within the range of 600 to 800ºC and Laves phase between 600 and 825ºC.

To prevent different types of embrittlement increase with thickness, welding is normally limited to maximum thickness of 3.0 mm.

Appropriate austenitic consumables are ER316L and 309LMo.

Group V

Cr content >20ºC. Super ferritic steels

445 - 1.4621:			
Cr = 20%	Ti	Nb	
446 - 1.4762 - S44600:			
Cr = 26%	C=0.15%	N=0,20 (Cr=23-27%; C=0.20% máx)	
1.4622 - S44330:			
Cr = 21%	C = 0.02%	Ti	Nb
447 - 1.4592:			
Cr = 30%	Mo = 4%	Ti	Nb

High Cr contents improve corrosion resistance but also favour the susceptibility to embrittlement by grain growth and the formation of secondary phases. Therefore, for these super ferritic steels, the higher Cr content, it is necessary to reduce the addition of interstitial elements (C+N), to maintain toughness.

Increasing the content of (C+N) and the heat input of the weld, grain growth in the heat affected zone will be increased and tenacity will decrease. Also, the higher the chromium content, the easier the embrittlement will occur at 475°C or the formation of the Sigma or Laves phases. For these steels keep low heat input has two purposes, to avoid as much as possible the growth of grain and to be the fastest cooling that will stop the precipitation to the edges of grain. These intergranular precipitates most affect tenacity and resistance to corrosion.

If cooling rate is slow and toughness and corrosion resistance are affected, a heat treatment after welding is needed to improve these properties. Temperature should be higher than 850ºC to avoid embrittlement phenomena due to the formation of sigma and Laves phases. Cooling should be fast in water to avoid intergranular precipitation.

Some steels of this group have Mo to improve oxidation resistance at high temperatures and scale formation; it excels the 316 in terms of this property. The austenitic consumables used are ER309LMo and ER 316L

In the **446 type**, the Cr content rises to 26%, improving corrosion resistance, but in order to maintain toughness, it is necessary to reduce the addition (C+N). During welding, there will be grain growth in the heat affected area which adds the effect of (C+N), which will produce toughness reduction.

Likewise, when chromium content is increased to 26%, embrittlement will be more easily produced at 475°C or by the formation of sigma or Laves phases. This steel will need post welding treatment so as to eliminate embrittlement caused by the secondary phases apart from eliminating residual stresses. Grain growth is not eliminated. Treatment should be at 850ºC and cooling in water.

Due to toughness problems, these steels are usually used in thin thickness, treatment is more necessary after welding when thickness increases.

Consumables used are the ferritic of similar composition and austenitic ER309, ER310 and ER312.

1.5.3 Applicable welding processes

All arc welding processes, GTAW, GMAW, PAW, SMAW, FCAW, SAW and with resistance (RW) and laser (LBW) are used.

Brazing and Soldering are possible with the limitations of these processes.

When cutting, plasma (PAC) and laser (LBC) processes are used.

Autogenous TIG welding (without filler materials), is possible up to 3 mm.

On pages 84-87, 1.10 WELDING PROCESS SELECTION GUIDE the important features of each process are included for a quick review.

Pages 88-167, include more detailed information of each process

1.5.4 Consumables

For ferritic steels there are usually two consumables options, **ferritic** with the same composition to maintain the same characteristics of corrosion resistance in welding and **austenitic**, to give the joint higher ductility, although the characteristics of corrosion resistance of the weld, will be different from the metal to be welded, depending on the consumable used, thickness, edges preparation of the joint and dilution.

Within the ferritic option, it is possible there is no suitable consumable for some ferritic steels, especially for the super ferritic ones.

The consumables for arc welding processes must be in accordance with

Coated electrodes (SMAW):

UNE ISO 3581/SFA 5.4

Solid rod for TIG welding (GTAW):

UNE EN ISO 14343/SFA A5.9

Solid wires for MIG/MAG welding (GMAW):

UNE EN ISO 14343/SFA A5.9

Flux[2] cored wires for MIG/MAG welding (FCAW):

UNE EN ISO 17633/SFA A5.22

Solid wire for submerged arc welding (SAW):

UNE EN ISO 14343/SFA A5.9

Flux[2] for submerged arc welding (SAW):

UNE EN ISO 14174

Table 8 includes some of the filler materials (consumables) used with electric arc welding processes. The most commonly used processes are TIG and MIG/MAG standard and better pulsed, which allow welding with lower heat input.

In the table, the consumable of any process that is not advisable to use may be included, like the coated electrode and submerged arc, because they are processes with a factor (η) of high heat efficiency, which introduce in the steel high heat input, therefore they are not recommended for ferritic steels.

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[1] Author's note Appendix 3, page 258.

Table 8. Filler materials for ferritic stainless steels welding.

STAINLESS STEEL		WELDING PROCEDURE	FILLER MATERIAL	EN	AWS/ASME
No. 1.4003	Consumable type No. 1.4316 308L	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged arc (SAW) Submerged arc Flux (SAW)	NIPPON INOX 502 NIPPON INOX 501 NIPPON T-308L NIPPON M-308L NIPPON FG-308S NIPPON UM-308L FLUX UM-308	EN ISO 3581 E 19 9 L R 32 EN ISO 3581 E 19 9 L B 22 EN ISO 14343 W 19 9 L EN ISO 14343 G 19 9 L EN ISO 17633 T 19 9 L R M3 EN ISO 14343 S 19 9 L EN ISO 14174 SA FB 2DC	SFA 5.4 E 308L-17 SFA 5.4 E 308L-15 SFA 5.9 ER 308L SFA 5.9 ER 308L SFA 5.22 E 308LTO-4 SFA 5.9 ER 308L
No. 1.4512 409	Consumable similar to the metal to be welded	TIG (GTAW) MIG/MAG (GMAW)	NIPPON T-409 NIPPON M-409	EN ISO 14343 W 19 L Nb Ti EN ISO 14343 G 19 L Nb Ti	SFA 5.9 ER 409 SFA 5.9 ER 409
	Consumable type No. 1.4316 308L	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged arc (SAW) Submerged arc Flux (SAW)	NIPPON INOX 502 NIPPON INOX 501 NIPPON T-308L NIPPON M-308L NIPPON FG-308S NIPPON UM-308L	EN ISO 3581 E 19 9 L R 12 EN ISO 3581 E 19 9 L B 32 EN ISO 14343 W 19 9 L EN ISO 14343 G 19 9 L EN ISO 17633 T 19 9 L R M3 EN ISO 14343 S 19 9 L	SFA 5.4 E 308L-16 SFA 5.4 E 308L-15 SFA 5.9 ER 308L SFA 5.9 ER 308L SFA 5.22 E 308LTO-4 SFA 5.9 ER 308L
No. 1.4015 430	Consumable similar to the metal to be welded	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW)	NIPPON INOX R 430 NIPPON T-430 NIPPON M-430	EN ISO 3581 E 17 R 32 EN ISO 14343 W 17 EN ISO 14343 G 17	SFA 5.4 E 430-17 SFA 5.9 ER 430 SFA 5.9 ER 430
	Consumable type No. 1.4316 308L	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged arc (SAW) Submerged arc Flux (SAW)	NIPPON INOX 502 NIPPON INOX 501 NIPPON T-308L NIPPON M-308L NIPPON FG-308S NIPPON UM-308L	EN ISO 3581 E 19 9 L R 32 EN ISO 3581 E 19 9 L B 22 EN ISO 14343 W 19 9 L EN ISO 14343 G 19 9 L EN ISO 17633 T 19 9 L R M3 EN ISO 14343 S 19 9 L	SFA 5.4 E 308L-17 SFA 5.4 E 308L-15 SFA 5.9 ER 308L SFA 5.9 ER 308L SFA 5.22 E 308LTO-4 SFA 5.9 ER 308L
No. 1.4509 441	Consumable similar to the metal to be welded	TIG (GTAW) MIG/MAG (GMAW)	NIPPON T-430 NIPPON M-430	EN ISO 14343 W 18 L Nb EN ISO 14343 G 18 L Nb	SFA 5.9 ER 430 L Nb (441) SFA 5.9 ER 430 L Nb (441)
	Consumable type No. 1.4316 308L	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged arc (SAW) Submerged arc Flux (SAW)	NIPPON INOX 502 NIPPON INOX 1 NIPPON T-308L NIPPON M-308L NIPPON FG-308S NIPPON UM-308L	EN ISO 3581 E 19 9 L R 12 EN ISO 3581 E 19 9 L B 32 EN ISO 14343 W 19 9 L EN ISO 14343 G 19 9 L EN ISO 17633 T 19 9 L R M3 EN ISO 14343 S 19 9 L	SFA 5.4 E 308L-16 SFA 5.4 E 308L-15 SFA 5.9 ER 308L SFA 5.9 ER 308L SFA 5.22 E 308LTO-4 SFA 5.9 ER 308L
	Consumable type No. 1.4332 309L	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW) MIG/MAG (FCAW) Submerged arc (SAW) Submerged arc Flux (SAW)	NIPPON INOX 73 NIPPON INOX B 309L NIPPON T-309L NIPPON M-309L NIPPON FG-309S NIPPON UM-309L	EN ISO 3581 E 23 12 L R 32 EN ISO 3581 E 23 12 L B 22 EN ISO 14343 W 23 12 L EN ISO 14343 G 23 12 L EN ISO 17633 T 23 12 L R M3 EN ISO 14343 S 23 12 L	SFA 5.4 E 309L-17 SFA 5.4 E 309L-15 SFA 5.9 ER 309L SFA 5.9 ER 309L SFA 5.22 E 309LTO-4 SFA 5.9 ER 309L

Table 8. Filler materials for ferritic stainless steels welding.

STAINLESS STEEL		WELDING PROCEDURE	FILLER MATERIAL	EN	AWS/ASME
No. 1.4521 444	Consumable type No. 1.4430 316L	Electrode (SMAW)	NIPPON INOX 510	EN ISO 3581 E 19 9 3 L R 32	SFA 5.4 E 316L-17
		Electrode (SMAW)	NIPPON INOX B 316L	EN ISO 3581 E 19 9 3 L B 22	SFA 5.4 E 316L-15
		TIG (GTAW)	NIPPON T-316L	EN ISO 14343 W 19 9 3 L	SFA 5.9 ER 316L
		MIG/MAG (GMAW)	NIPPON M-316L	EN ISO 14343 G 19 9 3 L	SFA 5.9 ER 316L
		MIG/MAG (FCAW)	NIPPON FG-316S	EN ISO 17633 T 19 9 3 L R M3	SFA 5.22 E 316LTO-4
		Submerged arc (SAW)	NIPPON UM-308L	EN ISO 14343 S 19 9 3 L	SFA 5.9 ER 316L
		Submerged arc Flux (SAW)	NIPPON FLUX UM-308	EN ISO 14174 SA FB 2DC	
	Consumable type No. 1.4459 309LMo	Electrode (SMAW)	NIPPON INOX R 309LMo	EN ISO 3581 E 23 12 2 L R 12	SFA 5.4 E 309LMo-16
		Electrode (SMAW)	NIPPON INOX B-309LMo	EN ISO 3581 E 23 12 2 L B 32	SFA 5.4 E 309LMo-15
		TIG (GTAW)	NIPPON T-309LMo	EN ISO 14343 W 23 12 2 L	SFA 5.9 ER 309LMo
		MIG/MAG (GMAW)	NIPPON M-309LMo	EN ISO 14343 G 23 12 2 L	SFA 5.9 ER 309LMo
		MIG/MAG (FCAW)	NIPPON FG-309LMo	EN ISO 17633 T 23 12 2 L R M3	SFA 5.22 E 309LMoTO-4
		Submerged arc (SAW)	NIPPON UM-309LMo	EN ISO 14343 S 23 12 2 L	SFA 5.9 ER 309LMo
		Submerged arc Flux (SAW)			
No. 1.4622	Consumable type No. 1.4430 316L	Electrode (SMAW)	NIPPON INOX R 510	EN ISO 3581 E 19 12 3 L R 32	SFA 5.4 E 316L-17
		Electrode (SMAW)	NIPPON INOX B 316L	EN ISO 3581 E 19 12 3 L B 22	SFA 5.4 E 316L-15
		TIG (GTAW)	NIPPON T-316L	EN ISO 14343 W 19 12 3 L	SFA 5.9 ER 316L
		MIG/MAG (GMAW)	NIPPON M-316L	EN ISO 14343 G 19 12 3 L	SFA 5.9 ER 316L
		MIG/MAG (FCAW)	NIPPON FG-316L	EN ISO 17633 T 19 12 3 L R M3	SFA 5.22 E 316LTO-4
		Submerged arc (SAW)	NIPPON UM-308L	EN ISO 14343 S 19 12 3 L	SFA 5.9 ER 316L
		Submerged arc Flux (SAW)			
	Consumable similar to the metal to be welded	TIG (GTAW)	NIPPON T-446Mo	EN ISO 14343 W ----	SFA 5.9 ER 446Mo
		MIG/MAG (GMAW)	NIPPON M-446Mo	EN ISO 14343 G ----	SFA 5.9 ER 446Mo
	Consumable type No. 1.4332 309L	Electrode (SMAW)	NIPPON INOX 73	EN ISO 3581 E 23 12 L R 32	SFA 5.4 E 309L-17
		Electrode (SMAW)	NIPPON INOX B 309L	EN ISO 3581 E 23 12 L B 22	SFA 5.4 E 309L-15
		TIG (GTAW)	NIPPON T-309L	EN ISO 14343 W 23 12 L	SFA 5.9 ER 309L
		MIG/MAG (GMAW)	NIPPON M-309L	EN ISO 14343 G 23 12 L	SFA 5.9 ER 309L
		MIG/MAG (FCAW)	NIPPON FG-309S	EN ISO 17633 T 23 12 L R M3	SFA 5.22 E 309TO-4
		Submerged arc (SAW)	NIPPON UM-309L	EN ISO 14343 S 23 12 L	SFA 5.9 ER 309L
		Submerged arc Flux (SAW)			
	Consumable type No. 1.4842 310	Electrode (SMAW)	NIPPON INOX 46	EN ISO 3581 E 25 20 R 32	SFA 5.4 E 310-17
		Electrode (SMAW)	NIPPON INOX B 310	EN ISO 3581 E 25 20 B 22	SFA 5.4 E 310-15
		TIG (GTAW)	NIPPON INOX B-310	EN ISO 14343 W 25 20	SFA 5.9 ER 310
		MIG/MAG (GMAW)	NIPPON T-310	EN ISO 14343 G 25 20	SFA 5.9 ER 310
		MIG/MAG (FCAW)	NIPPON M-310	EN ISO 17633 T 25 20 L R M3	SFA 5.22 E 310TO-4
		Submerged arc (SAW)	NIPPON FG-310	EN ISO 14343 S 25 20	SFA 5.9 ER 310
		Submerged arc Flux (SAW)	NIPPON UM-310		

1.5.5 Shielding gases

As general guidelines in the selection of shielding gases for ferritic stainless steels welding, it is necessary to consider:

- In order to keep the heat input as low as possible, it is advisable to use pulsed MIG and TIG and therefore take in consideration the most appropriate gases.
- Argon purity should be >99.996% whether used pure or mixed with other gases.
- In MIG welding, to improve fluidicity of the weld pool the addition to Ar, of O_2, CO_2 and He is advisable.
- The O_2 content in the mixture with Ar should be 2% maximum to avoid an excessive reduction of steel elements due to the formation of oxides and slags. The CO_2 content in the mixture with Ar should be 2% maximum to avoid adding C to the weld pool and increase the content of interstitial elements (C+N). With stabilised steels, mixtures with CO_2 should not be used to prevent C from interfering with the stabilizing action of Ti and Nb.
- The use of He in the mixtures with Ar, may increase the heat input and increase grain growth.
- Mixtures with H_2 should not be used to avoid cracking, neither as shielding gas nor as backing gas (backing).
- Mixtures with N_2 should not be used neither as shielding gas nor as backing gas (backing) to avoid:
    - Formation of Ti and/or Nb nitrides with stabilised steels.
    - Increase the content of interstitial elements (C+N), which is limited in many ferritic steels.

Apart from taking in consideration the recommendations made in chapter 12 on shielding gases, the most commonly used gases and mixtures for the main TIG and MIG processes may be reviewed below.

MIG WELDING

Mixtures Ar - O_2

The most used mixture to weld ferritic steel is Ar-2%O_2. The O_2 content should be 2% maximum to avoid an excess of oxides and slags. Higher fluidity and flatter beads than with the mixture Ar-2%CO_2

Mixtures Ar - CO_2

The most used mixture is Ar-2%CO_2. The CO_2 content should be 2% maximum so as not to add C to the addition of interstitial elements (C+N) and the O_2 which adds the CO_2, do not form an excess of oxides and slags with the Cr, Si and Mn. In stabilized steels welding this mixture should not be used to avoid the possible C addition and interfere with stabilizing action of Ti and Nb.

Mixtures Ar-He-CO_2

One of the most used mixtures is Ar-15% He-2%CO_2, to take advantage of the higher fluidity and penetration that He may provide, but it should be taken in consideration that the highest heat input that He may provide should favour grain growth and also how can affect CO_2.

Mixtures Ar-CO_2-H_2

As Ar-2%O_2-1%H_2mixture they should not be used because H_2 may cause cracking.

Mixtures Ar-CO_2-N_2

Ar-2%CO_2-2%N_2 mixture should not be used with ferritic steels to prevent the addition of C and N_2 as interstitial elements. These grades can be stabilized by the possible formation of carbides and nitrides of Ti or Nb, reducing their necessary content to stabilize C by forming Ti and Nb carbides and leaving chromium free.

TIG WELDING

Argon

With >99.996% purity it is the most used gas and with no additions of H_2 and N_2.

Mixtures Ar-He

One of the most used mixtures is Ar-30%He, to take advantage of the highest fluidity and penetration that He may provide, but it should be considered that the highest heat input that He may provide, should favour grain growth.

Mixtures Ar-H_2

Like the Ar-5%H_2 mixture, highly used in automatic TIG, they should not be used because H_2 may cause cracking.

BACKING GAS

Ar Gas

It is the most used gas, Ar with > 99.995 % purity and without H_2 o N_2 should be used.

Gas N_2

It is used among other applications, with duplex steels; it should not be used with ferritic steels, especially in stabilized ones.

Mixtures N_2-H_2

Like N_2-5%H_2 mixture that is widely uses as backing gas in welding benches for automatic TIG welding, they should not be used because H_2 may cause cracking.

1.5.6 Precautions to be taken in ferritic stainless steels welding

Weldability of ferritic steels has strong dependence on its chemical composition, due to the high variation of chromium content, the influence of the interstitial elements content (C+N) and stabilizing elements (Ti, Nb), grain growth, the possible formation of martensite and the formation of secondary phases.

The most important points to be considered are:

- Lack of toughness and ductility, especially in higher thickness
- The only practical means to avoid grain growth is to use the lowest possible heat input, compatible with good penetration. The most advisable processes are TIG and MIG / MAG standard and better pulsed.
- Stabilised steels will not have sensitization problems, but toughness will be low if the grain growth is not controlled and if it has a medium or high content of interstitial elements (C+N) >150 ppm (0.015 %.)
- Preheating and keeping interpass temperature may be necessary to reduce hydrogen pick up, to minimize residual stresses and to limit martensite formation.
- It should be considered that preheating and keeping interpass temperature, affects heat input increase and therefore grain growth.
- From the steels which are more frequently welded, more care should be taken with types 430 (1.4016) S43000, than with (1.4509) S43940, 439 (1.4510) S43035, 444 (1.4521) S44400; 409 (1.4512), which are stabilized.
- Post weld heat treatment is advisable to eliminate hydrogen and to prevent martensite in ferritic steels where, due to heating during welding, a certain affected area is created, where a ferrite to austenite change takes place and during cooling changes to martensite.

The most used consumables are austenitic to improve the joint ductility, except in applications in sulphides media, where alloys with Ni may not be used. Autogenous welding is possible in thin thickness in most alloys.

In general terms, it could be said that the precautions that should be taken are as follows:

A

EXCESSIVE GRAIN GROWTH

Above 950ºC there is grain growth, which may be in the heat affected zone, with ductility reduction. If low ductility is combined with degree of restraint[1] and high thickness, cracking risk will increase.

If the thickness is less than 6 mm then, in general precautions should not necessarily be taken.

If thickness is higher, it is advisable to:

- Use low heat input, to avoid excessive grain growth and the width where it takes place. If TIG and MIG equipment is available with the possibility of using pulsed arc; it should be used to limit the heat input.
- An austenitic consumable which provides with dilution, higher elongation and better toughness in the welded metal. As this type of steel, due to its lack of nickel, has a special resistance in atmospheres with sulphur, it should be taken into account that an austenitic material should not be used in these applications, since its nickel content will decrease its corrosion resistance in these media.
- The disadvantage of using preheating between 50 and 250ºC that will depend on the steel and thickness, is that it may help grain growth in the heat affected zone, but the advantage will be the reduction of cooling rate which will lead to greater ductility and as a consequence of this, residual stresses and racking risk may be reduced.

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[1] Author's note Appendix 3, page 258.

B

SENSITIZATION

In ferritic steels with high carbon content, corrosion resistance may be affected, if in the heat affected zone, chromium carbides are formed at the grain edges, leaving the low Cr areas sensitized and exposed to intergranular corrosion.

To prevent carbides formation and sensitization:

- **Reduce the level of interstitial elements C and N.** The precipitation speed will be lower if the C and N content is reduced. Improvements in the manufacturing of those steels make it possible to control (C+N), with the subsequent weldability improvement.
- **Use of stabilising elements**. The use of elements such as Nb and Ti causes the formation of Nb and Ti carbides or carbonitrides and this decreases the possibility of formation of Cr carbides and nitrides. This solution is effective to reduce sensitization, but embrittlement is not avoided. The carbides and carbonitrides of Nb and Ti likewise increase the transition temperature of the ferrite and decrease its ductility. In general, a stabilised ferritic stainless steel has the same toughness as an unstabilised one.
- **Solubilisation and tempering treatment.** It is only effective in ferritic steels with low interstitial element content (C+N), because precipitation speed is high enough to produce carbide precipitation after energetic tempering.
- **Annealing treatment.** This treatment facilitates the precipitation of carbides and nitrides and likewise gives time for the Cr to diffuse and eliminate the Cr-depleted zone when carbides and nitrides are formed. With this, corrosion resistance is restored, if steel service temperature is high, treatment will not be necessary.

C

EMBRITTLEMENT

When ferritic stainless steel is exposed to certain temperature ranges, due to welding heat input or heat treatment, processes that increase its fragility may take place.

Embrittlement of 475ºC. When a ferritic steel is subjected for long periods of time at temperature between 400 and 550ºC. From the ferritic matrix α precipitates the ferrite phase α', rich in chromium (60-85%Cr).

The formation of this second phase α' affects steel properties:

- Increasing tensile strength (with hardening by α' precipitation).
- Decreasing ductility and toughness.
- Decreasing corrosion resistance, due to a reduction in Cr in the α phase.

It is called "embrittlement of 475ºC" because the maximum precipitation occurs at this temperature. This precipitation, within this temperature range, is produced in ferritic steels with a Cr content between 12-17%, the structure being more fragile from 17%, this fragility is more resistant at 475ºC for ferritic steels with medium and high chromium content. The loss of toughness with this embrittlement process is reversible with a heat treatment between 570 and 675ºC for 1 hour.

Embrittlement by sigma phase formation. The σ phase takes place when, during a long exposure, the steel is subjected to temperatures between 600 and 800ºC.

The σ phase is formed at a higher speed in ferritic steels than in austenitic steels. It embrittles ferritic steel and reduces corrosion resistance.

It is brittle and has high hardness up to 700 HV, while the ferrite matrix has only 250 HV.

1.5.7 Heat input

The first solution to prevent grain growth in the heat affected area is to decrease the heat input.

In the TIG (GTAW) and MIG/MAG (GMAW) welding, with the use of the pulsed arc, the heat input can be reduced. Section 1.9 WELDING PROCESSES AND HEAT INPUT contains information about how it could be calculated and the variables that influence the process.

1.5.8 Preheating and interpass temperature

Preheating and the interpass temperature are used to reduce the pick up of hydrogen, to minimise residual stresses and to limit martensite formation by decreasing the cooling rate to room temperature.

A disadvantage would be that it favours grain growth in the heat affected zone. The preheating temperature for ferritic steel is up to 250ºC and it is only advisable to do so for:

- Unstabilised steels, with medium and high Cr content and high C content and with possibility of martensite formation, such as steels 430, 434, 442 and 446.
- When thickness is above 6 mm, there is also a risk of cold cracking by H_2 in the weld, then also it is necessary to consider the type of joint, degree of restraint[1] and if the type of consumable is ferritic. The hydrogen may come from the coating of an electrode, from ambient air, from submerged arc flux[2] from a lack of drying after cleaning and the like.

1.5.9 Post weld heat treatments

Once welding is finished, heat treatments (PWHT) to ferritic stainless steel may be:

- **Heating to facilitate hydrogen diffusion.** This should be considered as a low temperature heat treatment. It consists of increasing the temperature, immediately after finishing welding, 100ºC above the preheating temperature and maintaining it for 3-4 hours. This facilitates the diffusion of H2 of the welding, especially important when the consumable is ferritic and of the heat affected zone, reducing the risk of cold cracking by H2. This process is more important the higher the thickness.
- **Stress relief.** In order to eliminate welding stresses and improve stress corrosion resistance.
- **Annealing** for ferritic steels which have partial transformation during heating of the weld to austenite and then, during cooling to martensite. This treatment also eliminates transformation products developed during welding, such as embrittlement of 475°C and sigma phase.

Normally, among ferritic steels of the first IV groups, only the first generation (group II), is post weld treated, in particular type 430. Post weld heat treatment is carried out with superior to 6 mm thickness. Heat treatment varies considerably depending on the information of steels manufacturers, 750-800ºC and between 1-2 hours is normally advisable.

In general, cooling is carried out in a furnace to minimize the strains that could occur with faster cooling. Furnace cooling should be up to 600°C followed by air cooling to prevent embrittlement at 475°C. For high thickness, cooling is usually with water.

Table 9 includes the advisable heat treatments of some steels of each of the V groups.

GROUP	STEEL	THERMAL TREATMENT (ºC)
I	409 - 1.4512 - (S40900)	800 ±30
	4003 - 1.4003 - (S40977)	730 ±30
II	430 - 1.4016 - (S43000)	800 ±30
III	441 - 1.4509 - (S43940)	900 ±30
	430Ti - 1.4510 - S43035	800 ±30
IV	444 - 1.4521 - S44400	850 ±30
V	446 - 1.4762 - S44600	850 - 900

Table 9. Advisable treatments

[1-2] Author's note Appendix 3, page 258.

1.5.10 Hardness

Ferritic steels do not harden with thermal treatments, they do not perform tempering. It can increase its hardness and strength by cold rolled or drawn work, but in a limited way.

Table 10 shows a comparative summary of the hardness of ferritic and austenitic steels and of the most used consumables in their welding.

METAL	METAL HARDNESS HB	CONSUMABLE MIG/MAG/GMAW	METAL HARDNESS WELDING PURE HV
FERRITIC			
1.4003 (S40977)	180	UNE EN ISO 14343 G 19 9L /SFA 5.9 ER308L	160
		UNE EN ISO 14343 G 23 13L / SFA 5.9 ER309L	
409-1.4512 (S40900)	179	UNE EN ISO 14343 19 L NbTi / E SFA-5.9 ER409	150
		UNE EN ISO 14343 G 19 9 L / SFA 5.9 ER 308L	160
430-1.4016 (S43000)	180	EN ISO 14343 G17 / SFA 5.9 ER 430	180-230
		UNE EN ISO 14343 G 19 9 L / SFA 5.9 ER 308L	160
		UNE EN ISO 14343 G 23 12 L/ SFA 5.9 ER 309L	
444- 1.4521 (S44400)	217	UNE EN ISO 14343 G 19 12 3 L Si / SFA 5.9 ER 316L	160
439 1.4510	183	UNE EN ISO 14343 G 19 9 L/ SFA 5.9 ER 308L	160
446-1.4762- S44600	207	UNE EN ISO 14343 G 23 12 L / SFA 5.9 ER 309L	160
AUSTENITIC			
304L-1.4307 (S30403)	201	UNE EN ISO 14343 G 19 9 L S /SFA 5.9 ER 308LSi	160
316L-1.4404 (S31603)	217	UNE EN ISO 14343 G 19 12 3 L Si / SFA 5.9 ER 316L Si	160
321- 1.4541 (S32100)	217	UNE EN ISO 14343 G 19 9 Nb Si / SFA 5.9 ER 347Si	225
347- 1.4550 (S34700)	201	UNE EN ISO 14343 G 19 9 Nb Si / SFA 5.9 ER 347Si	225

Table 10. Hardness of ferritic and austenitic steels and of most used consumables in their welding.

1.5.11 Equivalences between USA, JAPAN and EUROPE standards for ferritic stainless steels

USA - JAPAN			**EUROPE**	
AISI	**JIS**	**UNS**	**EN / DIN**	**EN / DIN**
405	SUS 405	S 405 00		
409		S 409 00	1.4512 (EN)	X2CrTi12
409 L				
	SUS 410 LC			
410 S		S 410 08	1.4516 (EN)	X6CrNiTi12
410 Ti	SUS 410 T			
418				
429	SUS 429	S 429 00		
430	SUS 430	S 430 00	1.4016 (EN)	X6Cr17
430 F	SUS 430 F	S 430 20		
430 Cb		S 430 40	1.4511	X3CrNb17
430 Ti	SUS 430 Ti	S 430 35		
430 Ti	SUS 430 Ti	S 430 36		
434	SUS 434	S 434 00	1.4113	X6CrMo17-1
436			1.4536	
439		S 430 35	1.4510 (EN)	X3CrTi17
439 L				
440 A		S 440 00	1.4522	
440 B		S 440 00		
441			1.4509 (EN)	X2CrTiNb18
442				
443	SUS 443	S 443 00		
444	QS 192	S 444 00	1.4521 (EN)	X2CrMoTi18-2
446	SUH 446	S 446 00	1.4749	X18CrN28
455				
490				
501				
XM-15				
	QS 25T			
XM-27	QS 261	S 446 27		

1.5.11 Equivalences between USA, JAPAN and EUROPE standards for ferritic stainless steels

USA - JAPAN			**EUROPE**	
AISI	**JIS**	**UNS**	**EN / DIN**	**EN / DIN**
XM-33		S 446 26		
18-2	QS 192	S 444 00	1.4521 (EN)	X2CrMoTi18-2
19-3	QS 192	S 444 00	1.4521 (EN)	X2CrMoTi18-2
25-4-4		S 446 35		
26-3-3		S 446 60		
29-4		S 447 00		
29-4C		S 447 35		
29-4-2		S 448 00		
P9		S 504 00		
		S 890 40		
		S 890 25		
		S 890 26		
			1.4000 (EN)	X6Cr13
			1.4002 (EN)	X6CrAl13
			1.4003 (EN)	X2CrNi12
			1.4017 (EN)	X6CrNi17-1
			1.4024	
			1.4505	
			1.4506	
			1.4513 (EN)	X2
			1.4520 (EN)	
			1.4526 (EN)	
			1.4575	
			1.4590 (EN)	
			1.4592 (EN)	
			1.4605 (EN)	
			1.4724	
	Y 4L			
	SIC 8			
	SIC 9			
	SIC 10			
	SIC 12			

1.5.12 Equivalences between USA, JAPAN and EUROPE standards for heat-resistant ferritic stainless steels

USA - JAPAN			EUROPE	
AISI	**JIS**	**UNS**	**EN / DIN**	**EN / DIN**
			1.4713	X10CrAl7
			1.4742	X10CrAl18
			1.4781	X10CrAl24

1.6 WELDING OF MARTENSITIC STAINLESS STEELS

The most used martensitic stainless steels are:

AISI	EN	UNS
410	1.4006	S41000
420	1.4021	S42000

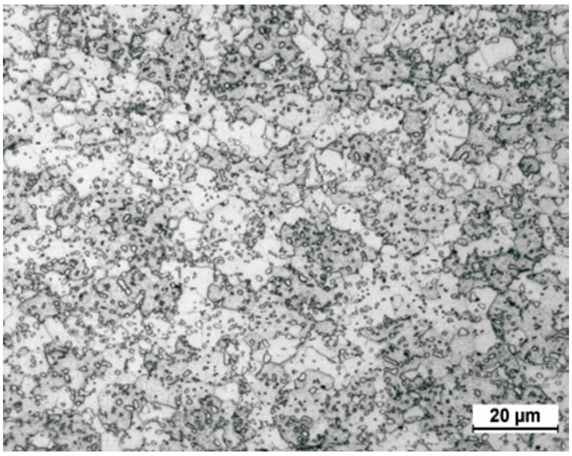

Fig. 16 - Martensitic stainless steel microstructure.

1.6.1 Main characteristics

- It hardens with heat treatment.
- Magnetic.
- Average corrosion resistant.
- Low weldability.
- Low toughness and ductility values.
- High carbon content to improve tensile strength and hardenability.
- High resistance to wear.
- These steels contain very little, if any, or no Ni and Mo.
- Thermal expansion coefficient similar to carbon steel and one and a half times less than austenitic stainless steel.
- Thermal conductivity is half of carbon steel.
- Basic element ranges: C= 0.08% - 1.2%; Cr=11.5% - 17%. Added elements: Mo≤1.8%; Ni≤6%; V≤0.20%

The high hardenability of this group of steels leads to the formation of martensite in the weld and in the heat affected zone.

Martensite is prone to cracking which will increase with carbon content. This tendency may be reduced by preheating to 200-300ºC which should increase with thickness. As martensite formation is likely, despite preheating, post-heating at 650-750°C for 30-60 minutes is recommended. The treatment for thick or complicated shapes should start immediately after welding.

One of the best known steels of this group is AISI 410, and there are two possibilities for filler material (Table 11):

- Use AISI 410 with low or medium carbon content to avoid excessive hard areas or where post weld heat treatment is not possible.
- Use austenitic filler material. In this case the metal will brittle in the heat affected area.

Non hardenable NiCr or NiCrMo filler materials may also be used but costs will increase.

1.6.2 Applicable welding and cutting processes

As these steels can be hardened, they are harder to weld and cut than other stainless steels. The most frequently used welding procedures are MIG and TIG.

It is very important during the cutting procedure to avoid excessive hardness at the edges, as this causes welding problems.

Section 1.10 WELDING PROCESS SELECTION GUIDE on pages 84-87 contains the important characteristics of each process for quick reviews. A more detailed review of each welding and cutting process is included on pages 88-167.

1.6.3 Consumables

The consumables used in arc welding must comply with:

Coated electrodes (SMAW):
UNE ISO 3581/SFA 5.4
Solid rod for TIG welding (GTAW):
UNE EN ISO 14343/SFA 5.9
Solid wires for MIG/MAG welding (GMAW):
UNE EN ISO 14343/SFA 5.9
Flux[2] cored wires for MIG/MAG welding (FCAW):
UNE EN ISO 17633/SFA 5.22
Solid wire for submerged arc welding (SAW):
UNE EN ISO 14343/SFA 5.9
Flux[2] for submerged arc welding (SAW):
UNE EN ISO 14174

Table 11. Filler materials for welding martensitic stainless steels.

BASE METAL	FILLER MATERIAL			
STAINLESS STEEL	WELDING PROCEDURE	FILLER MATERIAL	EN	AWS/ASME
With similar composition				
No. 1.4009 - 410	TIG (GTAW) MIG/MAG (GMAW)	NIPPON T-410 NIPPON M-410	UNE EN ISO 14343 W 13 UNE EN ISO 14343 G 13	SFA 5.9 ER410 SFA 5.9 ER410
No. 1.4351	TIG (GTAW) MIG/MAG (GMAW)	NIPPON T-410NIMO NIPPON M-410NIMO	UNE EN ISO 14343 W 13 4 UNE EN ISO 14343 G 13 4	SFA 5.9 ER 410NiMo SFA 5.9 ER 410NiMo
With austenitic material				
No. 1.4316 - 410	Electrode (SMAW) Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW)	NIPPON INOX 502 NIPPON INOX B 308L NIPPON T-308L NIPPON M-308L	UNE EN ISO 3581 E199L R32 UNE EN ISO 3581 E199L B22 UNE EN ISO14343 W 19 9 L UNE EN ISO 14343 G 19 9 L Si	SFA 5.4 E 308L-17 SFA 5.4 E 308L-15 SFA 5.9 ER 308L SFA 5.9 ER 308LSi
No. 1.4551	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW)	NIPPON INOX 507 NIPPON T-347 NIPPON M-347	UNE EN ISO 3581 E199Nb R32 UNE EN ISO 14343 W 19 9 Nb UNE EN ISO 14343 G 19 9 Nb	SFA 5.4 E 347-17 SFA 5.9 ER 347 SFA 5.9 ER 347Si
With nickel-based alloys				
No. 1.4547-254SMO	Electrode (SMAW) TIG (GTAW) MIG/MAG (GMAW)	NIPPON NI 209 NIPPON T-209 NIPPON M-209	UNE EN ISO 14172 ENiCr22Mo9 UNE EN ISO 18274 S NiCr 22 Mo 9 Nb UNE EN ISO 18274 S NiCr 22 Mo 9 Nb	SFA 5.11 ENiCrMo-3 SFA 5.14 ERNiCrMo-3 SFA 5.14 ERNiCrMo-3

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[1] Author's note Appendix 3, page 258.

1.6.4 Equivalence between standards in USA, JAPAN and EUROPE for martensitic stainless steels

USA - JAPAN			**EUROPE**	
AISI	**JIS**	**UNS**	**EN / DIN**	**EN / DIN**
403	SUS403	S 403 00		
		S 408 00		
410	SUS 410	S 410 00	1.4006 (EN)	X12Cr13
414				
	SUS 410 J1			
410 S		S 410 08	1.4006 (EN)	X12Cr13
		S 410 50	1.4030	
F6NM		S 415 00	1.4313 (EN)	X3CrNiMo13-4
416	SUS 416	S 416 00		
	SUS 416 HS2			
	SUS 416 L			
416Se				
420		S 420 00	1.4021 (EN)	X20Cr13
		S 420 10	1.4021 (EN)	X20Cr13
420	SUS 420 J1	S 420 00	1.4028 (EN)	X30Cr13
	SUS 420 J2			
	SUS 420 J2C			
	SUS 420 J2L			
420 F	SUS 420 F	S 420 20		
F3NM		S 424 00	1.4320	X2CrNiMo13-4
	SUS 429 J1			
431	SUS 431	S 431 00		
440 A		S 440 00		
440 C	SUS 440 C	S 440 04		
	SUS 440 F			
XM 12		S 155 00	1.4545	X5CrNiCuNb15-5-4
			1.4031 (EN)	X39Cr13
			1.4034 (EN)	X46Cr13
			1.4116 (EN)	X50CrMoV15
			1.4122 (EN)	X39CrMo17-1
			1.4418 (EN)	X4CrNiMo16-5-1
			1.4922	X20CrMoV12-1
			1.4935	X20CrMoWV12-1
	QD 51			
	QPD 5			
	Y 2L			
	Y 2LF			

1.6.5 Equivalence between standards in USA, JAPAN and EUROPE for martensitic stainless steels for high temperature use

USA - JAPAN			EUROPE	
AISI	**JIS**	**UNS**	**EN / DIN**	**EN / DIN**
F 91			1.4903	X10CrMoVNb9-1
			1.4913	X19CrMoVNbN11-1
			1.4922	X20CrMoV12-1

1.7 WELDING OF DISSIMILAR STEELS

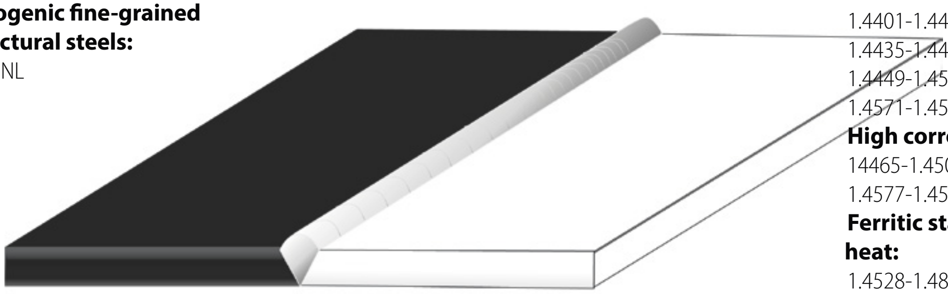
In many applications, mainly in the chemical, nuclear and petrochemical industries, the welding of dissimilar materials is required. Often, certain sections of a plant may be subject to combinations of mechanical, thermal and chemical requirements, and in the design stage the appropriate materials are selected for each requirement. A joint of dissimilar materials is needed where these meet.

The term "black-white joint" is used when a carbon or low alloy steel is welded to a stainless steel, but a joint between two different stainless steels is also common.

Some examples include:

- The loads that may be applied to the joint.
- The appropriate consumables for each type of load.
- Graphs where two metals are joined with the same thickness and edge preparation, so that each metal takes part in the weld pool in a 1: 1 ratio.

The proportion of each metal, according to the joint configuration and the dilution for the welding process and consumable should be estimated for each particular application.

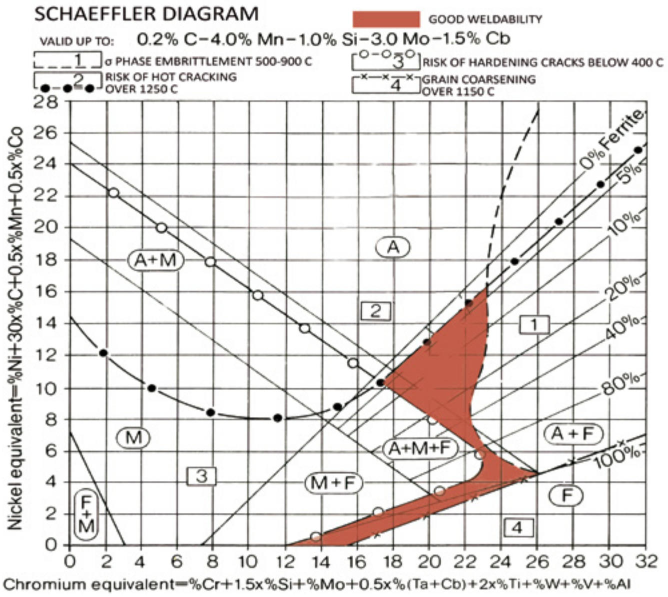


Structural steels
S 235, S 275, S 355
Heat treated steels:
C15, C22, C25
Cast steel:
GS38, GS45, GS52
Shipbuilding steels:
A, B, C
Steels for boilers:
HI, HII, HIII
Heat resistant steels:
15Mo
Fine-grained structural steels:
S355N, S420N
Weather resistant structural steels:
WT St E37-3
Cryogenic fine-grained structural steels:
P215NL

Ferritic stainless steels:
1.4016-1.413-1.4510-1.4511-1.4512
Austenitic stainless steels:
1.4300-1.4301-1.4306-1.4311-
1.4401-1.4404-1.4406-1.4429-
1.4435-1.4436-1.4438-1.4439-
1.4449-1.4541-1.4543-1.4550-
1.4571-1.4573-1.4580-1.4583
High corrosion resistant special steels:
14465-1.4505-1.4506-
1.4577-1.4578-1.4586
Ferritic stainless steels, resistant to heat:
1.4528-1.4829-1.4833-
1.4845-1.4878
Austenitic-ferritic steels (duplex):
1.4162-1.4362-1.4462-
1.4507-1.4410-1.2707

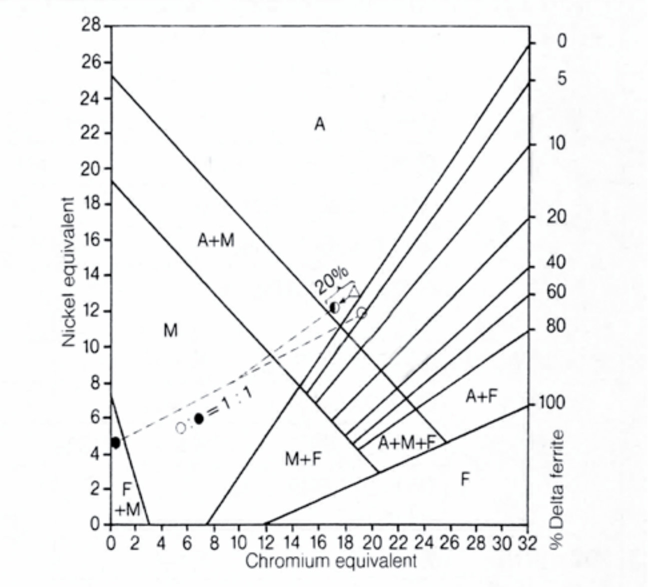
Fig. 17 - Welding of dissimilar steels.

1.7.1 Consumables



The characteristics of the different GROUPS are:

Example GROUP 1



The consumable is 18Cr/8Ni/6Mn:G

- Fully austenitic.
- Resistant to brittle fracture.
- Resistant to hot cracking due to high manganese content.

Steel joined St37-3 and 1.4541 (X6CrNiTi1810)

● = S235J2G3
○ = 1.4541
Dilution between steels to join ●:○=1:1
△ = Consumable E188MnB22
Dilution of steels to join with consumable: 20%

Fig. 18 - Example GROUP 1.

Appropriate consumables

Welding process	Consumable	EN	AWS/ASME
Electrode (SMAW)	NIPPON INOX 26	UNE EN ISO 3581 E 18 8 Mn B 2 2	SFA 5.4 E307-15
TIG (GTAW)	NIPPON T-307	UNE EN ISO 14343 W 18 8 Mn	SFA 5.9 ER307
MIG/MAG (GMAW)	NIPPON M-307	UNE EN ISO 14343 G 18 8 Mn	SFA 5.9 ER307
MIG/MAG (FCAW)	NIPPON FG-308S	UNE EN ISO 17663 T 18 8 Mn P M 1	SFA 5.22 E 307LTO-3
Submerged arc (SAW)	NIPPON UM-308L	UNE EN ISO 14343 S 18 8 Mn	SFA 5.9 ER 307
Flux[2] submerged arc (SAW)	NIPPON FLUX UM-380	UNE EN ISO 14174 SA FB 2 DC	

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[2] Author's note Appendix 3, page 258.

Example GROUP 2

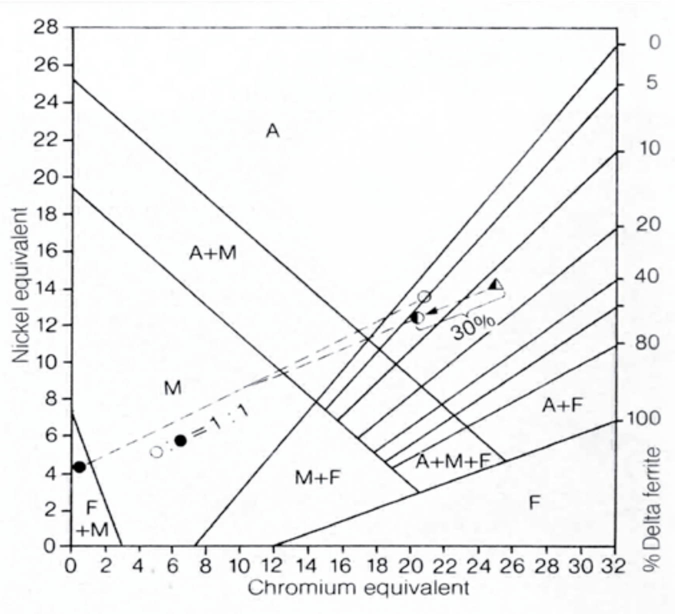

Fig. 19 - Example GROUP 2.

The consumable is E23122LR32

- Not fully austenitic.
- Ferrite content is in the order of 12%, which is reached in the weld metal with a normal dilution with the base metals to be joined to become a typical standard alloy 304 (18Cr/8Ni) or 316 (18Cr/8Ni/2Mo) with 5% ferrite, with good resistance to hot cracking and corrosion.

Steels joined St37-3 and 1.4541 (X6CrNiTi1810)

●= S235J2G3
○= 1.4541
Dilution between steels to join●:○=1:1
△ = Consumable E23122LR32
Dilution of steels to join with consumable: 30%

Appropriate consumables:

Welding procedure	Consumable	EN	AWS/ASME
Electrode (SMAW)	NIPPON INOX 52	UNE EN ISO 3581 E 23 12 2 L R 3 2	SFA 5.4 E309LMo-17
TIG (GTAW)	NIPPON T-309 Mo	UNE EN ISO 14343 W 23 12 2 L	SFA 5.9 ER309LMo(*)
MIG/MAG (GMAW)	NIPPON M-309 Mo	UNE EN ISO 14343 G 23 12 2 L	SFA 5.9 ER309LMo(*)
MIG/MAG (FCAW)	NIPPON FG-309Mo	UNE EN ISO 17663 T 23 12 2 L R M21 3	SFA 5.22 E 309LTO-4(*)
Submerged arc (SAW)	NIPPON UM-309Mo	UNE EN ISO 14343 S 23 12 2 L	SFA 5.9 ER 309LMo(*)
Flux[2] Submerged arc (SAW)	NIPPON FLUX UM-380	UNE EN ISO 14174 SA CS 2 Cr DC	

(*) Approximate specification

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[2] Author's note Appendix 3, page 258.

Example GROUP 3

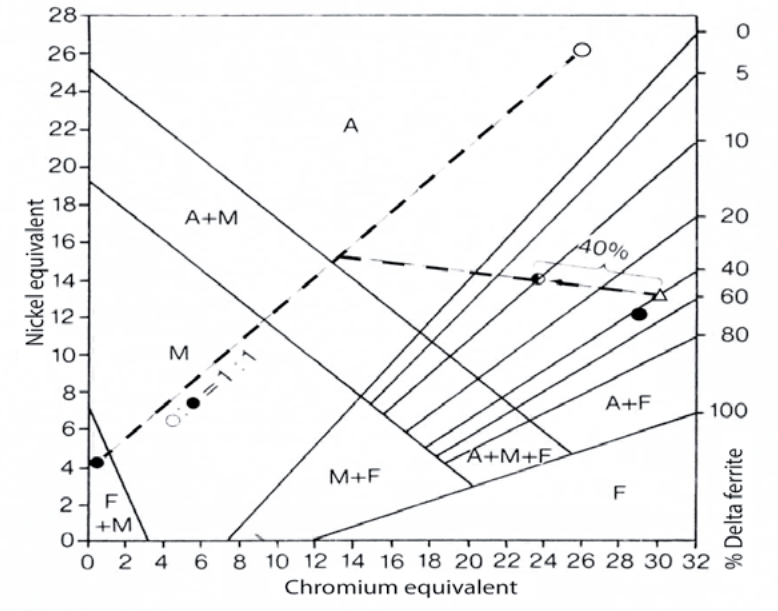

Fig. 20 - Example GROUP 3.

The consumable is 29 Cr / 9 Ni:

- Austenite with 40% ferrite, which allows it to achieve hot cracking resistance with normal dilution with the metals to be joined, in applications where metals have high impurity content.
- Good coefficient of thermal expansion, which facilitates the welding of joints subjected to high stresses and between carbon steels with high C contents to high alloy steels. These characteristics appear in many repairs.

Steels joined St37-3 and 1.4578 (X4CrNiMoNb2525)

● = S235J2G3
○ = 1.4578
Dilution between steels to join ●:○=1:1
△ = Consumable E299R32
Dilution of steels to join with consumable: 40%

Appropriate consumables:

Welding process	Consumable	EN	AWS/ASME
Electrode (SMAW)	NIPPON INOX 29	UNE EN ISO 3581 E 29 9 R 3 2	SFA 5.4 E312-17
TIG (GTAW)	NIPPON T-312	UNE EN ISO 14343 W 29 9	SFA 5.9 ER309LMo(*)
MIG/MAG (GMAW)	NIPPON M-312	UNE EN ISO 14343 G 29 9	SFA 5.9 ER309LMo(*)
MIG/MAG (FCAW)	NIPPON FG-312	UNE EN ISO 17663 T 29 9 R M3	SFA 5.22 E 309LTO-4(*)
Submerged arc (SAW)	NIPPON UM-312	UNE EN ISO 14343 S 29 9	SFA 5.9 ER 309LMo(*)
Flux[2] Submerged arc (SAW)	NIPPON FLUX UM-380	UNE EN ISO 14174 SA AF 2 56 54 DC	

(*) Approximate specification

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[2] Author's note Appendix 3, page 258.

Example GROUP 4

The consumable is nickel based and the Schaeffler diagram may not be applied. Alloys of this nickel base group should be used:

- When the joint has a post weld heat treatment or support temperatures above 300ºC.
- For applications where the joint must be resistant to brittle fracture, hot cracking and corrosion.
- When the joint has to be resistant to brittle fracture due to temperature changes. This is the result of its high coefficient of thermal expansion.

Appropriate consumables:

Welding process	Consumable	EN	AWS/ASME
Electrode (SMAW)	NIPPON NI 207	UNE EN ISO 14172 E Ni 6082 (NiCr20Mn3Nb)	SFA 5.11 ENiCrFe-3
	NIPPON NI 209	UNE EN ISO 14172 E Ni 6625 (NiCr22Mo9Nb)	SFA 5.11 ENiCrMo-3
TIG (GTAW)	NIPPON T-207	UNE EN ISO 18274 S Ni 6082 (NiCr20Mn3Nb)	SFA 5.14 ERNiCr-3
	NIPPON T-209	UNE EN ISO 18274 S Ni 6625 (NiCr22Mo9Nb)	SFA 5.14 ERNiCrMo-3
MIG/MAG (GMAW)	NIPPON M-207	UNE EN ISO 18274 S Ni 6082 (NiCr20Mn3Nb)	SFA 5.14 ERNiCr-3
	NIPPON M-209	UNE EN ISO 18274 S Ni 6625 (NiCr22Mo9Nb)	SFA 5.14 ERNiCrMo-3
MIG/MAG (FCAW)	NIPPON FG-207	UNE EN ISO 12153 T Ni 6082 R M21 3	SFA 5.34 ENiCr3T0-4
	NIPPON FG-209	UNE EN ISO 12153 T Ni 6625 P M21 2	SFA 5.34 ENiCrMo3T1-4
Submerged arc (SAW)	NIPPON UM-207	UNE EN ISO 18274 S Ni 6082 (NiCr20Mn2Nb)	SFA 5.14 ERNiCr-3
	NIPPON UM-209	UNE EN ISO 18274 S Ni 6625 (NiCr22Mo9Nb)	SFA 5.14 ERNiCrMo-3
Flux[2] submerged arc (SAW)	NIPPON FLUX UM-380	UNE EN ISO 14174 SA AF 2 Cr DC	

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[2] Author's note Appendix 3, page 258.

Table 12. Consumables for welding dissimilar steels.

This table shows an initial proposal for the appropriate consumable for dissimilar metal joints, which must comply with the requirements of the joint, after their dilution in the welding process with the metals to join.

Base Material	C Steel	Cr-Mo Steel	AISI 201-202	AISI 301	AISI 302-302B	AISI 303-303Se	AISI 304	AISI 304L	AISI 305	AISI 308	AISI 309	AISI 309S	AISI 310	AISI 310S	AISI 314	AISI 316	AISI 316L
C Steel	(3)																
Cr-Mo Steel	(9)	(8)															
AISI 201-202	(4) E309	(4) E309	(2) E308														
AISI 301	(4) E309	(4) E309	(2) E308	(2) E308													
AISI 302-302 B	(4) E309	(4) E309	E308	E308	E308												
AISI 303-303Se (I)	(5) E309	(5) E309	E308 E312	E308 E312	E308 E312	E308 E312											
AISI 304	(4) E309	(4) E309	E308	E308	E308	E308 E312	E308 (14)										
AISI 304L	(4) E309	(4) E309	E308	E308	E308	E308 E312	E308	E308L									
AISI 305	(4) E309	(4) E309	E308	E308	E308	E308 E312	E308	E308	E308 E310								
AISI 308	(4) E309	(4) E309	E308	E308	E308	E308 E312	E308	E308	E308	E308							
AISI 309	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308	E308	E308	E309						
AISI 309S	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308	E308	E308	E309	E309S (15)					
AISI 310	E310 (6)	E310 (6)	E308	E308	E308	E312	E308	E308	E310 E308	E308	E309	E309	E310				
AISI 310S	E310 (6)	E310 (6)	E308	E308	E308	E312	E308	E308	E310 E308	E308	E309	E309S (15)	E310	E310			
AISI 314	E309 (4)(6)	E309 (4)(6)	E308 E312	E308 E312	E308 E312	E312	E308 E312	E308 E312	E312	E308 E312	E309 E312	E309 E312	E310 E312	E310 E312	E310 E312		
AISI 316	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308	E308	E308	E309	E309S (15)	E316	E316	E316	E316 (11)	
AISI 316L	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E309 E316	E316	E316	E316	E316	E316	E316L
AISI 317	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E309	E316	E317	E317	E317	316	316
AISI 317L	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E309	E316	E317L (15)	E317	E316	E317L	E316L
AISI 321	E309 (4)(6)	E309 (4)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E308 E347	E308 E347	E308	E308	E308	E308	E308L
AISI 330	E312 (5)(6)	E312 (5)(6)	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E309	E312 E310	E312 E310	E312 E310	E312 E309	E312 E309
AISI 347	E312 (5)(6)	E312 (5)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E308 E347	E308 E347	E308 E347	E308 E347	E308	E308 (11)	E316L
AISI 348	E312 (5)(6)	E312 (5)(6)	E308	E308	E308	E308 E312	E308	E308L	E308	E308	E308 E347	E308 E347	E308 E347	E308 E347	E308	E308 E316	E316L
ASTM 316Ti	E309Mo	E309Mo (6)	E309Mo	E309 E316L	E309 E316L	E309Mo E308	E316 E308	E316L E308L	E316L E308L	E316 E308	E316 E309	E309	E309	E309	E309	E316	E316L
2304	E309Mo	E309Mo (6,16)	E309Mo	E309Mo	E309Mo	E309Mo	E308Mo E309Mo	E308Mo E309Mo	E308Mo E309Mo	E308Mo E309Mo	E308Mo E309Mo	E308Mo E309Mo	E309Mo	E309Mo	E309	E309Mo	E309Mo
2205	E309Mo E2209	E309Mo (6,16)	E309Mo	E309Mo E2209	E309Mo E2209	E309Mo E2209	E309Mo E2209	E309Mo E2209	E309Mo	E309Mo	E309Mo	E309Mo	E309Mo	E309Mo	E309	E2209 E316L	E2209 E316L
2507	E309Mo	E309Mo (6,16)	E309Mo	E309Mo	E309Mo	E309Mo	E309Mo E2209	E309Mo E2209	E309Mo	E309Mo	E309Mo	E309Mo	E309Mo	E309Mo	E309	E2209 E316L	E2209 E316L
AISI 403 - 405 - 410	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 414	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 416 (I)	E309	E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 420	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 430	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 430F (I)	E309	E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 431	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 440 A-B-C	(3) (7)	(8) (7)	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309	(4) E309
AISI 446	(3) (7) (6)	(8) (7) (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E310 (6)	E309 E310 (6)	E309 E310 (6)	E309 E310 (6)	E130 (6)	E310 (6)

Notes:

1. Arc welding procedure is not recommended.
2. The filler metal has lower strength than the base metal.
3. Use the appropriate electrode for the carbon steel composition.
4. Make a first pass on the less alloyed steel, complete the connection with E308.
5. Make a first pass on the less alloyed steel; the more alloyed one with E312; complete the joint with E308.
6. It is advisable to use ENiCrFe3 for a joint subject to high temperatures, in sulphurous atmosphere or when one of the base metals contains copper.
7. E309 or E310 may be used when an intermediate composition is not needed in the tank.
8. Use electrode E8015-B2L, E8016-B2 and E8018-B2 for low alloy steel.
9. Use electrode E7015, E7016, E7018 y E7028 for carbon steel.
10. Make a first pass on the Cr-Ni steel with E312; complete the joint with E310.
11. E16-8-2 is recommended to minimize brittleness in extended service at high temperature.
12. Use a special electrode with an intermediate composition (also for the C content) when the hardness of the deposited, hardened and tempered material should equal that of the base material.
13. Use the undesignated electrode 28 Cr according to AWS. The typical composition of the deposited metal is: C =0.10%, Mn = 1.0%, Si = 0.50%, Cr = 29%, N = 0.15%.
14. Use the E308L electrode for cryogenic applications.
15. An undesignated electrode according to AWS. The "S" indicates C = 0.08% max. (E309 contains C =0.04% max.; E317 contains C=0.08% max.)
16. Preheat the Cr-Mo steel. The preheating temperature should be the adequate thickness of the Cr-Mo steel.

E317																		
E317	E317L (15)																	
E308	E308 E347	E347																
E312 E309	E312 E309	E312 E309	E330															
E308L (11)	E308L	E347	E312 E309	E347														
E308L (11)	E308L	E347	E312 E309	E347	E348													
E316L	E316L	E318	ENiCrFe3	E318	E318	E318												
E309Mo	E309Mo	E309	ENiCrFe3	E309	E309	ENiCrFe3 E318	E2209											
E2209 E317L	E2209 E317L	E309Mo	ENiCrFe3	E309Mo	E309Mo	E309Mo	E2209	E2209										
E2209 E317L	E2209 E317L	E309Mo	ENiCrFe3	E309Mo	E309Mo	E309Mo	E2209	E2209	E2594									
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)								
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	(12) E309							
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E410 (4)	E410 E309						
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E410 (7)	E309	E420 E410 (7)					
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E430 (7)	E310 E309	E410 (7)	E430 (7)				
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E309	E309	E309	E309	E309			
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E410 (7)	E310 E309	E410 (7)	E430 (7)	E309	(12) E309		
(4) E309	(4) E309	(4) E309	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309Mo	E309Mo	E309Mo	E410 (7)	E410 (7)	E309	E420 (7)	E430 (7)	E309	(12) E309	(12) E309	
E310 (6)	E310 (6)	E310 (6)	(5) E312	(4) E309	(4) E309	(4) E309	(4) E309	E309Mo	E309Mo	E410 (7)	E410 (7)	E309	E430 (7)	E430 (7)	E309 E310	E309 E310	E309 E310	28Cr (13)E310
AISI 317	AISI 317L	AISI 321	AISI 330	AISI 347	AISI 348	ASTM 316Ti	2304	2205	2507	AISI 403-405-410	AISI 414	AISI 416 (I)	AISI 420	AISI 430	AISI 430F (I)	AISI 431	AISI 440 A-B-C	AISI 446

1.8 STAINLESS STEEL WELDING CONSUMABLES

The main objective when selecting a suitable consumable for a specific welding process and application will be to produce a joint with mechanical, physical and chemical properties equal or superior to those of the base metal, and a welded metal with some improvement, such as corrosion or wear resistance.

A consumable with the same composition as the base metal will have some metallurgical characteristics that may be different and these will depend on factors such as the heat input and the joint configuration, among others.

Once the chemical composition of a consumable that meets the above mentioned main objective has been selected, there may be other secondary objectives that should be taken in consideration such as:

- Manual or automatic welding.
- Welding position. Deposition rate.
- Homologations.
- Efficiency.
- Storage precautions.
- Fumes.
- Costs.

Therefore, it is advisable to ask the consumable supplier for information that helps to select the correct consumable, covering characteristics such as diameter, coating type, solid or tubular wire, type of metal transfer, deposition rate, type of packaging, electrodes/kg, storage precautions, protective material, fumes extraction and cost of certificates.

1.8.1 Mostly used consumables and main standards

Coated electrodes (SMAW):
UNE ISO 3581/SFA 5.4

Solid rod for TIG welding (GTAW):
UNE EN ISO 14343/SFA 5.9

Solid wires for MIG/MAG welding
(GMAW):
UNE EN ISO 14343/SFA 5.9

Flux[2] cored wires for MIG/MAG welding
(FCAW):
UNE EN ISO 17633/SFA 5.22

Solid wire for submerged
arc welding (SAW):
UNE EN ISO 14343/SFA 5.9

Flux[2] for submerged arc
welding (SAW):
UNE EN ISO 14174

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[1] Author's note Appendix 3, page 258.

AWS/ASME SFA Tables 5.4; 5.9 and 5.22 show the main consumables used with each welding process.

In general, consumables for different metals and welding processes are over-alloyed in relation to the base metal to compensate the losses that occur when passing through the electric arc. For example, a sheet of 1.4404 (AISI 316L) has a Cr content between 16.50-18.50%, Ni between 10.0–13.0% and Mo between 2.0–2.5%, while ER 316L rods and wire (UNS S31683) for TIG and MIG welding have Cr contents between 18.0-20.0%, of Ni between 11.0–14.0 and of Mo between 2.0–3.0%. In the case of Ni for duplex steels this over alloy is not only to compensate the losses generated when passing through the arc, it is mainly to improve the formation of austenite and maintain the austenite-ferrite balance.

Coated electrodes are used for both austenitic and duplex steels, rutile types are used for standard applications. But when higher quality welding and better mechanical properties are required, basic electrodes should be used.

Tubular wires can be selected for welding in all positions or specifically horizontally or vertically. It is advisable to follow the instructions regarding the shielding gas and its flow, in order to obtain the weldability offered by the manufacturer.

In submerged arc welding it is recommended to know manufacturer's information of the flux[2] to understand its behaviour regarding various elements and if losses should be expected or if its behaviour is neutral.

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[2] Author's note Appendix 3, page 258.

Table 13. Consumable for stainless steels welding.

Stainless steel to be welded			Commonly used consumables according to UNE EN ISO INOXFIL denominations appear in parentheses				
UNE-EN 10088		AISI -American Iron and Steel Institute-	UNE EN ISO 3581	UNE EN ISO 14343-A	UNE EN ISO 14343-A	UNE EN ISO 14343-A	UNE EN ISO 17633
			Coated electrodes (SMAW) (1)	Varillas TIG (GTAW)	TIG rods MIG/MAG (GMAW)	Submerged arc wires (SAW)	Tubular wires MIG/MAG (FCAW)
X5CrNi18-10	1.4301	304	E 19 9 L	W 19 9 L (ACX 602/603)	G 19 9 LSi (ACX 605)	S 19 9 L (ACX 602/603)	T 19 9 L
X2CrNi18-9	1.4307	304L	E 19 9 L	W 19 9 L (ACX 602/603)	G 19 9 LSi (ACX 605)	S 19 9 L (ACX 602/603)	T 19 9 L
X2CrNi19-11	1.4306						
X5CrNiTi18-10	1.4541	321	E 19 9 Nb	W 19 9 Nb	G 19 9 NbSi (ACX 647)	S 19 9 Nb	T 19 9 Nb
X6CrNiNb18-10	1.4550	347					
X5CrNiMo17-12-2	1.4401	316L	E 19 12 3 L	W 19 12 3 L (ACX 652/653)	G 19 12 3 LSi (ACX 655)	S 19 12 3 L (ACX 652/653)	T 19 12 3 L
X2CrNiMo17-12-2	1.4404	316L					
X6CrNiMoTi17-12-2	1.4571	316Ti	E 19 12 3 Nb	W 19 12 3 Nb	G 19 12 3 NbSi (ACX 618)	S 19 12 3 Nb	T 19 12 3 Nb
X6CrNMoNb17-12-2	1.4580	318					
X2CrNiMo18-15-4	1.4438	317L	E 19 13 4 N L	W 18 15 3 L	G 18 15 3 L	S 18 15 3 L	T 19 13 4 L PC
X10CrNi18-8	1.4310	302	E 19 9 L	W 19 9 L (ACX 602/603)	G 19 9 LSi (ACX 605)	S 19 9 L (ACX 602/603)	T 19 9 L
X2CrNiN18-7	1.4318	301L	E 19 9 L	W 19 9 L (ACX 602/603)	G 19 9 LSi (ACX 605)	S 19 9 L (ACX 602/603)	T 19 9 L
X12CrNi23-13	1.4833	309S	E 23 12 L	W 23 12 L (ACX 709)	G 23 12 LSi (ACX 732)	S 23 12 L (ACX 709)	T 23 12 L
X8CrNi25-21	1.4845	310S	E 25 20	W 25 20 (ACX 610)	G 25 20 (ACX 610)	S 25 20 (ACX 610)	T 25 20
X2CrTi12	1.4512	409	E 19 9 L	W 19 9 L (ACX 602/603)	G 19 9 LSi (ACX 605) G 18 8 Mn (ACX 682)	S 19 9 L (ACX 602/603)	
X6Cr17	1.4016	430	E 19 9 L	W Z18 L Nb (ACX 525) W 19 9 L (ACX 602/603)	G Z18 L Nb (ACX 525) G 18 8 Mn (ACX 682) G 19 9 LSi (ACX 605)	S 19 9 L (ACX 602/603)	T 19 9 L
X3CrTi17	1.4510	430Ti/439	E 23 12 L	W 23 12 L (ACX 709) W Z18 L Nb (ACX 525)	G 23 12 LSi (ACX 732) G 18 8 Mn (ACX 682) G Z18 L Nb (ACX 525)	S 23 12 L (ACX 709)	T 23 12 L
X2CrMoTi18-2	1.4521	444	E 19 12 3 L	W 19 12 3 L (ACX 652/653)	G 19 12 3 LSi (ACX 655)	S 19 12 3 L (ACX 652/653)	T 19 12 3 L
X2CrTiNb18	1.4509	441	E 23 12 L	W 23 12 L (ACX 709) W Z18 L Nb (ACX 525)	G 23 12 LSi (ACX 732) G Z18 L Nb (ACX 525)	S 23 12 L (ACX 709)	T 23 12 L
X6CrMo17-1	1.4113	434	E 19 12 3 L	W 19 12 3 L (ACX 652/653)	G 19 12 3 LSi (ACX 655)	S 19 12 3 L (ACX 652/653)	T 19 12 3 L
X2CrNiN23	1.4362	Duplex 2304	E 23 7 N L/ E 22 9 3 NL	W 23 7 N L/ W 22 9 3 NL (ACX 609)	G 23 7 NL/ G 22 9 3 NL (ACX 609)	S 23 7 N L/ S 22 9 3 NL (ACX 609)	T 22 9 3 N L
X2CrNiMoN22-5-3	1.4462	Duplex 2205	E 22 9 3 NL	W 22 9 3 NL (ACX 609)	G 22 9 3 NL (ACX 609)	S 22 9 3 NL (ACX 609)	T 22 9 3 NL
X12Cr13	1.4006	410	E 13 / E 19 9 L	W 13 / W 19 9 L (ACX 602/603)	G 13 / G 19 9 LSi (ACX 605)	S 13 / S 19 9 L (ACX 602/603)	T 13 / 19 9 L
X20Cr13	1.4021	420	E 13 / E 19 9 L	W 13 / W 19 9 L (ACX 602/603)	G 13 / G 19 9 LSi (ACX 605)	S 13 / S 19 9 L (ACX 602/603)	T 13 / 19 9 L
X30Cr13	1.4028	420	E 13 / E 19 9 L	W 13 / W 19 9 L (ACX 602/603)	G 13 / G 19 9 L (ACX 605)	S 13 / S 19 9 L (ACX 602/603)	T 13 / 19 9 L

(1) There are basically two types of coatings: Basic (B) or with DC (direct current) and rutile or titanium (direct or alternating current.

Note: Page 261 includes Appendix 4 with the characteristics of welding wires supplied by INOXFIL, under rule UNE EN ISO 14343-A.

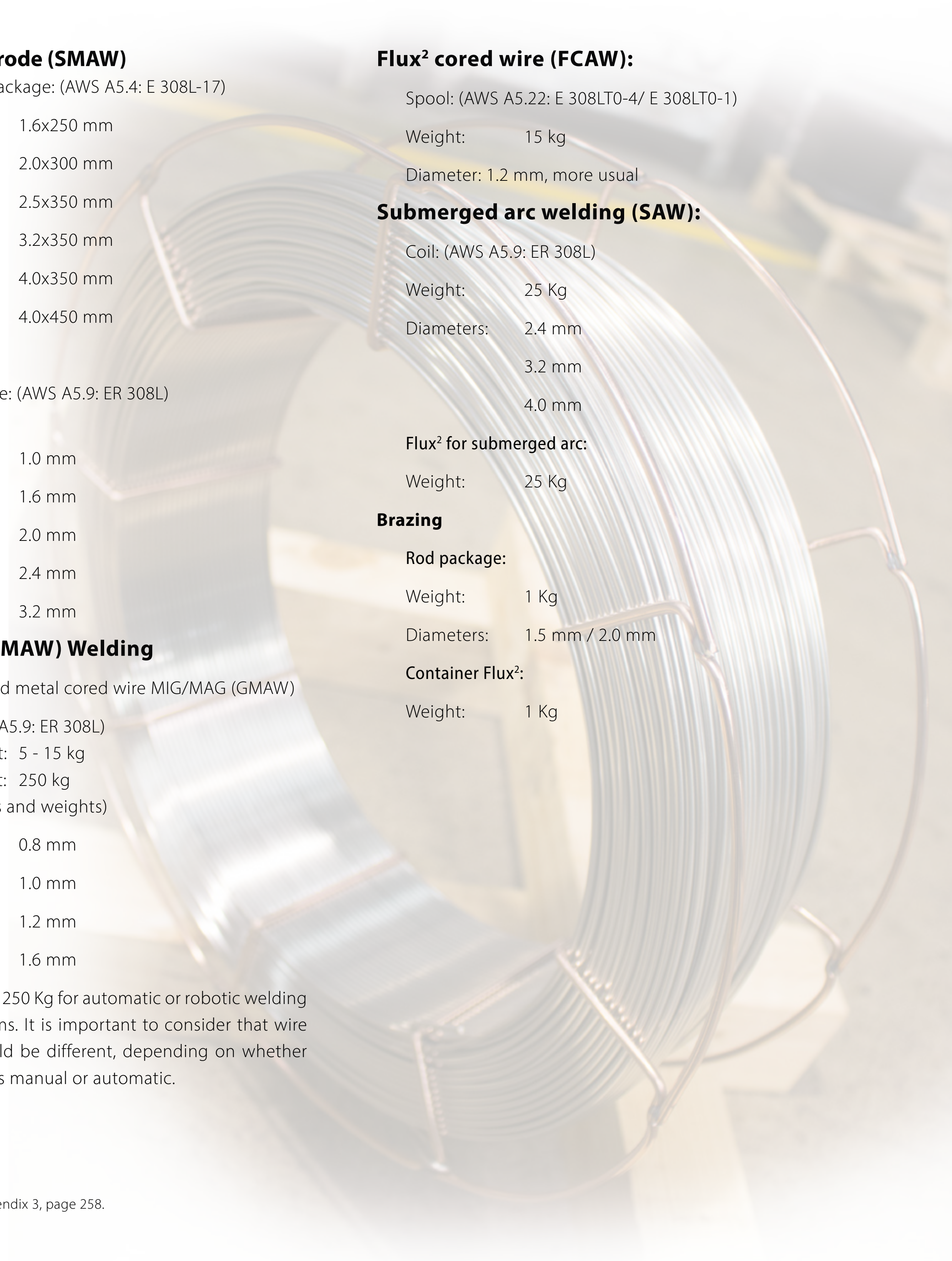
Table 14. Chemical composition of duplex consumables.

Process	ISO	AWS	Cr	Ni	Mo	N	Cu	W
SMAW	(E23 7 NL)	(E2307)	22.5-25.5	8-10	0.1-0.8	0.08-0.20	-	-
	E22 9 3 NL	E2209	21.5-23.5	8.5-10.5	2.5-3.5	0.08-0.20	<0.75	-
	E25 7 2 NL	-	24-28	6-8	1-3	<0.20	<0.75	-
	-	E2553	24-27	6.5-8.5	2.9-3.9	0.10-0.25	1.5-2.5	-
	E25 9 3 Cu NL	E2593	24-27	8.5-10.5	2.9-3.9	0.10-0.25	1.5-3.5	-
	(E25 9 4 NL)	E2594	24-27	8-10.5	3.5-4.5	0.20-0.30	<0.75	-
	E25 9 4 NL	E2595	24-27	8-10.5	2.5-4.5	0.20-0.30	0.4-1.5	0.4-1
FCAW	(T23 7 NL)	(E2307T)	22.5-25.5	8-10	0.1-0.8	0.08-0.20	-	-
	T22 9 3 NL	E2209T	21-24	7.5-10	2.5-4	0.08-0.20	<0.5	-
	(T25 9 4 NL)	E2553T	24-27	8.5-10.5	2.9-3.9	0.10-0.20	1.5-2.5	-
GMAW GTAW (SAW)	(ER23 7 NL)	(ER2307T)	22.5-25.5	8-10	0.1-0.8	0.08-0.20	-	-
	ER22 9 3 NL	(ER2209)	21-24	7-10	2.5-4	0.10-0.20	<0.3	-
	(ER22 9 3 NL)	ER2209	21.5-23.5	7.5-9.5	2.5-3.5	0.08-0.20	<0.75	-
	ER25 7 2 L	-	24-27	6-8	1.5-2.5	-	<0.3	-
	ER25 9 3 CuNL	(ER2553)	24-27	8-11	2.5-4	0.10-0.20	1.5-2.5	-
	(ER25 9 3CuNL)	ER2553	24-27	4.5-6.5	2.9-3.9	0.10-0.25	1.2-1.5	-
	ER25 9 4 NL	ER2594	24-27	8-10.5	2.5-4.5	0.20-0.30	<1.5	<1
	(ER27 9 5 NL)	(ER2707)	26-28	8-10	4-5	0.25-0.35	-	-

Table 15. Mechanical properties of duplex consumables.

Process	ISO/EN	AWS	Yield Strength Rp0.2% (MPa)	Tensile Strength Rm (MPa)	Elongation (%)	Charpy V impact CVN	Corrosion Pitting Temperature CPT (ºC)
SMAW	(E23 7 NL)	(E2307)	675	800	28	40J to -40ºC	15
	E22 9 3 NL	E2209	675	800	28	50J to -40ºC	25
	E25 7 2 NL	-	590	750	25	50J to -50ºC	40
	-	E2553	-	760	25	50J to -50ºC	>40
	E25 9 3 Cu NL	E2593	700	875	25	50J to -50ºC	>40
	(E25 9 4 NL)	E2594	700	875	25	50J to -50ºC	40
	E25 9 4 NL	E2595	700	875	25	50J to -50ºC	>40
FCAW	(T23 7 NL)	(E2307T)	650	800	30	50J to -40ºC	15
	T22 9 3 NL	E2209T	650	800	30	40J to -50ºC	25
	(T25 9 4 NL)	E2553T	675	850	30	40J to -50ºC	40
GMAW GTAW (SAW)	(ER23 7 NL)	(ER2307T)	675	800	30	150J to -20ºC	17
	ER22 9 3 NL	(ER2209)	625	810	30	60J to -50ºC	25
	(ER22 9 3 NL)	ER2209	625	810	30	60J to -50ºC	25
	ER25 7 2 L	-	725	850	30	60J to -50ºC	40
	ER25 9 3 CuNL	(ER2553)	725	850	30	60J to-50ºC	>40
	(ER25 9 3CuNL)	ER2553	725	850	30	60J to -50ºC	>40
	ER25 9 4 NL	ER2594	650	850	25	60J to -50ºC	40
	(ER27 9 5 NL)	(ER2707)	800	950	30	100J to -50ºC	55

1.8.2 Consumables supply types



Coated electrode (SMAW)

Electrodes package: (AWS A5.4: E 308L-17)

Diameters: 1.6x250 mm

2.0x300 mm

2.5x350 mm

3.2x350 mm

4.0x350 mm

4.0x450 mm

TIG welding

Rods package: (AWS A5.9: ER 308L)

Weight: 5 Kg
Diameters: 1.0 mm

1.6 mm

2.0 mm

2.4 mm

3.2 mm

MIG/MAG (GMAW) Welding

Solid wire and metal cored wire MIG/MAG (GMAW)

Spool: (AWS A5.9: ER 308L)
Spool weight: 5 - 15 kg
Drum weight: 250 kg
(various sizes and weights)

Diameters: 0.8 mm

1.0 mm

1.2 mm

1.6 mm

Special drums of 250 Kg for automatic or robotic welding for power systems. It is important to consider that wire tensioning should be different, depending on whether the application is manual or automatic.

Flux[2] cored wire (FCAW):

Spool: (AWS A5.22: E 308LT0-4/ E 308LT0-1)

Weight: 15 kg

Diameter: 1.2 mm, more usual

Submerged arc welding (SAW):

Coil: (AWS A5.9: ER 308L)

Weight: 25 Kg

Diameters: 2.4 mm

3.2 mm

4.0 mm

Flux[2] for submerged arc:

Weight: 25 Kg

Brazing

Rod package:

Weight: 1 Kg

Diameters: 1.5 mm / 2.0 mm

Container Flux[2]:

Weight: 1 Kg

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[2] Author's note Appendix 3, page 258.

1.9 WELDING PROCESSES AND HEAT INPUT

The most commonly used processes for welding and cutting stainless steels are:

Fused joining processes, where the edges of the joint are heated to a temperature higher than that of the metals to be joined. It may be with or without consumable (autogenous).

Shielding Metal Arc Welding - SMAW

Gas Tungsten Arc Welding - GTAW

Gas Metal Arc Welding - GMAW

Flux[2] *Cored Arc Welding - FCAW*

Plasma Arc Welding - PAW

Submerged Arc Welding - SAW

Laser Beam Welding – LBW

Laser Hybrid Welding

Electrical resistance joining procedures, using clean parts subjected to pressure, to allow good contact between the surfaces to be joined. Heat is generated by the electrical resistance of metals at the interface of the pieces to be joined, due to the flow of the electrical current. The general process is called Resistance Welding (RW).

Resistance Spot Welding – RSW

Projection Welding – PW

Resistance Seam Welding – RSEW

Flash Welding – FW

Upset Welding – UW

High Frequency Welding

Joining processes for clean pieces, in solid state and with no filler material, a non-consumable rotary tool is used, which generates heat by friction, producing the necessary strains, without melting the material.

Friction Stir Welding – FSW

Joining processes without melting the metals to join, through an overlap connection which should have an appropriate capillary gap. A deoxidant (flux[2]) acts on the surfaces to be joined that form the capillary gap, and an alloy consumable is used with a melting range below the melting temperature of the metals to be joined which should penetrate through the capillary gap. There are two types depending on the melting temperature of the filler metals. Brazing with melting temperature >450ºC and Soldering with melting temperature <450ºC.

Welding with low melting point

Brazing-B

Soldering-S

Cutting procedures, where the heat needed to produce the cutting is generated by plasma arc or laser beam.

Plasma Arc Cutting - PAC

Laser Beam Cutting - LBC

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[2] Author's note Appendix 3, page 258.

1.9.1 Heat input from the welding process and relative thermal efficiency

The contribution of theoretical heat which is transferred to the joint by an electric arc welding process is given by the formula:

$$\text{Heat input (J/cm)} = \frac{\text{Voltage (V)} \times \text{Intensity (A)}}{\text{Welding speed (cm/minute)}} \times 60 \times \eta$$

The η factor (thermal efficiency) is defined for the welding process, which takes into account, with the same heat input, the relative heat loss for each process.

For example, if slag is produced, as in the case of welding with coated electrode, submerged arc or MIG/MAG (FCAW), the protection of the weld pool by these slags reduces the heat lost by radiation and these processes will have higher thermal efficiency (Table 16). This produces the first estimation. Changing the process, without changing the heat input (parameters), could direct more or less heat to the joint.

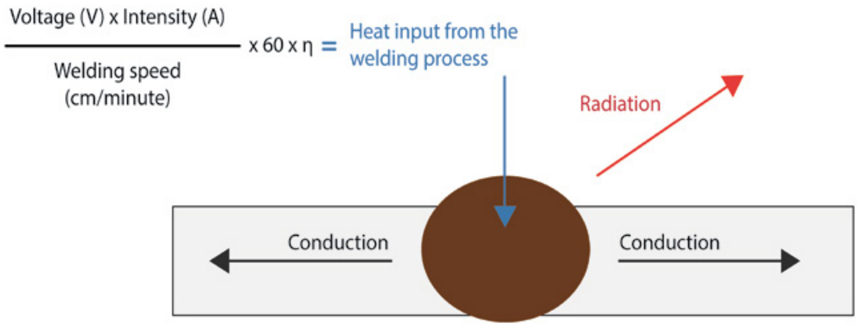
Table 16. Relative thermal efficiency of the main welding processes

Welding procedure	Relative thermal efficiency (η)
TIG	0.65
MIG with Ar	0.70
MAG with CO_2	0.85
Coated electrode	0.90
Submerged arc	1.0

1.9.2 Heat input balance of a welding process

The heat input from the process should be sufficient to (Fig. 21):

- Increase the temp. of the base metal.
- Latent heat of fusion of the molten base metal.
- Increase the temperature of consumables.
- Melting heat of melted consumables.
- Heat lost by radiation.
- Heat extracted from the joint by conduction through the joined metals and any supports and tooling.



$$\text{Heat input (J/cm)} = \frac{\text{Voltage (V)} \times \text{Intensity (A)}}{\text{Welding speed (cm/minute)}} \times 60 \times \eta = \begin{array}{l}\text{Increase of the base metal temperature}\\ \text{Latent heat of fusion of the molten base metal}\\ \text{Increase the consumables temperature}\\ \text{Melting heat of melted consumables}\end{array} + \text{Radiation} + \text{Conduction}$$

Fig. 21 - Balance of heat input with an electric arc welding process.

1.9.3 Variables that influence heat input by the welding process

In addition to the relative thermal efficiency (η), it is necessary to take in consideration other factors relating to the metal type, its physical properties (thermal conductivity and electrical resistivity), thickness, type of joint, use of copper supports with or without refrigeration, tools to remove part of the heat intended for welding and shielding gas

Although some of these factors are difficult to quantify, they may be taken in a relative manner, which helps to have a criterion that allows modifying the parameters to maintain the joint quality and to maintain or increase productivity.

1.9.3.1 Physical properties of the metal to be welded

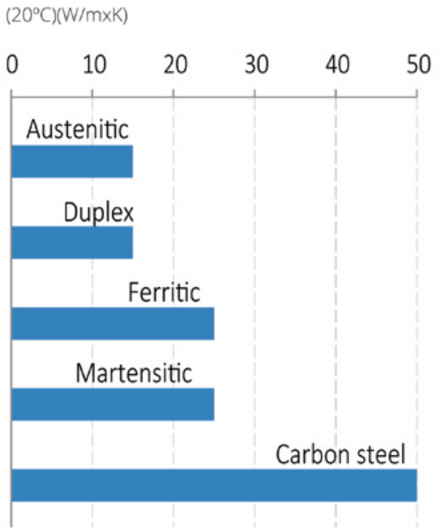
Variables that affect the energy balance will affect welding. The fundamental variables are thermal conductivity, coefficient of thermal expansion and electrical resistivity

	Units	Austenitic		Austenitic-ferritic (duplex)		Ferritic		Martensitic		Carbon steel
Density	(Ton/m^3)	8.0		8.0		7.8		7.8		7.8
Coefficient of thermal expansion (0-538ºC)	10^{-6}m/m/ºC	17-19		14		11-12		11.6-12		11.7
Thermal conductivity (20ºC)	W /(m·K)	16.2		17		24-26		28.7		51
Electrical resistivity	(Ωxmm^2)/m	0.75		0.75		0.60		0.60		0.19
Melting point		AISI	ºC	EN	ºC	AISI	ºC	AISI	ºC	ºC
		304 304L	1400-1450	1.4462	1385-1445	409	1480-1530	410	1480-1510	1540
		316 316L	1375-1400			430	1425-1510	420	1450-1510	

Table 17. Physical properties of stainless steel.

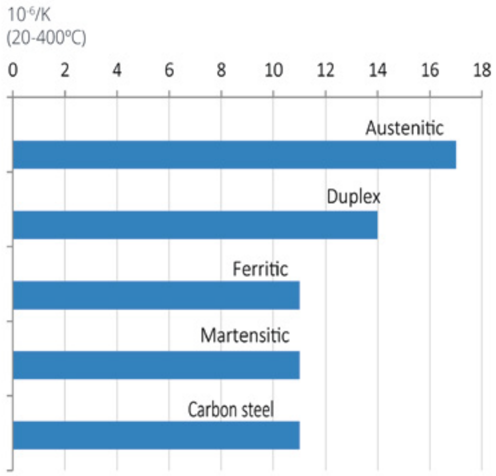
Thermal conductivity:

Low thermal conductivity steels, such as austenitic and duplex steel, will concentrate heat near the weld, producing a high temperature gradient with the rest of the metal, which will increase the tendency to generate strains. Likewise, the temperature of the weld and the heat affected area will remain sufficiently high to allow carbides to form and intermetallic phases to precipitate. It is especially important consider this property when different metals are welded in the same welding workshop, as there is great difference between their thermal conductivity values.



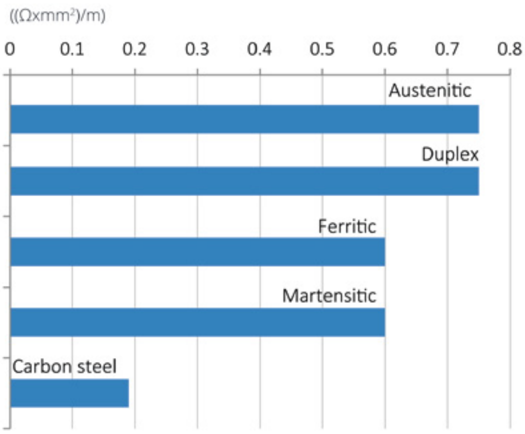
Coefficient of thermal expansion:

It is important because when is high, such as in austenitic stainless steels where it is around 50% higher than in carbon, ferritic or martensitic steel, significant strains will occur. To minimize strain, the coefficients should be closer than for carbon steel. Duplex steels have an intermediate value.



Electrical resistivity:

If it is high, such as in austenitic and duplex steel, the current required for the same heat input is reduced, in comparison with carbon, ferritic and martensitic steels with lower electrical resistivity. If the metal also has lower melting temperature, as in austenitic stainless steel, the intensity required to weld will be lower



1.9.3.2 Variables that affect the joint type and edge preparation

These may affect welding quality and productivity:

Type of joint:

This influences the cooling rate. Taking the butt joint as a reference, Fig. 22 shows examples of joint types and their influence on heat dissipation in 2 and 3 dimensions, for thin and thick materials.

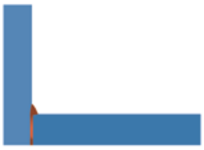
Type of joint	Heat dissipation for 2 dimensions	Heat dissipation for 3 dimensions
	1	1
	0.45-0.67	0.67
	0.9	0.67
	0.9	0.9

Fig. 22 - Examples of joint type and their influence on heat dissipation.

Thickness:

In thin materials, heat dissipation at the weld bead is parallel to the sheet surface in two dimensions. When the material is thick, heat dissipation is in three dimensions.

Heat dissipation in two dimensions is lower than in three. Therefore, thin materials are easier to weld and the heat affected area can be exposed to high critical temperature for longer leading to the formation of carbides and intermetallic phases.

Edge design and tolerances:

The fluidity of the weld pool is important. In stainless steel it is less fluid than in carbon steel. Therefore, penetration will be lower with the same parameters. In order to achieve sufficient penetration, the joint will require bezels with higher angles, thinner beads and larger root openings than for carbon steel.

It is most convenient to machine the edges, but a grinder or beveller may be used with appropriate discs if burrs are removed, to leave uniform and technical gaps and avoid overheating the stainless steel. The tolerances for robotic or automatic welding must be lower.

Good joint fit allows the welder to weld with straight beads, without oscillations, with a low heat input and fewer defects.

Edge Cleaning:

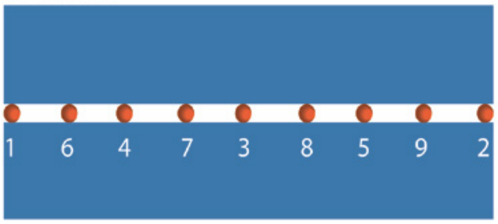
If plasma or laser cutting is used to prepare the edges, high melting point slags are produced. If these slags are not removed before welding, they may get incorporated into the weld creating corrosion points and internal stresses. Brushing with a stainless steel brush may not be enough to remove the strongly attached slag.

Tack weld and fix

Tack weld is required before welding, at the correct separation, to fix the assembly to be welded. Tack weld for austenitic stainless steels should be closer than carbon steel, ferritic and martensitic stainless steel, because their coefficient of linear expansion is around 50% higher, which will cause higher strain. Tack weld for duplex stainless steel, should be at intermediate level, because they have average coefficient of expansion.

If a tack weld sequence is not established, the edge separation will close, which will not allow for correct penetration. In order to avoid this and to allow adequate heat distribution, correct tack weld sequence and interval should be used. (Figure 23)

WRONG



RIGHT

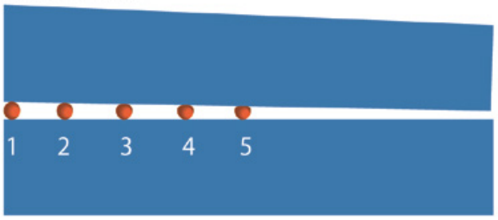


Fig. 23. Tapping sequence.

Thickness (mm)	1 - 1.5	2-3	4-6	>6
Distance between taps	30-60	60-120	120-160	160-200

1.9.3.3 Influence of shielding gas in heat input

The use of a gas or mixture for a given welding process may alter the heat input to the weld.

For example, in automatic TIG welding of austenitic stainless steel, 2-10% of the argon is usually replaced by hydrogen. With the Ar- 5% H_2, mixture, voltage increase will be obtained for the same current, which will increase the heat input to the joint. This higher input may be used to increase penetration or increase the welding rate.

Likewise, the heat input may be increased, with the same intensity, using Ar-He mixtures. (Fig. 24).

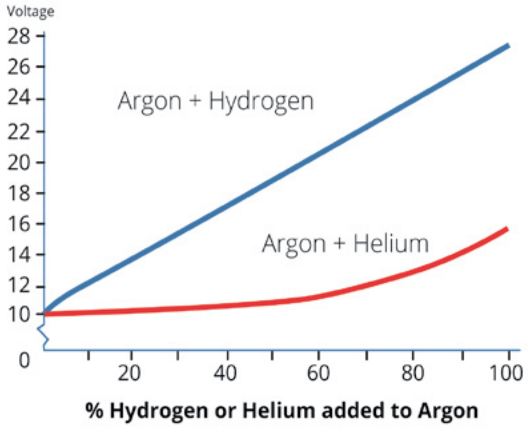


Fig. 24 - Ar-He

1.9.4 General precautions when welding stainless steel

The following should be considered:

- The micro structure may be predicted from the chemical composition with the help of diagrams such as Shaeffler or De Long and the cooling rate of the weld.
- The welding cooling rate depends mainly on the thermal conductivity of the steel, thickness, process, parameters and efficiency of the welding process.
- Technological properties, such as mechanical strength, ductility/formability, and corrosion resistance in various media.
- Three different areas:
    1. The non-welded area with standard and known steel micro-structure, mechanical properties and corrosion resistance.
    2. The welded area, formed by the dilution of melted metals being joined and the consumable, if any.
    3. The heat affected zone, with a micro structure, mechanical properties and corrosion resistance that will depend on the variables of the welding process.
- A preliminary welding procedure should be carried out, to avoid the risk of unexpected defects, when welding new structural forms or steels.

Austenitic stainless steels:

In general, they have excellent weldability. It is desirable for the final weld to be around 5% ferrite, with the dilution between the base metal and consumable. Appropriate heat input for most austenitic steels should be around 2.5 KJ/mm. If the weld is of stabilised steel or totally austenitic, lower heat input contributions in order of 1.5 KJ/mm, should be used to avoid hot cracking. Austenitic steels have a coefficient of thermal expansion 50% higher than ferritic and duplex steels. This means that welding will produce higher deformations and stresses.

Austenitic manganese steels offer relatively high corrosion resistance at a moderate cost. These steels have lower weldability than that of the standard austenitic Cr-Ni stainless steels.

Ferritic stainless steels:

The main limitations of ferritic steels welding in relation to the austenitic steels, is the lack of toughness in thick materials.

Welding properties are strongly affected by welding parameters. Heat input as low as possible is recommended to avoid grain growth in the heat affected zone.

The use of electrodes with moisture or shielding gases containing hydrogen should be avoided.

Due to the lower coefficient of thermal expansion and higher thermal conductivity of ferritic steels, deformations, overlaps and stresses during welding will be lower compared to austenitic and duplex steels.

Duplex stainless steels:

The weldability and welding characteristics of duplex steel are better than those of ferritic steel, but in general inferior to those of austenitic steel. The latest duplex steels with higher nitrogen content have better weldability. Welding properties are strongly influenced by welding parameters and therefore by heat input, so it is important to follow a correct welding procedure to obtain an appropriate joint.

Duplex steels solidify with a strongly ferritic structure from which partly becomes austenite during cooling. Consumables have higher nickel content to obtain a ferrite-austenite balance similar to that of the base metal. Autogenous welding, (without filler consumable), is not normally recommended for duplex steels. The duplex micro structure is more sensitive to multipass welding than austenitic steels. In order to reduce this effect, it is necessary to maintain an inter pass temperature of 150ºC for standard and lean duplex steels and 100ºC for super duplex steels

Martensitic stainless steels:

Martensitic steels can be hardened, so are more difficult to weld than other types of stainless steels. Welding produces martensite in the heat affected area, which is prone to cracking. Hardness increases with carbon content and makes welding more difficult. The presence of hydrogen increases the risk of hydrogen induced cold cracking.

However, martensitic steels may be welded, with the appropriate precautions to avoid cracking. Preheating, post weld heat treatment and appropriate consumables are all required to obtain reliable joints. If post weld heat treatment is not possible, austenitic or duplex consumables should be used to improve ductility.

1.10 WELDING PROCESS SELECTION GUIDE

The following information provides a quick review of the main characteristics of commonly used welding procedures

WELDING PROCEDURE	CHARACTERISTICS
Coated electrode (SMAW)	• Most suitable for outside welding. • More appropriate than other processes, due to assistance from the coating, when the metal is not clean, or for repairs. • High quality welds may be obtained using basic electrodes, with good mechanical properties and low porosity level. • Slag cleaning and low arc time make the cost high..
TIG (GTAW)	• The welder needs good training in order to achieve the quality offered by this process. • The highest weld quality can be achieved, with good penetration, low porosity level and with very little finishing work. • Most widely used process for high quality pipe welding. • Thin materials can be welded without consumables (Autogenous welding). • Heat input control is improved using pulsed TIG, for thin materials, with fewer deformations. • Welding speed can be increased for austenitic steels using Ar-H_2 mixtures, especially in automatisms. • Suitable for stainless steel cladding on carbon steel with good dilution control (5-10%).
PLASMA WELDING (PAW)	• When a TIG process is automated, it usually becomes plasma welding. The "pilot" arc produces an easy start arc without failure. • Plasma arc penetration is narrower and deeper, while TIG arc penetration is wider and shallower. • The joint preparation to plasma welding should be higher quality, with closer tolerances than TIG process. • Plasma welding can be faster than the TIG procedure. Shielding gas may help increase the speed. • The plasma procedure avoids inclusions of tungsten electrode in the weld pool. • Although the cost of plasma equipment is slightly higher than the cost of TIG equipment, the total cost of the weld joint is usually lower using the plasma procedure, due to these differences.
MIG/MAG (GMAW) with solid wire or tubular metal cored	• Easy to learn. • High welding and deposition rates, but lower than for submerged arc welding, although with poorer quality than TIG. It can join thin materials with pulsed arc transfer and appropriate shielding gas. • Welds with low slag content are possible, with adequate shielding gas. • When welding stainless steel, spatters should be avoided as they are potential corrosion points. In these cases, pulsed arc should be preferred or spray arc for thick materials.

MIG/MAG (FCAW) with tubular wire flux[2] cored with slag	• Easy to learn. • The recommendations of the wire manufacturer should be considered regarding the wire length and the shielding gas, to achieve good slag separation. • Slag, like coated electrode welding and shields, supports and helps improve the molten pool. It has higher tolerance to contaminants and cleanliness requirements than MIG / MAG welding (GMAW), which may cause cracking and pores. • A higher deposition rate is achieved with tubular wire than with solid wire, therefore higher productivity may be obtained with FCAW tubular wire than with solid MIG / MAG wire. • In terms of cost it is necessary to consider the time to eliminate the slag and the lower efficiency of tubular wire compared to solid wire, as it contains flux[2] and formers of slags. • Drag, feeding to weld pool and storage (humidity) of tubular wire is always more critical than for solid wire. • It releases more fumes than the GMAW and SAW process. • Self-shielded wire eliminates the requirement for gases (MIG / MAG) and permits welding outside.
SUBMERGED ARC WELDING (SAW)	• Higher welding and deposition rates. • Welds of excellent quality with low porosity level can be achieved. • The welder is not subject to radiation from the electric arc, as welding is automatic and under flux[2]. • It is used in cladding of stainless steel on carbon steel, with one or several wires and with band. • Although most applications are for materials over 6 mm thick, there are also applications for thinner materials.
LASER BEAM WELDING (LBW)	• Needs joints with reduced gaps, as a general rule, less than 10% of the thinnest material to be welded. • Quality welds with little finishing work. High welding rate. • Good penetration. • Good control of heat input on thin materials and with low strains. • No contact with the piece to be welded is necessary. • Generally it is used in one pass, on one side and without filler consumable. • The process cost, safety, edge preparation, tooling and elimination of potential plasma formation that distorts the beam should be considered.
HYBRID LASER ARC WELDING (LAHW)	• The consumable filler allows the laser to be used on thicker materials, to weld materials with higher tolerances, to improve the quality of the welding and to control hot cracking.

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[2] Author's note Appendix 3, page 258.

TORCH BRAZING – TB	• This procedure is only appropriate for certain applications, as it does not melt the metals to be joined and uses an alloy as the consumable with physical and chemical properties dissimilar to those of stainless steel. • Low cost of initial investment in torch, gas cylinders and safety measures is necessary. • Reduced maintenance costs • Economical for complicated assemblies. • The joints need little of no final review, but the remains of the flux[2] should be eliminated • Expert welders with the required torch skills are needed, they need to know the safety precautions for handling of gas cylinders and work point, in the case of piped oxygen, acetylene or propane gases. • The cleanliness of the joint is essential to facilitate a wetting action and for the alloy can penetrate. • The design of the joint to form the capillary may have a high cost. An excessive gap may increase consumable alloy use and increase the cost of each joint. This is especially important when the consumable alloy has a high Ag content. • Dissimilar metals may be joined, as any differences between their properties will not cause any problems, because neither metal melts. • If necessary, assemblies made may be disassembled. • Complicated joints may be produced, without deformations, where accuracy and repeatability are necessary. • Residual stresses are small, if any. • Several parts may be pre-assembled and all the welds may be performed at the same time. • If a significant number of repetitive joints are required, this process can be easily automated. • If necessary, the joints can be easily repaired.
TORCH SOLDERING – TS	• Soldering is similar to brazing, as the metals to be joined are not fused and they have similar joint execution stages. • Soldering differs from brazing as: • Melting temperature of the filler alloy should be below 450ºC while in brazing it should be higher than this temperature. • Mechanical properties are lower than brazing. • Alloy cost is lower in soldering.
RESISTANCE SPOT WELDING (RSW)	• This is limited to lap joints. • In general, the skills required by the operator is less than that required for arc welding. • The initial investment cost of welding equipment may be high, depending on the dimensions and the degree of automation. • Ease of automation and possibility of high production volumes. • No filler consumables or shielding gas are needed.

SELECTION CRITERIA / PROCESS		COATED ELECTRODE (SMAW)	TIG (GTAW)	PLASMA/WELDING PAW	MIG/MAG - (GMAW) Solid or tubular cored	MIG/MAG - (FCAW) Flux[2] cored wire with slag	SUBMERGED ARC (SAW)	LASER BEAM WELDING (LBW)	HYBRID LASER WELDING (LAHW)	TORCH BRAZING- (TB)	TORCH SOLDERING (TS)	RESISTANCE SPOT WELDING (RSW)
Training level		2	3	3	1	1	2	4	4	2	2	1
Process	Manual	M	M	M(a)	M	M				M	M	
	Automatic/robot		AT	AT	AT		AT	AT	AT	AT	AT	AT
Type of joint	Butt	A	A	A	A	A	A	A	A			
	T type	A	B	B	A	A	B	B	B			
	Lap									A	A	A
Welding position	All	T	T	T	T(e)	T(e)		T		T	T	T
	Flat and Horizontal in angled						H		H			
Equipment portability		4	3	3	3	3	2	1	1	4	4	1
Equipment investment cost		1	2	2	2	2	3	4	4	1	1	3
Operating factor		1	2	2	3	3	4	4	4	1	1	4
Deposition rate		2	1(f)	1	3	3	4	1	3	1	1	(NA)
Use of filler consumable		1	4	4	3	2	4(b)	4	4	2	2	(NA)
Welding rate		2	1(f)	4	3	3	4	4	4	1	1	4
Thickness to be welded (mm)												
0.02-0.5		D	B	A	D	D	D	A	D	A	A	A
0.5-1.25		C	A	A	B	C	D	A	D	A	A	A
1.25-2.5		B	A	A	B	C	D	A	D	A	A	A
2.5-6.0		B	A	A	A	B	C	A	B	A	A	A
6.0-12.0		A	B	B	A	A	B	B	A	D	D	D
12-24		A	C	C	A	A	A	C(c)	B	D	D	D
24-60		A	C	C	A	A	A	D	C	D	D	D
>60		A	C	C	A	A	A	D	D	D	D	D
Ease of welding (thin to thick)		B	A	A	B	B	C(d)	B	B	D	D	D

NA	Not Applicable	**C**	Restricted use	
A	Most suitable	**D**	Not recommended	
B	Satisfactory	**1** Lowest	**4** Highest	

(a) Although it may be used in manual processes, automatic processes are preferred.

(b) Refers to wire, a part of the flux[2] is removed in the form of slag and the rest is recycled..

(c) Welding on both sides.

(d) Although most of the applications are in materials > 6 mm, there are applications for thinner materials.

(e) Using short or pulsed arc transfer.

(f) Using several welding torches and/or with threaded filler, the deposition rate (kg / h) and the welding rate (m/min) may be increased.

M Manual process.

AT Automatic or robotic process.

T All positions.

H Flat and Horizontal in angled

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[2] Author's note Appendix 3, page 258.

2 TIG process. *Gas Tungsten Arc Welding -GTAW*

2.1 PROCESS DESCRIPTION

The TIG (Tungsten Inert Gas) procedure, also known as GTAW (Gas Tungsten Arc Welding), was initially developed for stainless steel welding and welding of metals and alloys that are difficult to weld. After a few years, its use has expanded to welding and refacing of most commercial metals.

The TIG procedure (Fig. 25) is an electric arc welding process in which an inert gas is used to shield the joint area from the atmosphere. The heat required for welding is generated by an electric arc that jumps between a tungsten electrode, which is hardly consumed and the piece of metal to be welded. The TIG process differs fundamentally from MIG/MAG welding in that the electrode does not melt neither or is used as filler metal consumable. This separation between the heat input and the supply of consumable allows the TIG procedure to achieve better penetration.

Joints where filler metal is needed, the weld pool is fed with a rod that melts with the base metal, in the same manner as oxyacetylene welding.

Where the filler material is needed during automated TIG welding, coiled wire is supplied to the weld pool through a feeder.

Process designation

- **TIG (Tungsten Inert Gas)**
- **UNE – EN ISO 4063: 2011**

Process 141:

Arc welding with inert gas and tungsten electrode, with solid wire or rod solid as consumable. TIG welding.

Process 142:

Arc welding with inert gas and tungsten electrode, without filler consumable (autogenous). TIG welding.

Process 143:

Arc welding with inert gas and tungsten electrode, with tubular wire or rod tubular as consumable. TIG welding.

Process 145:

Arc welding with reducing shielding gas and tungsten electrode, and solid wire or rod solid as consumable.

Process 146:

Arc welding with reducing shielding gas and tungsten electrode, with tubular wire or rod tubular as consumable. TIG welding.

Process 147:

Arc welding with active gas and tungsten electrode. TAG welding (Tungsten Active Gas).

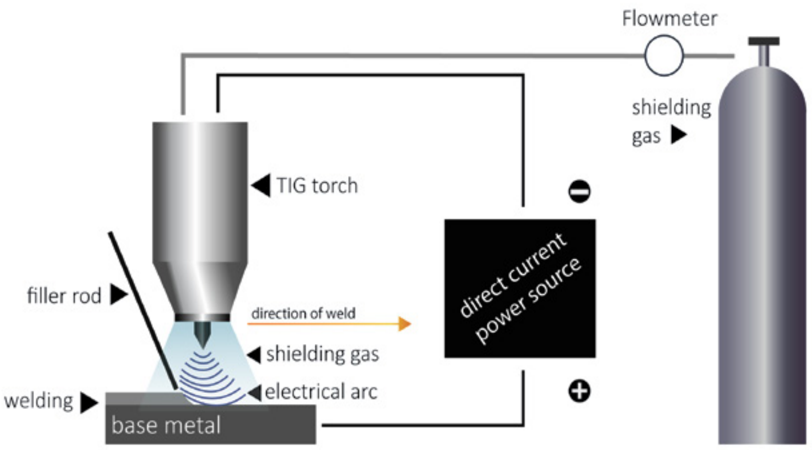


Fig. 25 -. TIG process.

2.2 ADVANTAGES AND LIMITATIONS

ADVANTAGES

1. Welding quality superior to other ordinary processes.
2. Penetration control is better than for other processes. This is especially important in the root pass in weld of pipes, welding thin materials and refacing.
3. The TIG process with pulsed arc allows a better control of the heat input and minimizes strains.
4. Welding in all positions.
5. Heat input and consumable input can be independently controlled. This is important to control penetration.
6. No slag is produced so it is easier to use this process for automatic or robotic welding.
7. Potential corrosion due to slag inclusions is eliminated.
8. Welding takes place without spatters.
9. Cleaning after welding is minimal.
10. Almost all industrially used metals may be welded. For example, stainless steel, aluminium, copper, nickel and its alloys, carbon and low alloy steels

LIMITATIONS

1. The deposition rate (Kg/h) for manual welding is lower than for other processes.
2. Expert welders are required, to achieve optimal quality manual welds.
3. It is an economical process for thin materials (<10 mm). The process profitability may be improved if it can be automated.
4. The process is very sensitive to wind, that may eliminate the shielding gas.
5. It requires good protection against ultraviolet radiation.

2.3 CURRENT TYPES

A TIG welding installation may supply direct current (DC) or direct and alternating current (DC/AC). The welding characteristics for each current are very different, so it is important that these are understood.

2.3.1 Welding with direct current -DC

When welding with direct current, the circuit may be connected with "straight polarity" or with "reverse polarity".

The connection with straight polarity (DCSP) has the electrode connected to the negative pole and the piece to be welded to the positive pole. The electrons circulate from the electrode to the piece to be welded, as indicated in Fig. 26.

Direct current welding with reverse polarity (DCRP) has the opposite connections, and now the electrons circulate from the piece to the electrode, as indicated in Fig. 27.

When welding with straight polarity, the electrode is sharp and the electrons produce considerable heating effect on the metal.

When welding with reverse polarity, the electrode is not sharp and it is exactly the opposite case, the electrode receives most of the heat which may melt the electrode. Therefore, for any given current, a larger diameter electrode is required when welding with DCRP than with DCSP.

These opposite heating effects do not only affect welding, but they also influence the weld penetration. CCPD welding will produce a narrower and deeper penetration, while CCPI welding, due to the larger diameter of the electrode and the lower current intensities that are generally used, produces a wider and relatively shallow weld. These differences may be seen in Figures 28 and 29.

The electrons leave the electrode. Most of the heat is received by the metal. The electrode is smaller in diameter.

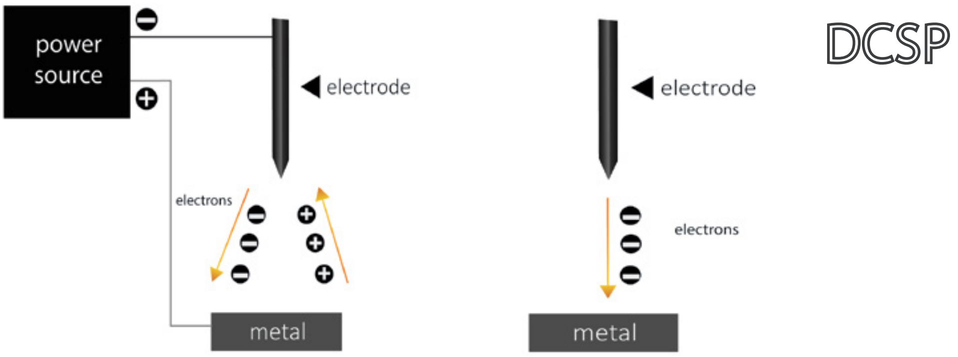


Fig. 26 - TIG welding with DCSP.

The electrons come out of the metal. Most of the heat is received by the electrode. The electrode is of larger diameter. DCRP

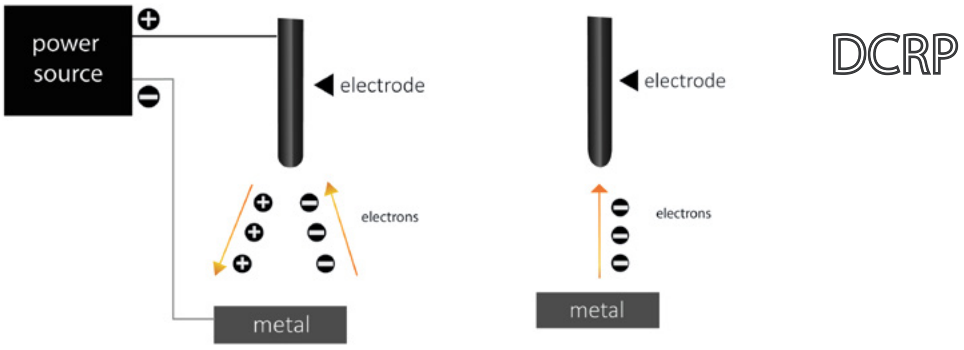


Fig. 27 - TIG welding with DCRP.

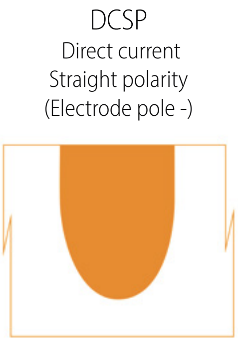


Fig. 28 - Type of penetration, direct polarity.

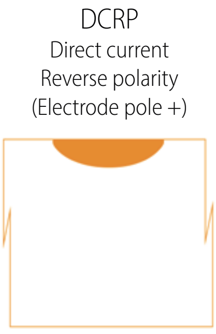


Fig. 29 - Type of penetration, reverse polarity.

Although aluminium welding usually uses alternating current, it is important to consider the "cleaning effect" that takes place with direct current reverse polarity (DCRP). The surface "cleaning effect" takes place as the electrons exit the metal and they break the surface oxide layer.

2.3.2 Welding with alternating current -AC

Theoretically, welding with alternating current AC is a combination of welding with DCSP and welding with DCRP. This may be better explained by graphically showing the three current classes. Figure 30 shows how an alternating current may be formed by a half wave of DCSP and another half wave of DCRP.

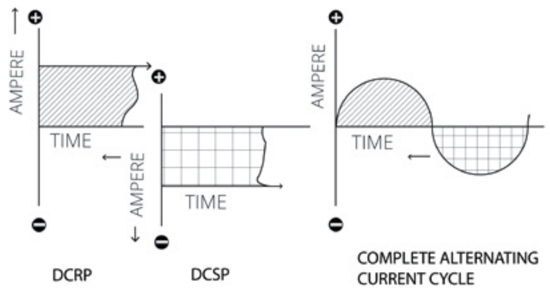


Fig. 30 - Alternating current.

In reality, moisture, oxides, etc., on the surface of the piece tend to partially or completely prevent current circulation in the reverse polarity direction. What happens is a current rectification. For example, if no current flows in the direction of the reverse polarity, the current wave is represented by Fig. 31.

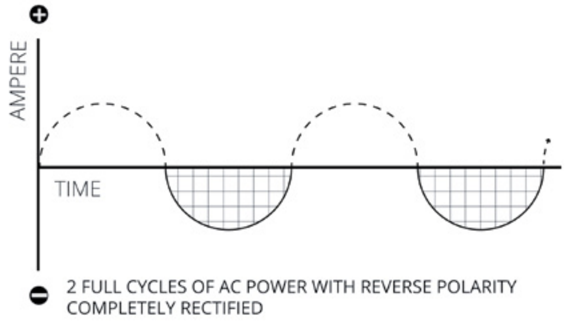
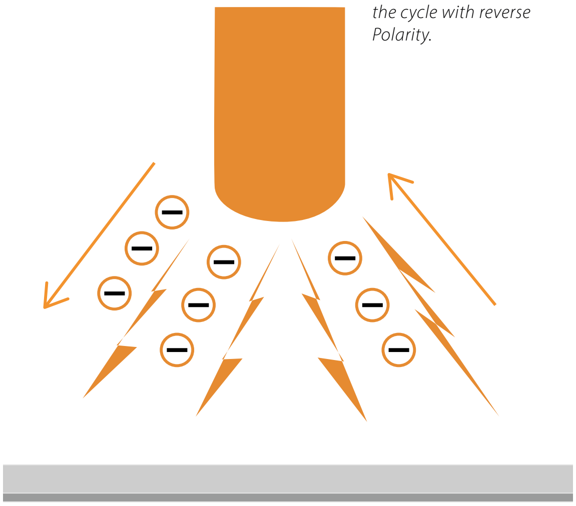


Fig. 31 - Rectification of alternating current.

This is avoided by adding a high voltage and high frequency current to the welding current. This high frequency current jumps the space between the electrode and the piece to be welded, passing through the oxide film and thus opening the way for the welding current to follow Fig. 32



High frequency produces ionization and helps the electrons begin to flow during the cycle with reverse Polarity.

Fig. 32 - Effect of high frequency.

By superimposing this high frequency current on the welding current, the following advantages are obtained:

1. The arc may be initiated without the electrode touching the piece to be welded.
2. Better electric arc stability is achieved.
3. It is possible to make a longer arc. This is useful, in particular, in refacing operations.
4. Tungsten electrodes have a longer useful life.

Fig. 33 shows a typical profile to compare the welding produced with alternating current AC stabilized with high frequency and welding with DCSP and with DCRP.

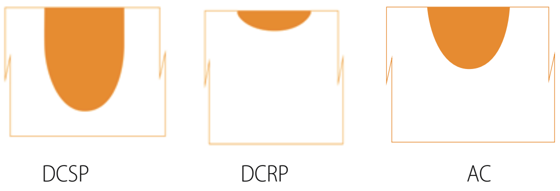


Fig. 33 - Different types of penetrations depending on the connection used

2.3.3 Welding with alter current square wave

Aluminium TIG welding with alternating current with sine wave may not meet the most stringent quality requirements due to:

1. Tungsten inclusions due to excessive electrode current.
2. Alumina inclusions.
3. Large weld pools.
4. Welding in difficult positions.

Square wave equipment allows better quality due to:

1. The wave can be adjusted by current and time, to improve penetration or cleaning. (Fig. 34)
2. It improves the cleaning effect.

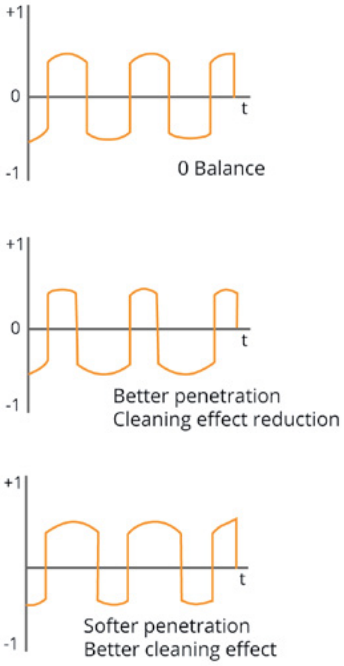


Fig. 34 - Wave adjustment in current and time.

2.4 TIG PROCESS COMPONENTS

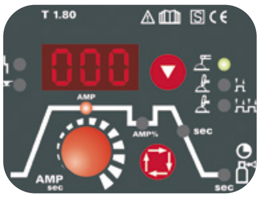
It consists of:

1. Power supply or Energy group.
2. Torch and spare parts.
3. Gas supply with regulator.

POWER SUPPLY OR ENERGY GROUP

When selecting the welding equipment, it is important to decide which benefits are required:

- Welding with direct current for stainless steel, carbon steels, copper, nickel and titanium welding.
- Alternating current welding to weld aluminium, magnesium and their alloys.
- Installation for fixed or portable station.
- Maximum intensity that will be needed.
- Utilization factor.
- Manual welding or automatic or robotic assembly, in which case it will be necessary for the equipment to be prepared to accept the necessary interface connection.



Portable TIG equipment 180A, at 35%
Welding current: 5-180A
Duty Cycle 35%:
180A
Vacuum voltage: 90 V
Pulsed arc
Arc start: with high frequency HF and Lift arc (by contact)
Weight: 6.9 Kg
Dimensions: 430x135x250.
Digital display: with gas pre-flow, start current with ramp up, welding current, soft final current with ramp down and gas backflow.

Fig. 35 - Portable TIG equipment.COURTESY OF NIPPON GASES

Fixed workstation TIG equipment 560A, at 60% water cooled
Current: 5-560 A
Duty cycle 60%: 560A
Duty cycle 100%: 420 A
Vacuum voltage: 79 V
Pulsed arc /Water cooled/Weight: 128 Kg
Dimensions: 1080x690x1195 mm.
Digital display: with gas pre-flow, start current with up ramp, welding current (standard and pulsed), soft final current with down ramp and gas post-flow

Fig. 36 - Fixed workstation TIG equipment. COURTESY OF NIPPON GASES

WELDING TORCH

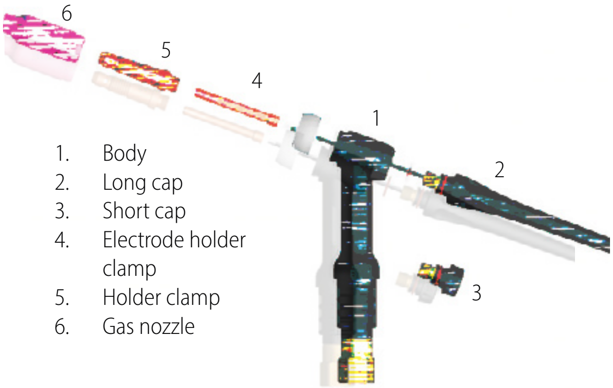
The torch feeds the welding current and the shielding gas to the welding area. All torches are duly insulated with cooling (gas or water) to conduct the maximum current. Water cooling is used for torches with intensities higher than 200.

The current is fed to the welding area through the tungsten electrode, which is fixed in place by the electrode holder clamp. The gas leaves the welding area through the gas nozzle which is located in the body of the torch.

The electrode should protrude approximately 3 to 5 mm out of the tip of the nozzle for butt welding and approximately 6 to 10 mm for lap or angle welding. Always make sure that the welding current is disconnected before adjusting the electrode.

Depending on the welding application, manual, automatic, for small spaces, the torch may adopt different configurations: normal, straight or with short cover.

Fig. 37 - Types of TIG torches. COURTESY OF FRONIUS



1. Body
2. Long cap
3. Short cap
4. Electrode holder clamp
5. Holder clamp
6. Gas nozzle

Fig. 38 - Exploded view of an air-cooled TIG torch.

SPARE PARTS

The metal to be welded determines whether direct or alternating current is used and the choice of tungsten electrode. The thickness and position to be welded determines the welding current, the diameter of the tungsten electrode and the choice of spare parts, clamp, clamp holder and gas nozzle.

Gas nozzle: the diameter is chosen depending on the thickness to be welded and it should supply the gas flow required to shield the weld pool and the surrounding area. An excessive flow may drag air into the welding zone and increase costs. For most applications, standard nozzles are sufficient, but one of the biggest problems with TIG welding is turbulence within the shielding gas flow and its tendency to contaminate due to the air producing oxidation porosity.

Gas LENS nozzles avoid this problem, which produce an exceptionally stable flow of shielding gas, with the following advantages

1. Minimum gas flow rate, which avoids turbulence.
2. Better protection of more distant areas, which allows welding with nozzle separation of up to 25 mm.
3. Better visibility and accessibility. When working at a higher distance from the welding area, the tungsten electrode may extend out of the nozzle, eliminating the "blind spot" in the weld pool. With this electrode protruding from the nozzle it becomes easier to weld in corners and other hard to reach places.

Shielding gas flow without "Gas Lens" nozzle

Shielding gas flow with "Gas Lens" nozzle

Fig. 39 - Gas Lens nozzles.

SELECTION AND IDENTIFICATION OF TUNGSTEN ELECTRODES

It is important to select and prepare the most appropriate electrode for TIG welding in order to achieve optimum quality. The factors to determine the most appropriate electrode are: the material to be welded, welding thickness, polarity and welding current.

The most commonly used tungsten electrodes are specified in Table 18 where each electrode is identified by the colour of its alloy.

ELECTRODE PREPARATION

Advantages of longitudinal grinding

Tungsten electrodes should be prepared with the grooves remaining in a longitudinal position.

If the electrodes are transversely grinded (even cross-polished) the electric arc jumps across the grinding grooves. The arc start is initiated in the area before the tip of the electrode, has large dispersion and oscillation, with less deep and non-uniform penetration.

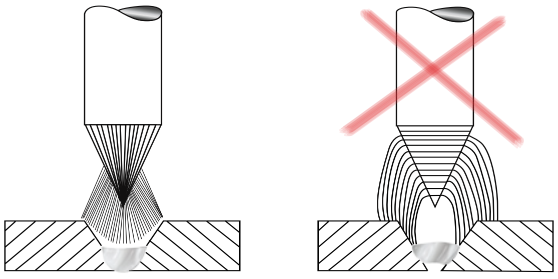


Fig. 40 - Grinding of tungsten electrodes.

An electrode with transverse sharpening overheats before a longitudinally sharpened electrode, resulting in a shorter electrode life.

Through the longitudinal grinding the electrons circulate without interruption. In these conditions the arc is narrow, remains stable and penetration is correct. When high frequency starts, the electrode undergoes an appreciably lower thermal load and therefore has longer duration. It is important that the electrode is correctly prepared for manual welding, for automatic welding or robotic welding it is essential.

Electrode	Classification AWS A5.12	Classification EN ISO 6848	Distinctive
T-Pure	**EWP**	**WP**	**green**
Application: aluminium, magnesium and its alloys with AC and rounded preparation. Good arc stability for AC welding, reasonably good contamination resistance. It should be used with low current. It maintains a well prepared rounded tip			
T-2% Th	**EWTh2**	**WT20**	**red**
Application: stainless steel, carbon steels, copper, nickel and alloys with DCSP and sharp tip. Easy arc start. High current can be used. High arc stability. High wear resistance that avoid the weld pool contamination. Difficulty keeping the prepared rounded tip with AC. Thorium is slightly radioactive, but the main problem in use is the dust that is formed in grinding which is much more harmful. In general, they have been replaced by electrodes T-2%La and T-2%Ce.			
T-2% Ce	**EWCe-2**	**WC20**	**grey**
Application: behaviour similar to electrodes with thorium. Easy arc start, good arc stability, long duration. Possible substitute for thorium electrodes. Welding of stainless steel, carbon steels, copper, nickel and alloys with DCSP and sharp tip. They may also be used with AC but in this case with a prepared rounded tip.			
T-1% Zr	**EW Zr1**	**WZ3**	**brown**
Application: aluminium magnesium and alloys with AC where it is necessary to avoid weld contamination, due to the long duration of the prepared rounded tip. Preferred electrode when contamination of the weld pool with the electrode may not be allowed. Good arc initiation.			
T-2% La	**EWLa-2%**	**WLa-20**	**blue**
Application: stainless steel, carbon steel, copper, nickel and alloys with DCSP and sharp tip. They may be used with AC with aluminium and magnesium, but in this case with the prepared rounded tip. Similar behaviour to the behaviour of thorium electrodes. Easy arc start, good arc stability, long duration. High intensities can be used. Possible substitute for thorium electrodes.			

Table 18. Most commonly used tungsten electrodes.

Diameter (mm)	DCSP Electrode (-)	DCRP Electrode (+)	AC	
	T-Pure T-Th;T-La;T-Ce;T-Zr	T-Pure T-Th;T-La;T-Ce;T-Zr	T-Pure	T-Th;T-La;T-Ce;T-Zr
1.0	15 - 80	--	10 - 60	15 - 80
1.6	70 - 150	10 - 20	50 - 100	70 - 150
2.0	140 - 200	10 - 25	70 - 140	100 - 200
2.4	150 - 250	15 - 30	100 - 160	140 - 235
3.0	180 - 300	15 - 35	130 - 190	180 - 280
3.2	250 - 400	25 - 40	150 - 210	225 - 325
4.0	400 - 500	40 - 55	200 - 275	300 - 400
4.8	500 - 750	55 - 80	250 - 350	400 - 500
6.4	750 - 1000	80 - 125	325 - 450	500 - 630

Table 19. Intensities for the main applications.

CLEANING

Regardless of the joint type, proper cleaning around the welding area is essential before welding, if good mechanical properties and appearance of the bead are desired.

A brush and adequate solvent may be sufficient for small surfaces. Large surfaces or series productions may require other cleaning procedures such as steam degreasing or bathing, which may be cheaper. In any case, the complete elimination of oxides, oil or any type of dirt from the surfaces to be joined is essential.

When using chemical solvents, the necessary precautions should be taken to eliminate the toxic fumes generated by decomposing by welding heat of residues of chemical cleaning. The suction cleaners specially designed for welding capture fumes in the area where they originate, before they spread or leak outside.

2.5 JOINT TYPES

The main joint types used in TIG welding are: butt, lap, corner, "T", and flange.

The selection of the appropriate design for a particular application depends mainly on the following factors:

- Mechanical properties.
- Costs of edge preparation and welding.
- Type of material to be welded.
- Dimension, shape and appearance of the total welded assembly.

Rods will not be used as filler consumable, if adequate reinforcement and penetration may be obtained without it. The most frequently used types are described, but different types may be used to meet the requirements of special applications..

2.5.1 Butt joints

Butt joints with straight edges for thickness <6 mm are the simplest to prepare and may be welded without filler material depending on the thickness of the base metal. The edge separation should be sufficient to achieve 100% penetration. If the thickness to be welded is very thin and no filler material is used to avoid leaving an excessive overbead, the necessary precautions should be taken to guarantee that it will not be perforated, such as the use of equipment with a sufficiently low current and/or the use of copper backing supports.

The use of filler material will be necessary to join the edge separation left to ensure penetration. (Fig. 41)

Fig. 41 - Butt joint with straight edges.

For butt joints with thickness> 6 mm and single sided welding, a butt joint with "V" preparation is used. If total penetration thickness between 10 and 25 mm is required, filler material should be used to fill in the "V". The "V" angle should be approximately 60º and the root face 3 to 6 mm, depending on the thickness of the pieces to be welded. (Fig. 42)

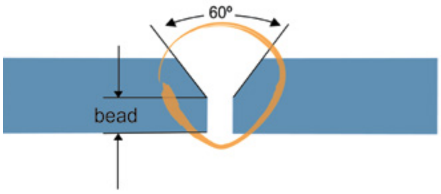


Fig. 42 - Butt joint with "V" edges.

The "flange" butt joint should be used in places where the thickness is relatively thin and some reinforcement is desired. (Fig. 43)

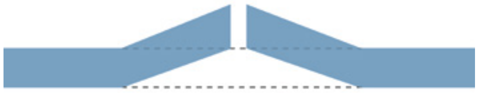


Fig. 43 - joint with flanged edges.

The double "V" butt joint preparation is generally used to join higher than 12 mm thickness, where the design of the assembly allows access to the lower part of the joint to accommodate the second pass. With this type of joint and an appropriate welding technique, a defect free weld may be obtained with 100% penetration. (Fig. 44)

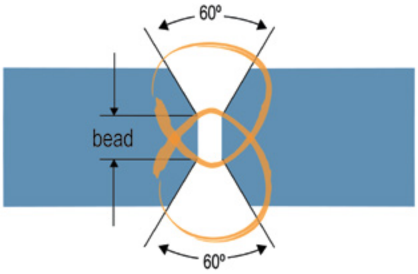


Fig. 44 - Butt joint with double "V".

2.5.2 Lap joints

This joint type has the advantage of totally eliminating the need for edge penetration. The only requirement for a correct joint is that the sheets must be in perfect contact along the joint length.

If the material is less than 6 mm thick, it may be welded with or without filler material.

When no filler material is used, care must be taken not to cause perforation. In general, this lap joint is not recommended for materials higher than 6 mm thick, except in joints where high quality is not required

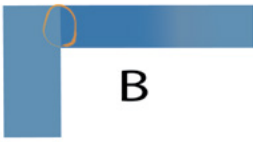
When it is used, always add filler material to ensure good fusion and joint termination. The number of passes will depend on the thickness of the pieces. (Fig. 45)

Fig. 45 - Lap joint.

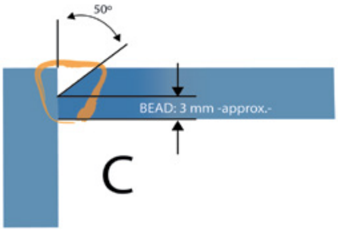
2.5.3 Corner joints

This is frequently used in the manufacture of boxes and containers. (Fig. 46)

Type A is used for thickness up to 3 mm. The use of filler material may not be necessary if the amount of molten base metal is sufficient to obtain a defect free weld with the necessary resistance.



Type B, for medium thickness where it is necessary to use filler material to achieve the adequate effort.



Type C, is used for thick materials where it is impossible to achieve 100% penetration without the indicated preparation

Fig. 46 - Corner joints.

2.5.4 "T" joints

All T joints require filler material. The number of passes per side of the joint will depend on the thickness of the material and on the size of welding required.

When 100% penetration is desired, as shown in Fig. 47, the current values should be checked as adequate for the thickness.

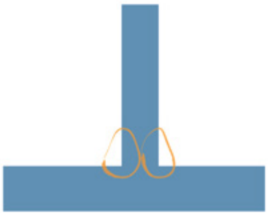


Fig. 47 - "T". joint.

2.5.5 "Flange" joints

These are used only with thin materials and filler material is not needed. Preparation is simple and welding is economical. However, this joint should not be used when it has to be subjected to stresses at the root of the joint. (Fig. 48)

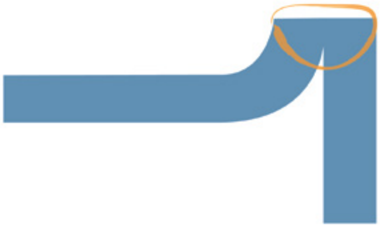


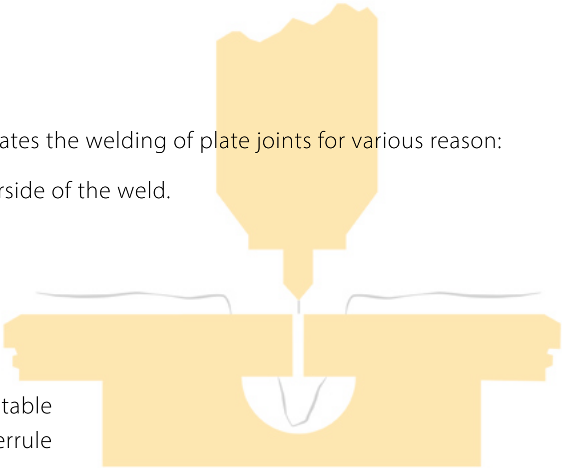
Fig. 48 - Flange joint.

2.6 WELDING WITH “BACKING”

This weld is typically used in food and chemical industry. Backing facilitates the welding of plate joints for various reason:

- Backing usually allows the introduction of gas to protect the underside of the weld.
- It eliminates some of the heat generated by welding.
- It supports and shapes the weld pool.
- It allows higher welding rates.

In case of a long joint, such as in the manufacture of storage tanks, a table of appropriate dimensions is used, depending on the diameter of the ferrule and the weld length



2.7 CHECKING THE EQUIPMENT

In order to obtain the quality that TIG welding offers, the correct positioning of the welding installation should be carefully checked before welding.

1. Check the shielding gas. After welding, the tungsten electrode should have good appearance once it is protected and cooled by the shielding gas. If the electrode has a dirty appearance, in general there is a defect in the gas circuit or the shielding gas is not appropriate.
2. Check the welding current and the gas flow.
3. Select the correct size of the tungsten electrode and the nozzle.
4. Check if the torch is water cooled and if the flow is sufficient, otherwise the torch could overheat and deteriorate.
5. Check that the work lead is correctly connected to the base metal in a clean place to ensure good contact.


PHOTOGRAPH COURTESY OF FRONIUS

2.8

PIPELINE WELDING

Stainless steel pipe is used in most industries, but is particularly used in the food, chemical and pharmaceutical industries.

There are applications where the finishing quality of the pipe inner surface is essential and where, over time, any welding defect may contaminate the product it contains.

ADVANTAGES OF PIPE WELDING WITH TIG PROCEDURE

1. Good penetration control.
2. Better mechanical properties and corrosion resistance are obtained than those obtained with other processes.
3. The shape of the weld pool gives an idea of the penetration achieved. This is essential to give correct torch.
4. Due to low level of fumes and absence of spatter, the welder can see better the joint that with other welding processes.
5. There will be no possibility of slag entrapment due to the absence of fluxes.
6. In many cases, pipe welding is possible without filler materials.
7. Backing gas may be used inside the pipe to prevent internal joint oxidation.
8. It allows welding in all positions for a large variation of joint designs.

During pipe manufacturing, quality controls may be easily established to comply with current regulations or with the particulars required in the flow design. In tube-tube joint welding, the quality of the joint may be guaranteed provided:

1. TIG welders specialized in pipe welding are employed, the appropriate controls are established and any defects repaired.
2. Automatic orbital TIG welding is used. This may require higher investment in equipment that will be generally easily recovered by reduced welding costs, reducing/eliminating repair costs and, above all, obtaining higher quality.

Penetration is one of the most critical factors when evaluating the quality of a stainless pipe welding. This must have two characteristics:

1. Uniformity in all sectors of the tube-tube joint without affecting the position in which the welding has been performed, whether horizontal, vertical or ceiling.
2. Repetitiveness, that is to say, that for a certain joint (tube diameter, thickness, edge preparation, etc.) and the same welding parameters (current, voltage, welding speed, diameter of the filler rod, etc.) an adequate penetration is always achieved.

This is more difficult to achieve with manual welding than with automatic welding. The use of automatic orbital TIG welding easily achieves both characteristics, since the agreed and fixed parameters during previous testing are memorised and subsequently repeated along the entire pipeline. Attention to the quality of the pipe, the cutting and edge preparation (if necessary, depending on the thickness) are essential, in order to obtain all the advantages of this procedure.

Furthermore, the reasons why automatic orbital TIG welding is increasingly used are:

1. Greater head simplicity.
2. Requirements issued by foreign companies to their suppliers, in order to comply with the regulations of their country.
3. Cost reduction by elimination or reduction of defects or faster execution in the case of a large number of repeated identical joints where an automatic process allows time optimization.

2.9 ORBITAL TIG WELDING COMPONENTS

An installation for automatic orbital TIG welding is composed of:

TIG pulsed electronic equipment which allows adjustment of:

1. Gas pre-flow.
2. Gradual increase in current to avoid defects at start up.
3. Peak current.
4. Base current.
5. Gradual decrease in current to avoid end crater.
6. Gas post-flow
7. Welding rate.
8. Wire feed rate (if necessary).
9. Divide the joint into sectors, with welding parameters potentially changing in each sector. This ensures penetration during horizontal welding, vertical descending welding, ceiling welding and vertical ascending welding.
10. Simulate the welding process without electric arc.
11. Torch water cooling through closed circuit.

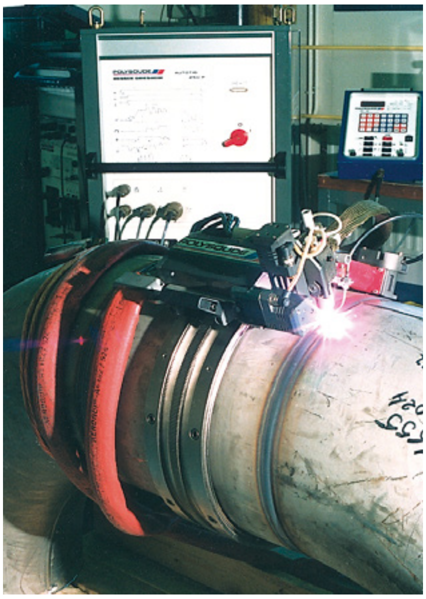
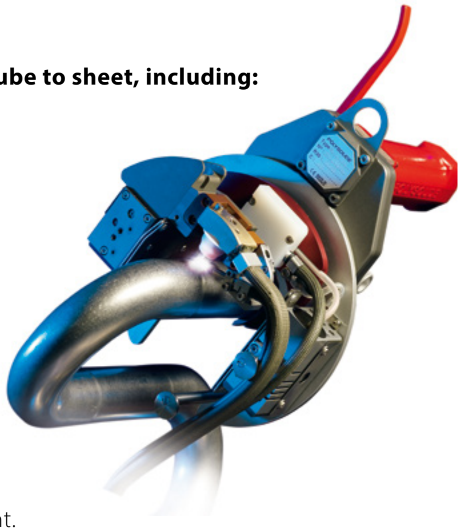


Fig. 49 - Orbital TIG installation. Power supply and motorized trolley flexible and adaptable for all tube welding tasks. Includes wire feeder. COURTESY OF POLYSOUDE.

Head tube to tube or tube to sheet, including:



1. Torch.
2. 360º rotation torch motor.
3. Torch height adjustment system.
4. Remote control of the welding instructions without being close to the TIG equipment.
5. Programming control as required. It retains in the memory a large number of welding procedures for various types of joints (optional).
6. Extension to supply energy to the torch for welding, shielding gas and cooling water.
7. Wire feeder (optional).
8. Tube fixing elements (optional).
9. Cutting and edge preparation equipment (optional).

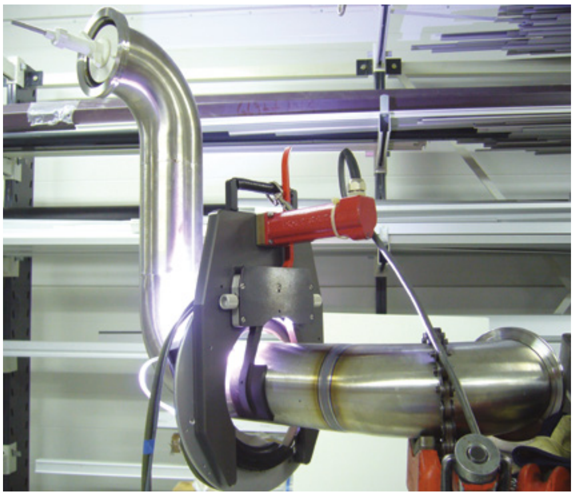


Fig. 50 -Tube to tube open head welding. COURTESY OF POLYSOUDE

For tube-tube connections (Fig. 50 and 52), heads may be open or closed. Closed heads allow optimum gas protection and are used for thin materials where the thread filler is not necessary. Open heads allow the adaptation of most of the applications of orbital TIG, to work in assembly or in workshop and with or without filler rods.

Tube-tubesheet joint (Fig. 53A) may be externally or internally welded, with the following configurations.

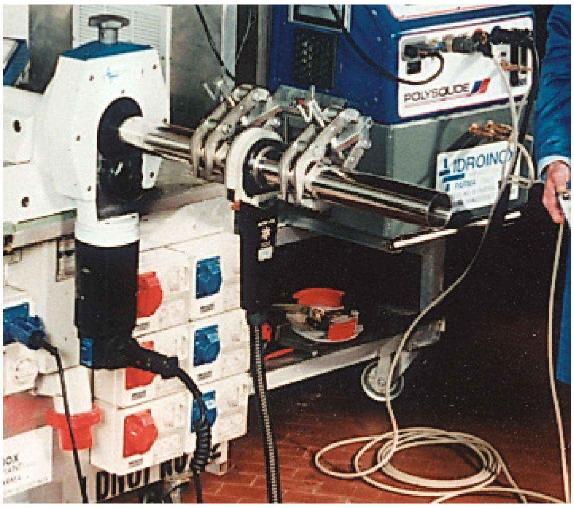


Fig. 51 - Closed head for tube to tube orbital welding. COURTESY OF POLYSOUDE

Fig. 52 - Tube to collector/bottom joint head. COURTESY OF POLYSOUDE

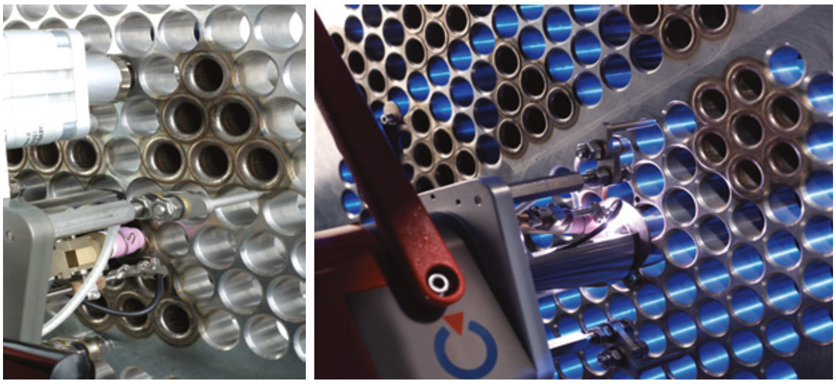


Fig. 53 - Tube to sheet welding head. COURTESY OF POLYSOUDE

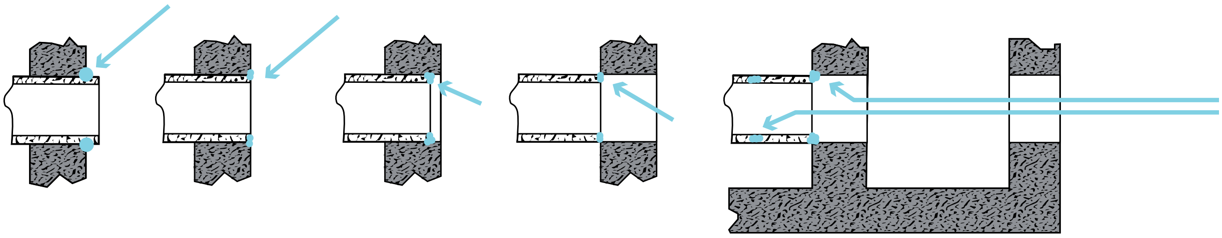
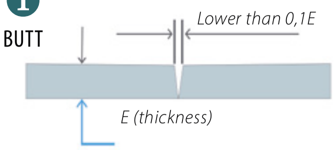


Fig. 53A - Tube-tubesheet joint with different configurations. COURTESY OF POLYSOUDE

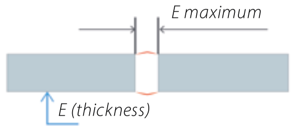
Table 20. TIG welding parameters (GTAW)

Thickness (mm)	Type of welding	Welding current				Diameter electrode (mm)	Welding speed (mm/s)	Filler rod diameter (mm)	Gas cup or nozzle size			Argon (S/Q) gas flow l/min	Remarks
		Type	Current (A)						Ceramics 250A max.	High impact 300A max	Metallic		
			Flat	Vertical	Overhead				Consult torch instructions				
1.6	BUTT ❶❷ / ANGLE ❺❻/ CORNER ❼/ ANGLE ❽❾	C.C. DIRECT POLARITY	80-100 100-120 80-100 90-110	70-90 80-100 70-90 80-100	70-90 80-100 70-90 80-100	1.6	5.1 4.2 5.1 4.2	1.6	4,5,6		6	5.6	
2.4			100-120 110-130 100-120 110-130	90-110 110-120 90-110 100-120	90-110 100-120 90-110 100-120	1.6	5.1 4.2 5.1 4.2	1.6 or 2.4					
3.2			120-140 130-150 120-140 130-150	100-130 120-140 110-130 115-135	105-125 120-140 115-135 120-140	1.6	5.1 4.2 5.1 4.2	2.4					
4.8			200-250 225-275 200-250 225-275	150-200 175-275 200-250 150-225	150-200 175-225 150-200 175-225	2.4 2.4-3.2 2.4 2.4-3.2	4.2 3.4 4.2 3.4	3.2	6,7,8		6,8	7	
6.4			275-350 300-375 275-350 300-375	200-250 225-275 200-250 225-275	200-250 225-275 200-250 225-275	3.2		4.8			8		1, 2 PASS S 1,2 PASS S 1 PASS
12.7	BUTT ❸❹/ LAP ❻/ ANGLE ❽❿		350-450 375-475 375-475	225-275 230-280 230-280	225-275 230-280 230-280	3.2-3.8		6.4					2, 3 PASS S 3 PASS S 3 PASS

❶ BUTT



❷ BUTT



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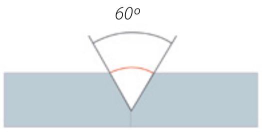
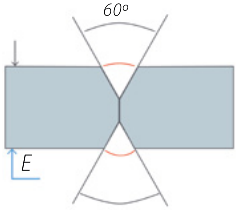
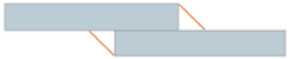


❹ BUTT

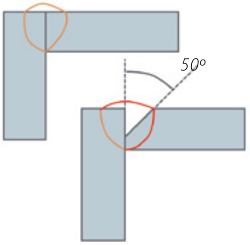


❺ LAP



❻ LAP

❼ IN EXTERIOR CORNER



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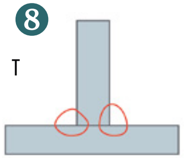
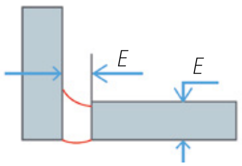


❾ IN INTERIOR CORNER



❿ IN EXTERIOR CORNER

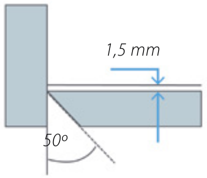


Table 21. Shielding gases

TIG WELDING		COMPOSITION	UNE N14175	WELDING	THICKNESS (mm)										PRODUCTIVITY			QUALITY	WELDING	FUMES
					1	2	3	4	5	6	7	8	9	10	WELDING RATE	PENETRATION	PREHEATING DECREASE	BEAD APPEARANCE	POROSITY	
AUSTENITIC STAINLESS STEEL	SANARC AS	Ar	I1	M	*	*	*	I	I	I	I	I	I	I	I	I		*	*	*
	SANARC EASY 4	$Ar-H_2$	R1	M	I	I	*	*	*	I	I	I	I	I	I	I		*	*	*
	SANARC EASY 5 SANARC FLASH 4	$Ar-H_2$	R1	M,A	I	I	I	I	I	*	*	*	*	*	*	*		*	*	*
	SANARC HR	$Ar-He-H_2$	R1	A	I	I	I	I	I	*	*	*	*	*	*	*		*	I	*
FERRITIC STAINLESS STEEL	SANARC AS	Ar	I1	M	*	*	*	I	I	I	I	I	I	I	I	I		*	*	*
	SANARC H5; H3	Ar-He	I3	M,A				*	*	*	I	I	I	I	*	*		*	I	*
DUPLEX STAINLESS STEEL	SANARC AS	Ar	I1	M,A	*	*	*	I	I	I	I	I	I	I	I	I		*	*	*
	SANARC T1;T3	$Ar-N_2$	N2	M,A	*	*	*	*	*	*	*	*	*	*	I	I		*	*	*
	SANARC H30	Ar-He	I3	M,A	I	I	I	I	I	*	*	*	*	*	*	*		*	I	*
NICKEL & ALLOYS	SANARC AQ	Ar	I1	M	*	*	*	I	I	I	I	I	I	I	P	P	P	*	P	I
	SANARC H5;H30	Ar-He	I3	M,A				*	*	*	I	I	I	I	I	I	I	*	I	*
	SANARC H50;H70	Ar-He	I3	M,A					I	I	*	*	*	*	*	I	I	I	*	*

Recommended	*	Appropriate	I	May be used	P	Not applicable		Manual welding	M	Automatic welding	A

GAS SELECTION GUIDE FOR TIG PROCEDURES

Metal	Designation	Characteristics
Stainless steel	SANARC AS	It provides ease of arc initiation and good control of the molten pool and penetration.
	SANARC AQ	Its purity is superior than SANARC AS and may be used to reduce pores and with radiographic control.
	SANARC H30	Due to its helium content, it provides higher heat input and higher welding rate, which has special application in automated welding and for thick materials.
	SANARC HR	It is mainly used with automatism or robot welding at high speed, in the manufacture of austenitic stainless steel tanks and pipes.
	SANARC EASY 4	It is used for manual welding of austenitic stainless steel to leave a bead with good appearance.
	SANARC EASY 5 SANARC FLASH 3	It is used in austenitic stainless steel automatic welding, to increase the welding speed. Suitable for the manufacture of tanks and pipes.
	SANARC T1 SANARC T3	It is used in austenitic-ferritic stainless steels joints. The nitrogen content stabilizes the austenite.

PROTECTIVE EQUIPMENT

As with all industrial equipment, certain precautions should be taken.

In the case of TIG welding, the welder must be properly protected against the action of the electric arc. This requires adequate clothing to cover all exposed skin and a welder's helmet with appropriate shade filter lens to protect eyes and face.

The type of glass will depend on the intensity of the electric arc. Table 22.

Lens shade nº	Welding current
6	Up to 30 amp
8	30 -75 amps
10	75-200 amps
12	200-400 amps
14	More than 400 amps

Table 22. Types if shade filter lens

PHOTOGRAPH COURTESY OF FRONIUS

3 MIG/MAG process. *Gas Metal Arc Welding (GMAW)*

3.1 PROCESS DESCRIPTION

MIG / MAG welding (GMAW) process uses an electric arc between a consumable continuous electrode (commercially called wire) and the base metal to be welded. The electric arc and the weld pool are protected using a gas or mixture of gases. (Fig. 54)

Welding with tubular wire (FCAW) uses an installation similar to MIG / MAG (GMAW) and until 2011 was considered within this MIG / MAG (GMAW) process. But as from that year, it was considered an independent process by the International Institute of Welding (IIW). The differences between the two processes will be described at the end of the review of the MIG / MAG process.

The arc support is basically molten metal vapour and ionised gas. The metal transfer may be MIG short arc (or short-circuit) or MIG spray arc, depending on how it is verified.

Commercially, this process is named of three ways:

- Semiautomatic.
- MIG (Metal Inert Gas) with inert gas.
- MAG (Metal Active Gas) with active gases.

According to the regulations, the variations are as follows, depending on the use of solid wire ("solid wire") or tubular (metal cored wire) and the use of inert or active gas.

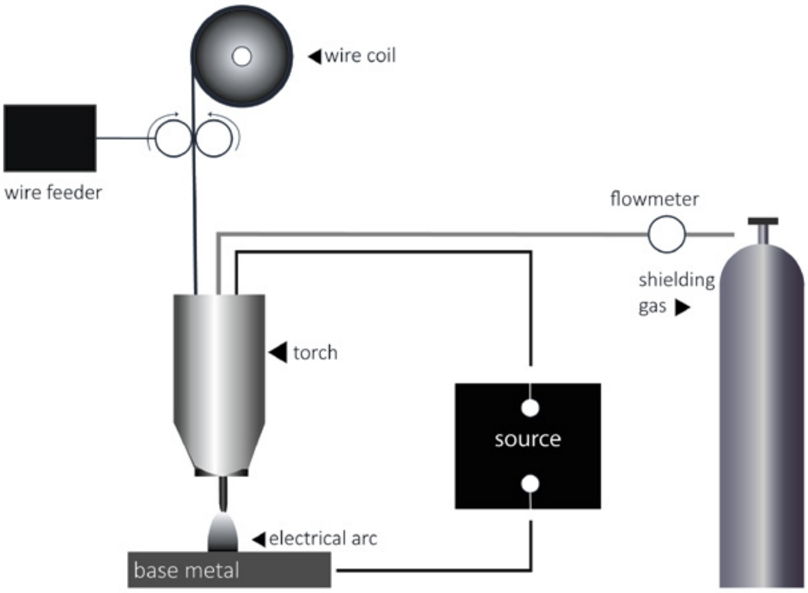


Fig. 54 - MIG/MAG procedure (GMAW).

MIG / MAG installation with independent feeder. COURTESY OF NIPPON GASES

Designation of the process: according to the regulations, the variations are as follows:

GMAW (Gas Metal Arc Welding)

UNE – EN ISO 4063: 2011

Process 131: arc welding of solid wire continuous electrode and inert gas: MIG welding

Process 133: arc welding with metal cored wire filled with metallic powder and inert gas: MIG welding

Process 135: arc welding with solid wire electrode and active gas: MAG welding

Process 138: welding with metal cored wire filled with metallic powder and active gas: MAG welding

3.2 ADVANTAGES

MIG / MAG welding characteristics have the following advantages:

- It is the only process with electric arc and consumable electrode that welds all metals and alloys that are commercially used.
- Continuous feeding, so no time is lost in the electrode change. The deposition rates are much higher than those obtained with coated electrodes, and have lower costs as productivity is increased.
- It may be easily adapted to automatic and robotic welding.
- It may be welded in all positions.
- Post welding cleaning operations are superior to those of TIG welding, but MIG/MAG welding with solid wire and metal cored does not leave slag, in contrast to FCAW metal cored wire, which does leave slag.
- Using a pulsed arc avoids spatters, which in stainless steel may generate corrosion areas and minimises heat input to reduce strains.

3.3 LIMITATIONS

- The equipment is more complicated and expensive than the coated electrode.
- In places that are more difficult to access it is more complicated to weld with MIG/MAG equipment than with coated electrode equipment, since it is necessary to bring the torch nozzle close enough for the shielding gas can protect the weld.
- The solid or metal cored wire does not form slag and the impurities formed in the weld pool can not be removed there.

3.4 MIG / MAG PROCESS COMPONENTS

It consists of:

1. Power supply or Energy Group.
2. Wire feeder.
3. Control.
4. Torch without cooling or water cooled.
5. Regulated gas supply.
6. Consumable wire.
7. Hose assembly containing the spiral conduit where the consumable wire is fed, power cables, gas conduit
8. Water cooling circuit if the torch is water cooled

3.5 WELDING TORCH

MIG welding torches are more complex and expensive than those used for coated electrode welding, they have more functions and most of their components should be changed as often as determined by the welding application and the quality required.

Types of welding torches: for manual or automatic welding, air-cooled (shielding gas) or by water, "push-pull", with fumes extraction.

Welding torch functions.

- The weld wire passes through the wire conduit of the torch. The current at the contact tube is connected.
- Shielding gas passes through the torch and is directed towards the weld pool.
- If the welding current and/or torch utilisation factor is high, the use of water cooling may be needed, instead of air cooling (shielding gas).
- The switch of start and end controls for the wire and gas supply are incorporated.
- Manual welding and automatic or robotic welding.
- The spare parts that wear out and should be replaced when necessary to maintain the quality of the welding process are incorporated. These are the gas nozzle, the contact tube, the diffuser and wire conduit.

Welding torch components:

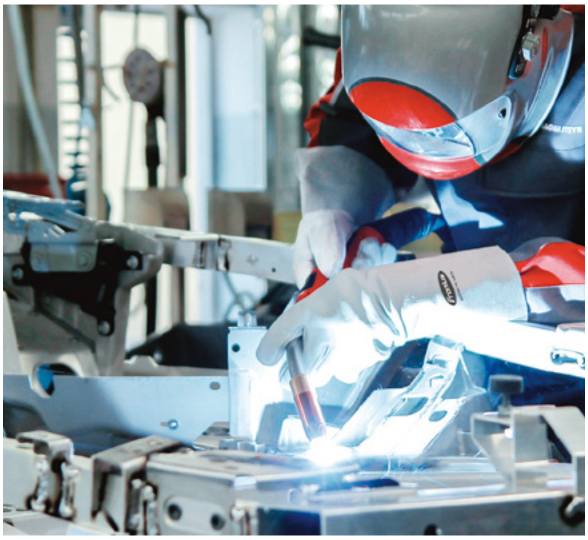
- Connector.
- Hose set containing the power cable, wire conduit and gas conduit.
- Torch body.
- Straight or curved neck.
- Gas nozzle.
- Diffuser.
- Contact tube (contact tip).

Fig. 55 - Standard manual torch with or without water cooling. Photograph courtesy of FRONIUS

Fig. 56 - Push–pull manual torch. Photograph courtesy of FRONIUS

Fig. 57 - Torch for gas-cooled automatic welding. Photograph courtesy of FRONIUS

Fig. 58 - Gas nozzles. Photograph courtesy of FRONIUS

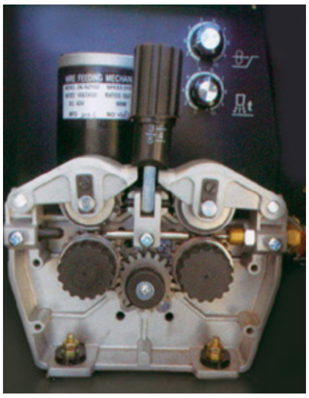


MIG WELDING. PHOTOGRAPHY COURTESY IF FRONIUS

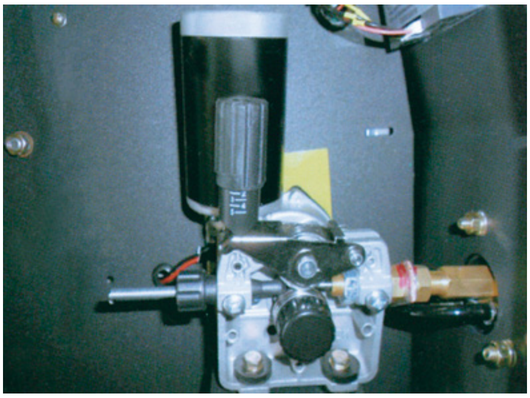
3.6 WIRE FEEDER

Through the feeder, the wire passes through the spiral pipe of the torch hose, enters the torch and the current is connected at the contact tube (contact tip).

The feeder is highly important, since the quality and appearance of the welds depend on the wire reaching the contact tube, at a speed that is as uniform as possible. Therefore, wire feeding should be constant and without slipping rollers. Feeders use 2 or 4 rollers. For critical applications, 4 rollers are used.



Set of 4 rollers

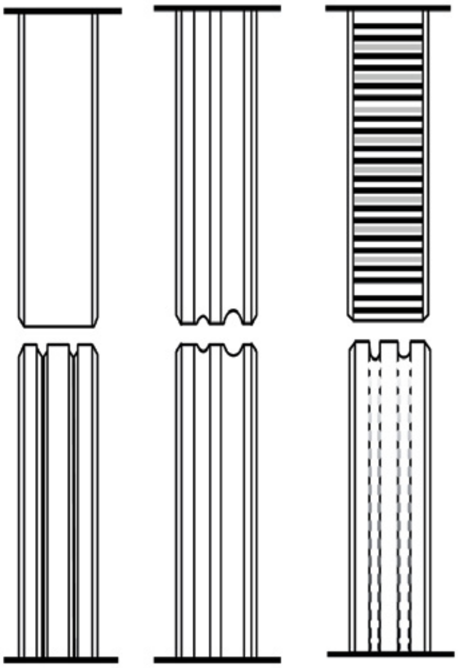


Set of 2 rollers

Fig. 59 - Wire feeder MIG/MAG.

Commonly used rollers are:

- For solid hard wires, such as carbon and stainless steels, with the V-shaped guide slot for the lower rollers and flat for the upper rollers. These rollers are not recommended to be used with soft solid wires, since they would laminate and would cause problems in the wire liner or in the contact tube.
- For soft solid wires, such as aluminium and magnesium, with the U-shaped guide slot for both rollers, lower and upper rollers.
- For tubular wires, U-shaped slot rollers with grooves are used to transmit the maximum thrust with the minimum pressure.



Solid wires:	Soft wires:	Tubular wires: - Lower roller with grooves
Carbon steel,	Aluminium	
Stainless steel	- Lower roller with U-guide	
- Lower roller with V-guide	- Upper roller with U-guide	
- Flat upper roller		

Fig. 60 - Types of MIG / MAG wire feed rollers.

3.7 METAL TRANSFER TYPES

3.7.1 Transfer by short circuit or Short Arc Transfer

The end of the wire torches the weld pool making a short circuit, so the current begins to increase until a short circuit current, then the metal is transferred and after the arc is reignited.

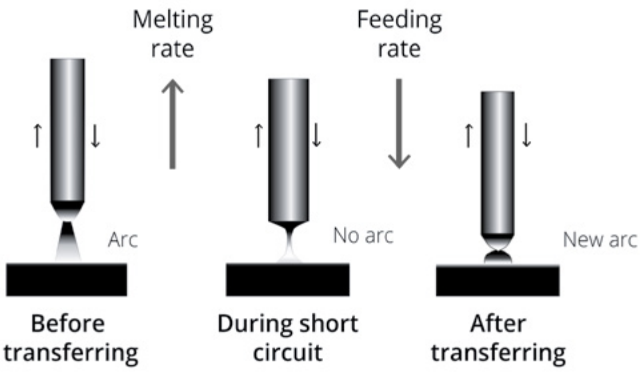


Fig. 61 - MIG Short arc or short circuit.

It is used with low intensities and usually with small wire diameters. It is used in welding in position and for welding thin materials. (Fig. 61)

Characteristics:

1. Low voltages and intensities.
2. Small wire diameters.
3. Low heat input.
4. Small weld pool.
5. Welding thin materials.
6. Welding in "position" and with wide root openings.
7. Small amount of wire deposition.
8. Little distortion.
9. If the wire feed, parameters, shielding gas and power cable are correct, spatters will be low.

3.7.2 Spray Arc Transfer

The weld metal is transferred to the weld pool in the form of droplets. There is no "contact" with the metal to be welded as it was the case in the short-circuit transfer.

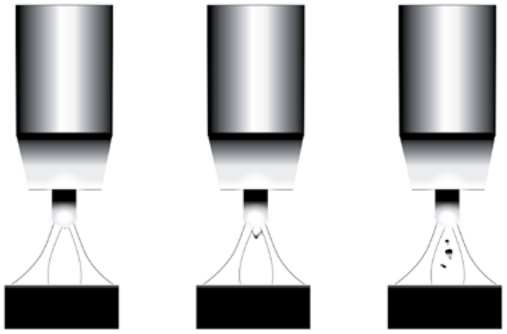


Fig. 62 - MIG Spray arc.

It is used with high intensities and welding in flat and horizontal positions, reaching high deposition rates without visible spatters. It is used for higher than 3 mm thick materials. (Fig. 62)

Characteristics:

1. Voltages and intensities of current are used that are higher than transition voltages and intensities, which are the minimum necessary to achieve this type of transfer. These values depend on the wire diameter and type, and the shielding gas. (Table 23)

Diameter (mm)	Ar-O_2 (A)	Ar-He-CO_2 (A)	Ar-CO_2-H_2 (A)
0.8	150	160	145
1.2	195	205	185
1.6	265	280	255

Table 23. Minimum transition current for long-arc welding. Values with NIPPON- 308L (ER-308L) wire.

2. High heat input.
3. Large weld pools.
4. Welding thick materials.
5. Horizontal welding (except when using spray arc with pulsed arc).
6. Greater distortion.
7. Less or not spatters.
8. High wire deposition.

3.7.3 Pulsed Arc Transfer

Although the conventional MIG process is used in all industries and it is easy and quick to learn and introduce, experience shows that when high quality welding is required, care should be taken to avoid the most frequent defects in terms of porosity, lack of fusion and poor finishing due to excessive spatters. This is especially important when short circuit transfer is used in welding where low intensities and small molten pools are required. The problem is directly associated with the difficulty to select the appropriate parameters and the training required by the welder..

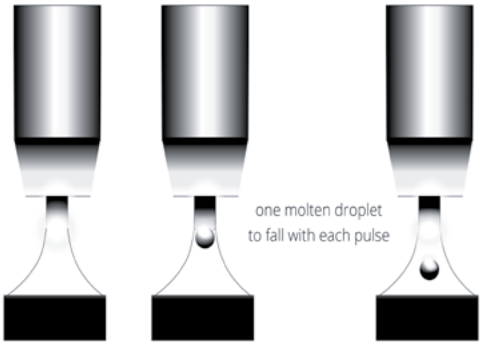


Fig. 63 - MIG Pulsed Arc.

The pulsed MIG process is used in some applications as an alternative to the short arc MIG process, with the advantage of causing less spatters and maintaining the weld in all positions. Also as alternative to spray arc MIG when it was necessary a lower heat input, to weld lower thickness, with less deformation, in all positions and without spatter.

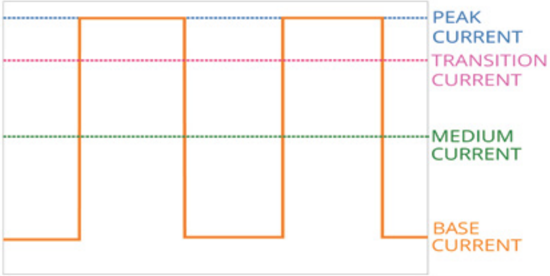


Fig. 64 - Pulsed current diagram.

The current type may be seen in Fig. 64. With each peak the transfer of a drop of wire to the weld pool takes place. In practice, the parameters to be pre-selected are:

1. Metal to be welded.
2. Wire diameter.
3. Shielding gas.
4. Wire feeding rate.

Most of this equipment incorporates:

- A standard program, with parameters to weld most applications.
- Free programs where each company may store its own parameters.

Note: Besides all the welding types included in Fig. 64, new variants of the MIG / MAG process nowadays available should be added. The new digital and programmable welding equipment allows a continuous improvement of the quality and productivity. Some of them would be: Rotating arc, High performance short arc, High performance spray arc, Modified short arc, Modified pulse arc.

3.8 CONSUMABLES FOR MIG/MAG WELDING (GMAW)

Two types of wires are used that do not leave slag:

- Solid.
- Tubular (cored metal), filled with metallic powder.

The consumables summary section, contains information about the types and compositions of consumables for this process.

Selection of the appropriate consumable for an application should aim to produce a welded metal with two basic characteristics:

- The mechanical, physical and chemical properties should be equal or superior to the properties of the base metal, or to provide the welded metal with some improvement, such as corrosion wear resistance. A welded metal, even with the same composition as the base metal, will have metallurgical characteristics that will depend on factors such as heat input and bead type.
- High quality welded metal, with the use of a suitable wire.

In general, the same wire should not be used for manual and automatic welding or robotic welding, since the wire tensioning should be different to have good dragging and feeding.

The wire diameters used are: 0.6; 0.8; 1.0; 1.2; 1.6; 2.0; 3.0 and 3.2 mm, the most commonly used wires are 0.8; 1.0; 1.2 diameters.

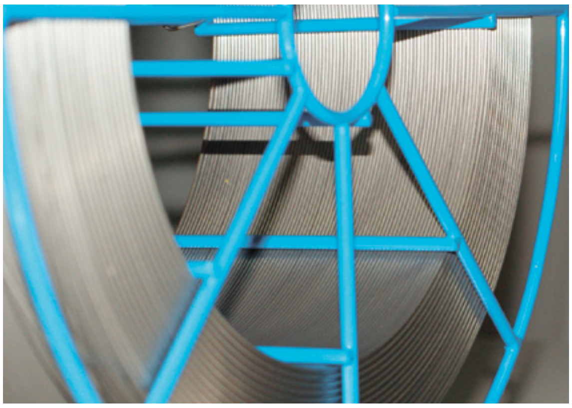


Fig. 65 - Supply of MIG / MAG wire COURTESY OF INOXFIL

Feeding mechanisms are:

- Metal or plastic coils from 5 to 15 Kg.
- Drums with 250 Kg, specially designed for automatic or robotic welding, to be placed in the feeding systems.

Process	GMAW	
UNE-DIN EN ISO 4063:2011	131, 133, 135, 138	
METAL	STAINLESS STEEL	
	UNE-DIN EN ISO 14343 A	AWS A5.9/A5.9M
Solid Wire	G 19 9L	ER 308L
Tubular (metal cored)		EC 308L

Table 24. Example of designation of a solid and tubular consumable for MIG / MAG (GMAW) welding.

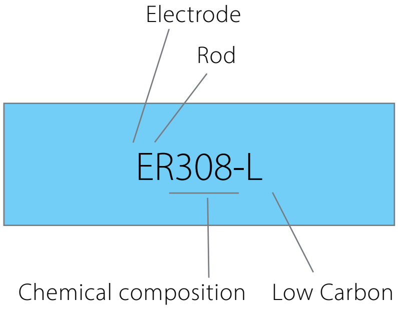
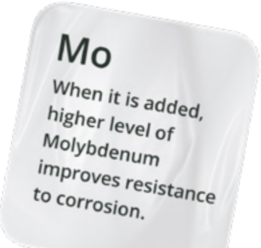


Fig. 66 - Designation of solid wire according to AWS A5.9.



Mo

When it is added, higher level of Molybdenum improves resistance to corrosion.

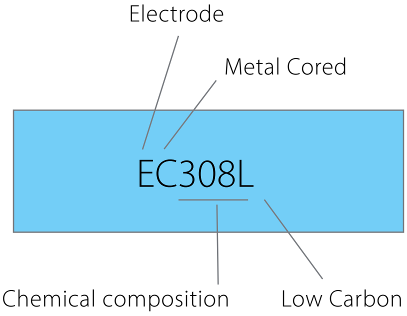


Fig. 67 - Designation of tubular wire (metal cored) according to AWS A5.9.

Si

When it is added, higher amount of silicon improves fluidity of the molten pool.

The advantages of tubular wires ("metal cored") over solid wire are as follows:

- Higher deposition and welding rate, maintaining low spatter levels and without slag, which can be used in automatic and robotic welding.
- Lower penetration, which facilitates the welding of thin thickness.

3.9

DIFFERENCES BETWEEN SOLID WIRE (GMAW) AND TUBULAR METAL CORED WIRE (GMAW-C)

In solid wire welding the current is transported throughout the whole section and the current density will be (Current (A)/ πR^2), while in tubular metal cored wire welding the current will be mainly externally transported through the tube and the inner powder part will be less conductive, so the power density will be higher for the same wire diameter. Therefore, for the same wire current and wire diameter, the tubular wire will have higher deposition rate than the solid wire.

TUBULAR WIRES:

- Higher range of welding intensities.
- Easier thin thickness welding without penetration.
- Higher wire diameters can be used, for example, if a certain thickness is welded with solid wire of 1.0 mm diameter, it can be replaced with a 1.2 mm diameter tubular wire.

SOLID WIRES:

- Depending on the transfer and gas may have higher penetration in the centre, which may cause perforations, this does not happen with a tubular wire.
- The cost of tubular wire (€/Kg) is higher than the cost of solid wire and has lower efficiency, but this difference in cost is compensated by higher productivity or a lower welder labour cost, considering the same length may be welded with tubular wire in less time than with a solid on
- The cost of shielding gas for welding with tubular wire could be a little higher than that used with a solid one, but it is also compensated as in the previous case with an increase in productivity or a reduction in labour cost.

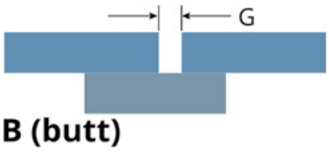
MIG WELDING PARAMETERS FOR SHORT / SPRAY / PULSED ARC (Table 25)

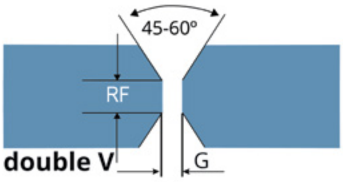
MATERIAL:	STAINLESS STEEL (AISI 304, AISI 304L, AISI 316, AISI 316L)
	SHORT ARC, SPRAY, PULSED ARC
SHIELDING GAS:	SANARC 2
CONSUMABLES:	NIPPON M-308L (ER308LSi)
	NIPPON M-316L (ER316LSi)

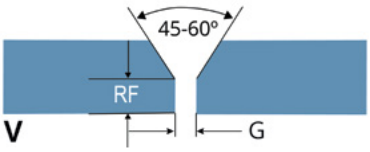
THICKNESS (mm)	WIRE DIAMETER (mm)	WELDING POSITION (*)	JOINT DESIGN (**)	ROOT OPENING - G (mm)	ROOT FACE - RF (mm)	WIRE FEEDING RATE (mm/sec)	CURRENT (CCPI) (Amps)	WELDING RATE (mm/sec)	VOLTAGE (Volts)	No. of PASSES
PULSED ARC										
1.6	1.0	F	T	-	-	100	90	5	20	1
	1.0	F	B	-	-	80	90	13	18	1
3.2	1.0	V(D)	T	-	-	85	90	6	19	1
	1.0	F	T	-	-	85	130	4	24	1
	1.2	F	B	1.6	-	74	120	5	22	1
	1.2	V(A)	T	-	-	63	90	3	18	1
4.8	1.2	F	T	-	-	127	100	5	24	1
	1.0	F	B	-	-	106	106	6	24	1
	1.0	V(A)	T	-	-	106	120	6	21	1
	1.0	V(A)	T	-	-	106	115	6	21	1
	1.0	F	T	-	-	85	140	7	24	1
9.5	1.2	F	B	1.6	-	80	110	7	24	1
	1.2	V(A)	T	-	-	59	90	3	19	1
	1.2	F. H	V-60º	1.6	0-1.6	127	110	5	24	2
	1.0	F. H	V-60º	1.6	0-1.6	95	175	6	24	2
	1.2									
SHORT ARC										
3.2	1.2	F	T	-	-	74	135	3	21	1
	1.2	F	B	1.6	-	53	125	4	20	1
4.8	1.0	F	T	-	-	102	95	4	22	1
	1.0	V(A)	T	-	-	95	125	7	21	1
	1.2	F	T	-	-	74	150	4	22	1
SPRAY ARC										
3.2	1.2	F	T	-	-	116	200	6	29	1
	1.2	F	B	1.6	-	108	195	10	29	1
4.8	1.0	F	T	-	-	191	175	6	29	1
	1.0	F	B	1.6	-	159	185	15	28	1
	1.2	F	T	-	-	116	210	7	28	1
9.5	1.2	F	B	1.6	-	108	200	10	28	1
	1.0	F. H	V-60º	1.6	0-1.6	191	175	7	28	2
	1.2	F. H	V-60º	1.6	0-1.6	116	210	6	29	2

(*) WELDING POSITION:
F = Flat
V(A)= Vertical up
H = Horizontal
(D)= Vertical down
O = Overhead

(**) Type of joint







GAS FLOW: 14-18 L/min.

THESE PARAMETERS SHOULD BE CONSIDERED GUIDELINES AND SHOULD BE ADJUSTED TO ACHIEVE CORRECT APPLICATIONS.

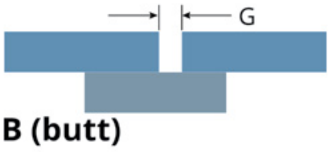
MIG WELDING PARAMETERS FOR SHORT / SPRAY / PULSED ARC (Table 25)

MATERIAL:	STAINLESS STEEL (AISI 304, AISI 304L, AISI 316, AISI 316L)
	SHORT, SPRAY, PULSED ARC
SHIELDING GAS:	SANARC 2
CONSUMABLES:	NIPPON M-308L (ER308LSi)
	NIPPON M-316L (ER316LSi)

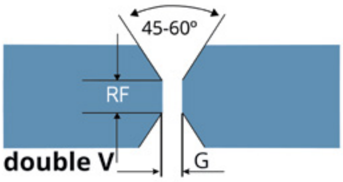
THICKNESS (mm)	ROD DIAMETER (mm)	WELDING POSITION (*)	JOINT DESIGN (**)	ROOT OPENING - G (mm)	ROOT FACE - RF (mm)	WIRE FEEDING RATE (mm/sec)	CURRENT (DCRP) (Amps)	WELDING RATE (mm/sec)	VOLTAGE (Volts)	No. of PASSES
PULSED ARC										
1.6	1.0	F	B	-	-	81	80	15	19	1
3.2	1.2	F	T	-	-	42	75	3	19	1
	1.2	F	T	-	-	55	95	4	20	1
	1.2	F	T	-	-	64	110	4	22	1
4.8	1.2	F	B	1.6	-	59	90	4	22	1
	1.0	F	B	1.6	-	116	90	11	24	1
9.5	1.0	V(A)	V(60)	-	-	74	78	2	20	1
	1.0	F. H	V(60)	1.6	-	116	100	4	23	2
	1.2	F. H	T	1.6	-	87	165	6	23	2
SHORT ARC										
1.6	1.0	F	B	-	-	76	100	10	17	1
	1.2	F	T	-	-	51	95	4	19	1
	1.2	F	T	-	-	64	115	3	21	1
	1.2	F	B	1.6	-	51	100	4	20	1
4.8	1.2	V(A)	T	-	-	42	85	3	16	1
	1.2	V(A)	T	-	-	42	75	2	18	1
9.5	1.0	F	T	-	-	127	145	4	21	1
	1.0	F	T	-	-	138	150	4	23	1
	1.0	F	B	1.6	-	148	126	10	21	1
	1.0	F. H	V(60)	1.6	0-1.6	127	110	5	24	2
SPRAY ARC										
4.8	1.0	F	T	-	-	159	170	4	26	1
	1.0	F	B	1.6	-	180	175	12	29	1
9.5	1.0	F. H	V(60)	1.6	0-1.6	180	165	6	28	2
	1.2	F. H	V(60)	1.6	0-1.6	108	200	6	27	2

(*) WELDING POSITION: F = Flat; V(A)= Vertical up; H = Horizontal; (D)= Vertical down; O = Overhead

(**) Type of joint

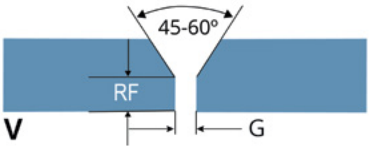


B (butt)



double V

T



V

GAS FLOW: 14-18 L/min.

THESE PARAMETERS SHOULD BE CONSIDERED GUIDELINES AND SHOULD BE ADJUSTED TO ACHIEVE CORRECT APPLICATIONS.

3.10 FLUX[2] CORED ARC WELDING - (FCAW)

3.10.1 Process description

The tubular wire welding process (FCAW – Flux[2] Cored Arc Welding) uses the heat generated by an electric arc between a continuous tubular wire that is consumed and the metal to be welded. The joint is protected by the flux[2] contained in the tubular wire and that may be helped by an external gas supply. The installation of this process is similar to that of the MIG/MAG (GWAW) process and the characteristic that differentiates the FCAW process from other welding processes is the deoxidizing content inside the wire, which will generate slag in the weld bead.

The FCAW process has two variants, depending on the mode used to protect the weld pool and joint from air.

- UNE EN ISO 4063: 2011. Process 114: Arc welding with tubular wire filled with flux and without shielding gas. This is called self-protected FCAW SS, where the weld is protected by the gases generated by the combustion and vaporization of flux[2] inside the wire. (Fig. 68)
- UNE EN ISO 4063: 2011. Process 136: Arc welding with tubular wire filled with flux and with active shielding gas. This is called FCAW GS with shielding gas, which uses a shielding gas in addition to the protective properties of the flux[2] inside the wire. (Fig. 69). This FCAW process with shielding gas is the most used.

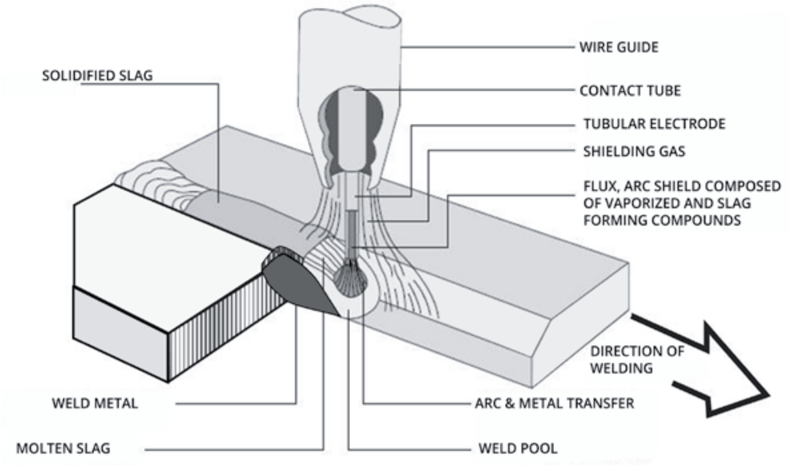


Fig. 69 -.Welding with protected tubular wire (with shielding gas).

With both methods, the flux[2] inside the wire produces a fine slag which protects the solidifying of weld bead. Welding with tubular wire (FCAW) is normally a semi-automatic process, although it may also be fully automatic.

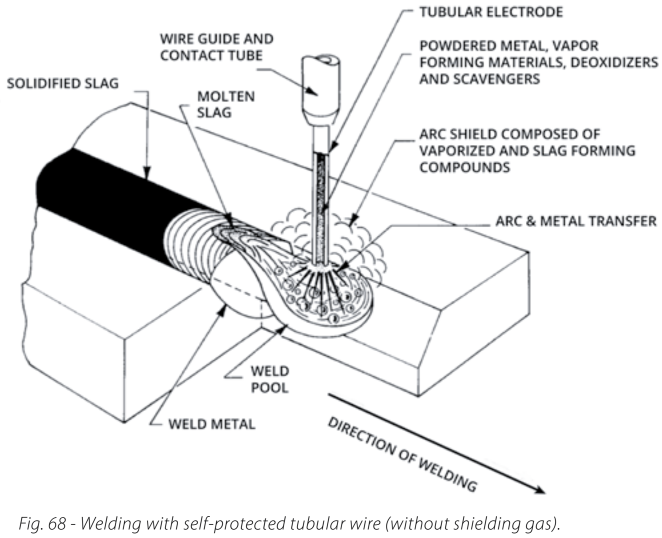


Fig. 68 - Welding with self-protected tubular wire (without shielding gas).

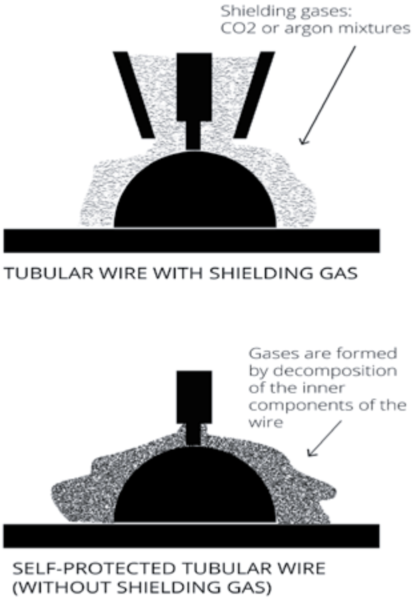


Fig. 70 - Differences between the two types of tubular wires (FCAW) with shielding gas and self-protected (without shielding gas).

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[2] Author's note Appendix 3, page 258.

3.10.2 Electrode extension

Electrode extension is the distance between the end of contact tip and the end of the wire. It will vary, depending on the process used (Fig. 71). It is an important variable because it affects the arc energy, the deposition rate (Kg/h), the penetration, the arc stability and quality. It is important to know this variable since welding with tubular wire, with the approrpriate electrode extension for a solid wire, of 10-12 mm, will result in a weld with pores, with poor penetration and with poor slag detachment.

In general, manufacturers recommend tubular wires of 20 to 30 mm for the wires protected with shielding gas and of 30 to 50 mm for self-protected wires (without gas). A minimum electrode extension may be necessary for the latter, in order to obtain good protection. The torches for these self-protected wires may carry an insulated guide tube to maintain these high electrode extensions.

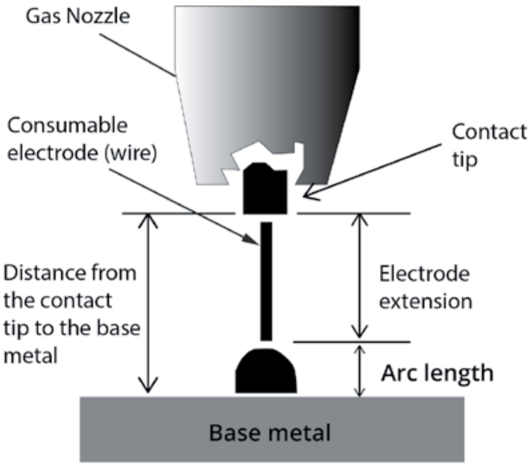

Fig. 71 - Electrode extension

3.10.3 Advantages

Welding with tubular wire (FCAW), has the following advantages:

1. High welding quality and appearance. Similar to welding with coated electrodes (SMAW), but at a lower cost.
2. A higher deposition rate is achieved with tubular wire than with solid wire, therefore higher productivity may be obtained with FCAW tubular wire than with solid MIG / MAG wire (GMAW).
3. Metallurgical improvement in the weld, which is produced by the flux[2].
4. Slag generation protects, supports and improves the weld pool.
5. Higher tolerance to contaminants and initial cleaning requirements, which may cause cracks and pores, than in MIG / MAG welding (GMAW).
6. Using self-shielded wires eliminates the need to handle gases.

3.10.4 Limitations

The limitations that may restrict its application are:

1. The process generates slag that needs to be removed. This may constitute a disadvantage compared to welding with MIG / MAG (GMAW) wires without slag, considering the time it takes to eliminate it between passes, especially in the root pass and in robotic welding where the slag would cause problems with the tools to fix the pieces to be welded.
2. The efficiency is lower than that of solid wires because it contains flux[2] and slag formers.
3. Not all metals can be welded. It is limited to carbon steels, stainless steels and nickel based steels.
4. The equipment is more expensive and more complex than the coated electrode process (SMAW) equipment, since the feeder and the power supply need to be close to the welding site.
5. The tubular wires that need shielding gas have limited use outside, as wind may displace the shielding gas.
6. It generates higher volume of fumes when compared to the GMAW and SAW process.

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[2] Author's note Appendix 3, page 258.

3.10.5 Wire feeder and rollers

The wire feeder and the rollers are two critical points. These components are already important in the MIG/MAG (GMAW) process with solid wire, thus in the FCAW process they are even more important as it uses tubular wire. It is not essential for the feeder to have 4 rollers, but higher quality equipment has 4 rollers.

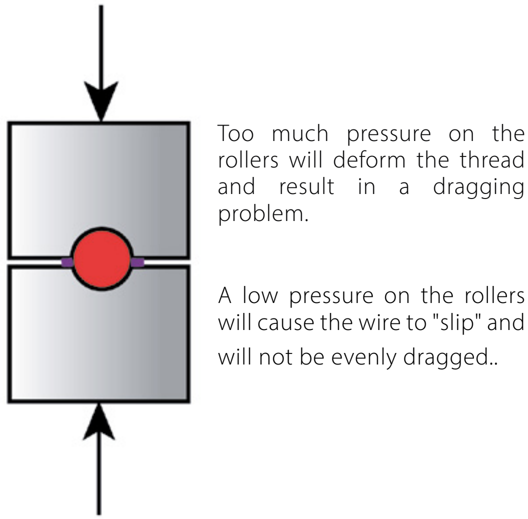


Fig. 72 - Excessive pressure on the rollers is harmful.

Fig. 73 - Straightener.

Suitable rollers for solid wire have a lower V shaped roller and a flat upper roller. If a tubular wire is excessively tight, it may strain it and cause dragging problems. To avoid this, special rollers may be used, such as a lower roller with grooves and a flat upper roller, to avoid using too high pressure that would deform the wire and would pass properly through the wire conduit and the contact tip.

To improve the drag of a tubular wire, a straightener may be placed before entering the rollers (Fig. 73), which has the following advantages:

1. It reduces the wire tension when in the coil
2. It diminishes the friction that takes place in the spiral conduit facilitating the rollers thrust.
3. It facilitates tracking the wire tip at the joint, as the wire is straight at the point of contact.

3.10.6 Consumables

The appropriate consumable for an application should be selected producing a weld with two basic characteristics:

- Mechanical and physical properties equal to or superior to the properties of the base metal or that improves the base metal in any way, such as corrosion resistance or wear resistance. A welded metal, even with the same composition as the base metal, will have metallurgical characteristics that will depend on factors such as heat input and the bead configuration.
- High quality weld. This will be achieved with a suitable wire, which in case of a tubular wire (FCAW) will be able to:
    1. Allow welding with slag in the most appropriate position, or that required by the application.
    2. Allow welding on surfaces with potential dirt or rust, with better results than solid wires, due to the flux[2] and the slag.
    3. Allow welding outside using self-shielded tubular wires (FCAW SS), by releasing gases that eliminate the influence of air in the weld pool and in the heat affected zone.
    4. Achieve cost reductions.

---

[2] Author's note Appendix 3, page 258.

3.10.7 Identification of tubular wires

An example of a tubular wire designation may be seen in Table 26 (FCAW).

Process	FCAW	
UNE-DIN EN ISO 4063:2011	136	
METAL	STAINLESS STEEL	
	UNE-DIN EN ISO 17633 A	ASME II PART C SFA 5.22/ SFA 5.22M
	T19 9 L R M(C) 3	E308LT0-4

Table 26 Example of FCAW wire designation

Gas selection guide for MIG/MAG procedures		
WIRES	TYPE	COMMERCIAL NAME
Stainless steel	Solid:	NIPPON M-308L (ER 308LSi); M-316L (ER 316LSi); M-347 (ER 347Si); M-309L (ER 309LSi); M-312 (ER 312); M-307 (ER307); M-4462(--)
	Tubular:	NIPPON FG-308S (E 308LTO-4); FG-316S (E 316LTO-4); FG-347 (E 347TO-4); FG-309S (E 309LTO-4)
METAL	SHIELDING GAS	CHARACTERISTICS
Stainless steel	SANARC X1, X2, X3	They are used with alloys where it is necessary to maintain a low carbon content, improve the fluidity of the weld pool and decrease undercuts.
	SANARC 2	It is the most commonly used mixture to weld stainless steels with low carbon content..
	SANARC PERFECT 2	Suitable for welding austenitic stainless steels and austenitic-ferritic stainless steels (duplex), as its nitrogen content stabilises austenite.
	SANARC FLASH 2	It provides good bead appearance due to the hydrogen content and therefore should only be used in austenitic stainless steels welding. This mixture improves the bead appearance in relation to the Ar-CO2 mixtures.
	SANARC HC15 SANARC HL15 SANARC PERFECT 3	Depending on their helium content, they provide higher penetration and higher fluidity to the pool.
	SANARC HRC	It combines the advantages provided by hydrogen and helium, obtaining excellent bead appearance. Due to the hydrogen content, It is only suitable for austenitic stainless steels.
	SANARC 20	Most suitable mixture for welding with flux cored tubular wires.

Table 27. Gas selection guide for MIG / MAG procedures.

Table 28. Gas selection guide for MIG/MAG procedures

MIG WELDING		Composition	UNE EN 14175	THICKNESS															PRODUCTIVITY			WELDING QUALITY		FUMES
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Welding rate	Spatters	Penetration	Bead appearance	Porosity	
Austenitic stainless steel	SANARC PERFECT 2	Ar-He-CO$_2$	M12	—	—	—	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	—	*
	SANARC 2	Ar-CO$_2$	M12	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	—	*	*
	SANARC PERFECT 2	Ar-CO$_2$-N$_2$	Z	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	—	*	*
	SANARC FLASH H2	Ar-CO$_2$-H$_2$	M11	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	*	*	*
	SANARC X1-X2-X3	Ar-O$_2$	M13	—	—	—	*	*	*	*	*	*	*	*	*	*	*	*	—	—	—	P	—	—
Ferritic stainless steel	SANARC PERFECT 3	Ar-He CO$_2$	M12	—	—	—	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	—	*
	SANARC 2	Ar-CO$_2$	M12	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	—	*	*
	SANARC X1-X2-X3	Ar-O$_2$	M13	—	—	—	*	*	*	*	*	*	*	*	*	*	*	*	—	—	—	P	—	—
Duplex stainless steel	SANARC 2	Ar-CO$_2$	M12	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	—	*	*
	SANARC PERFECT 2	Ar-CO$_2$-N$_2$	Z	*	*	*	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*	—	*	*
Nickel & alloys	SANARC PERFECT 3	Ar-He-CO$_2$	M12	—	—	—	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	—	*

Recommended	*	Appropriate	—	it may be used	P

4 Laser beam cutting - (LBC)

Laser cutting competes with other cutting processes such as plasma, punching and water jet, with improved quality, speed and range of thickness and reduced cost. It is competitive in design and to produce small and medium cutting series.

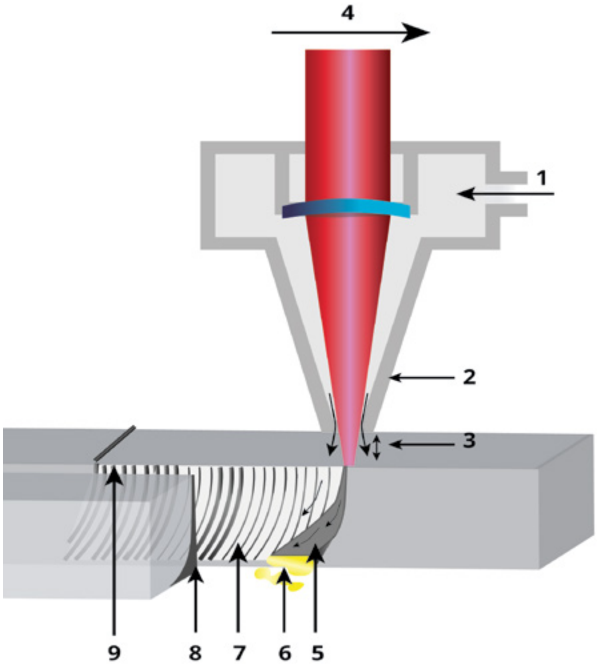
Many acquisition decisions of cutting facility companies have been due to:

- Increases in automatic and robotic welding which require an improvement in welding preparation.
- Increases in stainless steel cutting volumes, which also requires an increase in cutting quality.

Designation of the process:

Laser cutting (Laser Beam Cutting - LBC)

- UNE – EN ISO 4063: 2011
- **Process 84:** Laser cutting



1. Assist gas
2. Cutting nozzle
3. Nozzle offset
4. Cutting speed
5. Molten material
6. Dross
7. Cut roughness
8. Heat affected zone
9. Kerf width

Fig. 74 - Laser cutting.

4.1 ADVANTAGES

The main advantages for cutting stainless steel are:

- High quality cutting with straight edges.
- Low thermal deformations.
- Very narrow heat affected zone.
- Complicated cutting profiles with small spikes or sharp edges.
- Cutting of pieces with little final revision work.

4.2 DIFFERENCES BETWEEN CO_2 AND FIBRE LASER CUTTING

Until recently, CO_2 laser cutting was practically the only method used industrially for cutting metals with only 10% efficiency.

However, disk and fibre lasers with much higher efficiency now compete with CO_2 lasers, especially for thin materials and reflective materials such as aluminium, copper or brass. The main differences between CO_2 and disk and fibre are as follows:

Due to the importance of gases in cutting cost and quality it is necessary to use the purities recommended by the equipment manufacturer, an installation (pipe, panels and regulators) and a supply system that guarantees these purities, flows and pressures. CO_2 lasers require "resonator gases" and "assist" gases, while fibre lasers only require assist gases.

CO_2 Laser	Disk and fibre laser
Resonator gases needed.	No resonator gases.
	Operating and maintenance costs reduced.
The beam is guided by optics.	The beam is guided by fibre, without an optical path.
Energy efficiency in the order of 10%.	Energy efficiency higher than 25%.
Competitive compared to disk and fibre laser in materials thicker than 4 mm.	Higher cutting speeds. Competitive compared to CO_2 laser in materials thinner than 4 mm.
	Can produce high quality cuts of galvanized steel and reflective materials such as aluminium, copper or brass.
	Elimination of source heating times and cooling costs.

Incorporating cutting heads into lasers that can cuts bevels, means savings in edge preparation where a V preparation is needed.

Resonator gases

CO2 is the active gas in laser generation; the beam is formed by transitions between various vibrational energy levels in the CO2 molecule.

Nitrogen is an easily excited gas when it is subjected to an electrical discharge. The first nitrogen vibrational level has approximately the same energy as the highest CO2 level. Therefore, energy is transferred during collisions between the two molecules. Apart from taking part in the excitation, the N2 in the mixture increases the laser's power.

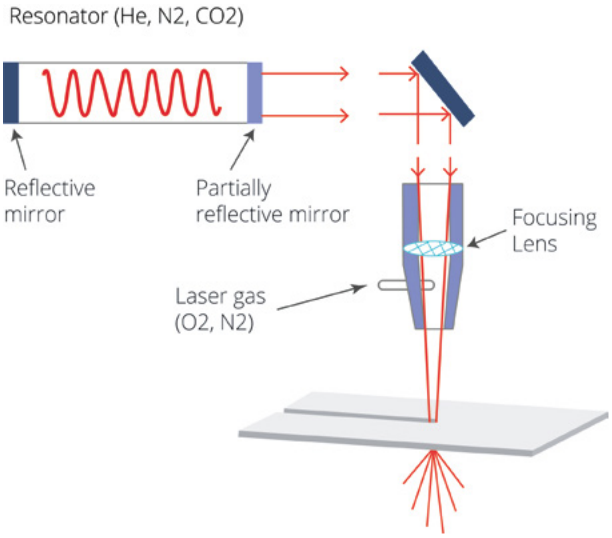


Fig 75 - Cutting with CO_2 laser.

Helium plays two important roles in the laser mixture:

a It accelerates relaxation transitions by helping CO_2 molecules to go to the lowest level.

b It helps in heat dissipation from electrical discharges, due to its high thermal conductivity.

Assist gas

Nitrogen is used to cut stainless steel under high pressure (30 bar). Its purpose is to remove molten metal by blowing on it, and to protect the metal edges from potential oxidation by the air.

It is recommended to use Lasersan N nitrogen with 99.999% N_2 purity, to obtain an oxide-free surface and in the case of CO_2 lasers, when the assist gas is also used in the laser beam guide. This purity of the assist gas nitrogen will be specified in the cutting installation manufacturer's manual.

Fig. 76 shows the lay out of a complete CO_2 laser cutting installation, including the gas supply.

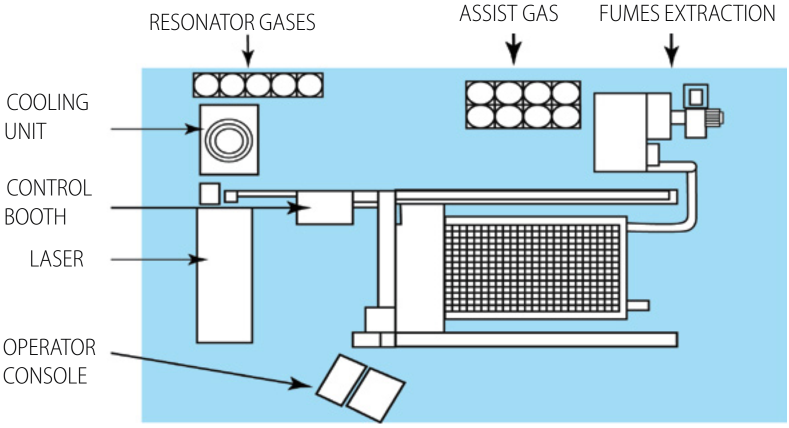


Fig. 76 - Distribution of components of a CO2 laser cutting system.

The power of CO_2 cutting lasers range between 0.5 and 7 KW. Table 29 shows the maximum thickness cut, the assist gases and the resonator gases.

Metal: STAINLESS STEEL				
Power (w)	Thickness (mm)	Resonator gases	Assist gas	Assist gas pressure (bar)
500-8000	0.5-30	He-50 (99,999%) N_2-50 (99,999%) CO_2-48 (99,998%)	Lasersan N (99,999%)	30

Table 29. Thickness, assist and resonator gases in CO_2 laser cutting.

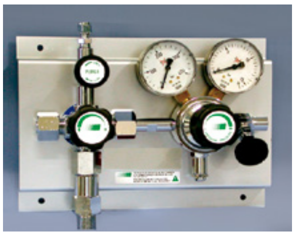
4.3 GAS SUPPLY SYSTEM

The components of the gas installation will depend on the type of laser and consumption::

Resonator gases

The usual supply system is using cylinders and the main components of the gas installation are:

- Simple panel 1 cylinder.
- Double panel 1 + 1 cylinders.
- Automatic or semi-automatic change over.
- Tapping point or workstation.
- Stainless steel pipe (better without longitudinal weld). Laser manufacturers recommend no more than 10 m long per gas.



Simple panel 1 cylinder (He-N_2- CO_2) COURTESY OF NIPPON GASES

Stations of automatic change over. COURTESY OF NIPPON GASES

Assist gases

The supply method for assist gases will depend mainly on the average and peak consumption, on the available space and the necessary safety conditions. The main supply methods are:

- Bundless
- Starcyl
- Microbulk
- Liquid tank

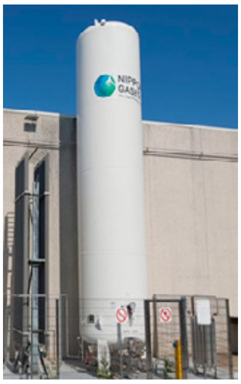
The main components of an assist gas installation are:

- Simple manifold 1bundle with heater.
- Double manifold 1+1 bundles with heater.
- Starcyl panel and back p with wimple manifold 1 bundle.
- Microbulk panel and back p with wimple manifold 1 bundle.
- Liquid tank.
- Tank regulation panel.
- Tapping points or workstations.

Stainless steel pipe of sufficient diameter to supply the pressures and flow rates are required by the application according to the specifications of the laser manufacturers. Some gas supply companies use stainless steel pipe manufactured without longitudinal welding for this application. Welding between stainless steel pipes should use the TIG process with SAMARC AS as shielding gas and with SANARC AS or SANARC F5 as backing gas, in order to avoid generating particles that interfere in the correct operation of the laser, or reducing the life of the components. Some gas supply companies are already using longitudinal seamless piping.

Double manifold 1+1 bundles of N_2 COURTESY OF NIPPON GASES

Starcyl panel and back up with simple manifold 1 bundle. COURTESY OF NIPPON GASES



N_2 high pressure liquid tank. COURTESY OF NIPPON GASES

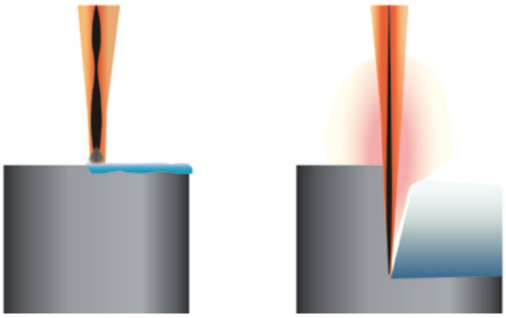
5 Laser beam welding (LBW)

A laser beam is basically formed by the excitation of laser gas, a mixture of CO_2, helium and nitrogen, using a high voltage and low current power supply. The electrical discharge excites the CO_2 molecules which later emit photons when returning to their original energy level. The gas mixture is placed between two mirrors placed at both ends of a tube, one is totally reflective and the other one partially reflective, in order to allow the beam to exit. Free photons bounce between the mirrors and excite the CO_2 molecules, starting a chain reaction of photon emission. A stream of photons, which is the laser beam, comes out through the partially reflective mirror.

A CO_2 laser emits a beam with a wavelength of 10.6 µm and the beam is conducted through mirrors, as this wavelength cannot be channelled through fibre. Its energy efficiency is close to 10% and is considered high when compared to Nd laser: YAG (2-3% efficiency).

Fibre and disk lasers have been used for industrial welding and cutting applications over the last few years, which has created competition between CO_2, fibre and disk, and they share market applications.

5.1 PROCESS ADVANTAGES

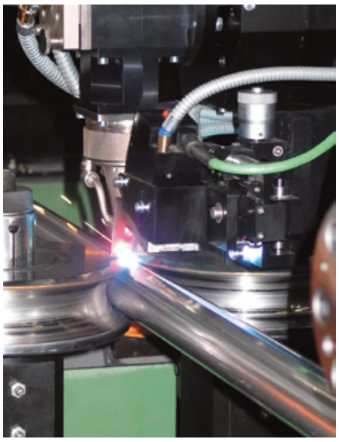

CONDUCTION WELDING

KEYHOLE WELDING

Fig. 77 - CO_2 laser welding.

The advantages of laser welding are:

- Reduced heat affected zone.
- Heat input adjustable to metal type and thickness.
- High welding rate.
- Few distortions.
- Quality welding without subsequent review.
- Several thickness can be welded from one side.
- Metals of various thickness can be welded.
- It can be combined with other processes, such as MAG Laser hybrid welding, which reduces the requirements for joint tolerances.


PHOTOGRAPH COURTESY OF ROFIN

Designation of the process:

Laser Beam Welding - LBW

UNE – EN ISO 4063: 2011

Process 52: Laser welding

There are two modes:

- Conduction welding.
- Keyhole welding.

Conduction welding applies to thin materials (<1.5 mm). Low power lasers are used and heating is produced by thermal conduction. The metal melts without vaporization.

Keyhole welding or deep penetration welding is performed with high power lasers (2 to 20 KW), melting a small volume in the form of a capillary through the material, generating a steam column surrounded by material in liquid state. (Fig. 78)

The vapour column is stabilised when the energy density of the laser radiation and the forward speed are balanced. The right energy should be applied to perform the fusion in the desired area. If the energy density is very high, total penetrations may take place instead of joints. If the energy density is too low, the metal vaporization would not form, nor would the Keyhole be formed. This process achieves high width/penetration ratios of 1 to 4 or even 1 to 10.

Shielding gases

They are used for two reasons:

1. To protect the molten metal from air.

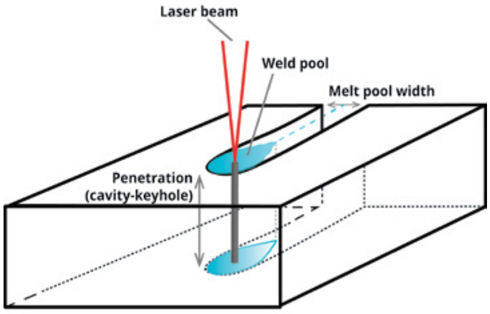
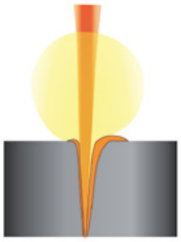
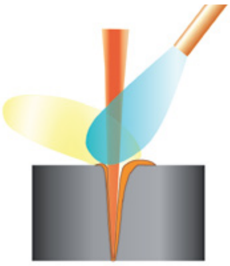


Fig. 78 - Keyhole welding.



WITH PLASMA



NO PLASMA

2. To eliminate the plasma formed by the ions and electrons of the vaporised metal that form a layer that is opaque to laser radiation, this complicates and absorbs some of the beam's energy.

Both objectives are achieved by blowing with helium or argon. Helium is preferable with higher energy applications, due to its higher ionisation potential. Argon, which ionises before helium, is preferable for low energy applications, due to its low ionisation potential and its lower cost.

Depending on the application, the following mixtures are used:

Ar-He, Ar-He-CO_2, He-Ar-O_2, Ar-N_2

Metal	Shielding gas
Austenitic stainless steel	SANARC AS/AQ
	SANARC EASY 5 SANARC FLASH 4
	SANARC H30/H50
	SANARC HS/HQ
	SANARC NS/NQ
Duplex stainless steel	SANARC NS/NQ
	SANARC T1/T3
	SANARC HN
Ferritic stainless steel	SANARC AS/AQ
	SANARC H30/H50
	SANARC HS/HQ

5.2 LASER ARC HYBRID WELDING - LAHW

A hybrid welding process combines two or more processes, to provide heat input to a single weld pool, which achieve welds with advantages over the processes that are combined. A hybrid welding process should not be confused with a process in which several welding processes are combined, forming two or more weld pools completely separated by solid metal, generated at the solidification phase.

A hybrid laser welding process, combines a laser process (Fibre, CO_2, ND: YAG) and an electric arc welding process (MIG/MAG, TIG, PLASMA), in a single weld pool to achieve advantages not achieved by combined processes. The most commonly used is the combination of a laser process and a MIG/MAG (GMAW) process.

The laser beam is focused perpendicular to the surface of the metal to be welded, while the electric arc is directed with a suitable inclination to the point of interaction of the laser beam with the base metal. This configuration generates mutual influence and assistance between both processes: laser with its high energy density and the electric arc with its high energy efficiency, and makes them interact at the same time and in the same area of the process, creating the same molten pool.

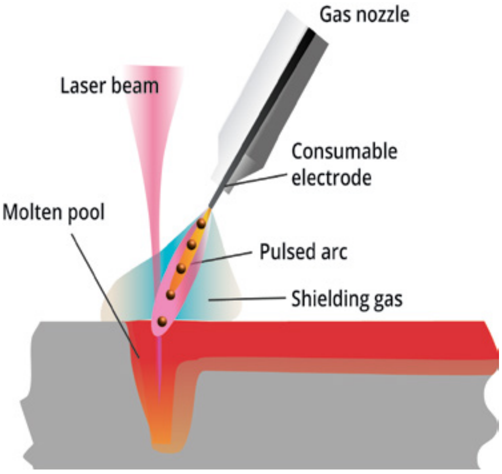


Fig. 79 - MIG / MAG laser hybrid welding.

5.2.1 Advantages

The laser provides:

- Narrower welds with deeper typical laser penetration.
- Higher welding rates.
- Stabilised MIG / MAG arc.
- Higher energy density.
- Narrower heat affected zone.

The MIG/MAG (GMAW) provides:

- Higher quality welds with higher separations, by solving problems caused by a specific source of energy, such as laser.
- Provides the consumable, which may help reduce susceptibility to porosity and cracking.
- Reduces cooling speed, which may help to obtain better mechanical properties and solve structural problems.
- A conventional and cheaper process.

Correctly combining the two processes achieves the following:

- Easier pre-assembly and higher productivity.
- Reduced distortion compared to MIG / MAG welding, due to the heat input of hybrid laser (LAHW) being higher than laser welding, but lower than MAG welding (GMAW), a relatively narrow welding is achieved (narrow weld) and a smaller heat affected zone.
- Compared to the MIG/MAG process, the cooling rate with the hybrid laser process is faster, which may be beneficial for austenitic stainless steel welding, avoiding sensitisation and embrittlement problems (sigma phase). The opposite may also happen when welding duplex steel, a higher cooling rate in the hybrid laser process may result in a structure similar to 100% ferrite, which will have low toughness and low corrosion resistance.
- Compared to autogenous laser welding, joint welding with greater edge separations can be achieved and a reduction in the number of returns caused by defects.
- It extends the field of applications for laser welding.
- Easier automation.

5.2.2 Limitations

- High investment costs, mainly due to the laser and its maintenance. This may be partially solved by using lower power lasers and by using the electric arc as a source of initial heat input, to preheat the base metal before laser welding. It also provides deeper penetration of laser welding, which has low energy efficiency. (CO_2 Laser Efficiency: 10%; Fibre Laser: 30%).
- The first lasers were CO_2 lasers, due to their higher industrial implementation, nowadays fibre lasers may be a better option.
- Weld preparation, thickness and position requirements.
- More variables to be adjusted.
- Higher series are needed for profitability
- The following table shows a comparison between CO2 and fibre lasers and the characteristics required for hybrid laser welding.

TYPE OF LASER	POWER	BEAM QUALITY	INVESTMENT COSTS	MAINTENANCE
FIBRE	4	4	4	4
CO2	2	3	3	3
Nd-YAG diode	1	1	1	1
Nd-YAG disc	1	3	2	2

Note: The score is a scale of 1 to 4, with 4 the highest.

Table 30. Comparison between the main types of lasers

5.2.3 Components

- Robot or automated control.
- Laser:
  - CO_2 laser, fibra, Nd-YAG.
  - Fibre optic cable.
  - Laser optical system.
- MIG/MAG (GMAW):
  - Power group.
  - Wire feeding system.
  - Hose connectors.
  - Welding torch.
- Hybrid welding head.

5.2.4 MIG/MAG (GMAW) welding information

Consumable wire:

According to AWS/ASME SFA 5.9 Consumable for MIG / MAG (GMAW) welding and TIG (GTAW) for stainless steels.

Stressing:

Suitable for automation so that the length of wire protruding from the nozzle remains straight.

Type of transfer:

It should be without projections, with long arc or preferably with pulsed arc.

Shielding gas:

Required for hybrid laser welding to protect the molten pool and facilitating long or pulsed arc transfer. If a CO_2 laser is used, then He-Ar-CO_2 mixtures should be considered to avoid possible plasma formed by ionising the gas that interferes with the laser beam.

5.2.5 Thickness

Thickness of stainless steel up to 25-30 mm may be welded in one pass and up to 60 mm, with multi-pass welding.

An example of AISI 316L stainless steel welding

Filler consumable: AWS/ASME SFA 5.9 ER 316LSi
Thickness: 20 mm
Penetration: 18 mm
Laser type: 19 KW fibre
Welding speed: 2.1 m/min
Wire feeding speed: 15 m/min
Edge separation: 0.2 mm
Electric arc: MIG/MAG (GMAW) pulsed
Voltage: 29.1 V
Current: 288 A
Shielding gas: Ar-2.5% CO_2 (25 L/min)
Backing gas: Ar (47 L/min)

6 Plasma Arc Cutting (PAC)

The energy needed to make the cut is generated by an electric arc between an electrode and the base metal in a highly ionised gaseous medium.

The plasma is formed by ionising the gas passing through an electric arc that is "strangled" by the special configuration of the nozzle.

The plasma transfers sufficient energy to make the cut. Appropriate pressures and flows to produce a blowing effect to dislodge the molten metal.

Designation of the process:

• Plasma Arc Cutting

• UNE – EN ISO 4063: 2011

Process 83: Plasma Cutting

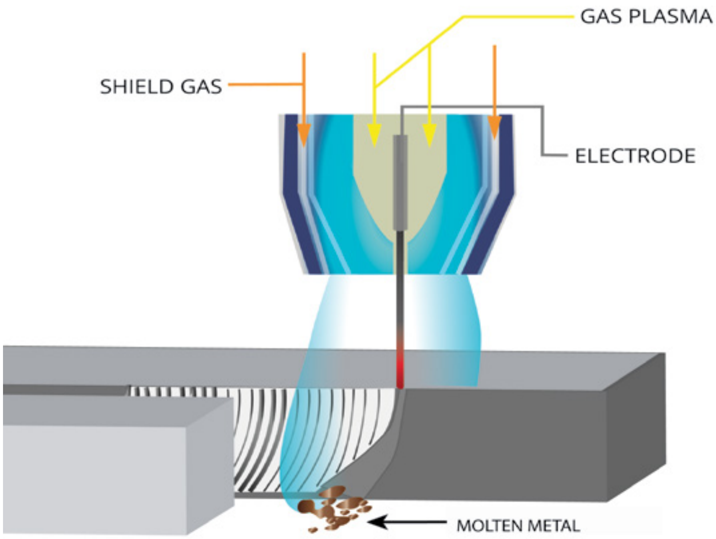


Fig. 80 - Plasma cutting.

Types of plasma cutting

The continuous development of this process has meant that the processes that are currently commercially used, depending on the configuration of the equipment, the cutting torch and the gases to be used, are as follows:

- Standard Plasma.
- Dual.
- Water injected.
- Under water.
- High definition.

The latest advances in plasma cutting technology aim at:

- Chamfer cutting.
- Improving the cutting quality.
- Vertical cutting.
- Increasing the cutting rate.
- Generating less slag and reducing secondary operations.
- Increasing the thickness to be cut.
- Improving the weldability of cut edges.
- Improving stainless steel cutting.

To achieve these benefits, the latest cutting equipment incorporates the air required for cutting, with other gases and mixtures such as oxygen, nitrogen, nitrogen-hydrogen (SANARC F5), argon-hydrogen (SANCUT R35) and argon-nitrogen-hydrogen (SANCUT RN).

The use of these gases has resulted in revised purities, strains and flow rates, and improved automatic consoles.

6.1 DRY PLASMA

Standard plasma

The arc is strangled only in a nozzle. Only cutting gas is used, shielding gas is not used.

In general, the cutting gas is added tangentially surrounding the electrode. The rotation of gases makes the coldest part (also heavier) move radially towards the outside, forming a protective layer on the inside of the nozzle. This helps to achieve longer nozzle duration. Standard plasma was the most commonly used method, until the introduction of Plasma Cutting with Water Jet.

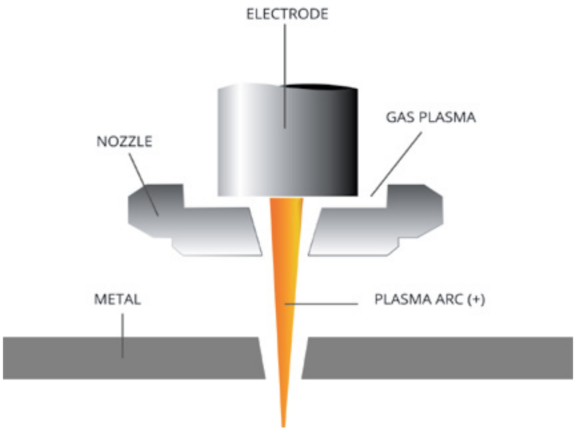


Fig. 81 - Standard plasma.

For stainless steel cutting the gases used are:

- Mixtures of Ar-H_2 y N_2-H_2. They are the most commonly used for high quality cutting of thick stainless steel and aluminium.
- Air. It was introduced for carbon steels cutting, allowing a faster cutting and with fewer losses than with nitrogen. However, as air is an oxidising gas, it results in shorter electrode life, increasing costs. The oxygen in the air provides additional energy by an exothermic reaction with the molten steel. Although this process may be used for cutting stainless steel and aluminium, the cutting surface will be oxidised.

Dual plasma

It is generated by modifying standard plasma. Both shielding and cutting gases are used. A secondary shielding gas is added around the nozzle. The cutting gas and the shielding gas are selected according to the metal to be cut. The speeds achieved are higher than with standard plasma. Speed and cutting quality in stainless steel and aluminium are very similar to standard plasma. To cut stainless steel the gases used are: Air, N_2 and Ar-H_2.

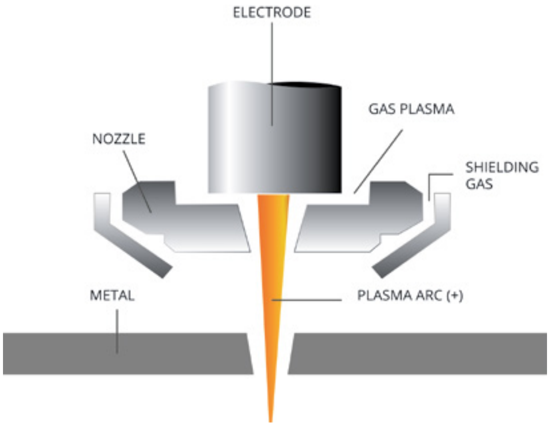


Fig. 82 - Dual plasma.

High definition plasma

Both shielding and cutting gases are used. This variation of plasma cutting produces a quality that is close to that of laser, in terms of perpendicularity and the "roughness" of the cutting, with a much lower investment.

The main characteristic is the creation of a Virtual nozzle through the gas flow,which strangles and stabilises the plasma arc. H-5 (Ar-35%H_2) and N_2.

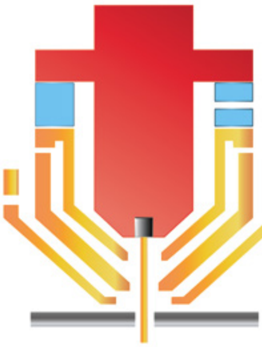


Fig. 83. High Definition Cutting Plasma.

6.2 UNDERWATER PLASMA

This process is especially indicated for machining cutting systems with numerical control and with noise levels, under normal operating conditions, below 85 dBA (standard cutting plasma produces noise levels between 105 and 115 dBA).

Underwater cutting compared to standard plasma cutting eliminates:

- Ultraviolet radiation.
- Fumes.
- Thin sheet distortion.

The sheet to be cut is placed on the cutting table with the cutting surface submerged in water between 6 cm to 8 cm. It uses a height control system acting on a voltage signal.

Underwater cutting is used for high volumes of stainless steel cutting, free of oxidation, using water jet and nitrogen as the cutting gas.

Experience shows that when cutting a particular material, the following must be taken into account:

- Cutting process (number of gases, with water jet).
- Welding torch design.
- Design and size of nozzle orifice.
- Types and flow of gases.
- Distance from the nozzle to the metal to be cut.
- Current.

Gas summary:

Generally, manufacturers of the welding torch and equipment provide a guide to help identify the optimal cutting conditions for each material and thickness.

Process	Thickness mm	Manual (M) Automatic (A)	Gases
Standard	1-38	M, A	Air, N_2
Dual	1-32	A	Air/Air F-5/N_2-S1 H-35/N_2-S1
High definition	0.5-50	A	N_2-S1/N_2-S1 F-5/N_2-S1 H-35/N_2-S1
Under water - with water jet)	3-50	A	N_2

Table 31. Summary of stainless steel plasma cutting applications and gases.

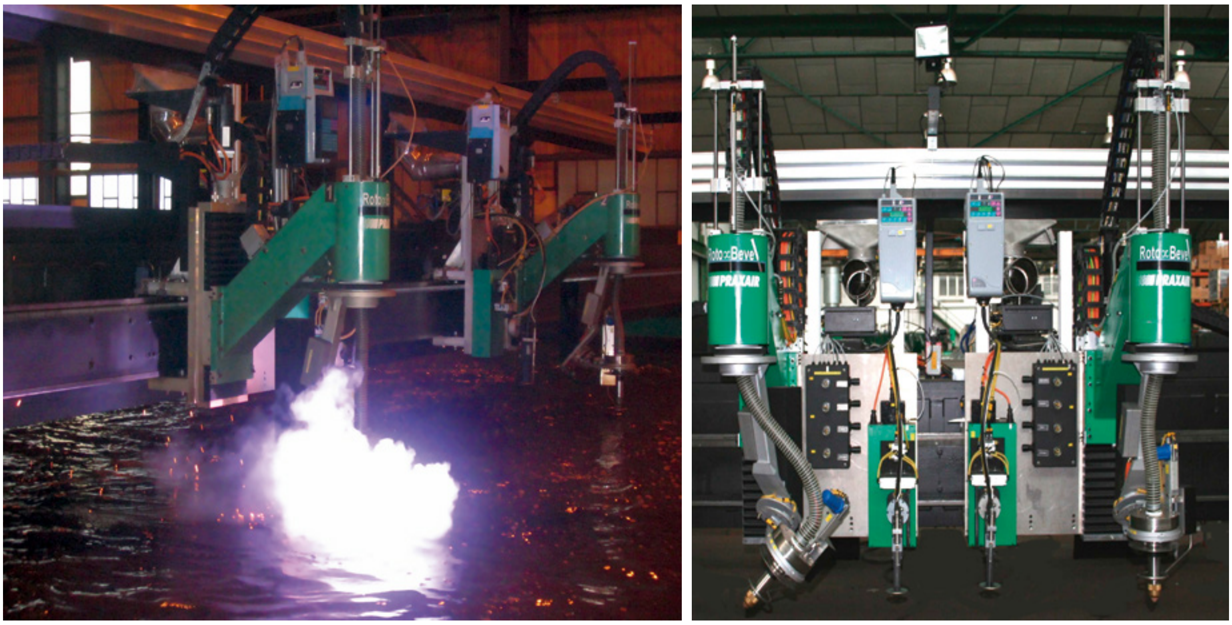
6.3 BEVELLING PLASMA ARC CUTTING

Incorporating a RotoBevel head to a plasma cutting station for bevelling with fixed and variable chamfers is an important step to reducing costs in weld preparation.

The special design of this station achieves cutting where rotation is higher than 360º and the chamfer angles continuously vary between -60º and 60º.

Until a few years ago, these cuts were only possible for carbon steels and with a triple station of oxyfuel torches.

This development provides cutting centres with the opportunity to supply cut metal with the edge preparation required for welding.



PLASMA WITH ROTOBEVEL.
COURTESY OF D. CÉSAR DEL CAÑO

6.4 PLASMA ARC GOUGING

Plasma arc gouging requires particular equipment and accessories for the welding torch.

Compared to the air arc process with graphite electrodes on stainless steel, its advantage is that it does not increase the carbon content if used with the appropriate plasma equipment, torch accessories and gases. These are SANCUT R35 (Ar-H_2) and Nitrogen. The figures indicate its application.

7 Plasma Arc Welding (PAW)

Heat is produced by an electric arc between a tungsten electrode and the base metal (transferred arc) or between the electrode and the nozzle (non-transferred arc)

A gas in plasma state is used as arc support, which is surrounded by shielding gas. The plasma state is formed when gas passes through the orifice of the nozzle that strangles the arc, reaching temperatures in the order of 28.000ºC.

Plasma welding with transferred arc may employ two techniques, depending on how the base metal is melted:

- STANDARD or "MELT IN", where specific penetration is achieved according to welding parameters. (Fig. 84)
- HOLE or "KEYHOLE", where the plasma arc is forced to completely penetrate the base metal, once the arc is passed, the surface tension forces close the "hole" producing the weld. (Fig. 85)

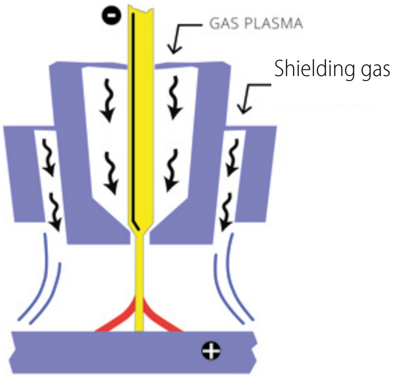


Fig. 84 - Standard procedure.

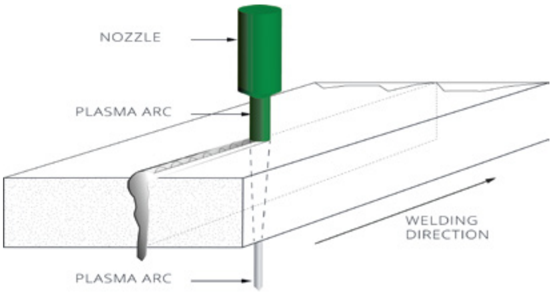


Fig. 85. - Keyhole procedure.

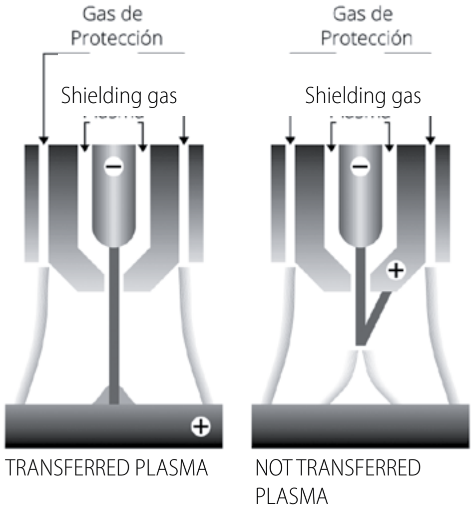


Fig. 86 - Transferred/not transferred plasma.

In practice, the equipment is classified according to the current used:

1. MICROPLASMA: currents between 0.1 and 50 A are commonly used.
2. PLASMA:

- Low current (<100 A)
- High current (>100 A)

Designation of the process:

- Plasma Welding (Plasma Arc Welding - PAW)
- UNE – EN ISO 4063: 2011

Process 152:
Plasma arc welding with powder.

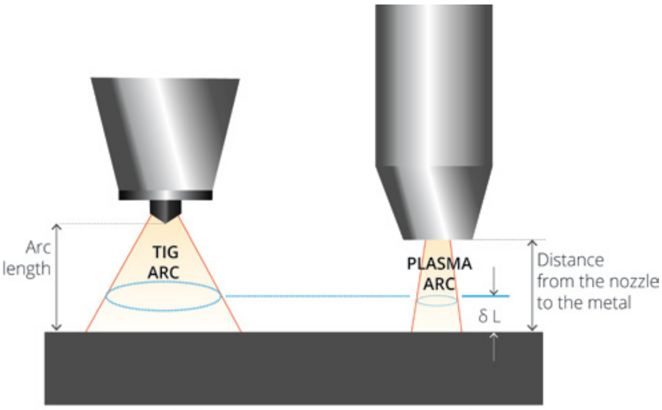
Process 153:
Plasma arc welding with transferred arc.

Process 154:
Plasma arc welding with non-transferred arc.

7.1 TIG AND PLASMA PROCESS DIFFERENCES

These procedures often compete. The main differences between the two are as follows:

- Higher tolerance of the plasma process to height variation between the torch and the base metal and higher tolerance in the TIG process to transversal variations.
- The plasma arc has a cylindrical and narrow configuration, unlike the arc in the TIG procedure that has a conical configuration. Any variation in the torch height to the base metal will affect the TIG procedure much more than the PLASMA, due to the heating surface of the base metal.
- The electrode in the plasma procedure is inside the torch, it is not possible to "touch" the base metal with the electrode, thus avoiding the resulting deterioration and inclusions in the pool.
- The TIG procedure requires a high frequency to initiate the arc. The plasma procedure has a permanent "pilot" arc that allows easy initiation without failure. This acquires special importance under automated welding



TIG area is much bigger than PLASMA area. For a distance (δ) from the nozzle to the metal, TIG AREA >> PLASMA AREA

Fig. 87 - Difference between TIG and PLASMA arcs.

- The penetration of the plasma arc is narrower and deeper, while the TIG arc is wider and less deep.
- The plasma procedure can weld at higher speeds than the TIG procedure.
- The plasma procedure may reduce joint preparation.
- Although the cost of the plasma equipment is higher than the TIG, in many cases, some of the above mentioned factors reduce the total cost of the joint under the plasma procedure.

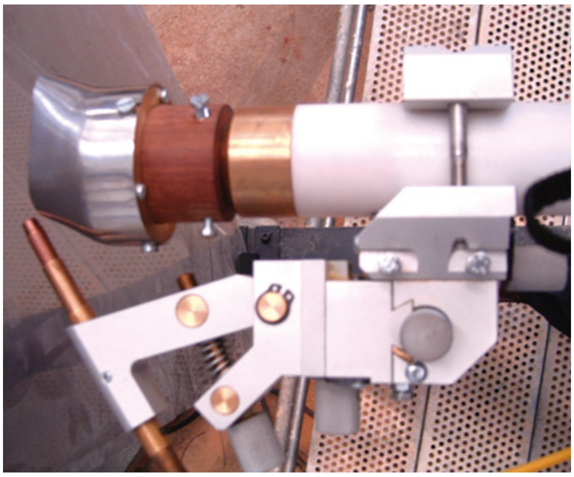


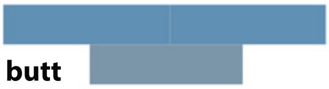
Fig. 88 - Torch for plasma welding with wire feeder and nozzle with the appropriate shape to increase the time that the welding bead is protected by the shielding gas. COURTESY OF NIPPON GASES

7.2 PLASMA WELDING PARAMETERS

Thickness (mm)	Type of joint (*)	Current (A)	Plasma gas		Shielding gas		Welding speed (cm/min)
			Gas	Flow (l/min)	Gas	Flow (l/min)	
Torch PT-16							
0.5	1	16	SANARC AS	0.3	Ar+1%H_2	7	25
1.5	1	45	SANARC AS	0.3	Ar+5%H_2	12	25
2.0	1	90	SANARC AS	0.5	Ar+5%H_2	14	30
3.0	2	80	SANARC AS	0.7	Ar+5%H_2	10	15
Torch PT-8 and Torch PT-300							
0.5	1	16	SANARC AS		Ar+1%H_2	7	25
1.5	1	45	SANARC AS		Ar+5%H_2	12	25
2.4	1	170	SANARC AS		Ar+5%H_2	15	50
4.5	1	260	SANARC AS		Ar+5%H_2	20	35
9.5	3	245 220	SANARC AS		Ar+5%H_2	20 20	25 20
3.0	2	80	SANARC AS		Ar+5%H_2	10	15

(*) Type of joint:

1

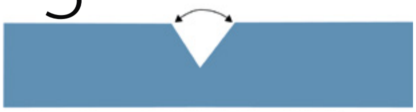


butt

2

angle

3



V butt (60º)

8 Submerged Arc Welding - SAW

8.1 PROCESS DESCRIPTION

Submerged arc welding (SAW) is caused by the heat generated by an electric arc between a consumable continuous electrode, commercially called a wire or rod, which may be solid or tubular, and the metal to be welded.

The separately fed flux[2] in front of the arc, protects the arc and the slag produced protects the weld pool.

Flux[2] is extremely important and in a similar manner to the coated electrode process, it impacts:

- Arc stability.
- Weldability.
- The mechanical properties of the welded metal.
- It may provide alloying elements to the pool and may likewise remove and carry harmful elements to the slag.
- The slag produced by the fusion of part of the flux[2] influences the final appearance of the bead, providing shielding from air pollution and slow cooling of the welded metal.
- From the point of view of safety, it conceals the electric arc, eliminating radiation and minimising smoke production.
- During welding some of the flux[2] is transferred to the molten pool, some forms removable slag so may be collected, sieved, reconditioned and reused.

The process may use one or several threads, strips or bands.

Most applications are automatic, although a semi-automatic process may also be used with thin wires (2.4 mm maximum diameter.)

Designation of the process:

Submerged arc welding (Submerged Arc Welding - SAW)

UNE – EN ISO 4063: 2011

Process 121:

Submerged arc welding with solid wire.

Process 122:

Submerged arc welding with strip.

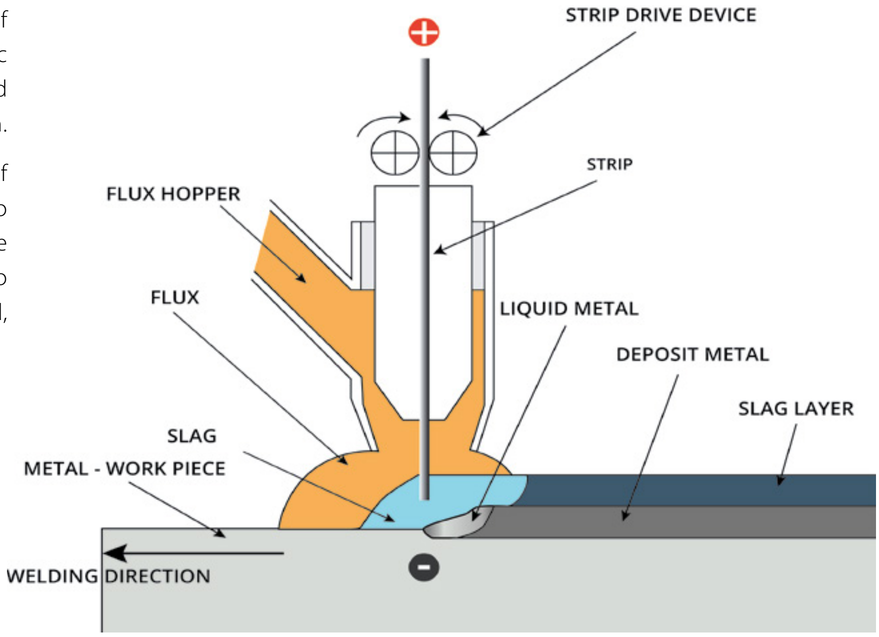


Fig. 89 - Diagram of the arc welding process.

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[2] Author's note. Appendix 3, page 258.

8.2 ADVANTAGES

Submerged arc welding, has the following advantages::

1. Automatic process with very high deposition rate
2. It produces high quality welds and refills.
3. It is possible to weld thick materials in one pass, while other processes require several passes.
4. When the arc is produced under the flux[2], there are no spatters.
5. The arc is covered by flux[2] and does not affect nearby workers. Furthermore, less smoke is produced than in other processes.
6. The SAW process is less sensitive to the wind than other processes, such as TIG (GTAW) or MIG/MAG (SMAW), due to better flux[2] shielding.
7. If welding has been correctly completed, the slag is detached and easily removed, leaving the beads practically ready for later stages, passivation, painting, etc.
8. Advantages of automatic processes with less dependence on labour and reduction of potential mistakes.

8.3 LIMITATIONS

1. It may only be used in a horizontal angle and cornice position.
2. Although it may also be used as a semi-automatic process with thin wires (2.4 mm maximum diameter), most applications are automatic with a higher initial investment.
3. Many joints require the use of backup or first passes using a MIG or TIG procedure, to support the first submerged arc passes.
4. In order to avoid flux[2] contamination and to avoid causing defects, proper storage is required and a flux[2] collection and reconditioning system during welding.
5. Although there are applications with high speed welds of thin materials, in general it is used in thickness greater than 6-10 mm.

8.4 SUBMERGED ARC WELDING PROCESS COMPONENTS

It consists of:

1. Power supply or energy group.
2. Control.
3. Head which includes:
4. Wire feeder.
5. Welding torch
6. Flux[2] hopper and conducting tube to welding site.
7. Accessories for mounting and positioning the head to the fixed or displacement system.
8. Winder for wire coil or system to carry the wire supply (reels, drums) to the feeder rollers.
9. Flux[2] recovery system including, suction, sieving to separate slag and drive. Flux[2] drying oven may also be included.
10. Head displacement system (car, column).
11. Joint tracking system.

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[2] Author's note. Appendix 3, page 258.

8.5 STAINLESS STEEL WELDING

The submerged arc process can be used to weld the following:

- Stainless steel with stainless steel of similar or dissimilar quality.
- Nickel-based stainless steel.
- Stainless steel with carbon steel or low alloy steel.
- Refacing stainless steel on carbon steel.

8.6 CONSUMABLES

Welding the various options seen in the previous section, where at least one of the sheets is stainless steel, using the submerged arc process, requires selecting the wire - flux[2] pair combination that achieves the desired chemical composition and mechanical properties for the weld, which depend on:

- The chemical composition of the base metals and their dilution in case they are different.
- The chemical composition of the wire.
- The flux[2].
- Welding parameters.

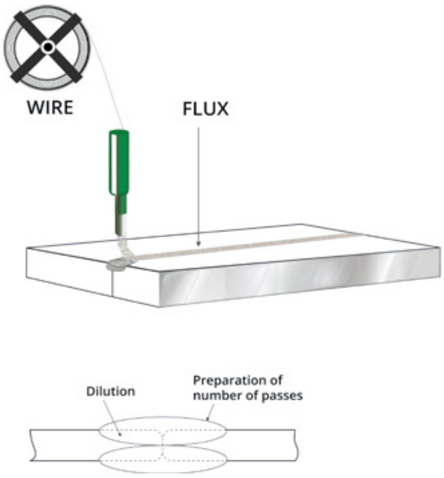


Fig. 90 - Wire/flux[2] pair selection.

8.6.1 Wire or band

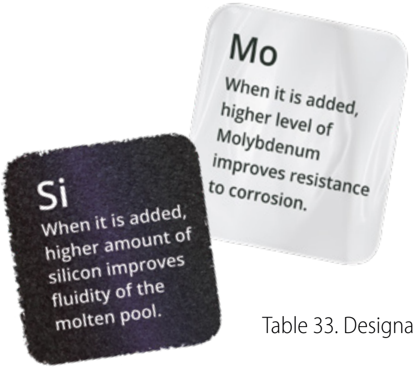
Solid or tubular wire is used for welding. Wire, strap or band is used for cladding

The information to select the wire type is included in each type of stainless steel, austenitic, duplex, ferritic or martensitic, or in section 1.7, for dissimilar steels.

They usually come in coils of 25 Kg, which should be placed in the winder. There are also drums of 100 to 250 kg. The diameters of the thread in general are 1.6; 2.0; 2.4; 3.2; 4.0; and 4.8 mm.

Process	**SAW**	
UNE-DIN EN ISO 4063:2011	12	
METAL	STAINLESS STEEL	
	UNE-DIN EN ISO 14343 A	AWS A 5.9/A 5.9M
Solid wire	G 19 9L	ER 308L

Table 32. Example of designation of a solid wire for submerged arc welding (SAW) according to UNE- DIN EN 4063:2011.



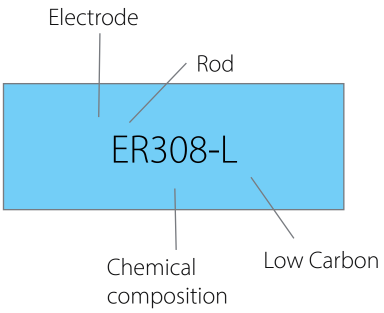


Table 33. Designation of solid wire according to AWS A5.9.

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[2] Author's note. Appendix 3, page 258.

The approximate range of intensities based on the wire diameter is as follows:

Ø (mm)	1.6	2.0	2.4	3.2	4.0	4.8
Intensities (A)	150-300	200-400	250-500	300-600	400-800	500-1000

8.6.2 Flux

It is a compound of mixed minerals. These include SiO_2, TiO_2, CaO, MgO, $Al2O_3$, MnO, K_2O, Na_2O, Li_2O, FeO, ZrO_2 and CaF_2.

The supplier should be asked for information regarding the flux[2] to use, and the storage, drying, current, range of intensities and granulometry recommendations. According to the manufacturing system, they are divided into molten, bonded, agglomerated and mechanically mixed, but the most commonly used are molten and agglomerated.

Molten flux[2]

The components are melted in an electric furnace, above the melting point of the component that has the highest temperature, at a temperature between 1500ºC and 1700ºC. It is cooled and crushed, passes through the appropriate sieves to obtain a dosage according to the desired granulometry and is packaged.

The characteristics of molten flux[2] are as follows:

- They are not hygroscopic, which facilitates their use and storage and eliminates potential welding problems.
- Chemically homogeneous welds can be achieved, due to this manufacturing system.
- Old flux[2] can be recycled and mixed with new flux[2] without significant changes in the granulometry and composition of the particles.
- Welding at high rates can be achieved.

Potential moisture can generally be eliminated by treating them at 200ºC and the maximum welding current is 800 A. However, manufacturer's recommendations in this regard should be followed.

Agglomerated flux[2]:

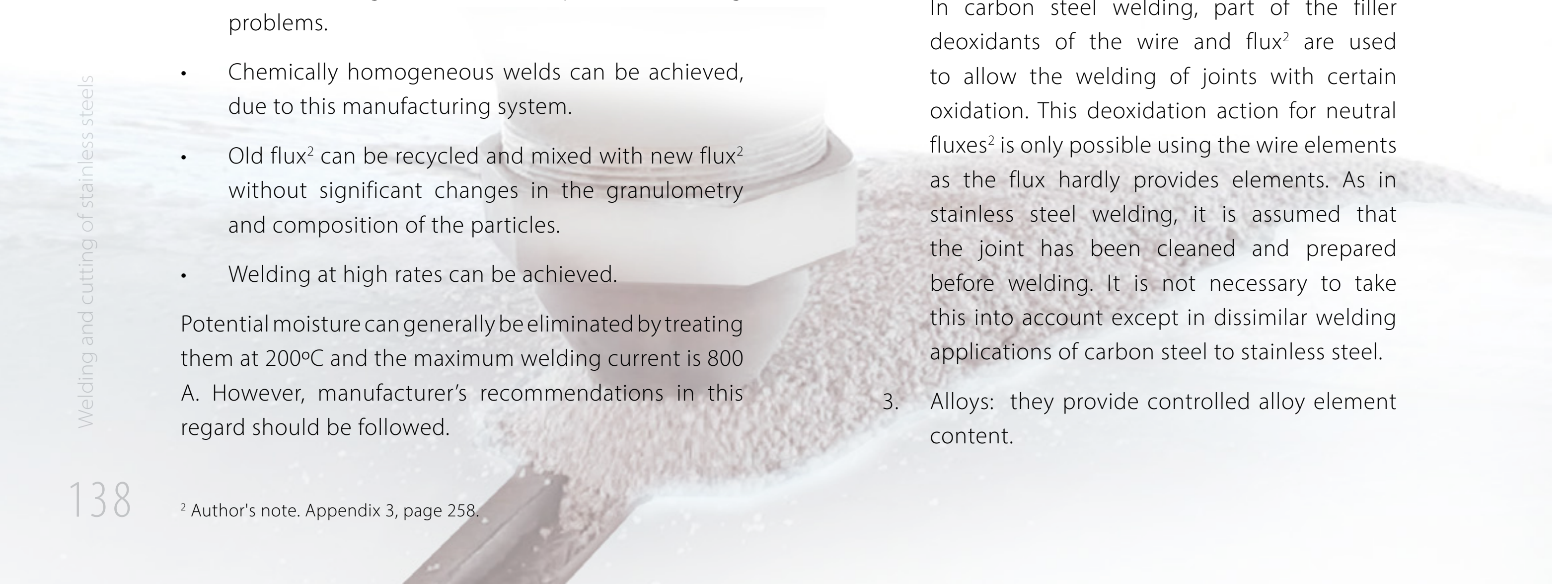
Agglomerated flux[2] is the most commonly used in the industry.

During the manufacturing process the components are mixed in a dry state. A binder is added and dried at relatively high temperatures. Subsequently, this is crushed and sieved until the appropriate granulometry is obtained.

As this flux[2] has not melted during its manufacture, it is porous and therefore usually hygroscopic. So its packaging needs to be adequate to protect the flux[2] from moisture. Manufacturer's storage recommendations should be followed and drying may be necessary before use or recycling.

Agglomerated fluxes[2] are different from molten fluxes[2] as:

- They provide more elements to the metal deposited.
- Depending on their chemical activity, they are classified into:
    1. Active: they add additional elements to those of the wire. They should not be used in multipasses in thickness higher than 25 mm, since the successive beads would not be homogeneous.
    2. Neutral: they do not add additional elements to those of the wire, even if there are variations in voltage or the height of the flux[2] layer. They should be used for thickness higher than 25 mm and especially when multipasses are needed. In carbon steel welding, part of the filler deoxidants of the wire and flux[2] are used to allow the welding of joints with certain oxidation. This deoxidation action for neutral fluxes[2] is only possible using the wire elements as the flux hardly provides elements. As in stainless steel welding, it is assumed that the joint has been cleaned and prepared before welding. It is not necessary to take this into account except in dissimilar welding applications of carbon steel to stainless steel.
    3. Alloys: they provide controlled alloy element content.



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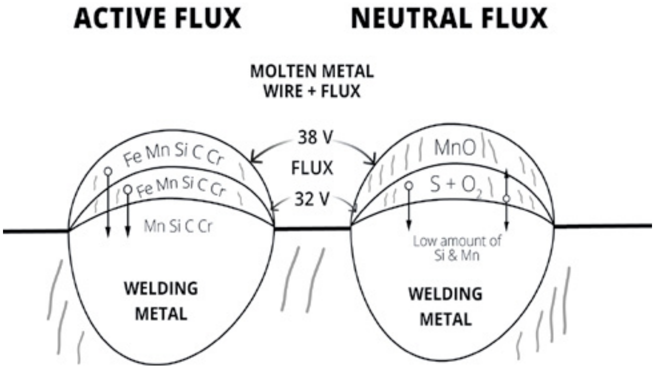
[2] Author's note. Appendix 3, page 258.



An active flux[2] will pass elements of Mn, Si, C, and Cr to the Weld pool, depending on the volume of melted flux[2] or the voltage.

A neutral flux[2] will not significantly gain or lose elements depending on the volume of melted flux[2] or the voltage.

Fig. 91 - Active Flux[2] / Neutral Flux[2].

- Depending on the slag formed, these may be basic flux[2], acid, rutile or a mixture.
- They should be stored in an appropriate place, following the manufacturer's instructions.
- The consumption of flux[2]/kg wire is lower.
- The drying temperature is 300ºC.

Process	**SAW**
UNE-DIN EN ISO 4063:2011	12
METAL	STAINLESS STEEL
	EN 760
Flux[2] UW 380	S A AF 2 63 DC

Table 34. Designation of flux[2] for submerged arc according to EN 760.

Code	**S A AF 2 63 DC**		
S	Submerged arc process (SAW)		
A	Manufacturing method: A = Agglomerated F = Molten M = Mixed		
AF	Type of flux[2]. MS = Manganese - Silicate CS = Calcium - Silicate ZS = Zirconium - Silicate RS = Rutile - Silicate AR = Aluminate - Rutile AB = Aluminate - basic AS = Aluminate-Silicate AF = Aluminate - Fluoride - basic FB = Fluoride - basic Z = Others		
2	Applications		
	1	Carbon steels, low alloy, high yield strength and creep resistance. No alloying elements other than Mn and Si.	
	2	Welding of stainless steels, nickel base, Cr steels, and heat resistant steels, the elements gained for these fluxes[2] of class 2, other than Mn and Si, should be indicated by their chemical symbols (for example Cr).	
	3	Refacing. The elements gained for these fluxes[2] of class 2, other than Mn and Si, should be indicated by their chemical symbols (for example C, Cr).	
63	Metallurgical behaviour		
	Loss	1 = > 0.7 2 = 0.5 – 0.7 3 = 0.3 – 0.5 4 = 0.1 – 0.3	
	Neutral	5 = 0 – 0.1	
	Gain	6 = 0.1 – 0.3 7 = 0.3 – 0.5 8 = 0.5 – 0.7 9 = > 0.7	
DC	Type of current AC = DC and AC DC = only DC		
	Diffusible hydrogen (ml/100g deposit maximum)		
	Symbol	H5	5
		H10	10
		H15	15

Table 35. Classification according to EN 760 for submerged arc flux[2].

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[2] Author's note. Appendix 3, page 258.

8.7 HEAT INPUT

This welding process is mainly used to weld thick materials with high heat inputs.

$$\text{Heat input (J/cm)} = \frac{\text{Voltage (V)} \times \text{Intensity (A)}}{\text{Welding rate (cm/minute)}} \times 60 \times \eta$$

Welding process	**η - Relative thermal efficiency**
TIG	0.65
MIG with Ar	0.7
MAG with CO_2	0.85
Coated electrode	0.9
Submerged arc	1.0

Table 36. Relative thermal efficiency of the main welding processes.

The slag that covers the molten pool prevents fast cooling and makes the η (relative thermal efficiency) factor of this process equal to 1.

Due to this characteristic, the submerged arc process has the following advantages compared to other processes: thick materials can be welded in one pass, higher beads and lower consumable consumption. It has limitations for welding thin materials and backing or first passes with MIG or TIG are required, to support the first submerged arc pass.

8.8 TYPE OF CURRENT AND POLARITY

The type of current and polarity influence the chemical composition of the filler metal and the shape of the bead.

Direct current may be used with constant current, or constant voltage with alternating current. Most applications require a current source with constant voltage and the electrode (wire), connected to the positive pole.

The connection of the electrode (wire) to the negative pole is preferred for refacing applications, where penetration, thinner dilution and higher deposition rate are preferred. Also when thin materials are welded and it is necessary to minimise penetration.

8.9 WELDING PARAMETERS

In certain applications, it may be that one parameter becomes the most important. However, in most applications, the parameters that affect heat input should be adjusted first:

- *Type of constant current or constant voltage.* Direct current may be used with constant current, or constant voltage with alternating current. Most applications require a current source with constant voltage. A variation in welding current causes a small variation in the arc voltage and the arc length tends to remain stable in all circumstances. Therefore, there will be small variations in the composition of the weld beads, since the height of the molten flux[2] will remain constant.
- *Current polarity.* Most applications use the electrode (wire), connected to the positive pole. Connecting the electrode (wire) to the negative pole is recommended for refacing applications.

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[2] Author's note. Appendix 3, page 258.

- *Wire diameter.* This is determined by the thickness and type of the preparation to be welded. Keeping the other parameters constant, when the wire diameter increases:
  - The current density decreases. The deposition rate decreases.
  - Penetration at a fixed intensity decreases.
  - The usable range of intensities increases.
- *Welding current.* Keeping the other parameters constant, when current increases, the following increases:
  - Penetration.
  - Current density.
  - Deposition rate (Kg / h).
  - Loss of elements due to combustion in the arc.

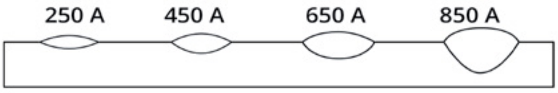

Fig. 92 - Bead type according to the welding current.

- *Voltage.* Keeping the other parameters constant, when the voltage increases, the following increases:
  - Arc height.
  - Bead width.
  - The amount of molten flux[2] and the amount of slag produced.
  - If the flux[2] is active, with multi passes the content of elements Si, Mn and other may be increased, depending on the flux[2].
- *Welding rate.* It determines the heat input per unit length. Keeping the other parameters constant, when the welding rate increases:
  - Penetration decreases. This happens with adequate welding rates. If the welding rate is excessively reduced, the penetration decreases and this is due to the formation of an excessively large pool which acts as a screen and prevents the heat from progressing to continue melting the metal.
  - Bead width decreases.
  - The tendency to form undercuts increases.
  - Porosity tendency increases.

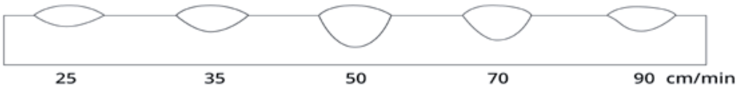

Fig. 93 - Variation of penetration with welding rate.

- *Joint preparation* Joint preparation is very important to the submerged arc process, as welding is produced with a high heat input and achieves high penetration. This means that the preparation provided by other processes may not be used. In general beads will be larger and the edge separations will be smaller. Fig. 94 shows the right type of preparation depending on material thickness.

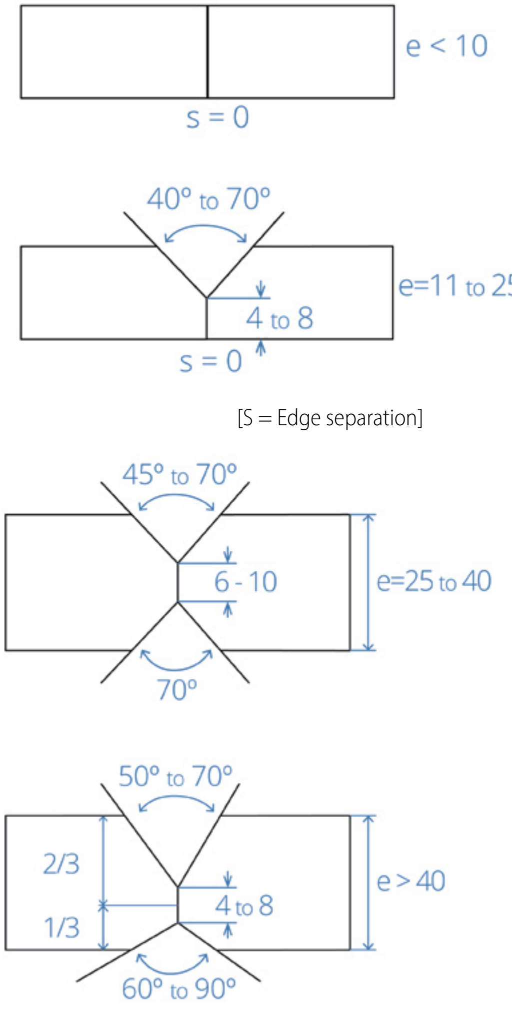

Fig. 94 - Type of edge preparation according to the thickness.

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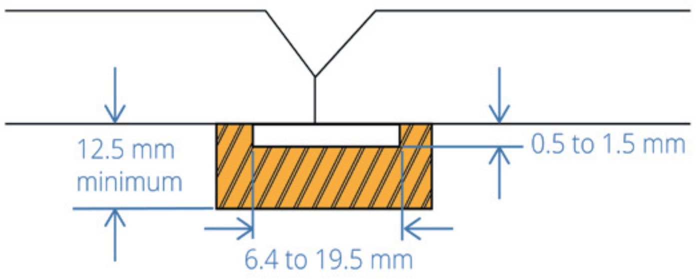
[2] Author's note. Appendix 3, page 258.

- *Use and type of support (backing).* If there is a risk that the first submerged arc pass, will cause the material to be perforated and detach, the following may be carried out:
    - The first pass on the same side should use a different process with less heat input, to support the first submerged arc pass and which does not need to be cleaned, depending on the quality required.
    - Use a backing plate of the same material as the one being welded and which may be removed or left after the welding is finished. The decision will be for engineers.
    - Weld a first pass on the opposite side which does not need to be cleaned before welding with the submerged arc, depending on the quality required.

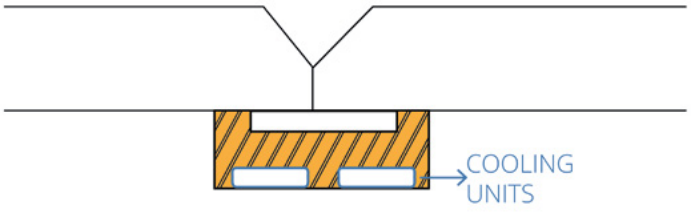
Selecting the optimal solution will require testing and/or homologation of the welding procedure of the two processes on the same joint.

- Use a ceramic support (backing).
- Copper backing with or without cooling may be used for thin materials, to eliminate some of the heat input and hold the pool.

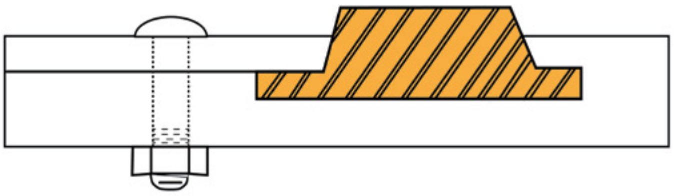
RECOMMENDED DIMENSIONS FOR BACKING BARS:



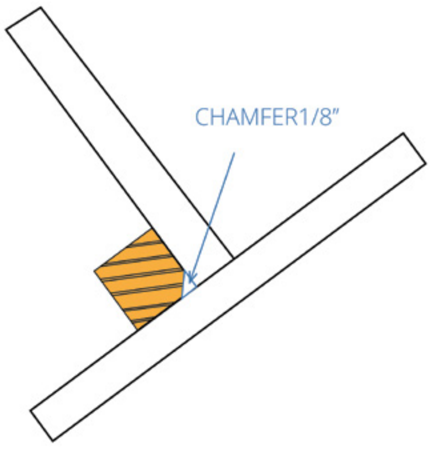
VARIOUS BACKING DESIGNS:



A - Water cooled backing system



B - Mechanical backing fastening system



C - Backing for filling welding. Attention to the position of the chamfer

Fig. 95 - Different backup options, ceramic and copper.

9 Resistance welding (RW)

9.1 PROCESS DESCRIPTION

This welding process involves the coordinated action in magnitude and time of an electric current and a mechanical force.

The electric current applied for a short period of time passes from the electrodes through the surfaces to be joined. The resistance to the passage of the current, which will be high in the surfaces to be joined, will generate the heat required to weld them, due to the Joule effect.

The force applied will vary at each stage of the weld, and will exert the required pressure before, during and after the passage of current, to keep the joint surfaces together and to ensure continuity. The current should be high enough to generate the heat required to raise the temperature to melt a small volume of metal with the characteristic shape of a "seed".

The weld must be cooled at a higher pressure than the weld pressure until the molten metal solidifies and acquires sufficient strength to maintain the joint.

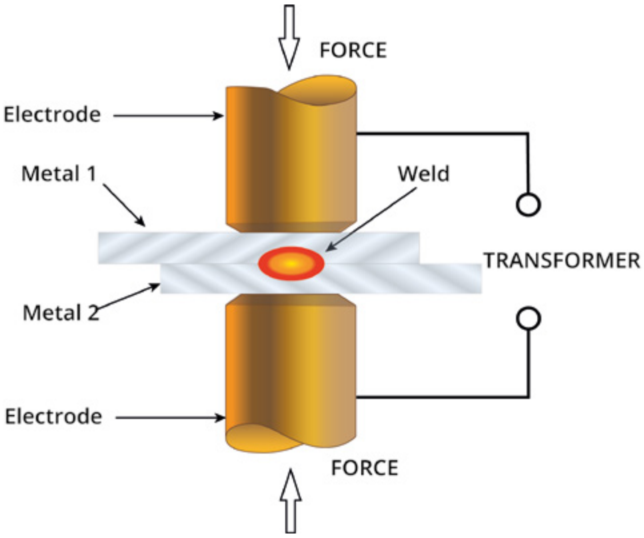


Fig. 96 - Resistance Spot Welding.

Designation of the process

According to UNE-EN ISO 4063: 2011, the numerical designation of resistance welding variations are as follows:

DESIGNATION	PROCESS
Resistance Welding	**2**
Resistance Spot Welding - RSW	**2.1**
Resistance Seam Welding - RSEW	**2.2**
Projection Welding - PW	**2.3**
Flash Welding - FW	**2.4**
Upset Welding - UW	**2.5**

STAGES OF THE WELDING PROCESS

The basic stages are as follows:

- *Positioning and squeezing. (Squeeze Time).* There is no current. Pressure is exerted ($P_{positioning}$), so that the surfaces to be welded are joined and there is sufficient continuity for the current to flow.
- *Welding (Weld time).* The current should increase sufficiently for the current density to generate the heat required to raise the temperature until melting point. Pressure is reduced until $P_{welding}$, which implies an increase in resistance and heat. If the current density and/or the pressure are very high, the molten metal could be ejected and welding would not take place. The current application time should be short, to avoid excessive heating of the electrode surfaces, which would reduce their service life.
- *Maintenance (Hold Time).* The current is cut off and the pressure is increased to ($P_{maintenance}$) until the molten metal solidifies and acquires the strength required to maintain the joint.
- *Word rate (Off time).* Once welding is finished, the pressure is reduced and the weld assembly is released.

If necessary, other stages may be added to the basic welding stages to improve welding, such as:

1. High pressure prior to squeezing to achieve better surface contact.
2. Preheating to reduce a high thermal gradient when welding begins.
3. Hardening and tempering to improve the mechanical properties of the joint.
4. The current should gradually increase when welding begins and gradually decrease when it ends.
5. Forging force, at the end of the welding time, for metal welding where a reduction in cracking or porosity risk is needed when cooling starts.

HEAT GENERATION

When current flows through the electrodes and the base metals being welded, the heat required for welding will be produced by the Joule effect

Q= I2Rt
Q= Generated heat (J)
I= Current (A)
R= Resistance of the circuit of which the joint is a part (Ohm)
t= Current flow time (sec)

As in any welding process, an efficiency factor will take into account the amount of heat lost by conduction and radiation, which is not used to melt the base metals.

As $I=\sqrt{(Q/Rxt)}$, that is to say, the welding current (I) is inversely proportional to the square root of time (t). If it is a short time, the current will be very high.

When two metals are joined there will be 7 resistances in series and each of them will produce a proportion of heat. (Fig 97)

R_{e1} and R_{e2} (electrode resistances)

R_{se1} and R_{se2} (resistances between the surfaces of the electrodes and the base metals)

R_{emb1} and R_{emb2} (resistances of the two base metals)

R_s (resistance between the surfaces to be joined)

When the current begins to flow, the resistance and heat gradient diagram is shown in Fig 97. The maximum resistance is R_s (resistance between the surfaces to be joined). It will be where the highest heat required for welding will be generated, the rest of the heat from other resistances should be minimised. The resistance from R_{e1} and R_{e2} (electrode resistances) may be minimised in the design of the equipment, the resistance from R_{se1} and R_{se2} (resistances between the surfaces of the electrodes and the base metals) is released by cooling the electrodes 1 and 2.

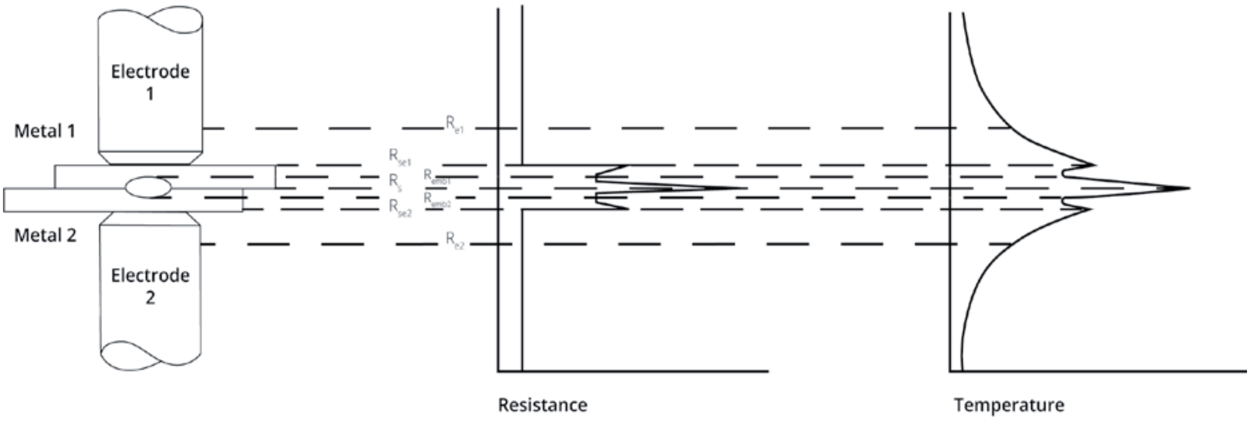


Fig. 97 - Graph of resistances and temperatures variation depending on their position in the current circuit.

The heat generated by R_s (resistance between the surfaces to be joined) dissipates more slowly and the current flow will cause the temperature between the surfaces to be joined to start increasing until it reaches the melting point of these metals. The temperature in the weld coincides with the peak of the temperature graph of Fig. 97. Therefore, the heat balance generated for a given current, time, metal and thickness will be:

Heat (j) =

(Heat generated by R_{e1} + R_{e2} *electrode resistance* + Heat generated by R_{se1} + R_{se2} *resistances between the surfaces of the electrodes and base metals* + Heat generated by R_s *resistance between surfaces to be joined*) – (Heat extracted by conduction by cooling the electrodes + Heat extracted by conduction through the base metals to be joined + Heat extracted by radiation)

9.2 ADVANTAGES AND LIMITATIONS

ADVANTAGES:

- Filler consumables or shielding gases are not needed.
- Ease of automation and high production volumes are possible.
- The skill required by the operator is less than the skill required for arc welding.

LIMITATIONS:

- The initial cost of the welding equipment investment is high.
- The joint type is limited to lap joints.

9.3 RESISTANCE WELDING TYPES

The most commercially important resistance welding processes are: spot welding, seam and projection welding, projections or protrusion welding.

RESISTANCE SPOT WELDING - RSW

This process uses two opposed electrodes that conduct the required current to generate the heat that increases the temperature until a reduced volume of metal is welded with characteristic form.

The metals most commonly used for electrodes are:

- Copper alloys.
- Alloys with refractory metals, such as combinations of copper and tungsten, which have a higher wear resistance.

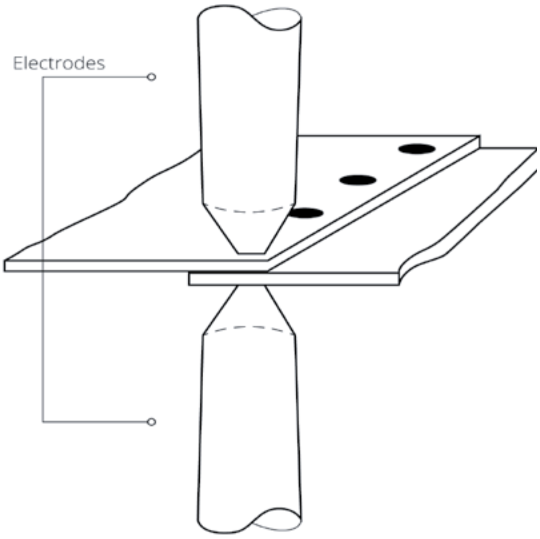


Fig. 98 - Spot Welding.

RESISTANCE SEAM WELDING - RSEW

This is a variation of spot welding where one or both electrodes are rotating wheels that make a series of spot welds superimposed or spaced along the joint.

The degree of overlap or distance between the spot welds depends on the movement of the wheels (electrodes) and the welding current applied.

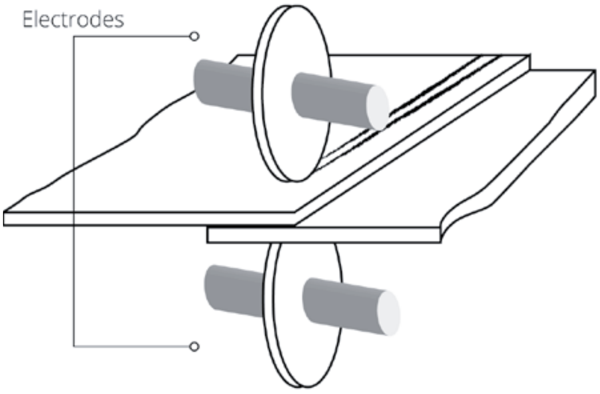


Fig. 99 - Seam Welding.

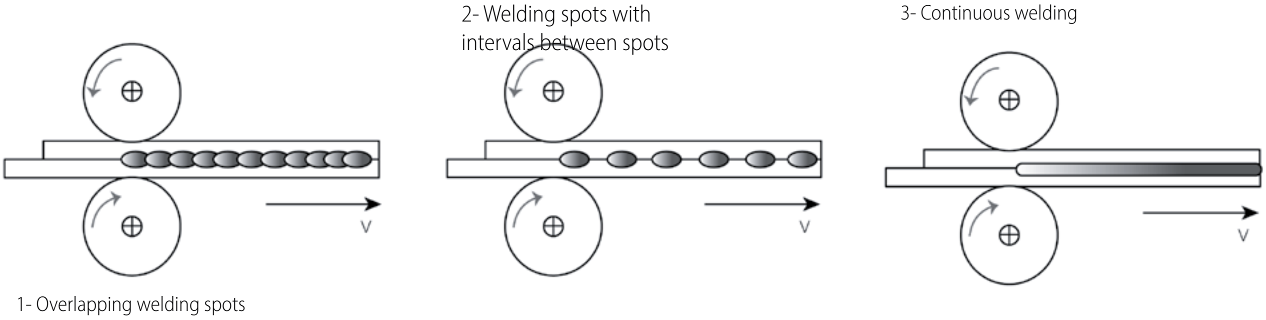


Fig 100 - Different types of seam welding.

The wheels rotate continuously at a constant speed and the current flows at intervals that coincide with the desired spacing between the welding spots along the joint. In general, the frequency of the current discharges is set so that there are overlapping welding spots, but if the frequency is sufficiently reduced, there will be an interval between the welding spots. If the welding current remains constant, instead of being activated and deactivated, continuous welding occurs. (Fig 100)

RESISTANCE PROJECTION WELDING - RPW

This process welds at one or more relatively small spots of contact (protrusions or protuberances), which are determined by the design of the pieces to be joined.

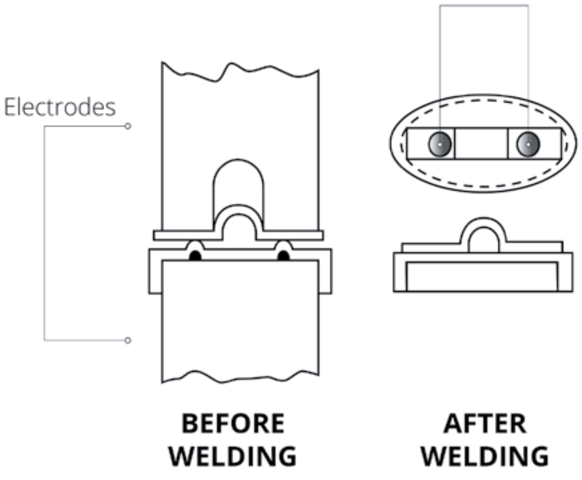


Fig. 101 - Welding by projection, projections or protrusion - (Projection Welding).

9.4 RESISTANCE WELDING PROCESS COMPONENTS

Example of resistance welding equipment and its specification:

Sequential spot welding machine with automatic cycle, to weld pipes or sheets of carbon steel, stainless steel, galvanised steel, etc. Reaching up to 172 spots per minute, using either single or double pulses.

Capacity:

- Sheets: Steel/stainless 4 + 4 mm / 2+2 mm
- Round: Steel/stainless 13+13 mm / 6+6 mm
- Spots per minute: 172
- Maximum power: 50 KVA
- Air pressure: 4-8 bar
- Distance between arms: 300 mm
- Arm length: 350 mm
- Single-phase connection 380 V. 50/60 Hz F. (50 A)
- Cooling water required for arms and electrodes.

Spot welding machine. COURTESY OF NIPPON GASES

9.5 PROCESS VARIABLES

CURRENT

This variable affects the heat generation (Q=I2Rt) more than the resistance and time variables.

A minimum current density and heat is required, to weld the two surfaces to be joined, and also cover conduction losses in the base metals and the electrodes.

If the current is kept constant, the contact surface with the electrodes increases, the current density, the amount of molten metal between the two surfaces and the strength of the joint will decrease. If the current density is excessive, molten metal will be expelled and defects will occur due to metal faults or cracks and low mechanical properties may result. Excessive current may cause heating in the base metals that may also pass to the electrodes and reduce their useful life

TIME

The heat generated is proportional to welding time. If the parameters are sufficient, the speed to generate heat will produce welds with adequate strength and without excessive heating of the electrode and deterioration.

If the time is excessive, the temperature of the molten metal between the welded surfaces will rise above the melting temperature of the base metals and an internal pressure may be generated by the formation of metal vapour, which may dislodge some of the molten metal in the joint. With an increase of time, heat losses also increase, which are mainly by conduction through the base metals and electrodes and a small amount by radiation, but these losses are uncontrollable.

The time and current may be complementary and the total heat may be modified by conveniently changing the amperage or the time.

PRESSURE

This variable affects the resistance through its influence on the contact surfaces of the two base metals to be welded. In resistance spot, seams and projection welding, the surfaces to be welded are joined due to the pressure exerted by the electrodes, to facilitate the current flow.

When pressure increases during welding, current increases up to a certain limit, but the effect on the total heat generated is inverse, when pressure increases, resistance to the current flow decreases and the heat generated between the surfaces to be welded also decreases. To increase the heat to the melting point before raising the pressure, it is necessary to increase the current or the time, to compensate for the reduction in resistance.

A metal surface has roughness, with its peaks and valleys. When they are joined together to be welded and subject to low pressure, the metal to metal contact is only at the peaks, leaving a small contact surface and the resistance will be high. When the pressure increases, the peaks are "crushed" and the surface increases, so the contact resistance decreases.

In most applications, the electrodes are softer than the metals to be welded. Therefore, under welding pressure, the contact between the electrode and the base metal will be better than between the surfaces of the metals.

ELECTRODES

They are very important in heat generation as they conduct the current to the assembly to be welded. In spot and seam welding the current density and the welding size depend on the electrode. They should have a sufficiently high electrical conductivity, mechanical strength and hardness to avoid deformations when applying repetitive and high force on the base metal. Deformations in the electrode could increase the contact surface of the base metal and decrease the current density and the welding pressure.

When the electrodes are worn down, the pressure will decrease and resistance to current flow between the electrode and the base metal surfaces and between the base metals will increase. An increase in heat on the three contact surfaces will cause excessive heating and molten metal will be expelled. The quality of the weld will decrease and the electrode will wear faster than normal.

Therefore, maintenance or regular replacement is necessary to maintain adequate heat generation and welding properties.

BASE METAL SURFACES

To obtain welds with uniform quality the surfaces to be welded should be clean. If they are dirty with oxides, grease, coating particles or other substances, the resistance and therefore heat generation will be affected, producing joints of low quality or non-uniform joints.

Dirt can contaminate the surface of the electrode and decrease its useful life.

BASE METAL

The metal properties that have the greatest influence on resistance welding are:

- Electrical resistance.
- Thermal conductivity.
- Coefficient of thermal expansion.

Comparing austenitic stainless steel with a carbon or low alloy steel:

- The **electrical resistance** of austenitic steel is higher.
- The **thermal conductivity** of austenitic steel is lower.

  Both properties present advantages in resistance welding of austenitic stainless steel compared to carbon and low alloy steels welding and lower current will be required to weld stainless steel than to weld the same thickness of carbon steel or low alloy.
- **Higher coefficient of expansion:** precautions should be taken to design tools to compensate for expansion, including additional water cooling.

10 BRAZING AND SOLDERING

10.1 BRAZING PROCESS DESCRIPTION

This process joins metals by heating them to the appropriate temperature, below the melting point of metals and joins them with a consumable alloy filler that melts at a temperature higher than 450ºC and a deoxidizer or a controlled, inert or reducing atmosphere, or vacuum, to eliminate surface oxides and to prevent oxidation during the process.

The important points to be taken into account are:

- The most commonly used heating method for brazing is the manual torch with oxygen and acetylene. There are other procedures that are used to improve welding productivity. These are fixed torches in automated stations, furnaces with controlled atmospheres, induction with high frequency and resistance.
- The joint preparation should be "lap" and with the appropriate gap.
- The surfaces should be clean without dirt and oxides.
- The following should be applied:
    - The deoxidizer (flux[2]) which should dissolve and displace the metal oxides on the surfaces to be joined and prevent new oxides. The deoxidant particles should be removed as recommended by the manufacturer.
    - An atmosphere that replaces the deoxidizer (flux[2]). In general, it will not be necessary to review as a deoxidizer is used.
    - The easiest manual welding involves touching the consumable alloy to the edge of the capillary gap of the joint and it should begin to melt. In automatic processes, the alloy may be previously placed in the joint as a rod, ring or paste, thereby ensuring that it has penetrated the entire joint.

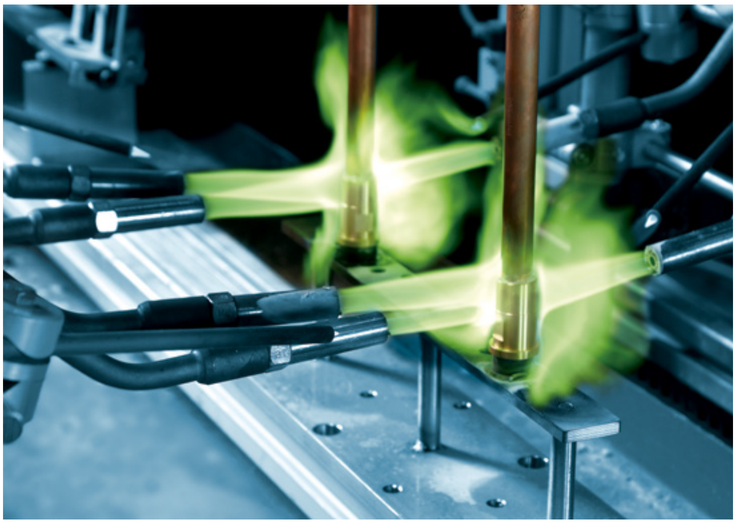


Fig. 102 - Brazing. PHOTOGRAPH COURTESY OF VULKAN EVERWAND

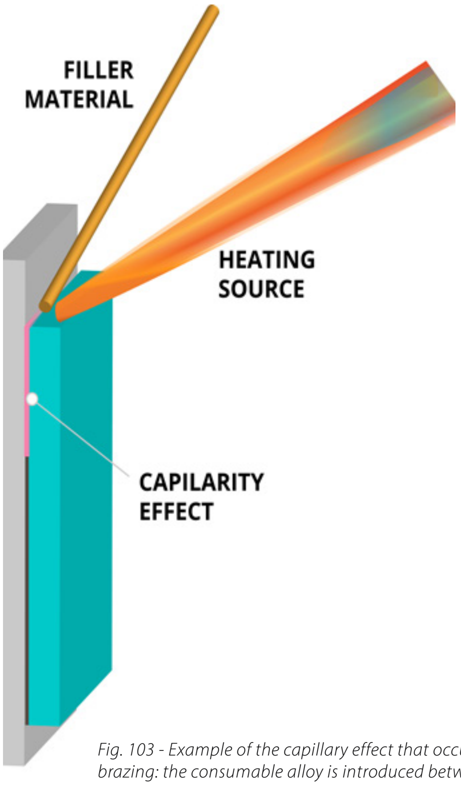


Fig. 103 - Example of the capillary effect that occurs in brazing: the consumable alloy is introduced between the surfaces of the joint by capillarity.

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[2] Author's note Appendix 3, page 258.

- The surface tension forces between the base metals and the molten consumable alloy are much higher than between the base metal and the molten deoxidizer (flux[2]), producing a displacement of the deoxidizer by the alloy and this penetrates the capillary gap.
- When the joint is cooled to room temperature, the capillary gap will be filled by the solidified alloy and the deoxidizer particles will be at the joint edges, which should be eliminated.
- The brazing process designation should always mention the heating.

Numerical designation of the process

According to UNE - EN ISO 4063: 2011, the numerical designation is as follows:

- Brazing, soldering and braze welding - 9
- Brazing B - 91

The most commonly used sources of heating are:

- Torch Brazing (TB) – 912
- Furnace Brazing (FB) – 913
- Induction Brazing (IB) - 916
- Resistance Brazing (RB) – 918

10.2 ADVANTAGES

- Economical for complicated assemblies.
- The joints need little final review or no review at all.
- Dissimilar metals may be joined, since they do not melt, there is no problem if they have different properties. Metals to non-metals may also be joined, with the corresponding restrictions.
- If necessary, the assemblies may be disassembled.
- Complicated joints are feasible, without distortions, where accuracy and repeatability are necessary.
- Residual stresses are very small, if any.
- Several parts may be pre-assembled and all the welds performed at the same time.
- The process can easily be automated, if a significant number of repetitive joints are required.
- If necessary, the joints are easy to repair.
- The welder needs less time to learn brazing skills than in fusion welding.

10.3 LIMITATIONS

- The mechanical properties and continuity of the joints are appropriate only for certain applications.
- The cleanliness of the joint is essential for the wetting action and for the alloy to penetrate.
- The joint design and capillary formation may be expensive.
- Manual brazing is easier to learn than fusion welding, but the corresponding skills are required to perform this type of joining.
- The total cost of these joints may be high due to the cost of consumable alloy and labour.

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[2] Author's note Appendix 3, page 258.

10.4 HEATING TYPES

The most commonly used heating process for brazing is manual oxygas torch with oxygen and a combustible gas, in general acetylene or propane.

Other heating sources are used to improve productivity, such as fixed torches in automated stations, furnaces, induction and resistance.

10.4.1 Torch Brazing - TB

Welding may be manual with a single welding torch and automatic with the number of torches needed to adequately heat the joint.

The combustible gases, acetylene, propane, propylene, natural gas or others may be used and as oxidizing gas, oxygen or air, depending on the required heat and the heating rate.

A manual torch is used when a fast heating procedure is required, with great flexibility and with low investment and equipment maintenance costs.

The design of the torch should incorporate or allow the appropriate safety measures to be adopted, such as casings.

	ACETYLENE	PROPYLENE	PROPANE	NATURAL GAS
Temperature with neutral flame (ºC)	3120	2870	2520	2540
Total O_2 required (neutral flame) Vol.O_2/Vol.Fuel	1:1.1	1:2.6	1:3.5	1:1.5
Relation Vol./weight gas (m^3/kg (15ºC)	0.91	0.55	0.54	1.4
Relative density (15ºC) air=1	0.906	1.48	1.52	0.62

Table 37. Comparison of the physical properties of combustible gases.

Characteristics of the flame

Capillary welding requires the flame to be of sufficient size to heat the joint area in the required time. This is achieved by choosing the appropriate nozzle or lance for the torch.

A flame that is too large may cause unnecessary gas expenditure and heat larger area than required.

A flame that is too small will probably make it difficult to heat the components to the correct temperature and ensure that both components reach this temperature at the same time.

A small flame also requires a wider and skilled torch movement.

When welding stainless steel, the flame should be slightly reducing for most applications. (Fig. 104)

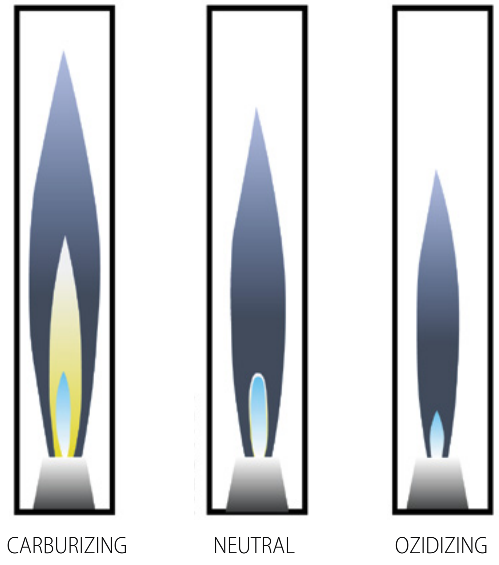

Fig.104 - Flame calibration.

Advantages of heating with oxyacetylene manual torch

- Low initial cost.
- Reduced maintenance cost.
- Moderate consumption cost.
- Flexible operations.
- Expert operators can perform very complicated operations.

Limitations

- Expert or semi-expert operators are required. Due to the human factor, the results will vary both by quality and work performance.
- It is necessary for the brazer not only to have the necessary skills with the torch to perform the weld, it is also necessary for the braze technician to know the safety precautions to handle cylinders or work stations, in the case of piped gases, oxygen and acetylene or other combustible gases.

10.4.2 Furnace Brazing - FB

Heating by means of furnace brazing with this type of heating has the following characteristics:

1. Heating may be electric or with gas and with automatic temperature control.
2. The components to be welded should be assembled, with the deoxidizer, in case it is used, and with the alloy pre-positioned in the joint. The alloy may be in the form of a rod, ring, sheet or paste and the deoxidizer is usually in the form of a paste.
3. It is used to weld a large number of assembled sets that are similar. Each of them may have several joints, which will be welded at the same time.
4. The joints to be welded, should be assembled, fixed and maintained in the correct position, if possible, so that gravity helps the molten alloy to penetrate.
5. This system produces uniform heating for weld complex assemblies, where local heating systems would result in stresses and strains.

Fig. 105 - Oxyacetylene equipment.
COURTESY OF NIPPON GASES

6. When the furnace has a controlled atmosphere, deoxidiser is not used in general. The gas atmosphere should remove metal oxides from the joint; and the gases formed due to the reduction of oxides or due to the degassing of the joint and prevent the formation of new oxides.
7. The furnace should be prepared with safety measures for the working atmosphere, especially if the atmosphere is flammable or toxic, with adequate ventilation and explosion protection.

The furnace may be as follows:

1. Discontinuous, batch:
   - Flexible production to easily start or stop it, and weld various parts.
   - Low initial costs.
   - Flexibility to weld various parts.
   - Medium to high production volumes.
   - With or without controlled atmosphere
2. Continuous:
   - With constant flow of braze joins of similar size.
   - Usually fed by moving belts which cross the heating zone at controlled rate.
   - With or without controlled atmosphere.
   - High production volumes

3. Vacuum:
   - Generally used to braze metals with very stable oxides such as titanium, aluminium, zirconium, stainless steel.
   - High quality applications where deoxidizer cannot be tolerated.
   - As deoxidizer is not used, cleaning is critical for the alloy to wet and flow into the joint.
   - The vacuum is maintained by continuous pumping, volatile components formed during welding are eliminated.
   - The cooling rate can be accelerated after brazing by breaking the vacuum by introducing inert gases into the furnace such as argon, nitrogen or helium with the required purity.
   - Suitable for medium to high production volumes.

Advantages of furnace heating

- Savings in labour costs, the operator loading the furnace, does not need to be a welder.
- High yields may be obtained by welding small assemblies.
- The work piece is protected from oxidation, thereby achieving savings in finishing work.
- Requires less deoxidant, and in some cases, it may not be required.

Limitations

- High initial cost
- Requires specialised know-how to use the equipment and establish the best working conditions, especially when changing the assemblies to be brazed.

10.4.3 Induction Brazing - IB

Heat is generated by an electric current induced in the assembly to be brazed, which is placed in or near a coil with alternating current and cooled by water, which acts as primary circuit.

Characteristics:

- The assembly to be joined is not part of the electrical circuit and acts as secondary circuit. In such assembly, heat is generated by the resistance it offers to the induced current flow generated by the primary circuit.
- A deoxidizer should be used if there is no controlled atmosphere.
- The consumable alloy should be pre-assembled and the design of the joint and the coil should enable all the surfaces to be brazed to be heated at the same time.
- This heating method is used when very fast heating is necessary, it can be automated and a controlled atmosphere can be used to braze without deoxidizer.

Advantages of induction heating

- High yields are achieved with joints duly prepared for this method.
- Very fast heating, which minimises any changes in the properties of the metals to be brazed.
- There is no temperature limit.
- Heating may be localised.
- Labour cost savings, the operator does not need to be a welder.

Limitations

- High initial cost
- Requires specialised know-how to use the equipment and establish the best working conditions, especially when changing the assemblies to be joined.

10.4.4 Resistance Brazing - RB

The heat required is generated by an electrical current which is conducted through two electrodes and the assembly to be brazed, which is part of the electrical circuit. Most of the heat is generated by conduction through the electrodes and another part is generated by the Joule effect, due to the resistance offered by the assembly to be brazed.

Characteristics:

- This heating method provides only homogeneous heating, which is necessary for brazing when the joints have a simple design that facilitates the current flow and therefore heating distribution.
- The consumable alloy in the appropriate form, rod, rings, sheet or paste, is pre-positioned or fed when the temperature of the pieces is suitable for brazing.
- The deoxidizer should be suitable for this application, taking into account that if it dries it may be insulating and prevent the process. The deoxidizer can be replaced by controlled atmosphere in this heating method.
- The components to be joined should be clean, otherwise the deoxidizer will not be able to carry out its task of cleaning metal oxides and preventing the formation of new ones during welding. The same reasoning is valid in the case of using controlled atmosphere.
- The surfaces to be brazed should be held between the two electrodes, which are water cooled, with adequate pressure until brazing is finished. Pressure is a process variable since it should be sufficient to:
  - Fix the components of the assembly during brazing.
  - Maintain good electrical contact.
- It should not strain the parts at brazing temperatures.
- Allow slight "adjustments" to the pieces, when the consumable alloy penetrates the capillary gap.

Advantages of resistance heating

- High-speed heating may be achieved for small assemblies.
- Heating may be localised.
- The human factor is largely eliminated.

Limitations

Good results are generally limited to high conductivity metals with the same approximate section as the electrode with respect to the joint surface.

10.5 CLEANING

It is essential to obtain a good quality brazing. Dirt, oils, remains from the handling must be removed both of the metals to be brazed as of the consumable alloy.

It must be uniform, either by chemical cleaning or mechanics, monitoring when detergents or solvents in degreasing baths can run out, or the cleaning fluids when cleaning is by ultrasound, or when brushing or blowing tools are worn out. Otherwise, the quality of the joints may not be guaranteed, especially with automatic processes

If cleaning is inadequate, the deoxidizer may be "depleted" in order to complete the cleaning, when its purpose is to eliminate surface oxides to allow the molten consumable alloy to "wet" the surfaces of the capillary gap and to penetrate the joint. Deoxidant entrapment inside the joint may also occur.

This is especially important in stainless steel, where surface oxides are very stable and specific deoxidants should be used for brazing..

10.6 JOINT DESIGN

A joint will be considered well designed when it allows correct penetration of the filler alloy between the gap of the two metals, without leaving empty spaces or trapped flux[2].

The main conditions for a correct joint (Fig. 106) are as follows:

1. Dimensions appropriate to welding temperature.
2. The surfaces to be joined should be parallel.
3. The surface of the metal should encourage wetting and allow the filler material to run.

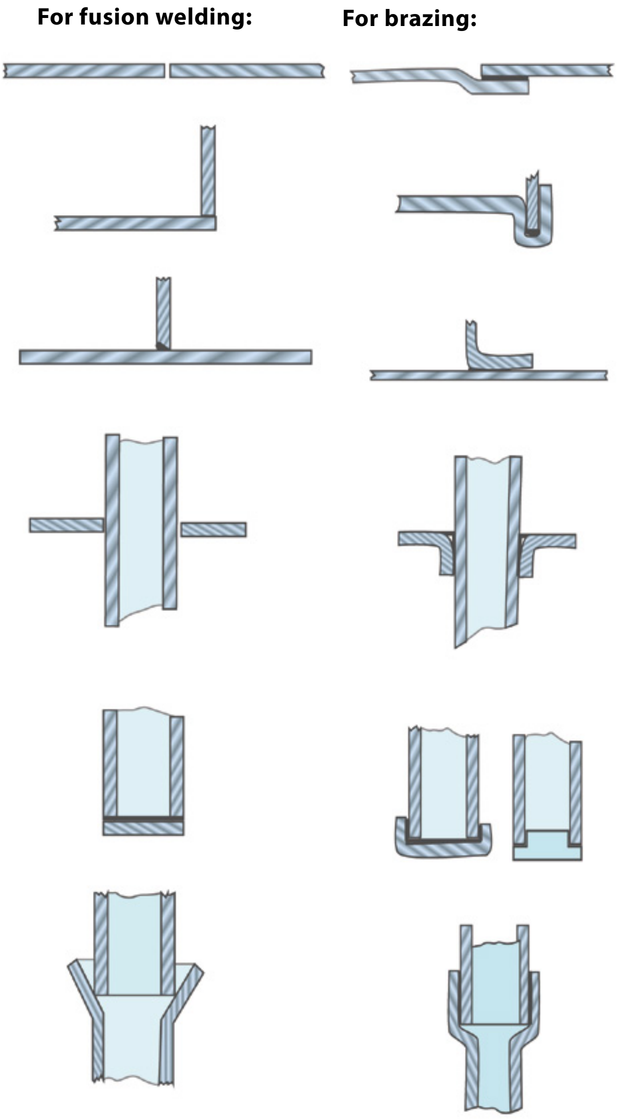

Fig. 106 - Joints used in fusion welding and brazing.

10.6.1 Types of joints

Joints may be: butt, lap and at an angle. It is practically impossible to comply with condition 2 of the previous section with a butt or angle joint, therefore they should be avoided. They should only be proposed, in the case of a lap joint, when the sudden change in thickness may generate a concentration of stresses not valid for the application.

The joints which are easier to weld and with better results are those in which the components to be joined are self-placed and do not need clamps to be held together. These clamps have some disadvantages, they absorb some of the heat, make it difficult for manual torch grazing to reach the joint correctly and prevent natural expansion and contraction during heating and cooling. They require maintenance since they strain and oxidize during use.

10.6.2 Lap Joint

It is recommended for joints of flat metals; to lap a length of 3 times the thickness of the thinnest component.

In the case of a tube up to 25 mm in diameter, it is recommended to lap a length of one tube diameter.

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[2] Author's note Appendix 3, page 258.

10.6.3 Joint Gap

The gap should be suitable for the brazing or soldering temperature and depends on the fluidity of the molten filler metal and the surface. For the cold design, the coefficients of expansion of the metals to be joined should be taken into account.

It is important to maintain a uniform gap for the entire joint, because if the gap is too small, the filler metal will not be able to penetrate and if it is too large, it will only penetrate the length where there is capillary action or it may also flow along the edges leaving the joint. In both cases the union will not have sufficient strength.

When brazing with silver alloys, the following gaps should be considered:

- Narrow - between 0.05-0.15 mm, which should be used when the consumable alloy has a high silver content, higher than approximately 40-45%.
- Wide - between 0.075-0.2 mm, which should be used when the consumable alloy has a low silver content

Care should be taken with joints of different metals where one side fits within the other, for example one austenitic and one ferritic, which have very different coefficients of expansion, as the austenitic coefficient is much higher. It may be that the gaps are appropriate at brazing temperatures, but during cooling and with the soldering metal already inside the joint, they close and become very tight so the soldering metal is under compression or exudes, and the soldering metal is subject to traction. Therefore, if possible, it is advisable that while the molten alloy is cooling and still does not have the required mechanical strength, it is subject to compression and not to traction. Therefore, austenitic steel should be on the outside.

10.7 MELTING RATE AND FLUIDITY

Pure metals have a fixed melting point, not a range, and have great fluidity, for example pure silver has a melting point of 961°C. Eutectic alloys such as 78% silver alloy and 22% copper alloy also have a fixed melting point of 778°C and also have great fluidity.

Alloys which do not have eutectic compositions melt within a range of temperatures that is sometimes called the fusion or plastic scale.

The lower temperature of this scale is the "solidus" temperature (the highest temperature, at which the filler material is completely solid) and the higher one is the "liquidus" temperature (lowest temperature at which the filler material is completely liquid).

An alloy such as NIPPON AG 450 (Ag=50%; Cu=15%; Zn=18%; Cd=17%) with a melting range of 625-635°C, if the heating is fast enough, it seems to melt as a eutectic alloy. For industrial applications, there are no alloys with melting temperatures lower than 620ºC.

10.8 LIQUATION

The silver-copper equilibrium diagram (Fig. 107), indicates that if a filler metal has a wide melting range, it is important to understand how this melting takes place:

- When the lower temperature of the scale ("solidus") is reached, part of the large or small soldering metal will begin to melt, which will penetrate the capillary gap of the joint and the rest will remain solid, remaining outside with a different composition and higher melting point. This process is called "liquation" and the result may be a joint of low quality and poor appearance.
- If the joint design requires good capillary penetration and a small external bead, it may be advisable to choose a soldering metal with a wide melting range and control the heating so that it goes beyond the "solidus" temperature and some penetrates the joint by capillary action but the "liquidus" temperature is not reached, and some remains solid to form that small bead. (For these applications, the Technical Sheets of the soldering metals used in the market, include the appropriate recommendations).

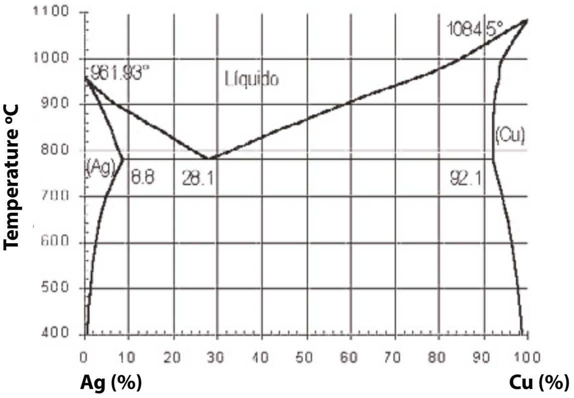
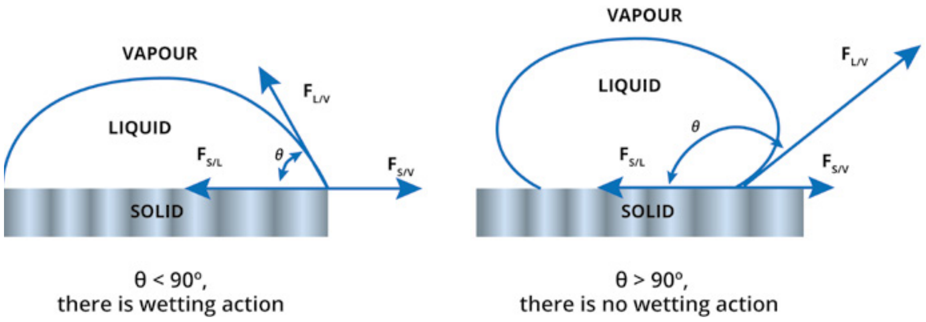


Fig.107 - Diagram of silver-copper balance.

The above comments help to emphasise that in order to correctly select an alloy, it is not only necessary to take into account the mechanical and physical properties and the melting range, it also needs to be appropriate for the joint design and the heating method.

10.9 WETTING ACTION OF MOLTEN FILLER METAL



θ < 90°,
there is wetting action

θ > 90°,
there is no wetting action

Fig. 108 - Scheme of forces that act as surface tension in brazing.

Where:

$F_{S/V}$ Surface tension force at the solid / vapour interface

$F_{L/V}$ -- Surface tension force at the liquid / vapour interface

$F_{S/L}$ -- Surface tension force at the solid / liquid interface

A balance of horizontal forces gives:

$$F_{sv} - F_{SL} = F_{LV} \cos \theta$$

The wetting characteristics depend on the angle formed between the molten filler metal and the metal to be brazed (θ"meniscus"):

If this angle (θ"meniscus") is inferior to 90º it is said that there is wetting action and the soldering metal will penetrate the capillary gap.

If $\theta < 90$: $F_{SV} > F_{SL}$ and there is wetting action.

If the angle (θ"meniscus") is bigger than 90º it is said that there is no wetting action and the alloy will not penetrate.

If $\theta > 90$: $F_{SV} < F_{SL}$ and there is no wetting action.

This angle will likewise depend on the action of the deoxidizer or controlled atmosphere, as it eliminates surface oxides and prevents new ones from forming during heating.

10.10 FILLER METAL SELECTION

The compositions and melting ranges of the silver alloys used in stainless steel welding may be obtained from:

AWS/ASME SFA 5.8

UNE EN ISO 3667

The selection of the most appropriate filler metal alloy for an application should consider:

- The mechanical and physical properties required at service temperature. It should be taken in consideration that the mechanical properties of silver alloys for brazing stainless steel drop quickly from 250°C.
- The melting range of the filler metal shall be lower than the melting temperature of the metal to be brazed. Silver alloys for brazing stainless steel have a melting range between 600-1200ºC.
- The required fluidity at brazing temperature, to penetrate the union by capillarity.
- The melting range should be sufficient so that the heating method avoids alloy liquation.
- Alloys with a melting range (temperature difference "solidus" and "liquidus") lower than 30°C are considered to have a small melting range:
  - Heating may be slow or fast.
  - The filler metal alloy may be pre-positioned within the joint or may be manually or automatically fed in as rod, ring, sheet or paste.
- Alloys with wider melting ranges:
  - Should be brazed only with fast heating (oxygen-acetylene torch or induction) that heat the joint quickly to brazing temperature (higher than the "liquidus" temperature), to prevent alloy liquation.
  - Feed the alloy to the joint after it has exceeded the brazing temperature, so the alloy will penetrate the capillary gap without liquation.

The following general rules should be taken into account:

- Alloys with higher silver content should be used when the "capillary gap" is narrow; a good ductility is necessary in the joint and when heating is slow.
- Alloys with lower silver content may be used when the "capillary gap" is wide. In this case heating should be fast.

Process	BRAZING	
METAL	STAINLESS STEEL	
Consumable alloy	UNE EN ISO 3667	AWS/ASME SFA 5.8
Rod NIPPON 450	B-Ag45CuZnSn 640/680	BAg-36

Table 38. Example of denominations for brazing

10.11 DEOXIDIZERS AND CONTROLLED ATMOSPHERES

All metals and alloys at room temperature have the natural reaction of forming a more or less stable layer of surface oxidation. At brazing temperatures other reactions may take place, depending on the atmosphere to which the joint is exposed, the most normal are oxidation, nitride and carbide formation. Deoxidizers, controlled atmospheres and vacuums are used to avoid these reactions.

As the chromium oxide layer of stainless steel is very stable, the function of the deoxidizer or the controlled atmospheres is very important to eliminate oxidation and to perform the brazing.

10.11.1 Deoxidizers

Before handling the deoxidizer, it is necessary to understand the safety instructions to safely handle it, to understand the fumes generated by the process, the advice to eliminate them and how to behave in the event of an accident. In general, they are based on fluorides and they are supplied in the form of powder, which should be dissolved according to the manufacturer's instructions. The deoxidizer is normally used in liquid or paste form and should be applied to all the surfaces to be joined and nearby areas to avoid contaminating the joint during the heating process.

The functions of the deoxidizer are as follows:

- To dissolve or eliminate from the capillary gap superficial oxides that all metals and alloys have at room temperature. It is not the function of the deoxidizer to eliminate oils and particles from other previous manufacturing processes or from poor storage, a prior cleaning process fulfils this purpose.
- To remain active for the temperature and time intervals covering from before the alloy begins to melt until the alloy flows through the capillary gap and solidifies. In general, they should begin to melt about 50°C lower than the filler alloy starts melting, so this may be a sign that the moment to add manually fed consumable alloy is close. The deoxidizer should remain active up to 50-100ºC above the "liquidus" temperature of the alloy.
- To protect the surfaces from the formation of new oxides or if they are formed to eliminate them, to allow the alloy to wet properly and to flow.
- To be sufficiently viscous at welding temperature, to allows the molten alloy to dislodge the deoxidizer from the joint.
- To be suitable for the heating method. There are appropriate deoxidizers for fast heating such as induction that if used with a furnace heating that is slow, may "run out" before time.

If there is insufficient deoxidiser that is not appropriate for the heating method or does not reach the welding temperature and burns, it will cause the deoxidizer to increase its viscosity so it may not be eliminated by the molten alloy and a defect called "deoxidant entrapment" results, or the alloy stops "wetting" the capillary gap and flowing.

Removal of deoxidizer residues

It is necessary to eliminate the deoxidizer residues because they are corrosive for stainless steel. They are generally based on fluorides. The removal method will depend on the deoxidizer:

- Most deoxidizer residues may be removed by immersion in hot water.
- When flux[2] is saturated with oxide, if the welded joint allows it, it may be necessary to immerse it in cold water, which will crack the deoxidizer residues and they will detach.
- If the residues do not detach with hot or cold water, baths should be used according to the supplier's instructions.

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[2] Author's note Appendix 3, page 260.

Typical characteristics of a deoxidizer for stainless steel

Information provided by the product technical sheet is as follows:

Applications:

- Brazing of carbon steels and especially stainless steels with filler materials such as NIPPON AG 545 (Ag=45%; Cu=27%; Zn=25%; Sn=3%), free from cadmium for applications in the food industry, with melting range 640-680ºC and recommended to be used with gap between 0.08-0.2 mm.
- It is also suitable when extended heating is required and some parts of the joint may overheat.

How to apply the deoxidizer:

It may be mixed with water to form a paste applied with a brush.

Melting range: 550-800ºC

Main components:

It contains complex potassium fluorosilicates.

Residue disposal: the deoxidant residues are insoluble in water. Elimination is recommended by immersing them in a hot solution of 10% caustic soda, then clean with a brush in hot water.

Safety Instructions:

- Irritant by inhalation, by ingestion and by skin contact.
- Keep out of the reach of children.
- Keep away from food and drinks.
- Do not smoke during use.
- Do not inhale the powder.
- In case of contact with eyes and skin, wash immediately with plenty of water and seek medical advice.
- Use in well-ventilated areas.

10.11.2 Controlled atmospheres

These are mainly used in furnace welding although they may also be used with other heating methods (resistance, induction). Their functions are:

- To eliminate surface oxides by means of a reduction reaction, being an alternative to deoxidants.
- To prevent new oxides from forming during welding.
- To influence the heat transfer rate to the assembly to be welded, both during heating and cooling.

The stainless steel brazing process uses two types of gases:

Inert:

They may be N_2, Ar and He, with the following functions:

- To eliminate the air or other gases that may contaminate and prevent them from entering again, maintaining a positive pressure inside the furnace.
- To help H_2, at the required concentration to come into contact with the metal surface, so that the reduction reaction of the metal oxides may take place.
- As H_2 is flammable, dilute the H_2 concentration to the required limit, if required for safety reasons.

Active:

- The gas should be a reducing gas. Therefore, H_2 or gases that generate an H_2, atmosphere when dissociated, such as methanol, are used. Their functions are:
- To perform the reduction reaction of surface oxides to allow sufficient wetting of the molten alloy.
- To maintain a reducing atmosphere to prevent new oxides from forming during welding.
- If a deoxidizer is used, they react with the vapours that may be released, so that they do not interfere with the brazing.

Although N_2 is considered inert, at high temperatures it reacts with metals such as Ti, Nb, Zr, for this reason, Ar is more frequently used.

The most commonly used atmospheres by mixing inert and active gases are:

N_2 (1-75)%- rest H_2

Ar (1-75)%- rest H_2

Figs 109 and 110 show an installation to supply a controlled atmosphere of H_2+N_2 o H_2+Ar, which would be composed of:

Hydrogen: semi-trailer of H_2 with a reserve of 1+1 bundles.

N_2 or Ar: liquid tank.

Purity of gases

All the gases that form the atmosphere inside the furnace should have the required uniform purity to ensure good wetting by the molten alloy. H_2O and O_2 are two of the most common impurities that may influence the surface tension forces between the solid-vapour and liquid-vapour phases and decrease wetting by the molten alloy.

The most common impurity from industrial processes that produce hydrogen is H_2O. Consult the furnace manufacturer, but it should be advisable to limit the H_2O content to <10 ppm in H_2 and N_2.

Fig. 109 - Supply of H_2 with installation of H2 with semi-trailer with battery reserve 1+1 blocks. COURTESY OF NIPPON GASES

Fig. 110 - Complete facility to supply atmosphere H2+N2 o H2+Ar. COURTESY OF NIPPON GASES

10.12 SOLDERING PROCESS

This process joins metals using a filler alloy with a melting temperature lower than 450ºC and without melting the metals to be joined. A deoxidizer or a controlled atmosphere is required, to eliminate surface oxides and to avoid oxidation during the process.

Numerical designation of the process

According to UNE - EN ISO 4063: 2011, the numerical designation is as follows:

- Brazing, soldering and braze welding - 9
- Soldering S – 94

Depending on the type of heating, the most commonly used are:

- Oxygas torch. (TS-Torch Soldering) - 942
- Furnace. (FS-Furnace Soldering) - 943
- Induction. (IB-Induction Soldering) - 946
- Resistance. (RB-Resistance Soldering) - 948
- By wave: (Wave Soldering) -- 951

Soldering and brazing have some common aspects.

1. The execution is similar, following the same stages:
   - Joint preparation with reference to lap joints and with the appropriate gap.
   - Cleaning.
   - Use of deoxidizer or controlled atmosphere, for metal, temperature and welding time.
   - Selection of the heating method. Some brazing methods are used, with the addition of other methods more specific to soldering, like wave soldering.
   - Consumable alloy supply.
   - Residue cleaning
2. Temperatures involved are lower than the melting temperature of the metals to be joined.
3. A consumable alloy is required.
4. Safety precautions are similar. Welder personal protection, contact with deoxidizers, residues and fumes.

There are also remarkable differences like:

1. The melting temperature of the filler alloy should be lower than 450°C, while in brazing it should be higher than this temperature.
2. Mechanical resistance is lower than brazing mechanical resistance.
3. The cost of the alloy is lower in soldering:
   - The alloys used in brazing are: 25-45% Ag and other elements copper (Cu), zinc (Zn), cadmium (Cd), tin (Sn), nickel (Ni), manganese (Mn).
   - Soldering alloys have very little or no Ag content:

     - Tin (Sn) – lead (Pb)

     - Tin (Sn) – silver (Ag)

     - Tin (Sn) – silver (Ag) – lead (Pb)

     - Tin (Sn) –zinc (zinc)
4. By using lower temperatures in soldering, the distortions and the influence on the properties of stainless steel will also be lower.

Selection of the consumable alloy

As in brazing, there are many different alloys available and the selection criteria are similar. It is necessary to take into account: mechanical strength and the required ductility, heating method and capillary gap, if there is corrosion, after soldering, the colour should be as similar as possible to stainless steel, that there may be contact with food, water, etc.

The two most commonly used alloys are:

- Tin (Sn) – Lead (Pb) with a Sn content higher than 50% to improve mechanical strength and to reduce the risk of galvanic corrosion in the soldered joint during service.
- Tin (Sn) – Silver (Ag), which improves the mechanical strength, ductility and corrosion resistance, compared to Sn-Pb alloys.

10.13 MAIN DEFECTS

DEFECT	CAUSE
The soft solder alloy has not sufficiently penetrated the capillary gap.	Inadequate cleaning, or the deoxidizer is insufficient to dislodge oxides.
	Too little flux[2], or flux[2] not suitable for the heating method.
	Alloy not suitable for the gap, or the gas is too narrow or too large.
	Poor heating technique in manual welding with torch.
	Poor temperature adjustment in furnace
	Inadequate controlled atmosphere, does not clean oxides or with excessive amount of moisture.
Excessive amount of alloy outside the joint.	Poor design of the joint.
	Temperature too high
	Welding time too long.
	Alloy not suitable for the gap.
	Too much filler material
	Poor operative technique, feeding the alloy to the joint in an unsuitable place.
Corrosion in the joint.	The deoxidizer has not been removed.
	Deoxidizer not suitable.
	Alloy not suitable.
	Stainless steel heating not sufficient in critical temperatures or time.
Deoxidizer trapped inside the joint.	Flux[2] not suitable for heating method or temperature.
	Flux[2] not suitable for the alloy.
	Poor cleaning of the joint, or insufficient deoxidizer.
	Poor heating technique in manual welding with torch.

10.14 SAFETY PRECAUTIONS

In Section 13 Professional exposure to chemical agents in stainless steel welding, the tips on fume extraction may be reviewed.

In general, the following points should be reviewed:

- Dimensions of the workplace where brazing takes place.
- Number of joining technicians.
- Volume of fumes and the potential particles generated depending on the materials used. For example, it is necessary to consider the deoxidizer as a potential generator of fluorides and to check if the filler metal has cadmium.
- Check if ventilation is sufficient
- Proximity of welders and other personnel to fumes and generated particles.

The safety measures for the heating method should be adopted. For example in the case of brazing with oxygen and acetylene torches, glasses, gloves and aprons should be approved for this process. Avoid contact with deoxidizers that may cause skin irritations and in case of contact with the eyes, immediately wash with water and see a doctor. Safety measures recommended by the deoxidizer supplier should be understood, especially if gas-flux[2] is used.

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[2] Author's note Appendix 3, page 258.

11 Shielded Metal Arc Welding - SMAW

Welding process where the heat required to melt the metal is produced by an electric arc between the end of a coated electrode and the metal of the joint to be welded.

The electrical circuit consists of an appropriate current generator and two terminals, one connected to the electrode clamp where the coated electrode is placed and another to the mass fixed to the metal or metals to be joined. The electrical circuit is closed by the arc that burns between the end of the coated electrode and the metal.

Touching the end of the electrode to the metal causes the arc to be primed. The Joule effect causes the current flowing through the electrode and the metal at contact tube to become heated. Then, by slightly separating the electrode and maintaining an appropriate separation, an ionized atmosphere will be generated that will allow the current to flow and maintain the electrical arc.

The electrical arc generates the required heat to raise the temperature above the melting point of the metal and the electrode, forming the molten pool.

As the molten pool progresses, it leaves behind welded metal and slag. (Fig. 112)

The coated electrode consists of a metal rod, with a composition similar to the metal to be joined and a concentric coating around the rod.

The main characteristics of the coated electrode are determined by its coating. Its functions are as follows:

1. To give stability to the arc, ensuring good ionisation between the end of the electrode and the metal.
2. To protect the molten droplets from contacting the air as they pass through the arc, the weld pool and the molten metal.
3. To reduce or eliminate impurities in the weld pool, mainly phosphorus and sulphur.
4. To allow the welded metal to slowly cool.

Reactions take place in the weld pool between the elements of the metal to be joined, the metal rod of the electrode and the coating. The above mentioned characteristics help to obtain the required mechanical properties.

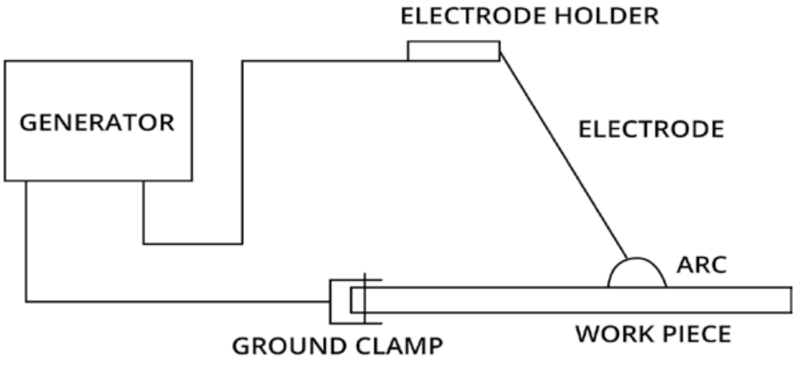


Fig. 111. Diagram of the coated electrode process.

Designation of the process:

Coated electrode welding

(Shielded Metal Arc Welding - SMAW)

UNE – EN ISO 4063: 2011

Process 111:

Arc welding with coated electrode.

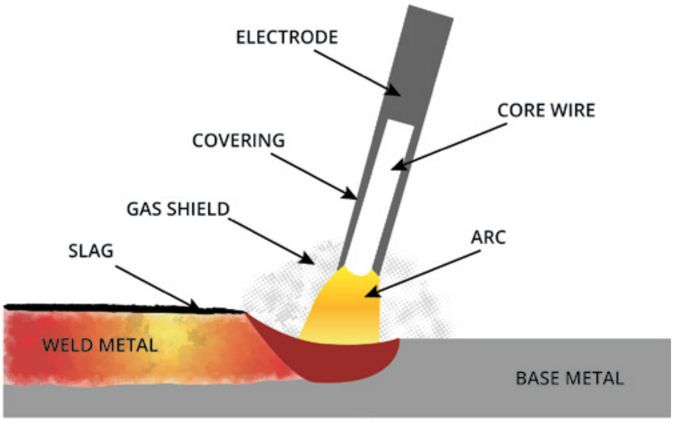


Fig. 112 - Coated electrode.

11.1 COATING TYPES

Coated electrodes are classified by the type of chemical reactions of slags. For stainless steel electrodes, one of most popular classifications is the AWS/ ASME SFA 5.4.

Example:

Electrode 308L-16 indicates it has rutile coating.

Electrode 308L-15 indicates it has basic coating.

The numbers 15, 16, 17 and 26 which follow the classification according to their chemical composition indicate:

(Electrode)-**15** indicates basic coating

(Electrode)-**16** indicates rutile coating

(Electrode)-**17** indicates rutile coating

(Electrode)-**26** indicates thick coating

The main coated electrodes used for various stainless steels may be seen in Table 39.

Coating		**Current**	**Applications**
15	Basic	DC	Vertical, overhead and applications in all positions such as pipes.
			Root passes in thick materials. Slightly convex section to prevent cracking.
			Welding of high alloyed stainless steels, which may tend to crack in the centre line of the bead.
16	Rutile	AC or DC Preferably DC	Welding in horizontal position.
			Vertical and overhead when basic coating is not available.
17	Rutile	AC or DC Preferably DC	Horizontal and angled cornice.
			When a concave bead is needed.
26	Thick	AC o DC Preferably DC	Horizontal and angled cornice.
			Recommended for high intensities and high deposition rates.

Table 39. Types of coating on stainless steel electrodes

11.2 STORAGE AND DRYING OF COATED ELECTRODES

MAINTENANCE

All coated electrodes are sensitive to moisture absorption, if they are not stored under correct environmental conditions, which should be supplied by the manufacturer.

Depending on the type of coating, moisture content may cause the formation of pores or cracks produced by hydrogen.

Basic electrodes are mainly used when the joint needs good mechanical properties and due to their coating they are especially sensitive to moisture. If they have not been stored under the appropriate moisture conditions, they may have pores and cracking due to the hydrogen in the welding metal. Electrodes can be dried and used.

For example, stainless steel electrodes should be kept in the original packaging, and stored in atmospheres with the following moisture and temperature limits recommended by some manufacturers:

TEMPERATURE	MAX RELATIVE HUMIDITY
5 - 15 ºC	60%
15-25ºC	50%
>25ºC	40%

One recommendation is a maximum storage time of 3 years. After this period the electrodes should be checked before use.

DRYING

Electrodes which have been heavily contaminated with moisture as a consequence of been exposed outside for long periods of time would doubtfully recover their initial state and should be discarded. The same should happen with electrodes that are missing coating in some places.

Electrodes that have been in substandard or unknown conditions, should be dried at the temperature and for the time indicated on the package. Generally, drying time should be 1-6 hours at a temperature between 200-350ºC.

An example of drying conditions:

ELECTRODE SFA 5.4	DRYING TEMPERATURE FOR 2 HOURS (ºC)
E 308L-16	350
E 308L-17	350
E 308L-15	200
E 347-17	350
E 347-15	200
E 316L-26	350

Once the electrodes have been dried, they should be kept in an oven between 75-125ºC or in a stove.

Depending on the manufacturer, it is not advisable to dry electrodes more than 2-3 times.

Electrodes with basic coating should be dried before use when the packaging has been opened and radiographic quality is required in the welded metal.

12 Shielding gases

12.1 INFLUENCE OF SHIELDING GASES IN WELDING

The main function of shielding gas is to move the air away from the welding zone to avoid molten pool contamination. This pool contamination is mainly generated by nitrogen, oxygen and water present in the atmosphere.

Nitrogen reduces ductility, impacts resistance and may cause cracking. In large quantities nitrogen may produce porosity.

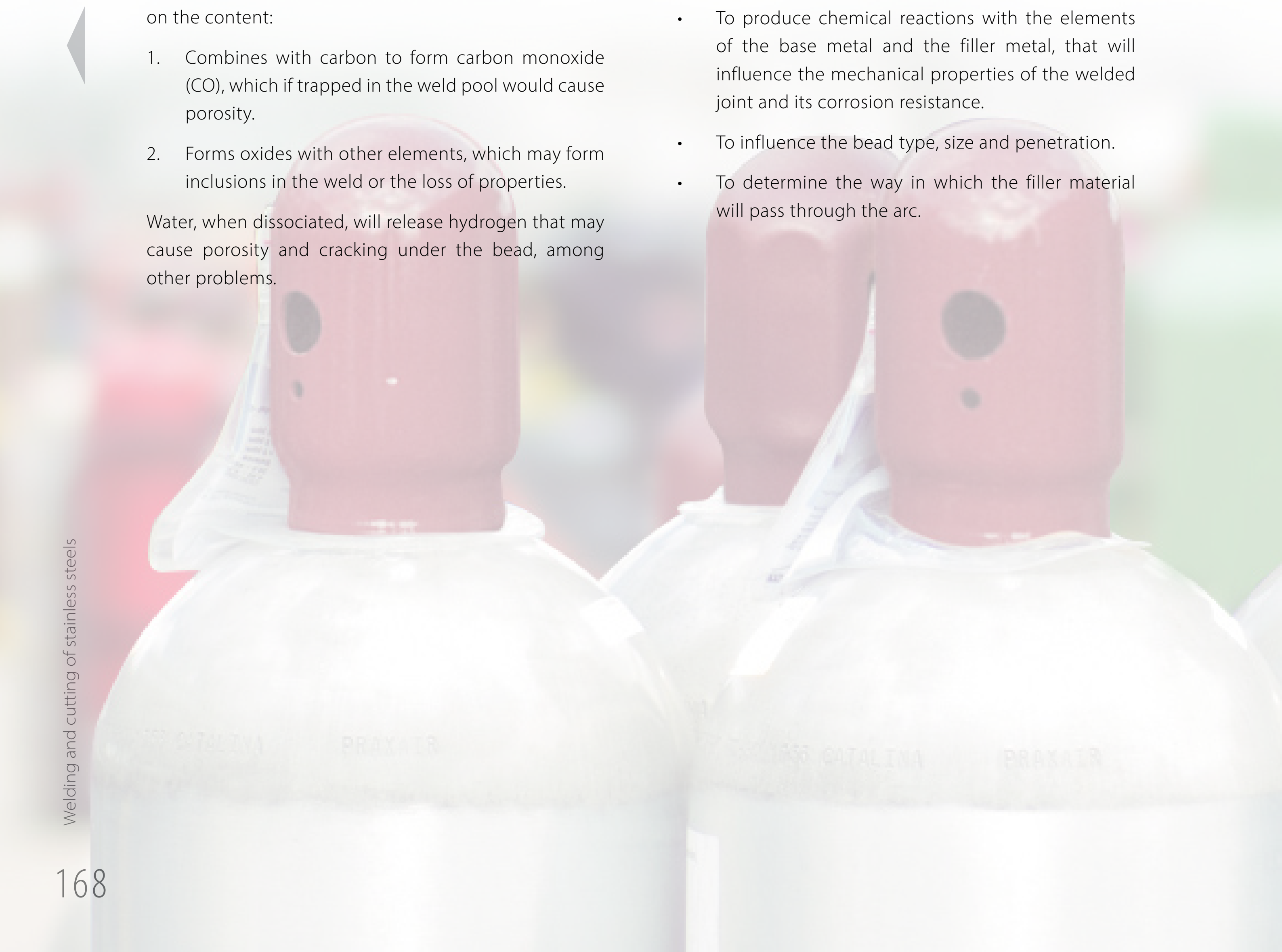
Excessive oxygen may cause other problems depending on the content:

1. Combines with carbon to form carbon monoxide (CO), which if trapped in the weld pool would cause porosity.
2. Forms oxides with other elements, which may form inclusions in the weld or the loss of properties.

Water, when dissociated, will release hydrogen that may cause porosity and cracking under the bead, among other problems.

Other functions of the shielding gas, which are not less important and which should be taken into account, provided that the quality of the welded joint or a calculation of costs are considered, are the following:

- Influence on the voltage and thermal energy released by the arc when welding. The higher the thermal conductivity of the gas, the higher the voltage necessary to maintain a stable arc and the higher the thermal energy provided to the weld.
- To produce chemical reactions with the elements of the base metal and the filler metal, that will influence the mechanical properties of the welded joint and its corrosion resistance.
- To influence the bead type, size and penetration.
- To determine the way in which the filler material will pass through the arc.



12.2 SHIELDING GAS SELECTION FACTORS

In some cases, one factor is so important that it determines the choice of gas. In other cases, it is necessary to evaluate several factors. The fundamental factors are:

1. Welding procedure.
2. Material to be welded.
3. Thickness of the material.
4. Welding position.
5. Filler material.
6. Mechanical properties required.
7. Penetration.
8. Welding speed.
9. Quality required.
10. Fumes.
11. Final appearance.
12. Costs.

12.3 MAIN GASES USED IN STAINLESS STEEL WELDING AND CUTTING PROCESS

	Ar	CO_2	O_2	He	H_2	N_2 (1)	AIR
MIG/MAG	■	■	■	■	■	■	
TIG	■			■	■	■	
PLASMA	■			■	■		
WELDING	■	■		■		■	
LASER WELDING	■	■	■		■	■	■
PLASMA CUTTING	■	■	■	■		■	
LASER CUTTING	■	■	■	■		■	

Table 40. Commonly used gases.

(1) Nitrogen is used:

- Backing gas in N_2- H_2 mixtures to shield the root bead in austenitic stainless steels.
- An addition in mixtures for the welding austenitic and duplex stainless steels.
- For cutting with CO_2 laser as pure gas in the resonator and as assist gas in stainless steels cutting.
- Cutting with fibre laser as assist gas.
- Plasma cutting.
- CO_2 laser welding as pure gas in the resonator.

12.4 PHYSICAL PROPERTIES OF GASES

12.4.1 Ionization energy

This is the energy, expressed in volt electrons (eV), needed to release an electron from an atom in a gaseous state, converting it into an ion, or an electrically charged atom. For example:

$Ar \rightarrow Ar^{+}e^{-}$

Argon gas with atomic number 18 and with 8 electrons in its last layer is much heavier than helium, which only has 2 electrons. The energy needed to release an electron from an argon atom is 15.759 eV while from helium is 24.586 eV.

Therefore,

- Argon ionisation will be easier than helium ionisation
- Once the gas is ionised, the electrons will be free to support the electric arc, the distance between the electrode and the base metal.
- To maintain the electric arc, it is necessary to maintain the energy level, which will depend on the gas used. For the same arc length, the voltage required for argon is much lower than helium.
- With Ar, the start of the arc will be easier and will have upper stability than with He. Both factors are important in welding with alternating current, where re-ignition is necessary with each cycle.
- For the same current and arc length, we will get a heat quantity = Voltage x Current, for argon lower than helium. It will be easier to weld thin materials with argon and helium should be taken into account, when heat input should be increased.

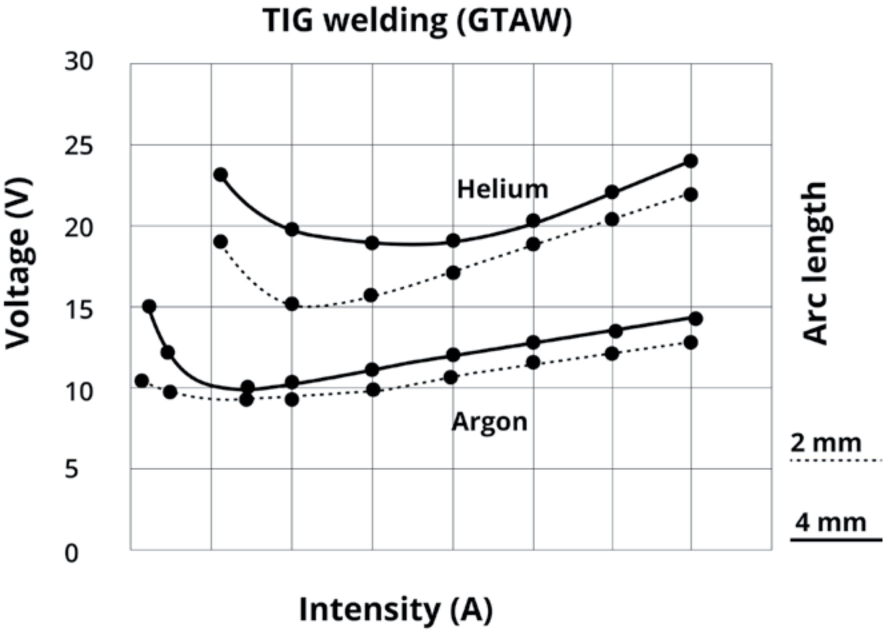


Fig. 113 - Relation between Voltage, Arc Length and Intensity. (Welding with alternating current).

12.4.2 Thermal conductivity

The thermal conductivity of a gas measures the ease with which it conducts heat. Also, it may be defined as the ability to transfer the kinetic energy of its molecules to other adjacent ones. The opposite is thermal resistivity, which is the ability to resist heat flow. It influences radial heat loss from the centre to the periphery of the electric arc column.

Argon has low thermal conductivity and forms an electric arc with two areas: one interior, in the centre, hotter and one external, significantly cooler. So, penetration will have a narrower shape at the root and wider at the top. Gas with high thermal conductivity conducts more heat from the inner part, in the centre of the arc, towards the outside, resulting in a wider and uniform penetration, a warmer arc. This happens when helium is used or mixtures of argon-helium, argon-hydrogen, argon-helium-hydrogen, argon-carbon dioxide..

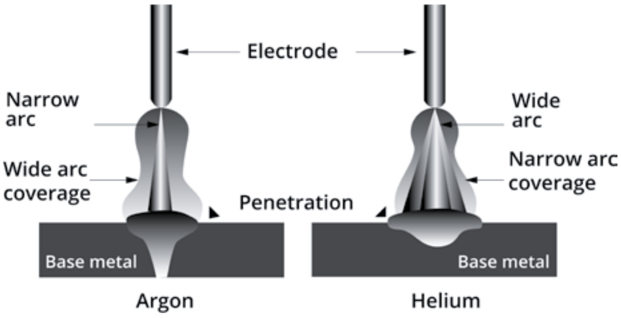


Fig. 114 - Comparison of arcs in an argon and helium atmosphere.

12.4.3 Dissociation

Dissociation measures the ease by which a molecule made up of several atoms breaks into the atoms that make it up. Gases such as CO_2, O_2 and H_2 may break up or dissociate their molecules due to the high temperatures in the electric arc. For example, CO_2 dissociates into one carbon atom and two oxygen atoms. When the dissociated gas reaches the surface of cold base metal, the atoms recombine generating additional heat. This process does not happen with gases like argon. Therefore, at the same temperature and keeping the rest of the variables constant, the heat generated at the metal surface may be significantly higher with gases such as CO_2, O_2, H_2 than with argon. (Table 41)

GAS	DISSOCIATION ENERGY (eV)
H_2	4.5
O_2	5.1
CO_2	4.3
N_2	9.8

Table 41. Dissociation energy of shielding gas components.

12.4.4 Reactivity

This property of shielding gases measures their capacity (at the arc temperature) to react with the chemical elements in the molten pool.

Argon and helium are completely inert and therefore, do not react chemically with the weld pool. Nitrogen is considered inert, however, at high temperatures in stainless steels welding, it may react with steels stabilised with Ti and affect the ferrite-austenite balance. Oxygen and CO_2, are reactive oxidant gases these gases will react with the molten metal in the arc and in the weld pool. This property influences the formation of welding fumes. Hydrogen is a reactive and reducing gas. It will react preferentially with the oxidising agents, helping to prevent the formation of oxides in the molten metal. In austenitic stainless steel welding, it produces oxide-free welds and increases the welding rate. However, this gas may cause detrimental effects, such as cracking under the bead, when it is used as a component in the shielding gas in non-austenitic stainless steels welding and high strength and low alloy steels.

12.4.5 Surface tension forces

There are surface tension forces in any liquid exerted by the molecules that are below the surface on those molecules that are on the surface. This force tends to contract the liquid and prevent it from flowing. The magnitude of these forces will vary with the chemical nature of the liquid.

Surface tension forces affect the molten metal in welding and strongly influence the bead. If they are high, they will generate a convex and irregular bead. On the other hand, if they are low, a flat bead with low tendency to undercutting will be achieved.

When pure argon is used as shielding gas in GMAW (MIG) carbon steels welding, excessively crowned and irregularly shaped beads will be formed. This is partially due to the fact that surface tension forces of the molten steel will be higher in an inert atmosphere. For this reason, the use of MIG with inert atmosphere for carbon steels welding is not recommended.

Iron oxides have a lower surface tension resulting in better adherence to the base metal. Therefore, the addition to argon or small amounts of O_2 or CO_2 in GMAW (MAG) welding of carbon steels with generate a molten pool with greater fluidity.

12.4.6 Purity

Some metals, such as carbon steel, have a relatively high tolerance to potential contamination from the shielding gas. Other metals, such as aluminium and magnesium, are quite sensitive to impurities. Finally, there are others that have an extremely low tolerance to gas impurities.

Metals may be classified according to their tolerance (from highest to lowest) to the potential contaminants in ppm that may appear in shielding gases:

- Carbon and copper steels.
- Stainless steel.
- Aluminium and magnesium.
- Titanium.

This classification should be considered as a guideline, since this tolerance may be stricter depending on the requirements of the welded joint. When a suitably pure gas is used and there are defects that may be caused by the shielding gas, once verified that the other variables such as the flow and the angle of the torch are correct for the application, it should be taken into account that the gas may be contaminated between the end of the supply point and its exit through the nozzle. In this case, it is necessary to check the entire gas circuit (regulator and its gasket, pipe elements, work station, hose and connections with solenoid valve).

12.4.7 Density

This is the weight of the gas per unit volume. Density is one of the most influential factors in the effectiveness of shielding gas. Heavier gases than air, such as argon and CO2, will need lower flow than lighter gases.

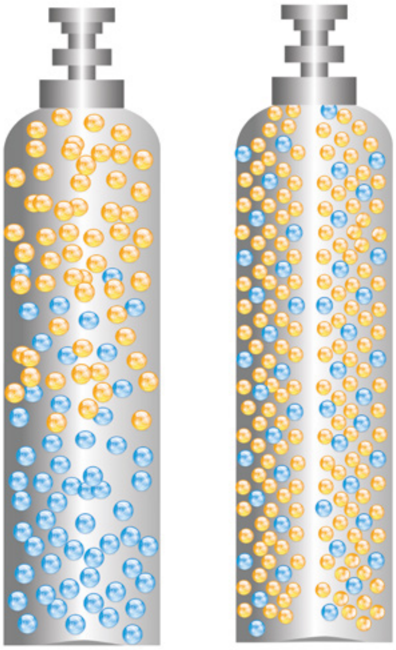


Fig. 115 - Left cylinder with lack of mixture homogeneity. Right cylinder with homogeneous mixture.

12.5 SUMMARY OF PHYSICAL PROPERTIES OF SHIELDING GASES

	Ar	CO_2	He	H_2	N_2	O_2
Atomic No.	18	-	2	1	7	8
Molecular weight	39.95	44.01	4.00	2.016	28.01	32.00
Specific weight (Air=1)	1.38	1.53	0.1368	0.0695	0.967	1.105
Density (0°C, 1 Atm)	1.678	1.849	0.176	0.085	1.188	1.3842
Potential ionization (ev)	15.7	14.4	24.5	13.5	14.5	13.2
Thermal conductivity (10^{-3} x Btu/hr x ft x °F)	9.69 (32)	8.62 (32)	85.87 (32)	97.22 (32)	13.93 (32)	14.05 (32)

Table 42. Physical properties of shielding gases.

12.6 CHARACTERISTICS OF THE GASES

ARGON

- Inert gas.
- High density.
- Low thermal conductivity.
- Low ionisation potential.
- Provides a very stable arc and remarkable protection.
- It is a commonly used component of most welding and cutting mixtures.

HELIUM

- Inert gas.
- Low density.
- High thermal conductivity.
- High ionisation potential.
- Suitable when high heat input (aluminium and copper) or an increase in welding rate is required (automation).

NITROGEN

- Mainly used in cutting.
- Mixed with hydrogen as backing gas.
- As a component in welding mixtures of austenitic steels, with the exception of stabilised and duplex.
- As assist gas in stainless steel laser cutting for stainless steels, galvanised steel and carbon steel when a slag-free edge is needed to facilitate subsequent painting.

HYDROGEN

- Active gas.
- It is mixed with argon or helium, to increase welding rate
- Provides a reducing atmosphere.
- In Ar-H_2 and Ar-He-H_2 mixtures in TIG and plasma welding and in Ar-He-CO_2-H_2 mixtures in MAG welding of austenitic steels.
- In Ar-H_2 mixtures for plasma cutting of stainless steel and aluminium.
- As a component in Ar- H_2 y N_2- H_2 mixtures in backing gas.
- As a component of controlled atmosphere, in furnace soldering and brazing.

OXYGEN

- Active gas.
- Its oxidising potential is higher than that of CO_2.
- Mixed with argon, it increases stability of the MAG arc.
- As oxidising gas in brazing.
- As assist gas in carbon steel laser cutting.

CARBON DIOXIDE

- Active gas.
- High thermal conductivity in relation to argon.
- When mixed with argon, it increases penetration

12.7 SELECTION OF THE SHIELDING GAS

The following points may help to select the most appropriate gas:

- Pure argon, or as a major component, has an advantage in manual welding and thin materials.
- In TIG welding argon provides a more stable arc, with easier start and less penetration than the arc obtained by mixing with helium and/or hydrogen.
- Argon has lower cost than helium because it is cheaper and requires a lower flow rate.
- In MIG / MAG welding, additions to CO_2, O_2 argon are necessary to stabilise the arc.
- Helium provides higher heat input. Its use mixed with argon should be considered to increase welding speed, to decrease or eliminate preheating when welding aluminium and copper and with base metals, where hydrogen may not be used and only argon is being used.
- H_2 is used mixed with argon in TIG and MIG/MAG welding of austenitic stainless steel, providing a reducing atmosphere and an increase in welding rate.
- The cost comparison of the two gases or mixtures, should not be done in €/m^3, it should be done in €/metre of welding
- The cost of the gas in €/metre of welding should be approximately between 5-10% of the sum, in €/m of the labour (welder), consumable and gas costs.
- For a given weld, the gas or mixture for manual welding may not be the most suitable for automatic or robotic welding, where a higher welding speed may be used.
- N_2 is used to stabilise austenite, in Ar-N_2 mixtures in TIG welding and in Ar-CO_2-N_2 mixtures in MIG/MAG welding of austenitic and duplex stainless steel, with the exceptions of those stabilised with Ti.

12.8 SELECTING THE PURITY OF THE SHIELDING GAS

In most applications, purity in argon gas of 99.996% is sufficient for welding stainless steel, but this purity is not sufficient when it is necessary to get lower porosity (radiographic control), a better bead appearance or longer duration of the tungsten electrode in TIG and plasma welding.

Therefore, higher purities, as indicated in Table 43, should be used. Depending on the purity, a lower O_2, N_2 and H_2O content is guaranteed.

Gas	**Purity (%)**
Argon - 46	99.996
Argon - 48	99.998
Argon - 50	99.999

Table 43. Purities of argon gas.

12.9 SHIELDING GASES IN TIG WELDING

Argon and helium inert gases are mainly used. Hydrogen is added to argon and helium in small quantities, mainly for automated stainless steel welding. Nitrogen is added to stabilise austenite in duplex stainless steels..

ARGON

It is used more extensively than helium due to the following advantages:

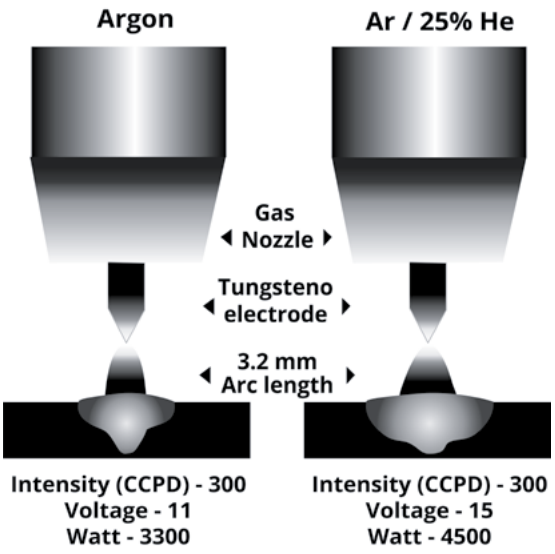
- Provides a more stable arc.
- For a given current and arc length, the voltage is lower.
- Better cleaning action in aluminium and magnesium welding with alternating current.
- Lower cost.
- Lower gas flow is needed, because it has higher density.
- Easier arc initiation.
- It is preferred for welding thin materials and welding in "out of position" (vertical and overhead) because it requires lower arc voltage (therefore, lower heat input) and to give a more stable arc in the range of 50 to 150 A, which includes most manual welding of thin materials.

HELIUM

It has a thermal conductivity that is much higher than argon which gives it special characteristics.

It will need higher voltages than with argon.

The V-I curves with argon and helium gases can be seen below. (Fig. 116)



For equivalent arc lengths, the voltage obtained with helium is appreciably higher than with argon. For the formula of heat input:

$$\text{HEAT INPUT (J/cm)} = \frac{\text{Voltage (Vol) x Intensity (A)}}{\text{Welding speed (cm/min.)}} \times 60$$

- The use of helium will provide higher heat input than argon.
- It will allow high speed welding, especially in automated applications where mixtures with H_2 may not be used.
- Argon-helium mixtures are used when a balance between the properties of argon and helium is needed

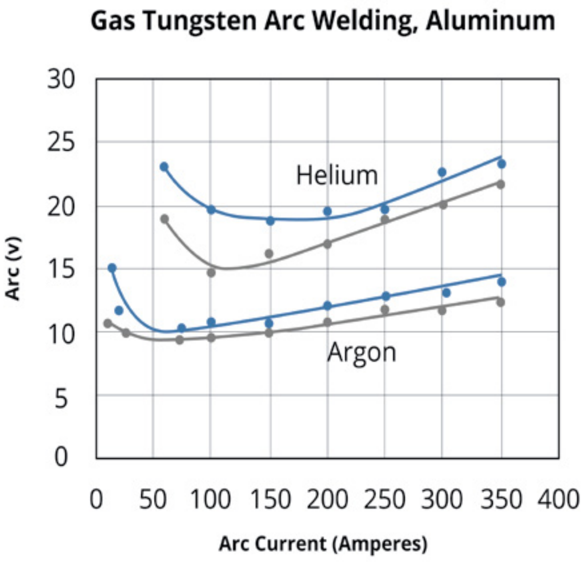


Fig. 116 - Relation between voltage and intensity with Ar and He.

ARGON - HYDROGEN

ARGON - HELIUM - HYDROGEN

These mixtures are used to increase the welding rate in special applications, such as automatic welding of austenitic stainless steels, where hydrogen does not cause adverse effects.

Hydrogen content is normally between 2% and 10%. These mixtures are often used for the 1.5 mm thick stainless steel butt joint welding, at speeds higher than those obtained with argon gas (30-50% faster). It is also used for welding beer barrels and tube to tube stainless steel. A content of up to 5% hydrogen is sometimes preferred for manual welding, to obtain welds with better appearance.

ARGON – NITROGEN

ARGON - HELIUM - NITROGEN

These gases are used for TIG welding of duplex stainless steels. The function of nitrogen is to help maintain the relationship between austenite and ferrite in these steels.

Table 44 indicates gas selection considerations.

Denomination	Characteristics
SANARC AS	It provides ease of arc start and good control of molten pool and penetration.
SANARC AQ	It has a purity superior to the SANARC AS and may be used to reduce pores and with radiographic control.
SANARC H30	Due to its helium content, it provides higher heat input and faster welding speed, which has special applications for automation and for thick materials, especially in applications in which Ar-H_2 mixtures may not be used.
SANARC HR	It is used with high rates in the manufacture of austenitic stainless steel tanks and tubes.
SANARC EASY 4	It is used in austenitic stainless steel manual welding to improve the bead appearance and increase the welding spedd in relation to SANARC AS.
SANARC EASY 5 SANARC FLASH 3	It is used in the manufacture of tanks and pipes in automatic welding, to increase the welding speed.
SANARC T1-T3	It is used in the joint of duplex stainless steels. The nitrogen content stabilises the austenite.

Table 44. Selection of shielding gases for TIG welding of stainless steels.

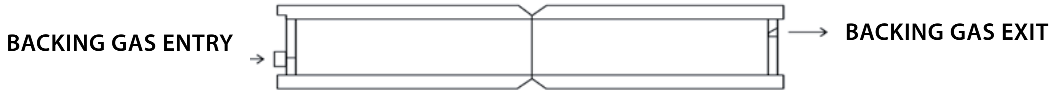
12.10 BACKING GAS

When welding, especially pipes, the inner part is unprotected, and this frequently causes defects that are not acceptable for the product the pipes contain. To avoid this, another gas is incorporated inside the pipe, with the precaution of not exerting a strong pressure that may affect the weld pool. (Fig. 117)

The gases and mixtures used are Ar, N_2, Ar- He, Ar-He-N_2, Sanarc F-5, F-10 (N_2-5/10%H_2), Sanarc EASY 5 (Ar-5%H_2), Sanarc FLASH 4 (Ar-10%H_2). Mixtures containing H_2 should only be used with austenitic stainless steels since they may cause embrittlement in the other types.

SANARC AS (Ar 99.996%)/ AQ (Ar 99.9990%)

SANARC AS and AQ are the most commonly used backing gases. Their mainly used to weld stainless steels, carbon, aluminium, titanium and their alloys. They may not be the most appropriate in some applications because they have a relative density to air of 1.38 and when the pipes to be welded have high diameter, it may eliminate the air of the lower parts, but may not adequately dislodge the air of the upper parts, causing potential oxidation and reduction in corrosion resistance by the heat of welding. To avoid this, the gas inlet and outlet may be conveniently placed, and/or mixtures of Ar with He and/or H_2 may be used with a relative density with the air close to 1.0 (see Table 45 Page179).



SANARC F5 / F10

These nitrogen mixtures with 5 and 10% hydrogen have a density of 0.87 and 0.90 in relation to the air; therefore they may provide better protection apart from a reducing atmosphere. Their main application is welding austenitic stainless steels with the exception of those stabilised.

SANARC EASY 5 / SANARC FLASH 3 / SANARC FLASH 4

These argon and hydrogen mixtures are used in welding austenitic stainless steels, with the advantage that they can be used as shielding gas and backing gas, with the consequent saving in the use of cylinders and avoiding the problems that nitrogen may cause in some applications.

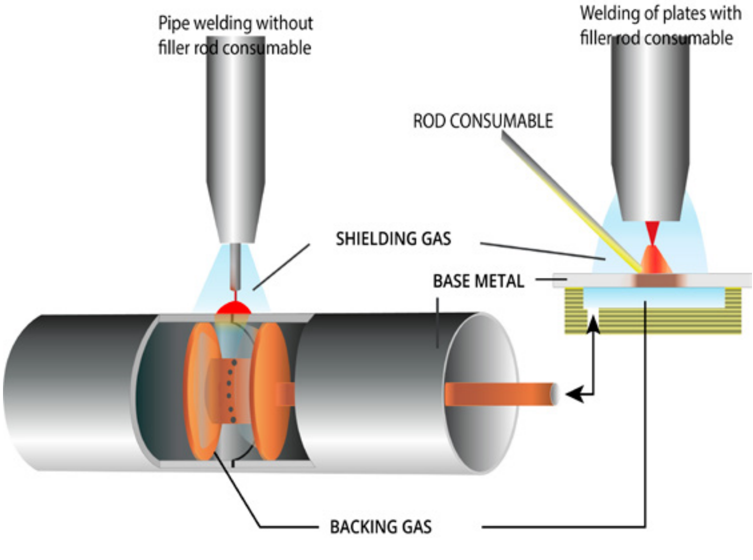


Fig. 117. - Devices to use the backing gas.

OTHER GASES AND MIXTURES

SANARC NS (N_2 99,996%) /

NQ (N_2 99,9990%)

Nitrogen, Sanarc NS and NQ, is more economical than argon gas and as pure. Its advantage is its relative density to air of 0.96, lower than that of argon at 1.38, which allows it to dislodge air also from the upper part of the pipe. The disadvantages are that it should not be used with stainless steels stabilised with Ti to avoid the formation of nitrides, the required quality should be used to control impurities such as H2O and it may affect the ferrite-austenite balance.

SANARC H30 (Ar 30%He)

This inert mixture has a relative air density very close to 1.01, which allows it to dislodge the air also from the upper part of the pipe, also ensuring a root bead free from oxidation in high diameter pipes. The disadvantage is its higher cost, due to its He content.

SANARC HN (Ar-He-N_2)

These Ar-He-N_2 mixtures should be taken into account in applications where mixture with a relative density close to that of air is needed and has an N_2 content that helps the ferrite-austenite balance that may be necessary in welding duplex steels. It should not be used with stabilised steels to avoid the formation of carbides. The disadvantage is its higher cost, due to the He content..

Metal	Backing gas
Austenitic stainless steels	SANARC AS/AQ
	SANARC N2/NQ
	SANARC F5 - SANARC F10 (Except for stabilised with Ti)
	SANARC EASY 5 SANARC FLASH 4
Duplex stainless steels	SANARC AS/AQ
	SANARC H30
	SANARC NS/NQ
	SANARC HN Ar-30%He-1/3%N_2
Nickel and alloys	SANARC AS/FQ
	SANARC F5 - SANARC F10 (Except for stabilised with Ti)
	SANARC EASY 5 SANARC FLASH 4

12.10.1 Importance of impurity control in backing gas

Section 12.8 Selecting the purity of shielding gases, emphasises the importance of that selection. One the gas or the mixture of the appropriate shielding gas has been chosen, it is assumed that impurities such as O_2, H_2O and N_2 in certain applications are already limited, but there are applications in which the control of impurities is critical and the content should be revised in terms of:

- The product sheet, or supplier's certificate of gas or mixture.
- The application directly, after having passed through the gas circuit.

A typical case in TIG stainless steel welding is reviewing the oxygen content of the backing gas inside the pipe itself before welding starts. There are various studies of welding procedures, where the oxygen content in ppm is compared with the expected discolourations in the areas next to the internal bead

As an example:

TIG orbital welding of austenitic stainless steel 1.4435 (316L), argon backing gas; heat input 0.2-0.3 KJ/mm

Discolouration helps to identify whether the backing gas has correctly eliminated the air inside the pipeline and has reduced the oxygen concentration enough so that during welding no oxide layer has been formed which may affect corrosion resistance in the bead nor in the heat affected area, which has been subjected to temperatures between 300 and 1000ºC:

With concentrations of $O_2 \leq 20$ ppm the discolouration will be yellow.

- *The oxide layer is mainly formed by chromium oxide Cr_2O_3*
- *Approximate thickness of 25-30 nm.*
- *With corrosion resistance similar to that of welded base metal tube.*

With $O_2 > 30$ ppm concentrations, the discolouration will be brown or blue.

- *The oxide layer is mainly formed by Iron oxide Fe_2O_3.*
- *Approximate thickness of 75-150 nm.*
- *With corrosion resistance lower than that of welded base metal tube.*

To avoid the formation of the iron oxide layer during welding that may affect corrosion resistance, the following steps should be taken:

- Use the required edge preparation.
- Avoid contamination.
- The welder producing manual welding should have the required skills to produce the required quality, or use orbital TIG.
- Ensure that oxygen concentration is lower than 20 ppm by measuring before welding.

12.10.2 Relative densities to air of gases and mixtures

In addition to their composition and impurities, the relative density to air of the gases and mixtures used as backing gas should be taken into account in order to appropriately locate the inlet and outlet holes and to encourage the removal of air from the pipe or piece to be shielded.

GAS/MIXTURE	RELATIVE DENSITY TO AIR
Air	1
Argon	1.38
Helium	0.14
Nitrogen	0.96
N_2-10%H_2	0.87
SANARC H30 (Ar-30%He)	1.01

Table 45. Relative densities to air of gases and mixtures.

12.11 TRAILING SHIELD GAS

High speed welding, especially in automatic welding, results in the weld bead leaving the area protected by gas, before it has cooled enough so that it is not oxidised by the atmosphere.

Gas is released in these applications, generally Ar, behind the torch and with a flow rate that does not interfere with the shielding gas.

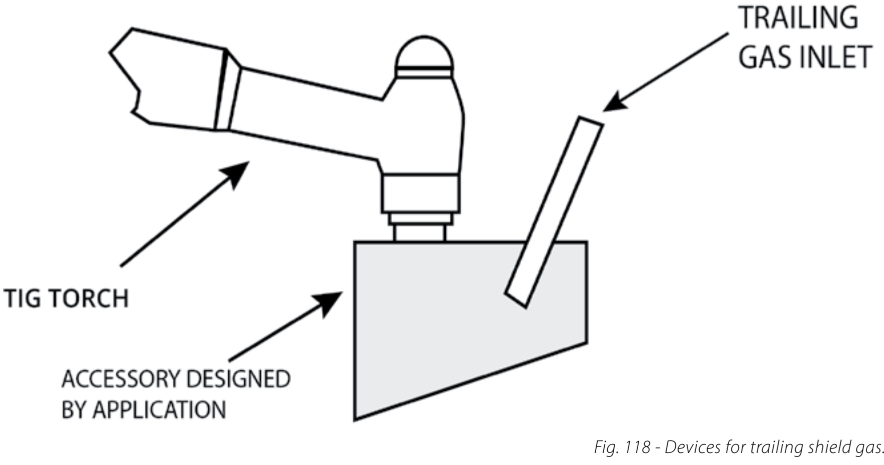


Fig. 118 - Devices for trailing shield gas.

12.12 SHIELDING GASES IN MIG/MAG WELDING

MIXTURES FOR SPRAY ARC

$Ar-O_2$ | $Ar-CO_2$

Although the use of pure gases is often essential in welding non-ferrous metals, they do not always provide the most appropriate characteristics for welding ferrous metals. The use of argon as shielding gas when welding carbon and stainless steels tends to throw the molten wire out of the weld pool. The transfer of metal tends to be erratic and with spatters. The use of argon-helium mixtures does not improve the transfer. The addition of oxygen or CO_2 to argon stabilises the arc, resulting in better transfer and decrease of spatters. At the same time, these additions change the cross section of the bead and result in better fluidity along the weld edges. Undercuts are reduced or eliminated with the change in the bead section and porosity is often reduced.

The amount of oxygen or CO_2 required to produce a significant change in arc stability or in metal transfer is quite small, 0.5% of oxygen will be enough. However, additions of 1 to 5% of oxygen and of 3 to 10% of CO_2 are more common. In the case of stainless steel oxygen is limited between 1-3% and CO_2 to 2.5%. These are also used for pulsed arc and short arc welding..

MIXTURES FOR SHORT ARC

$Ar-CO_2$ | $Ar-CO_2-H_2$ | $Ar-He-O_2$ |
$Ar-He-CO_2$ | $He-Ar-CO_2$ |
$Ar-He-CO_2-H_2$

Standard mixtures of $Ar-CO_2$ (12 a 15% CO_2) are not used for welding stainless steel, because increase the carbon content of the welded metal and reduce its corrosion resistance, especially in multi-pass welding. Therefore, less active mixtures with limited CO_2 content are used, such as:

98% Ar - 2% CO_2

97% Ar - 2% CO_2 - 1% H_2

69% Ar - 30% He - 1% O_2

90% He - 7.5% Ar - 2.5% CO_2

30% He - 0.7% CO_2 - Ar (rest)

65.5% Ar - 32% He - 2.5% CO_2 - 1% H_2

83% Ar - 15% He - 2% CO_2

With these mixtures, both helium and CO_2 increase the arc energy a given current. CO_2 also improves the arc stability. As a result, better adherence and weld bead may be achieved while maintaining a low carbon level from the CO_2.

The above mixtures are used for welding with solid wire or metal cored, for welding with flux cored wire, the most used gases are CO_2 or SANARC 20 (Ar-20% CO_2) mixture.

Denomination	Characteristics
SANARC X1-X2-X3	Mixtures of $Ar-O_2$ are used with alloys where it is necessary to maintain a low carbon content, improve the fluidity of the weld pool and reduce undercuts.
SANARC 2	Most commonly used mixture, with a CO_2 content of 2% to avoid excessive carbon intake and to weld stainless steels with low carbon content.
SANARC PERFECT 2	Suitable for welding austenitic stainless steels and austenitic-ferritic stainless steels (duplex), due to the nitrogen content to stabilise austenite.
SANARC FLASH 2	It provides a good bead appearance due to the hydrogen content and therefore it should only be used in welding austenitic stainless steels. This mixture improves the bead appearance in relation to the of $Ar-CO_2$ mixtures
SANARC HC15-HL15 SANARC PERFECT 3	Depending on the helium content, they provide higher penetration and higher fluidity to the pool. They are suitable for welding all types of stainless steels.
SANARC HRC	It combines the advantages of hydrogen and helium, producing excellent bead appearance. Due to its hydrogen content, it is only suitable for welding austenitic stainless steels.
SANARC 20	Suitable mixture for welding with flux cored wires. The instructions of the wire manufacturer should be complied with.

Table 46. Selection of shielding gases for MIG / MAG stainless steels welding.

12.13 SHIELDING GASES IN PLASMA WELDING

Two gases are used, the plasma gas and the shielding gas. Both gases may not be inert, as long as they do not affect the properties of the electrode and the welded metal.

For welding at low intensities (<100 A), argon is preferred as plasma gas because it has a low ionisation potential that ensures a correct initial and pilot arc. Considering the pilot arc is only used to maintain ionisation, the current of the pilot arc is not critical and may be set for a wide range of operating conditions. The recommended gas flow rate for the plasma or orifice gas is usually less than 2 L/min and the pilot arc current is generally set at 5 amperes. Table 47 shows the shielding gases for low current welding.

For high intensities (> 100 A), the plasma and shielding gases are usually the same. Table 48.

Although argon is adequate as plasma gas and shielding gas for the welding of all metals, it may not necessarily produce the optimum welding results. As in the TIG process, additions of hydrogen to argon produce a hotter arc and better heat transfer to the base metal. In this way, higher welding speeds may be obtained for a given current. The amount of hydrogen that may be used is limited, since excessive additions tend to cause pores or cracking in the bead.

The addition of helium to argon produces a hotter arc for a given current. The minimum amount of helium so that a change in heat may be seen should be at least 25-30%. Mixtures containing 75% helium behave in an analogous way to pure helium. Argon-helium mixtures containing between 50 to 75% helium are used for the KEYHOLE procedure in titanium high thickness welding high titanium materials and for all metals, when wider heat model is desired.

The shielding gas can be argon or argon-hydrogen mixture or a mixture of argon-helium, depending on the welding application.

The flow rates of the shielding gas are usually between 10 and 15 L/min for applications with low current; for high current, the flows will be between 15 and 30 L/min.

Thickness mm	Keyhole procedure	Standard procedure
Inferior to 1.5	Not recommended	SANARC AS/AQ SANARC HQ SANARC EASY 4 SANARC EASY 5
Superior to 1.5	SANARC AS/AQ SANARC H70 SANARC EASY 4 SANARC EASY 5	SANARC AS/AQ SANARC HQ SANARC EASY 4 SANARC EASY 5

Table 47. Gases for plasma welding with low current. The plasma gas is argon in all cases

Thickness mm	Keyhole procedure	Standard procedure
Inferior to 3.0	SANARC AS/Q1 SANARC EASY 4 SANARC EASY 5	SANARC AS/AQ
Superior to 3.0		SANARC H70

Table 48. Gases for plasma welding with high current. For plasma and shielding gases.

12.14 SHIELDING AND CUTTING GASES IN PLASMA ARC CUTTING

Depending on the technology of the cutting equipment used (single gas, two gases, water jet, oxygen and nitrogen), the choice of gas composition and its quality are of great importance both from the point of view of cutting quality as from the economic point of view.

Always be careful with the regulator, hoses (gas hoses should be used) and other gas conduits to maintain the required quality

Thickness mm	Type of cutting		Cutting process	Plasma gas	Shielding gas
	Manual	Automatic			
1.0-50	x	x	Standard	Air SANARC NS	
10-150		x	Standard	Air SANARC NS SANCUT R35+N_2	
1-50	x	x	Dual	Air SANARC NS SANCUT R35	Air Air SANARC NS
0.5-50		x	High definition	SANARC NS SANARC F5 SANARC EASY 5 SANCUT R35	Air SANARC NS
2-70		x	Underwater Water injection	SANARC NS	

12.15 GASES IN PLASMA GOUGING

This application uses plasma cutting equipment, which require special consumables for the torch.

Cutting gas	Shielding gas
SANCUT R35	SANARC NS

12.16 GASES IN CO_2 LASER CUTTING

12.16.1 Resonator gases

He, N_2 and CO_2 supplied in independent cylinders or a mixture of the three gases are required for the resonator. These will depend on the laser.

The flows recommended by the laser manufacturers are around:

CO_2	1.5 L/h
N_2	6.0 L/h
He	18.0 L/h

The supply is usually from cylinders with the following capacity:

CO_2	28 kg (15 m^3 approx.)
N_2	9.4 m^3
He	9.1 m^3

Approximate cylinders consumption is 1 bottle every 6 months of CO_2, 1 of N_2 every two months and 1-2 of He every month. There is equipment on the market which uses a single cylinder, with duration of one year and is located within the equipment.

Purity for the resonator gases is essential, to obtain quality cutting and not to damage the optics of the laser. The purity generally required for most laser suppliers is:

CO_2	- 48	(99.998%)
N_2	- 50	(99.9990%)
He	- 50	(99.9990%)

SUPPLY SYSTEM FOR RESONATOR GASES:

He - 50 | N_2 - 50 | CO_2 - 48

- Single or double panel for supply in 1 + 1 cylinders.
- Pipe installation of stainless steel AISI 316L of 8/6 mm diameter.
- Workstation panel.

Fig. 119 - Double panels 1+1 cylinders and workstation of He-50; N_2-50; CO_2-48. COURTESY OF NIPPON GASES

12.16.2 Assist gas

Similarly to resonator gases, nitrogen purity as the assist gas in cutting at high pressure (30 bar) requires the instructions supplied by the equipment manufacturer to be followed. The following general rules may apply:

- For thin materials, up to 4-6 mm (depending on the power of the equipment) SANARC NS (N_2 99.996%) may be used, although with SANARC NQ (N_2 99.999%), better quality may be obtained.
- For thicker materials, use SANARC NQ, if cutting with no discolouration is required.
- When nitrogen is the assist gas it is used to guide the beam, so the use of SANARC NQ is recommended.

The flows will depend on the laser, the thickness to be cut, whether the cut is made with high (normal) or with low pressure and the nozzle diameter.

Cutting with low pressure up to 6 bar with O_2 and N_2		**Cutting with high pressure at 22 bar in nozzle with N_2**	
Pressure bar	**Consumption L/h**	**Pressure bar**	**Consumption L/h**
1	520	6	6780
2	1040	8	9040
3	1560	10	11300
4	2080	12	13560
5	2600	14	15820
6	3120	20	22600

Table 49. Approximate flow rates used in CO_2 laser cutting.

ASSIST GASES: N_2 - NS/NQ

The methods used to supply assist gases will depend above all on the average and peak consumption, on the available space and on the safety conditions. The most common supply methods are:

- Bundles.
- Starcyl.
- Microbulk
- Liquid tank.

The main components of an assist gases installation are:

- Simple manifold 1 bundle with heater.
- Double manifold 1+1 bundles with heater.
- Starcyl panel and back up with simple manifold 1 blundle.
- Microbulk panel and back up with simple manifold 1 blundle.
- Liquid tank.
- Tank regulation panel.
- Tapping points or workstations.

Optional:

- Centralised alarm panel with pressure switches.
- Stations of automatic change over.

Pipe installation

Stainless steel pipe of the needed diameter to produce the pressures and flows required by the application and according to the specifications of the laser manufacturers. If welding stainless steel pipe is required, it should use the TIG process with Argon S1 as the backing gas, so that it does not generate particles that might interfere with the correct operation of the laser, or reduce the life of the components.

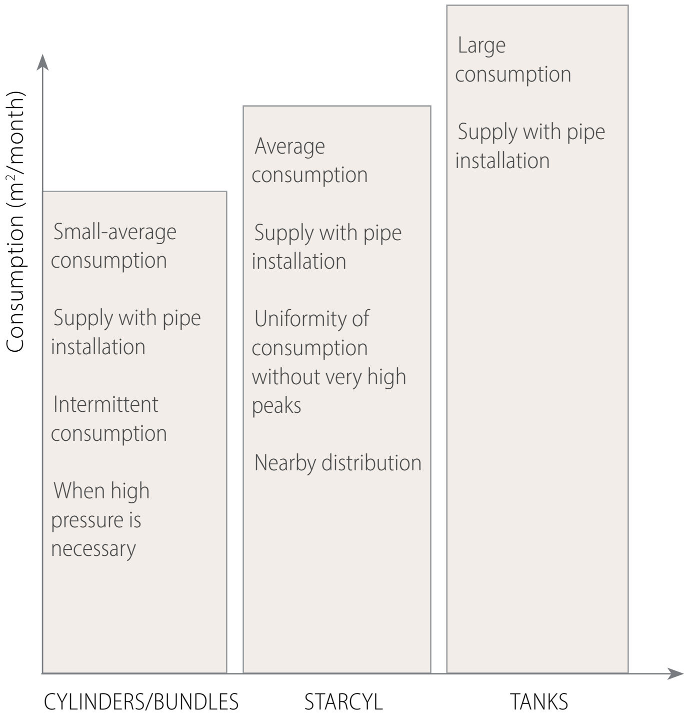


Fig. 120 - Supply system of assist gases according of consumption

Fig. 121 - Supply of assist gas. COURTESY OF NIPPON GASES

12.16.3 Control panels, manifolds and pipe installation for gas supplies

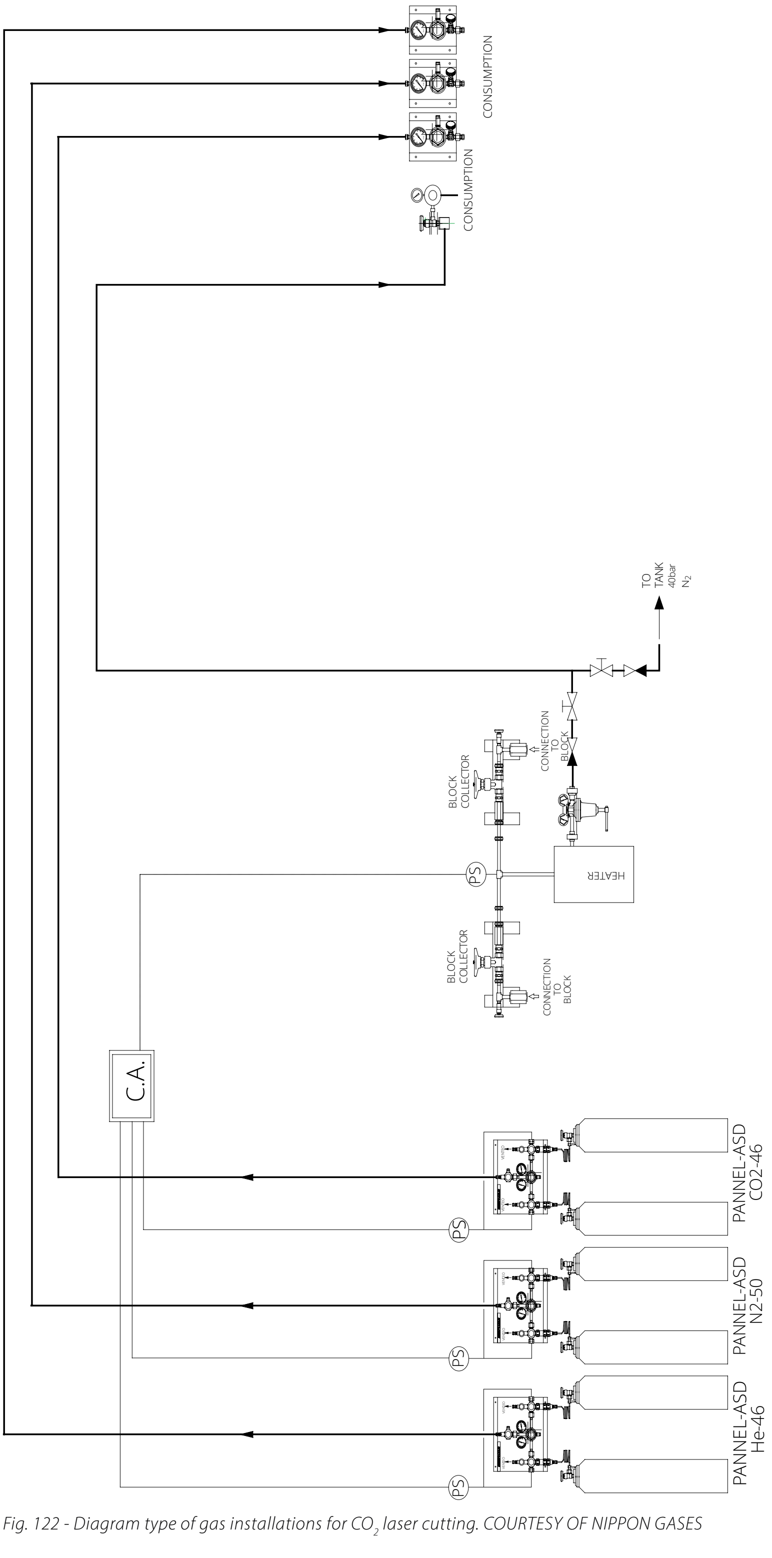


Fig. 122 - Diagram type of gas installations for CO_2 laser cutting. COURTESY OF NIPPON GASES

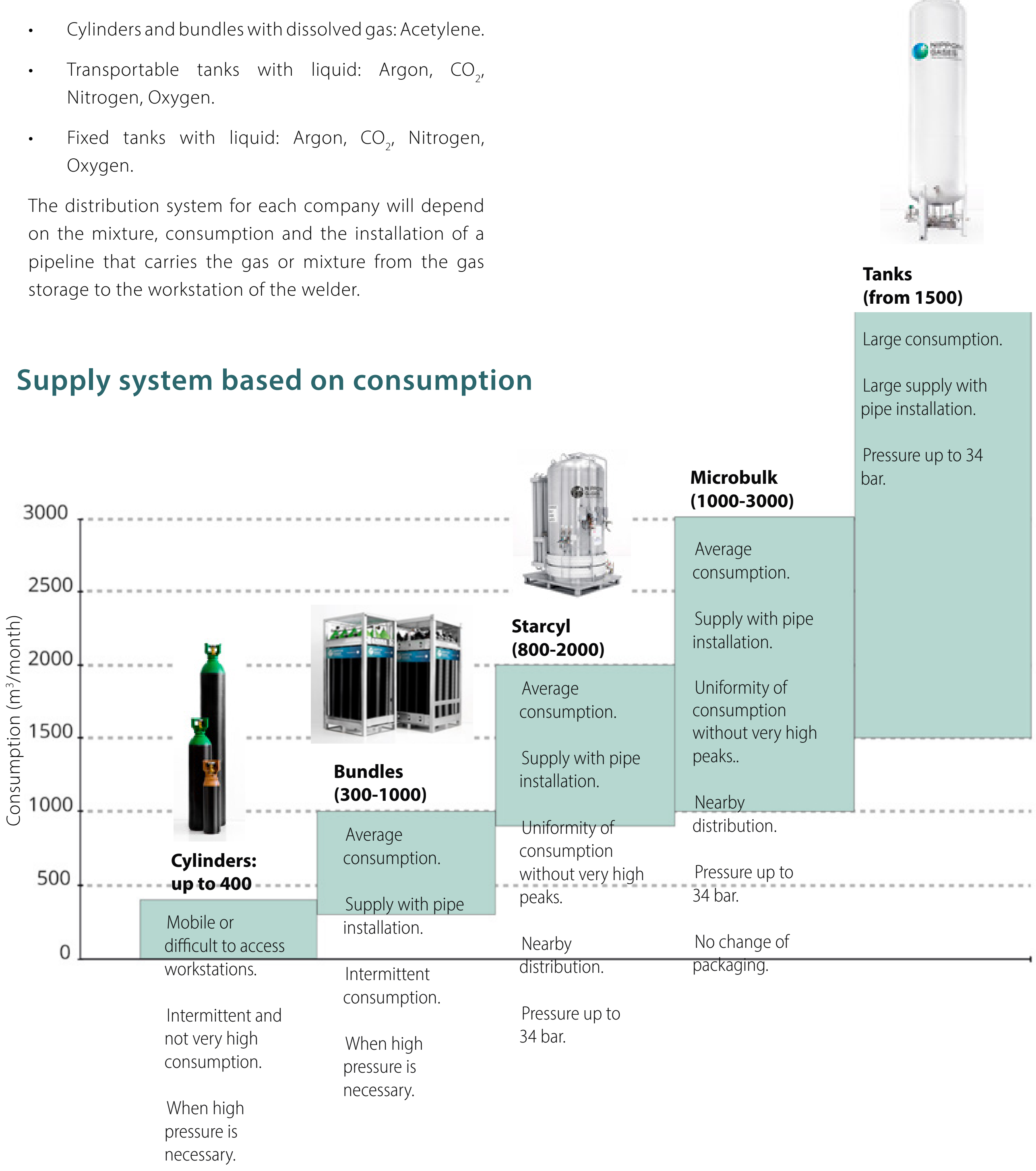
12.17 GAS SUPPLY SYSTEM

The shielding gas may be supplied in:

- Cylinders and bundles: Argon, Helium, CO_2, Nitrogen, Hydrogen, Oxygen and their mixtures.
- Cylinders and bundles with dissolved gas: Acetylene.
- Transportable tanks with liquid: Argon, CO_2, Nitrogen, Oxygen.
- Fixed tanks with liquid: Argon, CO_2, Nitrogen, Oxygen.

The distribution system for each company will depend on the mixture, consumption and the installation of a pipeline that carries the gas or mixture from the gas storage to the workstation of the welder.

Supply system based on consumption



Cylinders: up to 400

Mobile or difficult to access workstations.

Intermittent and not very high consumption.

When high pressure is necessary.

Bundles (300-1000)

Average consumption.

Supply with pipe installation.

Intermittent consumption.

When high pressure is necessary.

Starcyl (800-2000)

Average consumption.

Supply with pipe installation.

Uniformity of consumption without very high peaks.

Nearby distribution.

Pressure up to 34 bar.

Microbulk (1000-3000)

Average consumption.

Supply with pipe installation.

Uniformity of consumption without very high peaks..

Nearby distribution.

Pressure up to 34 bar.

No change of packaging.

Tanks (from 1500)

Large consumption.

Large supply with pipe installation.

Pressure up to 34 bar.

12.18 SELECTION OF SUPPLY SYSTEM FOR SHIELDING GASES

Once a gas or gas mixture has been selected, it is necessary to consider the most appropriate supply solution and the distribution system to get the gas to the point of consumption.

Type of supply

The most important characteristics that define the type of supply are:

- Required gas quality.
- Easy container handling.
- Consumption. Taking into account both average and peak consumption
- Required pressure and flow.
- Safety conditions.
- Economy.
- Uniformity of consumption.
- Guarantee of continuous supply.
- Accessibility to the point of consumption.
- Fixed or mobile workstations.
- Possibility of channelling the supply.
- Proximity of gas supply.

Some of the above mentioned characteristics may alone determine the preferred container

Cylinders

Their most important characteristics are:

- Easy to transport
- Mobile or hard-to-reach workstations
- Intermittent and not very high consumption
- Easy to find a nearby distribution point
- Occupy little space close to the workstation.
- Deliver high pressure when necessary.

Cylinders with pure gases or gas mixtures in gas phase

As gases have a relatively low density, the volume of gas may be reduced at atmospheric pressure by compressing the gas to a high pressure within a cylinder. The cylinder and the valve should be designed, manufactured and identified to withstand high pressure and to comply with the requirements set forth by the official regulations of each country.

The more commonly used capacities, pressures and contents are:

Gases/ Mixtures	Cylinders with gases or mixtures of gases in gas phase - Argon, Helium and welding and cutting gas mixtures with components (argon, helium, CO2, oxygen, hydrogen, nitrogen)					
	Type	Dimensions		Max pressure kg/cm^2	Capacity (approx.) m^3	Weight (approx.) kg
		Length mm	Ø mm			
Argon and mixtures, helium, oxygen, nitrogen, hydrogen	5L	570	145	200	1	7
	20L	960	145	200	4	32
	30L	1240	230	300*	9	70
	50L	1480	230	200	10	85
	50L	1480	230	300*	15	95
CO_2	50L	1680	330		37.5	105

*300 bar cylinders for argon and mixtures, helium and nitrogen.

Table 50. Gas cylinder capacities, pressures and contents.

Bundles

These bundles consist of a number of 12, 16 or 28 cylinders inside a frame, with all their outlets joined by hoses in order to produce a single outlet. The most important characteristics to choose for these containers are:

- Average consumption.
- Centralised supplies with canalisation.
- Intermittent consumption.
- Deliver high pressure when necessary.

Gases/ Mixtures	Bundles of cylinders with gases or gas mixtures in the gas phase - Argon, Helium and welding and cutting gas mixtures with components (argon, helium, CO_2, oxygen, hydrogen, nitrogen)							
	Number of cylinders	Dimensions			Max pressure kg/cm^2	Capacity (approx.)		Weight (approx.) kg
		Length mm	Width mm	Height mm		m^3	kg	
Argon and mixtures, helium, oxygen, nitrogen, hydrogen	12	1050	820	1940	200	120		1395
	12	1050	820	1940	300*	180		1520
	28	1790	1100	1800	200	280		2950
CO_2	12	1050	820	1940			450	1350

Table 51. Gas cylinder capacities, pressures and contents

*Bundles with cylinders 300 bar for argon and mixtures, helium and nitrogen

Mobile tanks with liquid content

Mobile tanks with contents lower than 500 kg, can transport more gas. The most important characteristics of these containers are:

- Average to high consumption but lower than the consumption required for a fixed tank.
- Uniformity of consumption with no high consumption peaks.
- Important specific consumption.
- Close to distribution area.

Can supply liquid and gas - Argon, Nitrogen, Oxygen -												
Type	Dimensions				Capacity				Empty weight kg	Full weight		
	Ø mm	Width mm	Length mm	Height mm	Liquid L	O_2 m^3	N_2 m^3	Ar m^3		O_2 kg	N_2 kg	Ar kg
I	508			1600	169	125	100	120	115	308	251	350
II		1100	1200	1400	666	480	385	470	560	1274	1066	1437
III		1420	1120	1765	630	479	314	425	712	1355	1085	1425

Table 52. Mobile tanks with liquid. Gas capacities, pressures and contents.

Fixed tanks

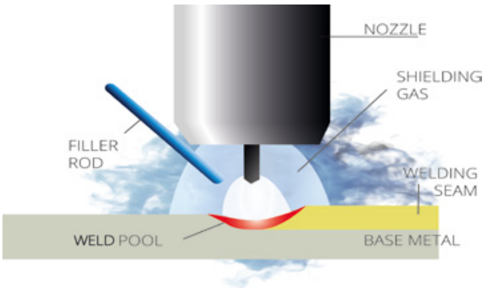
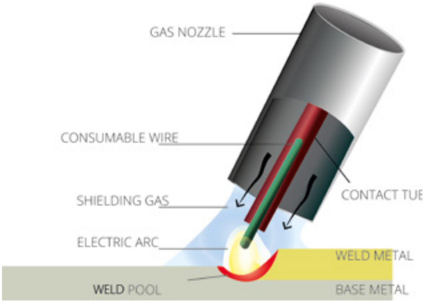
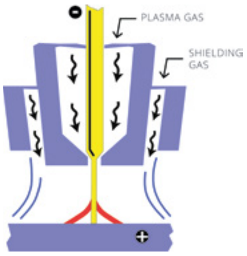
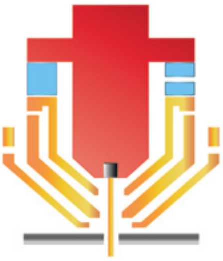
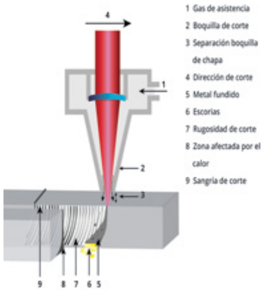
These hold over 2000 litres, they are filled from tank truck and have the appropriate gasifier attached to supply the required flow. The most important characteristics to choose this supply method are:

- Large consumption.
- Centralised supply with pide installation.

Tank (Can supply liquid and gas)	
Gases	Most common capacities
Oxygen, Nitrogen y Argon	3000, 5000, 12000 litres
CO_2	3600 litres

Table 53. Fixed tanks with liquid. Often used capacities.

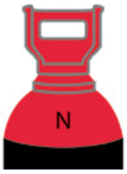
12.19 SHIELDING GASES SELECTION AND APPLICATIONS

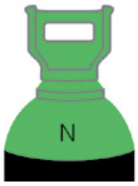
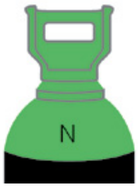
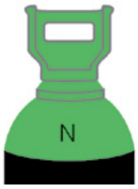
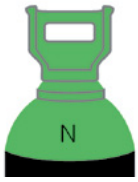
Welding procedure		**STAINLESS STEELS**	**DUPLEX STAINLESS STEEL**
TIG 		SANARC AS SANARC AQ SANARC EASY 4 SANARC EASY 5 SANARC FLASH 3 SANARC HR	SANARC T1/T3 SANARC HN
MIG 		SANARC 2 SANARC PERFECT 2 SANARC FLASH 2 SANARC HRC SANARC HC7 SANARC HC15 SANARC PERFECT 3 SANARC X1/X3	SANARC PERFECT 2
PLASMA WELDING 		SANARC AS SANARC EASY 4 SANARC EASY 5 SANARC FLASH 3 SANARC H30/H50/H70	
PLASMA CUTTING 		SANARC NS SANARC F5 SANCUT R35 SANCUT RN	
		SANARC NS	
LASER CUTTING 	RESONATOR GAS (laser CO_2)	HELIUM 50 NITROGEN 50 CO_2 48	
	ASSIST GAS	SANARC NS/NQ	

Main gases, identification and their applications

The following table (Table 54) indicates:

- The identification colour for each cylinder bottle of gas.
- Its valve connection.
- In parentheses the classification of the gas or mixture, according to UNE - EN ISO 14175.
- Main applications.

 SANARC AS (I1) SANARC AQ (I1) M21.7 x 1.814 RIGHT	TIG PLASMA MIG	• TIG welding for carbon and low alloy stainless steels, aluminium, copper and its alloys. Pipes, heat exchangers, distillation columns, cold boxes, armature welding, storage tanks, stainless steel ware, valve reloading and saw teeth. As backing gas in welding carbon steels where SANARC F5 (N_2-5% H_2) may cause cracks. • MIG welding of aluminium, copper, nickel and their alloys: • Aluminium: tanks, semi-trailers, fuel tanks, pressurised air tanks, irrigation pipes. Copper and bronzes: reload of valve electrode jaws, shafts, propellers and surfaces subject to frictional wear. • MIG brazing of galvanised steels. • The selection of the appropriate purity of the Ar will depend on the application and metal to be welded.
 SANARC T1 (N2) SANARC T3 (N2) M21.7 x 1.814 RIGHT	TIG	• TIG welding of duplex stainless steels. The nitrogen content helps stabilise austenite. • Pipes, heat exchangers.
 SANARC EASY 4  SANARC EASY 5 SANARC FLASH 3/4 M21.7 x 1.814 LEFT	TIG, PLASMA WELDING	• SANARC EASY 4: may replace argon with manual welding of austenitic stainless steels where better bead appearance, more fluid molten pool and higher welding rate is required. Manufacture of bellows and filters, boilers, mixers, exhibitors • SANARC EASY 5, SANARC FLASH 3, SANARC FLASH 4: main application is longitudinal for manufacturing pipes. • SANARC EASY 5: mainly applied in plasma welding stainless steel.
 SANARC HR (R1) M21,7 x 1,814 LEFT	TIG, PLASMA WELDING	• Automatic welding of austenitic stainless steels, preferably materials thicker than 2 mm. • Good bead appearance and high welding rate. Manufacture of tanks, boilers, mixers.

 SANARC F5 (N5) M21.7 x 1.814 LEFT	TIG (backing gas) PLASMA CUTTING	• Backing gas for manual and automatic TIG welding of stainless steel pipe. • Longitudinal TIG and Plasma automatic welding of stainless steel ferrules made in benches. This equipment has copper backing with gas outlet, in addition to fastening and forming the sheets, to protect the weld pool from underneath. • High definition plasma cutting of stainless steels for thin materials. • As backing gas in general stainless steel boiler making, manufacturing of equipment for the food industry.
 SANARC 20 (M21) M21.7 x 1.814 RIGHT	MAG	• Welding with tubular wires made of carbon steel, low alloy and stainless steel. • Welding with solid wire carbon and low alloy steels in places where metal transfer is required by short arc or thick materials where heat input and deeper penetration than those achieved with mixtures of Argon with lower CO_2 contents are needed. • Boiler making with thick materials, shipyards, construction of public works machinery, equipment for the mining industry, beams, rails, cranes.
 SANARC 2 (M12) M21.7 x 1.814 RIGHT	MAG	• It is the most commonly used mixture in MAG welding of austenitic stainless steels, where an oxidation level lower than that of Ar-O_2 mixtures is required. • The bead surface is smooth, requiring little finishing work since scarcely any slag is formed. Due to the low CO_2 content, the potential carbon intake is minimal. Construction of tanks, autoclaves, silos, trays, furnaces, tanks, chimneys, reactors. • **Welding with low slag content**: Welding carbon steels with SANARC 2 gas and NIPPON M-GV thread achieves a cord with minimum slag content. This is the main application when the piece has to be painted after welding.
 SANARC PERFECT 2 (Z) M21.7 x 1.814 RIGHT	MAG	• Mixture of Ar-CO_x-N_2 for austenitic stainless steels and duplex welding where nitrogen helps to stabilise austenite and which produces beads with very good appearance, depending on the weldability of the equipment. In applications where a lower level of oxidation than that of the Ar-O_2 mixture is required. Due to the low CO_2 content, the potential carbon intake is minimal. • Construction of tanks, autoclaves, silos, trays, ovens, tanks, chimneys, reactors.
 SANARC X1 (M13) SANARC X3 (M13) M21.7 x 1.814 RIGHT	MAG	• Welding of stainless steels, especially welding with spray arc transfer. • Stainless boiler making in general, manufacture of equipment for the food industry (dairy, meat, wine, canning, freezing, etc.), tanks, containers, fire extinguishers, stainless steel tanks, repair workshops.

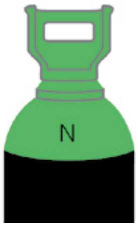
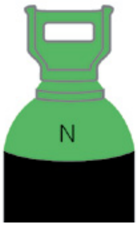
 SANARC HRC (M11) M21.7 x 1.814 LEFT	MAG	• Joints in austenitic stainless steels when excellent bead appearance is required. Welding with short, long and pulsed arc. • Stainless boiler making in general, manufacture of equipment for the food industry.
 SANARC HC15 (M12) SANARC PERFECT 3 (M12) M21.7 x 1.814 RIGHT	MAG	• Joints in stainless steels when the stability of the argon arc and the deeper penetration of helium is required in the same gas. Welding with short, long and pulsed arc. • Manufacture of equipment for the chemical, petrochemical, and food Industry.
 SANARC NS (N1) SANARC NQ (N1) M21.7 x 1.814 RIGHT	PLASMA CUTTING, LASER CO_2 CUTTING	• Dual plasma and high definition plasma cutting of stainless and aluminium steels. As assist gas in stainless steel, aluminium and galvanised steel CO_2 laser cutting. The purity of nitrogen influences the quality and brightness of the cutting. Low quality nitrogen may produce discolourations. In some laser equipment it is also used as a gas in the beam guide.
 SANCUT R35 (R2) M21.7 x 1.814 LEFT	PLASMA CUTTING	• High definition plasma cutting of stainless steels for thick materials.

Table 54. Colour of the gas cylinder bottle, its valve connection, classification according to UNE-EN ISO 14175 and main applications

13 Professional exposure to chemical agents in stainless steel welding

The manufacture of stainless steel products using welding processes requires an evaluation of how the resulting fumes affect the workshop environment and, if necessary, implement measures to monitor and mitigate or eliminate them.

It is important to monitor welding fumes, for the following reasons:

1. The health and safety of welders and other nearby workers.
2. To comply with Law 31/1995 on Prevention of Occupational Risks (LPRL, for its acronym in Spanish), amended and updated by Law 54/2003, of December 12. The purposes of the LPRL are to promote the health and safety of workers and establishes the following general principles:
    - Prevention of professional risks.
    - Elimination or reduction of work related risks.
    - Information, consultation, balanced participation and training of workers in the area of risk prevention.
3. To increase productivity, as a result of improving working conditions.

13.1 OCCUPATIONAL EXPOSURE TO CHEMICAL AGENTS AND PROFESSIONAL EXPOSURE LIMITS

The definitions of INSHT (National Institute for Occupational Safety and Health) covering Chemical Agents, Occupational Exposure and Professional Exposure Limits are:

Chemical agent

Any element or chemical compound, pure or mixed, in its natural state or produced, used or discharged, including dumping as waste, during a work activity, whether or not intentionally manufactured and whether or not commercialised.

Occupational exposure

Exposure to a chemical pollutant (agent), at work, in which an individual may suffer from the effects of a chemical agent, which may cause possible injury (risk) to his health.

Professional exposure limits

Reference values for the evaluation and monitoring of risks inherent in the exposure, mainly by inhalation, to chemical agents in the workplace and, therefore, to protect the health of workers.

In this document, the Limits of Environmental Exposure (VLA) will be considered as Limits of Professional Exposure, also considering the Biological Limit Values (VLB®) as a complementary indicator of exposure.

Taking into account the above definitions, this information helps:

- To understand:
    1. The chemical agents in the fumes generated by welding.
    2. The influence of welding processes and their variables.
- To assess the exposure by inhalation of welding fumes to compare them with the VLA (Environmental Limit Values) pursuant to current regulations:
- Following the standard UNE EN-689 of 1996 (Atmospheres in the workplace. Guidelines for the evaluation of exposure by inhalation of chemical agents to be compared with limit values and measurement strategy).
- Compare the results with the official INSHT indexes (National Institute for Occupational Safety and Health).

In general, all companies recognise the importance of the workshop environment and the resources required to minimise the effects that production may cause, including, but not limited to, fume extraction and personal protective equipment. Also, it is advisable that the company's training plan includes the accident prevention plan and especially to remember:

- Understand which chemical agents are potentially harmful.
- The correct use of the available measures, which are often underutilised or are not updated (filters).

13.2 COMPOSITION OF FUMES, SIZE AND MAIN AREAS WHERE THEY ARE GENERATED

The chemical agents that may be present in the welding generated fumes are:

1. Very small particles, which are formed, when the vaporised metal rapidly condenses in the air. According to AWS (Characterization of Arc Welding Fume):
    - All particles within the respirable range, 0.01-1.0 microns (1 micron=10^{-3} mm).
    - The appearance of the particles is spherical or forming chains or clusters of spheres.
    - They have complex chemical composition. Few particles have a pure chemical composition.
2. Gases formed by the electrical arc, ultraviolet light and heat.

Particles are too small to be seen with the naked eye, but as a whole they form a visible plume. Although in some welding applications, that characteristic plume is not seen it may not be guaranteed that there is no chemical agent with emission values higher than those permitted. For example, in the case of TIG stainless steel or aluminium welding, even if a large amount of fume is not observed, there may be ozone emissions higher than those permitted.

The health effects associated with the chemical agents forming the fumes specifically depend on the metals and gases that are present and may be in the short term produce initial symptoms of fever or long term damage to the lungs, neurological disorders and other diseases.

The chemical agents that may be found in fumes mainly come from:

- Decomposition residues from the consumable electrode.
- Oxidation of elements present in the arc.
- Photochemical reactions.
- Decomposition of base metal coatings.

13.3 WELDING PROCESSES AND THEIR RELATION WITH THE CHEMICAL AGENTS THAT MAY BE CONTAINED IN THE FUMES

The previous section discusses the four potential sources for harmful chemical agents (metal particles and gases) contained in welding fumes.

The first three depend on the welding process and the fourth does not exist in stainless steel, because there are no coatings. It is important to review the characteristics of each process, from the point of view, of the possible generation of chemical agents.

Coated electrode (GMAW)

The stainless steel rod which provides elements such as chromium, nickel, manganese will produce particles in the fumes of metallic elements Cr (VI), nickel and manganese Mn (IV).

The coating, depending on whether it is a rutile or basic electrode, will provide higher amounts of titanium dioxide (TiO_2), silica (SiO_2) or calcium fluoride (F_2Ca).

Compared to other processes, generates low amounts of ozone, nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are generated.

MIG/MAG with solid wire and tubular metal cored without slag (GMAW)

It generates fewer fumes and does not generate non-metallic elements of silica (SiO_2), calcium fluoride (F_2Ca) as the wire has no coating.

The welding wire is protected with gas, but also produces metallic particles of chromium, nickel and manganese.

This process uses higher intensities and therefore, higher amounts of ozone and nitrogen oxides may be formed

MIG/MAG with tubular wire with slag (FCAW)

This procedure has characteristics of the coated electrode and the MIG/MAG processes, because it has internal slag forming elements and uses high intensities. It will generate high amounts of fumes and in the case of basic wires, with fluorides.

Depending on the manufacture of the tubular wire, chromium, nickel and manganese elements may be contained in the tubular wire and in the internal part in the form of powder. With the fusion and the shielding or external gas, the metallic particles will form part of the fumes released.

Analogous to the coated electrode, it will generate a low amount of ozone, nitrogen monoxide (NO) and nitrogen dioxide (NO_2).

TIG (GTAW)

This process may be carried out with or without a filler rod. When it is used with a filler rod, it is always under the shielding gas and is fed directly to the weld pool, generating a low level of metallic particles.

The generation of ozone will depend on the level of current used and the shielding gas. The most commonly used gas is argon, but mixtures of argon-helium and argon-hydrogen only for austenitic steels, may significantly reduce the ozone content.

Submerged arc (SAW)

In this process the electric arc is not visible because it jumps between the consumable rod and the metal to be welded under the flux, therefore gases such as ozone, nitrogen monoxide (NO) and nitrogen dioxide (NO_2) will not be generated.

The greatest possible contaminant of nearby air is the fluoride content that flux[2], may provide, especially in the case of a basic flux[2].

Comparing the volume of fumes, in general, tubular wire welding (FCAW) generates more fumes than coated electrode, MIG/MAG (GMAW) and TIG (GTAW).

In case of carbon steel, a large volume of fumes comes from the coating, (galvanised, aluminised, primed) but since these coatings do not exist in stainless steel, most of the smoke formation will depend on the consumable wire in the case of MIG/MAG (GMAW) and of the rod and slag formers inside the tubular wire (FCAW). It is important to select the tubular wires that generate a low amount of fumes and may weld with mixtures of argon and CO_2 instead of CO_2.

Regarding the application of stainless steel welding processes in industry, the following approximation may be given:

- The processes most commonly used in production are TIG (GTAW), MIG/MAG (GMAW) and MIG/MAG (FCAW), in 90-95% of the applications.

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[2] Author's note Appendix 3, page 258.

- Coated electrode process (SMAW) is less used in production and more in repair in situ, especially in pipes, combined with the TIG process.
- Submerged arc process is used in few companies, mainly in boiler making that use thick thickness in automatic welding.

13.4 WELDING PROCESSES VARIABLES AND ITS INFLUENCE ON THE GENERATION OF FUME

There are variables that influence the volume of fumes generated within each welding process and understanding them may help to reduce them:

Welding current. In general, the generation of fumes grows exponentially with current. This is particularly seen when welding MIG/MAG with solid wire and if by increasing the current, there is a change in the transfer from short arc to globular, or from globular to spray arc, the size of the drops varies and the speed of fume generation will increase in relation to the metal deposited.

Welding voltage. With the increases in voltage, the generation of fumes increases, there is almost a linear relationship. A mixture of argon-CO_2 or argon-CO_2-O_2 as shielding gas increases the arc length (voltage), the time in which the droplets pass from the end of the wire to the weld pool will increase. This will facilitate the oxidation and increase the volume of fumes generated.

Electrode diameter. It has low influence on the fume generation, in general small diameters generate more fumes than large diameters.

Electrode angle with respect to the metal to be welded. It has a negligible effect on fume generation.

Welding speed. By increasing the speed the generation of fumes increases.

Continuous or pulsed current. Pulsed current is commonly used to reduce the generation of fumes, considering it brings other benefits to welding stainless steel.

Shielding gas. Fume generation in MIG/MAG (GMAW) and (FCAW) processes with shielding gas tends to be higher when the CO_2 content is higher. But in case this content is reduced in the mixture, it is necessary to review the increase in ozone. In TIG and MIG/MAG processes, replacing some argon by helium, from 15 to 30%, in the case of austenitic steels; and hydrogen from 2 to 10%, reduces the ozone content and increases the welding speed.

13.5 INFORMATION TO DETERMINE THE POTENTIAL CHEMICAL AGENTS

To understand the potential chemical agents (metallic particles and gases) that fume may contain, it is necessary to know the information about the metals to be welded, welding processes, consumables, shielding gases and degreasing products that are required. It is advisable to use the following information:

STAINLESS STEELS: UNE EN 10088:2015

CONSUMABLES:

- Safety sheet of consumable electrodes.
- Product sheets of consumable electrodes.
- AWS/ASME SFA 5.4; 5.9; 5.22; 5.11; 5.14; 5.34
- UNE EN ISO 3581; 14343; 17633; 14172; 18274; 12153; 14174

SHIELDING GASES::

- Safety sheet of welding shielding gases, backing gases (backing) and cutting.
- Product sheet of welding shielding gases, backing gases (backing) and cutting.
- AWS/ASME SFA 5.32:2011 Gases and mixtures for fusion welding and allied processes.
- UNE EN ISO 14175:2009. Shielding gases for fusion welding and allied processes.

DEGREASERS

- Safety sheet.
- Product sheet.

Note: do not weld near degreasing baths and cover the containers, to avoid the generation of harmful vapours from welding heat and radiation.

13.6 POTENTIAL CHEMICAL AGENTS (PARTICLES AND GASES)

With the help of the information contained in the previous section, the welding processes, the expected photochemical reactions and the welding heat, a list of the chemical agents, particles or gases that may be potentially present in the welding fume may be obtained.

With this information, for a specific production, welding process, consumables, etc., should be selected the chemical agents that could be present.

Chromium: in the form Cr (III), Cr (VI), where the most harmful for health is Cr (VI).

Nickel: in the form NiO, NiO_2, Ni_2O_3, apart from the limits set by the VLA, it has a "Sen" note and it is considered a sensitising element.

Manganese: as MnO_2; Mn(IV), whose Environmental Limit Value (VLA-ED) in the respirable fraction was reduced from 0.2 to 0.05 mg/m^3 in 2017.

Iron: as iron oxide (III): Fe_2O_3. In stainless steel, iron is the most common element. Compared to other elements, it is only relatively little toxic, but being subject to its influence over long periods, it can be detrimental as it may cause siderosis.

GASES:

Ozone. It is generated with the electric arc, when the ultraviolet (UV) radiation (130-240 nm) affects the oxygen molecules in the vicinity of the arc. The O_2 molecule dissociates into two oxygen atoms (O) which quickly react with other oxygen molecules (O_2) from the environment to form ozone molecules (O_3).

These are very unstable and reactive, so they react quickly with other compounds present. This means that the ozone concentration in the arc environment is constantly changing, depending on the close presence of other gases and particles with which it reacts.

Nitrogen monoxide (NO) and nitrogen dioxide (NO_2): formed by the chemical reactions of N_2 and O_2 of the air at high temperatures.

- T>1200ºC $N_2+O_2 \blacktriangleright 2NO$
- T<500ºC $2NO+O_2 \blacktriangleright 2NO_2$

The shielding gas should eliminate the air (N_2+O_2) from the vicinity of the weld pool and nearby areas of the metal affected by the heat. The amounts of NO and NO_2 will depend on:

- The volume of air between the temperatures 500 and 1200ºC.
- Sampling distance of the electric arc.
- Welding procedure.
- Parameters.
- Shielding gas.

Carbon monoxide (CO). It is formed from the reactions between carbon in the metal to be welded and the consumable, shielding gas and metal deoxidizers.

Particles of fluorides and silicates from silica (SiO_2) or calcium fluoride (F_2Ca), which are provided by the external coatings (coated electrode SMAW) or as dust inside the MIG/MAG (FCAW) tubular wires or the submerged arc fluxes[2].

Gases formed from particles not eliminated from degreasing solvents during the cleaning process.

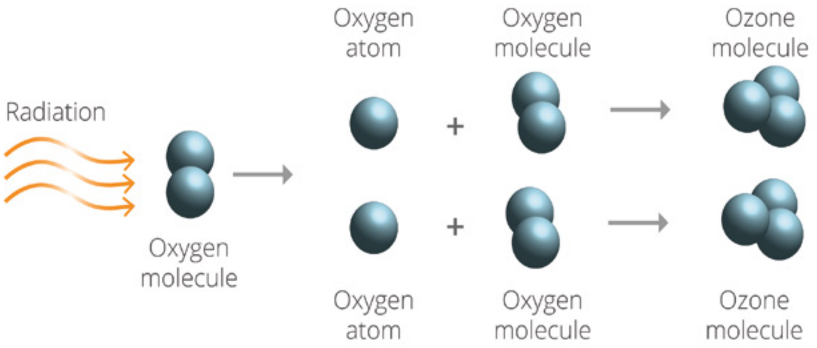

Fig. 123 - Ozone formation.

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[2] Author's note Appendix 3, page 258.

13.7 INFORMATION TO EVALUATE CHEMICAL AGENT INHALATION EXPOSURE

Once the potential chemical agents have been determined for a specific production the exposure evaluation should be carried out, based on measurements that allow the comparison of personal exposures with the applicable environmental value.

This evaluation will determine the preventive measures to be applied and review the PPE (Personal Protective Equipment).

The measurement strategy including the number of samples, the duration and the analysis of the samples, will preferably be carried out by one of the procedures described in:

UNE EN 689: 1996 (Atmospheres in the workplace. Guidelines to assess chemical agent inhalation exposure to be compared with limit values and the measurement strategy.)

INSHT (National Institute for Occupational Safety and Health). Technical notes

- NTP 7: welding. Prevention of Health Risks. Removal of harmful welding fumes.
- NTP 406: chemical contaminants: evaluation of occupational exposure (I).
- NTP 407: chemical contaminants: evaluation of occupational exposure (II).
- NTP 750: risk evaluation of chemical agent inhalation exposure. Simplified methodology.

AWS F1.1:2006 Method for sampling airborne particulates generated by welding and allied processes.

AWS F1.2: 2013 Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes.

AWS: F1.3M:2006 Sampling strategy guide for evaluating contaminants in the welding environment.

AWS: F1.5:2003 Methods for sampling and analyzing gases from welding and allied processes.

The standard UNE EN 689 and the Technical Notes of the INSHT should be sufficient, but the AWS information may also be useful.

13.8 COMPARISON OF DATA OBTAINED WITH THE PROFESSIONAL EXPOSURE LIMITS FOR CHEMICAL AGENTS IN SPAIN (LEP 2017)

The annual information issued by INSHT (National Institute of Occupational Safety and Health) should be followed to compare the data obtained with the level of permitted emissions. Professional Exposure Limits for Chemical Agents in Spain 2017 (LEP 2017), where the Professional Exposure Limits are defined as reference values for the evaluation and control of the inherent exposure risks, mainly by inhalation, to the chemical agents present in workplaces and, therefore, to protect the health of workers. The Environmental Limit Values (VLA, for its acronym in Spanish) in this document will be the Professional Exposure Limits).

When it is necessary to establish a regular measurement schedule, according to the results of the exposure assessment, these will be performed in a manner that enables comparison, indicates established trends and evaluates the effectiveness of control measures. Therefore, the parameters of the specific task that is being carried out will be set (for example, material used, type of tool, control measures, etc.) and other variables such as personal or environmental measurements.

13.9 NEWS ON THE PROFESSIONAL EXPOSURE LIMITS FOR CHEMICAL AGENTS IN SPAIN FOR 2017 (LEP 2017)

News regarding chemical agents:

1. The VLA of the following chemical agents potentially present in stainless steel have been included in Table 55, page 202:
    - Manganese. Respirable fraction.
    - Inorganic manganese compounds. Respirable fraction.
2. As from this edition, carcinogens and mutagens with an assigned limit value which were previously included in a separate table, are included in Table 55 together with the rest of the agents. The column "Notes" contains notes C1A, C1B, M1A or M1B when appropriate.

Definition of news in professional exposure limits for chemical agents in Spain for 2017 (LEP 2017).

Environmental Limit Values (VLA)

These are reference values for the concentrations of airborne chemical agents, and these represent the conditions most workers are believed to be exposed to day after day, based on current knowledge, throughout their working lives without suffering adverse effects to their health.

Daily Exposure (ED)

It is the average concentration of the chemical agent in the worker's breathing zone, measured or calculated in a weighted manner with respect to time, for the real workday and referring to a standard working day of 8 hours.

Short-term exposure (EC)

It is the average concentration of the chemical agent in the worker's breathing zone, measured or calculated for any period of 15 minutes throughout the working day, except for those chemical agents for which a lower reference period is specified, in the list of Limit Values.

Environmental Limit Value-Daily Exposure (VLA-ED®)

It is the reference value for the Daily Exposure (ED). In this way the VLA-ED® represent the conditions most workers are believed to be exposed to, based on current knowledge, 8 hours a day and 40 hours a week throughout their working life, without suffering adverse effects to their health..

Environmental Limit Value-Short Term Exposure (VLA-EC®)

It is the reference value for the Short Term Exposure (CE) which should not be exceeded by any CE throughout the working day. In the case of those chemical agents that have recognised acute effects but the main toxic effects of which are of a chronic nature, the VLA-EC® constitutes a complement to the VLA-ED® and, therefore, the exposure to these agents will have to be evaluated in relation to both limits.

On the other hand, chemical agents with mainly acute effects, such as, irritant gases are only assigned VLA-EC®

13.10 SENSITIZING CHEMICAL AGENTS

Sensitising chemical agents are substances and preparations which, by inhalation or skin penetration, may cause a hypersensitivity reaction, so that a subsequent exposure to that substance or preparation results in characteristic negative effects. In workplaces, exposures to these agents may happen through the respiratory, dermal or conjunctival airways, causing reactions in the exposure pathways. Initially, a person's response to a sensitising compound may be small or non-existent. However, after a person has become sensitised, a subsequent exposure may produce intense responses even at very low concentrations.

Sensitization is produced in most cases through an immunological mechanism. Allergic reactions may be very serious. The most common reactions depend on the exposure route and are: rhinitis, asthma, alveolitis, bronchitis, contact eczema, contact urticaria and blepharoconjunctivitis. Workers who have been sensitised to a particular compound may also have cross-reactivity to other compounds with similar chemical structure. Substances that are not sensitising, but irritating, may also cause or aggravate the allergic reaction of sensitised individuals.

Reducing exposure to sensitisers and structural analogues in general reduces the incidence of allergic reactions among sensitised individuals. However, for some sensitised persons, the only way to prevent the immune response to sensitising agents and their structural analogues is to completely avoid exposure, both in the workplace and outside the workplace.

The capacity to produce sensitization is included in the regulations on the classification of dangerous substances, which assign these agents the hazard indications H334.

“It may cause allergy or asthma symptoms or breathing difficulties in case of inhalation" and/or H317 "It may cause an allergic skin reaction", pursuant to Regulation (EC) No. 1272/2008 and the risk phrases R42 "It may cause sensitization by inhalation" and/or R43 "It may cause sensitisation by skin contact" pursuant to RD 363/1995.

In the list of Environmental Limit Values, the agents capable of producing these effects are marked with the notation "Sen". Chemicals which due to their nature are not included in the above mentioned regulation regarding the classification of dangerous substances, but which produce the effects discussed are also included in this note.

This notation does not necessarily mean that sensitization is the critical effect on which the VLA is based or that it is the sole effect of that agent.

VLAs based on sensitization aim to protect workers from this effect but do not try to protect workers who have already been sensitised.

Consequently, compounds with sensitising notation (Sen) pose a special problem in workplaces. In these cases, respiratory, dermal and conjunctival exposures should be eliminated or reduced to a level as low as technically possible, using appropriate control measures or even personal protective equipment. In any case, the corresponding VLA should be complied with.

13.11 LIST OF ENVIRONMENTAL LIMITS VALUES OF PROFESSIONAL EXPOSURE IN 2017

Table 55 lists the chemical agents that have an adopted limit value, which are the acronyms for the columns.

- CE: The CE number is the official number of the substance in the European Union.
- CAS: Chemical Abstract Service.
- VLA-ED®: Daily Exposure Values.
- VLA-EC®: Short-term Exposure Values.

Supplementary information of practical use:

H: Hazard Identification for each agent. In order to assess not only the existing exposure but also the risk associated with it, which also requires taking into account the severity of the effect, column H contains the hazard statements assigned in the Regulations on classification, labelling and packaging of substances and mixtures. The following hazard information is given in bold type refers to toxicological properties and specific health effects. ***** indicates that this chemical agent is included for the first time in that table.

CE No	CAS	CHEMICAL AGENT (year of incorporation or update)	LIMIT VALUES				NOTES	HAZARD IDENTIFICATION (H)
			VLA-ED®		VLA-EC®			
			ppm	mg/m^3	ppm	mg/m^3		
231-157-5	7440-47-3	Chromium metal (2008)		2			VLI	
		Cr (II) and Cr inorganic compounds (III) Insoluble, as Cr		2			VLI	
		Chromium (VI), inorganic compounds, except those expressly indicated. Soluble compounds, such as Cr		0.05			**C1B**, VLB®, c, Sen, r	**350i-317**-400- 410 except barium chromate
		Chromium (VI), inorganic compounds, except those expressly indicated. Insoluble compounds, such as Cr		0.01			**C1B**, c, Sen, r	**350i-317**-400- 410 except barium chromate
231-111-4	7440-02-0	Nickel metal		1			Sen, r	315-372-317
		Nickel, inorganic compounds except those which are expressly indicated. Insoluble compounds such as Ni		0.2			**C1**, c, Sen, r	
		Nickel, inorganic compounds except those which are expressly indicated. Soluble compounds such as Ni		0.1			**C1**, c, Sen, r	
231-107-2	7439-98-7	Elemental molybdenum: respirable fraction (2009)		10				
		Elemental molybdenum: respirable fraction (2009)		3			d	
		Molybdenum: insoluble compounds, such as Mo. Respirable fraction (2009)		10			c	
		Molybdenum: insoluble compounds, such as Mo. Respirable fraction (2009)		3			c, d	
		Molybdenum: insoluble compounds, such as Mo. Respirable fraction (2009)		0.5			c, d	
* 231-105-1	7439-96-5	Elemental manganese Respirable fraction		0.2				
231-105-1*	7439-96-5	Elemental manganese Respirable fraction (2017)		0.05			d	
*		Manganese inorganic compounds as Mn. Respirable fraction		0.2				

Table 55: lists of the chemical agents that have an adopted limit value (part 1)

CE No	CAS	CHEMICAL AGENT (year of incorporation or update)	LIMIT VALUES				NOTES	HAZARD IDENTIFICATION (H)
			VLA-ED®		VLA-EC®			
			ppm	mg/m^3	ppm	mg/m^3		
238-455-4	14464-46-1	Crystalline silica: cristobalite Respirable fraction		0.05			n, d, and eeITC/2585/2007	
238-878-4	14808-60-7	Crystalline silica: quartz (2015) Respirable fraction		0.05			n, d, and seeITC/2585/2007	
		Inorganic fluorides, such as F, except uranium hexafluoride and those expressly indicated		2.5			VLB®m, VLI	
233-069-2	10028-15-6	Ozone: heavy work	0.05	0.1				
		Ozone: moderate work	0.08	0.16				
		Ozone: light work	0.1	0.2				
		Ozone: heavy, moderate or light work (≤2 horas)	0.2	0.4				
233-271-0	10102-43-9	Nitrogen monoxide	25	31			VLBm, VLI	
233-272-6	10102-44-0	Nitrogen dioxide	3	5.7	5	9,6		270-**330-314**
211-128-3	630-08-0	Carbon monoxide	25	29			TRIA, VLB®, r	220-**360D-331-372**
204-696-9	124-38-9	Carbon dioxide	5,000	9,150			VLI	

Table 55: lists of the chemical agents that have an adopted limit value (part 2)

Notes. Only those corresponding to the Environmental Limit Values of the potential chemical agents from stainless steel welding have been incorporated.

c: the terms "soluble" and "insoluble" are understood

C1: carcinogens or suspected carcinogens for human beings. Check the classification for each specific agent according to Regulation (EC) No. 1272/2008.

C1A: a carcinogen for human beings, based on human evidence.

C1B: supposed to be a carcinogen for human beings, based on evidence in animals. RD 665/1997 applies.

d: see UNE EN 481: Atmospheres in the workplace. Definition of the fractions by the size of the particles to measure aerosols

n: in the extractive industries see Order ITC / 2585/2007, of August 30 (BOE nº 315 of September 7, 2007), by which the Complementary Technical Instruction 2.0.02 of the General Regulation of Basic Norms of Mining Safety is approved.

r: this substance has established restrictions on the manufacture, marketing or use in the terms specified in the "Regulation (EC) No. 1907/2006 on Registration, Evaluation, Authorization and Restriction of chemicals and preparations" (REACH) of December 18, 2006 (OJEU L 369 of December 30, 2006). The restrictions of a substance may be applied to every single use or only to specific uses. Appendix XVII of the REACH Regulation contains the list of all restricted substances and specifies the uses that have been restricted..

Sen: sensitising. See section 13.10.

TR1: Substances that are known or suspected to be toxic to human reproduction.

Substances are classified in category 1 reproductive toxicity when they are known to have caused adverse effects on sexual function and fertility, or on the development of people, or when there is evidence from animal studies that maybe supported by supplementary information that strongly suggests that the substance is capable of interfering with human reproduction.

TR1A: when the tests used for classification mainly come from human data.

VLB®: chemical agent which has specific Biological Limit Value in this document.

VLBm: chemical agent to which the Biological Limit Value of the methaemoglobin inducers is applied

VLI: chemical agent for which the EU established at the time an indicative limit value. All these chemical agents are included in at least one of the indicative limit values published to date. The Member States have a time fixed in these directives for their transposition to the limit values of each member country. Once adopted, these values have the same validity as the rest of the values adopted by the country.

y: reclassified, by the International Agency for Research on Cancer (IARC) group 2A (probably carcinogenic in humans) to group 1 (carcinogenic in humans).

Hazard indications H

H220 - Extremely flammable gas.
H270 - It may cause or aggravate a fire; oxidizer.
H314 – It causes severe skin burns and serious eye damage.
H317 – It may cause an allergic skin reaction.
H330 - Fatal in case of inhalation.
H331 - Toxic in case of inhalation.
H350i - May cause cancer by inhalation.
H351 - Suspected of causing cancer.
H360D - May damage the foetus.
H372 – It damages certain organs by long term or repeated exposure.
H400 - Very toxic to aquatic organisms.
H410 - Very toxic to organisms**.**

13.12 LIST OF BIOLOGICAL LIMIT VALUES IN 2017

Below is the list of Biological Limit Values for chemical agents, identified by their CAS and CE numbers, specifying in the INDICATOR column the biological matrix where the chemical agent is determined any of the metabolites or the biochemical parameter that may be altered due to exposure to xenobiotic.

The SAMPLING TIME column indicates when the sample should be taken in terms of the exposure. The indications of the above mentioned column, which will be subject to further details in the corresponding notes, should be understood in the context of a standard work week consisting of five days of work, with days of eight hours each, and two consecutive rest days. Adaptations to different temporary work patterns, for example for shift workers, both at the time of sampling and the VLB® value, should consider the pharmacokinetic and pharmacodynamics data of the chemical agent in particular. The indicated sampling time should be scrupulously respected, since the distribution and elimination of a chemical agent or its metabolites, as well as the biochemical changes induced by exposure, are time-dependent processes.

The VLB® values are applicable only if the sample is taken at the specified time.

The required observations of additional information are given in the NOTES column, using the corresponding letters.

In 2016 the fluorine and inorganic fluoride compounds that may be used in electrode coatings, fluxes[2] for submerged arc welding and fluxes[2] for brazing were included in the table of Biological Limit Value.

Of all the potential chemical agents in the table of Biological Limit Values (VLB), only those which may potentially appear in stainless steel welding have been included, including some of the degreasers that may be used in the cleaning processes of stainless steel.

Nº CE	CAS	CHEMICAL AGENT (year of incorporation/ update)
200-662-2	67-64-1	Acetone
231-158-0	7440-48-4	Cobalt and inorganic compounds except oxides
		Chromium (VI), water soluble fumes (2008)
231-954-8	7782-41-4	Fluoride (2016)
		Inorganic Fluorides (2016)
211-128-3	630-08-0	Carbon monoxide
201-167-4	79-01-6	Trichlorethylene (2011)

Table 56. List of biological limit values.

BIOLOGICAL INDICATOR (IB)	LIMIT VALUES VLB®	SAMPLING TIME	NOTES	HAZARD INDICATORS (H)
Acetone in urine	50 mg/l	End of working day (2)	I	225-319-336 EUH066
Cobalt in urine	15 µg/l	End of working week (1)	F	334-317 413
Cobalt in blood	1 µg/l		F, S	
Total chromium in urine	10 µg/l	Start and end of working day (4)		350i-317 400-410
	25 µg/l	End of working week (1)		
Fluorides in urine	2 mg/l	Before working hours (6)	F, I	270-330-314
	3 mg/l	End of working day (2)		
Fluorides in urine	2 mg/l	Before working hours (6)	F, I	
	3 mg/l	End of working day (2)		
Carboxyhemoglobin in blood	3.5% in total haemoglobin	End of working day (2)	F, I	220 360D-331-372
CO in alveolar air (final fraction of exhaled air)	20 ppm			
Trichloroacetic acid in urine	15 mg/l	End of working week (1)	I	350-341 319-315 336-412
Trichloroethanol in blood	0.5 mg/l		I, without hydrolysis	

NOTES:

Only those corresponding to the Biological Limit Values of the potential chemical agents from stainless steel welding and used as degreaser for cleaning have been included.

F Background. The indicator is generally present in detectable quantities in persons not exposed at work. These background levels are included in the VLB® value.
I. It means that the biological indicator is non specific since it may be found after exposure to other chemical agents.
S. It means that the biological indicator is an indicator of exposure to the chemical agent in question, but the quantitative interpretation of its measure is ambiguous (semi quantitative). These biological indicators should be used as a screening test when a quantitative test may not be taken or may not be used as a confirmatory test if the quantitative test is not specific and the origin of the determinant is doubtful.

13.13 MOST IMPORTANT RISK FACTORS BY EXPOSURE TO WELDING FUMES

Once the potential chemical agents (metal particles and gases) that may be contained in the fumes of a certain production have been selected, evaluated and compared with the annual values set forth in the INSHT, the necessary measures should be taken to reduce or eliminate them, including an evaluation of the risk factors, for example:

- Absence of ventilation equipment, design deficiencies or lack of maintenance or malfunctioning equipment.
- Lack of training of workers in the use of ventilation equipment.
- Misuse or poor selection of the appropriate screen and incorrect selection of inactinic glass.
- Welding performed in unfavourable positions that could force the welder to be overexposed.
- Absence of individual respiratory protection measures in welds in confined spaces.

Other risk factors

Preparation tasks immediately before or after welding, which may require measures of individual protection other than those of the electric arc, such as:

- In TIG welding (GTAW), regular sharpening of the electrode tip, especially when the electrode has thorium, radioactive material, the appropriate equipment should be used to capture the dust produced, reducing the risk of inhalation and the consequent internal irradiation of the welder and nearby workers.
- When grinding to prepare joints, repair defects or eliminate welding points, where metallic powders are produced.
- Smoking constitutes an addition to exposure to welding fumes as it causes COPD (Chronic Obstructive Pulmonary Disease.)
- Pregnancy and breastfeeding.

13.14 PRECAUTIONS AND SAFE PRACTICES

Local Exhaust Ventilation

Depending on each case, the following equipment may be appropriate:

- For jobs with fixed positions and on small parts:
  - Table - small welding cabin. Ventilation is produced through slits located on the opposite of the welder.
- For working in relatively fixed positions and with medium or large-sized parts:
  - Centralised ventilation equipment or with self-cleaning filters with the necessary suction arms each formed by articulated duct and suction hood..
- For other jobs:
  - Mobile equipment consisting of a trolley with wheels, containing the fan and filters, the duct and the suction capture hood. This may be placed in the desired position by means of articulated duct or flexible duct and clamped with a magnetic base support.

General ventilation

The general ventilation of the workshop where welding stations are located should provide a sufficient flow of air to dilute contamination to permissible levels and guarantee the extracted air is rapidly interchanged with clean air from the outside, using the exhaust ventilation equipment.

Consideration should be given to workstation extensions so as not to reduce the efficiency of general ventilation.

Maintenance of the exhaust ventilation system

The maintenance of the local exhaust ventilation equipment will be carried out, following the manufacturer's instructions.

A regular visual inspection of the ventilation equipment should be carried out, looking for external signs of damage. In the event that the welder himself has to carry out this visual inspection, the welder should be given the necessary training and time. When damage is detected, it should be immediately reported so damage may be repaired.

It is advisable to regularly check (at least every six months) the operation of the equipment, measuring the fundamental parameters and comparing the data with the design values. The results of these checks will be recorded and should be kept for at least five years.

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Signalling and access restriction

The areas in which stainless steel welding works are carried out should be delimited and have signs warning of the health hazard of breathing welding fumes. Only the personnel that work in those areas should be allowed access

Measures for confined spaces

Stainless steel welding works in confined spaces should be avoided as much as possible.

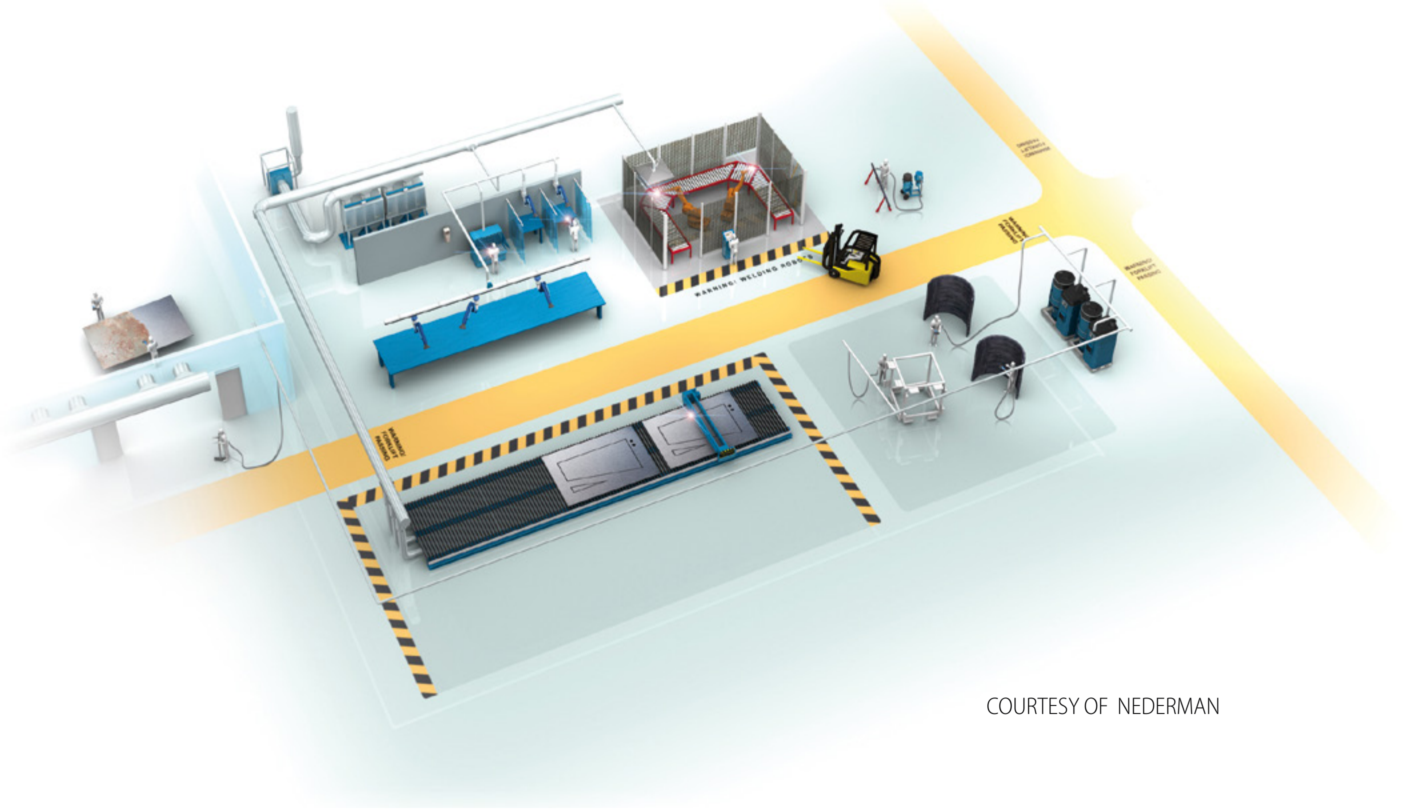
When it is essential to carry out welding works, control measures should consist of a combination of forced ventilation, individual respiratory protection and rotation of the welders.

Forced ventilation should disperse the fumes, preferably by means of flexible conduits connected to external fans, away from the face of the welder, dilute them, and ensure that clean air enters all workstations, taking care that induced currents do not interfere with the flow of shielding gas.

Individual protection should be used during the entire time the worker is in the confined space, and should consist of a closed head welding screen with filtered air input to the face under pressure inside the screen, preventing the entry of the pollutants. This type of respiratory protection should be complemented with auto darkening eyeglass protection when receiving the first radiation from the welding arc, since this allows permanent use of the respiratory protection, that is, even during welding breaks.

The rotation of the welders will be compulsory for works of prolonged duration.

The maintenance and monitoring measures of the two previous sections will also be extended to the impulse equipment. In any case, in confined spaces these tasks should always be carried out with express work permits, after a responsible person has verified the conditions in which the tasks will be carried out.



COURTESY OF NEDERMAN

13.15 PERSONAL PROTECTION EQUIPMENT

Personal respiratory protection

Except in situations of exceptional exposure or of very short duration, it will not be acceptable to entrust all risk control to the worker using respiratory personal protective equipment (PPE). However, in welding works of stainless steels or high alloy steels, with chromium or nickel, given the seriousness of the damage that may be caused, the employer will make available adequate protective respiratory equipment to the exposed workers, who request them, even if the existing technical control measures have duly proved they are adequate. In such case, the use of the equipment will be voluntary for workers. If during any task, despite using the best available technical and organizational control measures, it is not possible for worker exposure to be kept below the limit, the use of individual respiratory protection will be mandatory and if they were to be used for long periods, the use of air supply equipment and organisational measures to rotate workers will be implemented. In these cases health monitoring will be mandatory for workers. In fact, in all cases when individual respiratory protection should be used (occasional or specific exposure, inadequate collective protection measures despite their good design and implementation and even voluntary use by workers) it is more than advisable to use closed welding screens with filtered air, for its unquestionable greater comfort and due to the difficulty of making other protective equipment compatible with head welding screens, which are always preferable to hand-held ones.

In any case, if respiratory protection equipment dependent on the environment were used, they should be highly effective against solid particles (self-filtering FFP3 mask or mask with removable P3 filters) and compatible with the head welding screen.

The misuse of PPE may cause serious damage to the health of workers, so the employer will ensure that workers receive sufficient information and training regarding their correct use, with special attention to respiratory tract adjustments, as well as cleaning, maintenance, storage and replacement. For these purposes, the manufacturer's instructions shall be taken into account, among other sources

COURTESY OF NEDERMAN

Protection of pregnant and breastfeeding workers

Exposure of pregnant and breastfeeding workers to stainless steels welding fumes should be avoided.

13.16 REAL WORK CONDITIONS WITH POTENTIAL EXPOSURE STUDIED BY THE INSHT

In order to provide information on hazardous work situations for preventive purposes, the National Institute for Occupational Safety and Health (INSHT) provides complementary graphic and technical information for the user to identify real work conditions. BASEQUIM is the INSHT portal in collaboration with the autonomous communities, dedicated to work situations with potential exposure to dangerous chemical agents.

We hereinafter reproduce, a translation of the presentation of this portal, which explains its objectives:

"***Welcome to BASEQUIM***

This portal is dedicated to work cases with potential exposure to hazardous chemical agents. It is aimed at offering useful information from the point of view of occupational risk prevention that facilitates the definition of the appropriate preventive measures. To this end, for each work situation described, information is provided on the chemical agents that may be present when the task is performed, the health damages caused by the exposure to chemical agents considered, the risk factors and the precautionary measures.

In the preventive information provided for each work case, only risks from exposure to hazardous chemical agents are taken into account and therefore the preventive measures indicated refer only to the above mentioned risks.

It should also be taken into account that, depending on the activity carried out in the workplace, on the organization and the distribution of the premises, the performance of tasks that are the same or similar to those described may involve risks of exposure to other chemical agents generated in other tasks that are carried out in the same premises by the same or another worker or from the place of work and its facilities.

In the case a job involves (or implies) carrying out other tasks that could cause other hazardous work situations, this fact will be taken into account in the risk assessment and adopting the corresponding preventive measures.

The information contained on this page comes from various sources. A group of experts in Occupational Risk Prevention has selected the information and considered it should be divulged. Neither the INSSBT nor the authors of the contents assume any responsibility arising from the use that third parties may make of the information presented here.

The application of these contents to specific situations of occupational risk should be previously evaluated and carried out by competent professionals in Occupational Risk Prevention.

One of the objectives of this page is to help compliance with the legislation on Prevention of Occupational Hazards, but it should not be assumed that the content automatically complies with current legislation"

The purpose of these studies, mostly issued by official bodies, dedicated to the monitoring of health and hygiene at work and/or the prevention of occupational hazards, and product safety sheets (MSDS - Material Safety Data Sheet) , and/or SIS (Safety Information Sheet is:

- To help to understand the problems caused by fumes generated by welding with a specific procedure.
- To estimate the necessary means to reduce or eliminate the above mentioned fumes.

Two of these sheets, from Praxair and Acerinox, are included as appendices (page 239).

The limit values included in these studies should be updated according to the annual information in force issued by INSHT (LEP).

Due to the importance given by some companies to the content of Ni and Cr in fumes, which are common elements in the composition of stainless steels, we want to refer to three cases, to inform manual readers about studies carried out by official organisations. Given the length of these studies, reading the original and the bibliography included herein is recommended.

We recommend reading the documents: TIG manual welding of stainless steel and high alloy with chromium or nickel: exposure to metal fumes Author: I*nstituto Nacional de Seguridad, Salud y Bienestar en el Trabajo (INSSBT), O.A., M.P.*

Estudio de la exposición a los humos generados en la soldadura de acero inoxidable. (Study on the exposure to fumes generated in stainless steel welding)

Prepared by the Asturian Institute for the Prevention of

Occupational hazards (IAPRL).

Evaluación de la exposición a cromo (VI) en la soldadura al arco de aceros aleados. (Evaluation of the exposure to chromium (VI) in alloy steel arc welding)

Main author: José Luis Sanz Romera

Coauthors: Agurtzane Zugasti Makazaga, Natividad Montes Beneitez, Juan Porcel Muñoz

Study conducted by ORP 2012 and published by INSHT and ORP.

Fig. 124 - Hood suspended on the welding table. PHOTOGRAPH COURTESY OF NEDERMAN

We include a summary of this study as an example of the effectiveness that may be obtained in the reduction of welding fumes, with the use of adequate preventive measures. In this case, each welding station has a local exhaust ventilation system

Introduction:

The aim of this study is to understand the levels of exposure to chromium (VI) by arc welders of alloy steel who perform the activity in workstations with local exhaust ventilation.

Methodology:

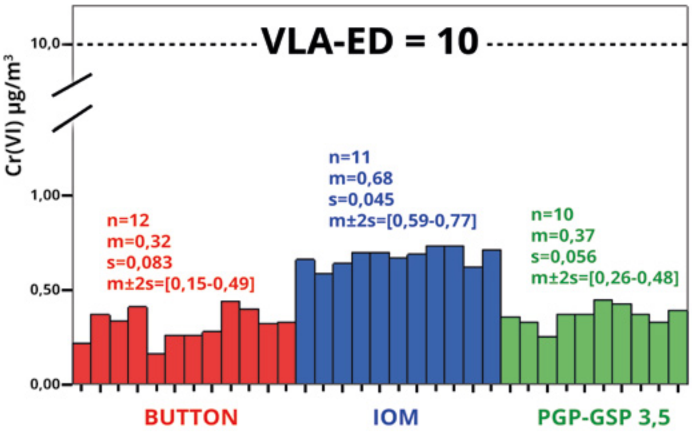
The study was carried out at a school of welders. Each welding station is independent of the rest and has a suspended hood-type exhaust system. The exposure to chromium (VI) was monitored while arc welding alloyed steels (MMA SMAW). For these purposes, during 3 months, 33 environmental samples have been taken and analysed.

Sampling:

To obtain the samples, 3 types of selective samplers were used for the inhalable fraction: IOM, PGP-GSP 3.5 and BUTTON [1]. In all cases the sampling was environmental and the volume of air of about 800 litres

Analysis:

The content of hexavalent chromium in the samples has been determined using the diphenyl carbazide method and ion chromatography with ultraviolet detection [2].



Results and Discussion:

The graph shows the chromium (VI) results. The influence of the type of sampler may be seen, with the highest values for the IOM sampler. A similar but less marked effect has been seen in the study of the behaviour of these samplers to determine the respirable fraction by gravimetry [3]. The results have been statistically analysed to obtain the mean value (m), the standard deviation (s) and the confidence interval (95%) for the concentration of Cr (VI) for each type of sampler. In all cases and independently of the sampler used, the concentration of Cr (VI) was lower than a 0,77µg/m³.

Conclusions:

There is a clear influence of the type of sampler in the capture of welding fumes and therefore in the results obtained for Cr (VI)

Regardless of the sampler type, in alloy welding positions (MMA) of alloyed steels that have localized exhaust, the environmental concentration of chromium (VI) found was about 15 times lower than the VLA-ED (10µg/m³)

Note: Although this study was carried out in 2012 and takes exposure limit values VLA-ED [2] of that year in 0.01 mg/m³, (10 µg/m³), this VLA-ED value has been maintained until at least 2017.

Bibliography:
[1]. CR-03/2006. Muestreadores de la fracción inhalable de materia particulada. Instituto Nacional de Seguridad Muestra e Higiene en el Trabajo INSHT.
[2]. MTA/MA-069/A12 (2012). Determinación de cromo hexavalente en aire. Método de la difenil carbazida y detección ultravioleta. Instituto Nacional de Seguridad e Higiene en el Trabajo INSHT.
[3]. Zugasti, A; Montes, N; Rojo, J.M.; Quintana, M.J. (2012) J. Environ. Monit, 14(2), 375-382. Field Comparison of three inhalable samplers (IOM, PGP-GSP 3.5 and BUTTON) for welding fumes.

APPENDIX: Most important chemical agents in manual TIG welding of stainless.

Chemical agent	Nº CAS	VLA-ED		VLA-EC		LEP notes	Biological indicator VLB (at sampling time)	Phrases H[1]	Physical state (presentation form)	Physical properties [2]
		ppm	mg/m^3	ppm	mg/m^3					
Chromium inorganic compounds (III)			2 (as Cr)						Fumes	PF: 1903ºC Pe: 2475ºC Insoluble
Soluble inorganic chromium compounds[3]			0.05 (as Cr)			Sensitiser C1B[4] VLB	Total chromium in urine 10µg/l Start and end of working day[5] 25µg/l End of working week[6]	350i May cause cancer by inhalation 317 May cause an allergic reaction on the skin 400 Very toxic to organisms Aquatic 410 Very toxic to aquatic organisms, with long-lasting harmful effects		
Insoluble inorganic chromium compounds[7] (VI)			0.01 (as Cr)			Sensitiser C1B[4]				
Insoluble inorganic nickel compounds[8]			0.2 (as Ni)			Sensitiser C1A[4]				PF: 1453ºC Pe: 2730ºC
Iron oxide (III)	1309-37-1		5 (as Fe)							PF: 1565ºC Pe: 2750ºC Insoluble
Manganese oxide	7439-96-5		0,2[9] (as Mn)							PF: 535ºC Pe: 1962ºC Insoluble
Ozone Heavy work Moderate work Light work Work ≤ 2 hours	10028-15-6	 0.05 0.08 0.10 0.20	 0.10 0.16 0.2 0.40						Gas	

NOTE:
The Professional Exposure Limits for Chemical Agents in Spain have been updated to those of the year 2017. These environmental limits of daily exposure (VLA-ED) are published annually by the I.N.S.H.T. and they have incorporated the following changes regarding manganese:

CHEMICAL AGENT	VLA-ED	VLA-EC
Elemental Manganese. Respirable fraction (2017)	0.05 mg/m^3	not established
Inorganic manganese compounds, such as Mn. Respirable fraction (2017)	0.05 mg/m^3	not established

(1) Phrase describing the nature of the dangers of a hazardous substance or mixture (Regulation (CE) Nº 1272/2008)
(2) PF: Fusion Point. Pe: Boiling point
(3) These are the collected common data of the soluble inorganic compounds of chromium VI which do not have specific entry in the tables of limit values of the LEP document for 2012 of the INSHT
(4) C1A: Category 1A carcinogen. C1B: Category 1B carcinogen (CLP Regulation)
(5) The value refers to the difference of the results of the samples taken at the end and at the start of the working day
(6) Meaning after four or five consecutive working days with exposure, as soon as possible after the end of the last working day
(7) These are the common data of the insoluble organic compounds of chromium VI that do not have specific entry in the tables of limit values of the LEP document for 2012 of the INSHT
(8) The classification as a carcinogen and the H phrases correspond to nickel monoxide and nickel oxide, which have the same ones
(9) VLA for "Elemental manganese and inorganic compounds like Mn" (No.CAS 7439-96-5)

14 Costs calculation

Welding processes are generally important in production and especially when the metal to be joined is stainless steel. Maintaining the quality requirements, it is advisable to regularly review the costs to make any necessary changes and help improve or maintain the competitive position of the product in the market.

Calculation of welding costs

All the changes that will be hereinafter proposed are aimed at reducing the costs of the joint, either by:

1. Increasing the welding rate.
2. Increasing the arc time.
3. Improving deposition efficiency.
4. Reducing the amount of consumable per metre of joint.
5. Reducing the cleaning time.
6. Fume reduction.

We should take into account not only the variables where costs may be reduced, but also the weight that each variable has in the total cost of the process, to conveniently assess the actions carried out. There are different programs in the market that allow a calculation of costs with higher precision, since they take into account more variables. The one explained below is simple and only takes into account three variables:

- The cost of welder's labour, including general expenses, represents 65-80% of the total cost. In the case of automatic welding or robotic welding, this refers to the cost and the amortisation of the investment.
- The cost of consumables represents 15-25% of the total cost.
- The cost of shielding gases represents 5-10% of the total cost.

Therefore, with a change in the welding process that involves a change in variables with a low weight in the total cost, such as the shielding gas or the consumable, and that even instead of reducing its cost it increases the cost, another variable may be improved, such as labour or the amortisation of the investment, which has a high weight in the total cost.

When manufacturing with stainless steel, there are some clear examples of the changes that are frequently made in the welding process and that, in general, generate cost saving:

- Substitution of the TIG procedure with the GMAW (MIG / MAG) procedure and its corresponding shielding gas. This change in the process depends on the thickness to be welded and the required quality. With this change longer arc time may be achieved.
- Substitution of the solid wire by a tubular wire without slag (metal cored) within the GMAW welding process (MIG / MAG), or one with slag FCAW (flux cored). This change is aimed at increasing the deposition rate (kg/h) and/or the welding rate.
- Partial or total substitution of repetitive and series manual welding (allowing the investment to be profitable), with automatic or robotic welding, as long as the knowledge and skills of the welder are not lost, as it may be necessary at any time.
- Use of a pulsed arc with its corresponding gas, instead of the spray arc used in the GMAW (MIG / MAG) process, which only allows butt welding in a flat position or in an angled horizontal position. With the pulsed arc, welding is possible without projections, but in all positions, the heat input, strains and the working time to clean the weld beads are reduced.
- Use of copper supports or backings (with possible water cooling) to weld at higher rates and less strains in automatic or robotic welding, especially for thin materials.

Calculation of welding process costs

Geometry of the joint

COMPANY:

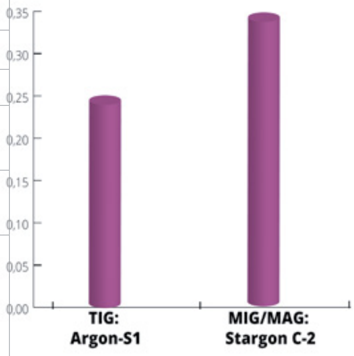
DATE

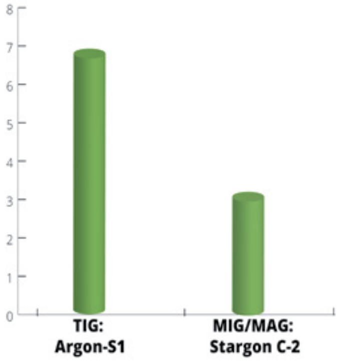
WELDING PROCESS	**Process 1**	**Process 2**
SHIELDING GAS	Gas 1	Gas 2
SUPPLY FORM	Method 1	Method 2
A - GAS PRICE (€/m³)		
B - GAS FLOW (l/min)		
C - WELDING RATE (cm/min)		
Total cost of shielding gas (€/m)		
$\frac{A\ (\text{€}/m^3) \times B\ (l/min)}{C\ (cm/min) \times 10}$ TOTAL %		
		LABOUR
A - LABOUR + GENERAL EXPENSES (€/h)		
B - ARC TIME (%)		
C - WELDING RATE (cm/min)		
Total cost of labour (€/m)		
$\frac{A\ (\text{€}/h) \times 100}{(B\ (\%)/100) \times C\ (cm/min) \times 60}$ TOTAL %		
		CONSUMABLES
A - CONSUMABLE PRICE (€/kg)		
B - DEPOSITION EFFICIENCY (%)		
C - WELDED METAL (kg/m)		
Total cost of consumables (€/m)		
$\frac{C\ (kg/m) \times A\ (\text{€}/kg)}{B\ (\%)/100}$ TOTAL %		
	METHOD 1	**METHOD 2**
SHIELDING GAS (€/m)		
LABOUR (€/m)		
CONSUMABLES (€/m)		
TOTAL COST (€/m)		

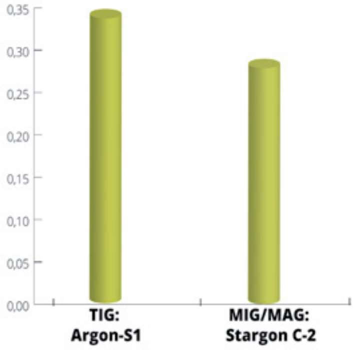
Below an example of cost comparison may be seen using two processes, the current TIG process and the proposed pulsed GMAW (MIG/MAG) process. The improvement proposal is to increase the welding rate (cm/min) or the arc time, maintaining an acceptable quality for the product. The data used as an example are:

- **METAL TO BE WELDED:** 304L of 3.0 mm thickness, in T joint and horizontal position.
- **CURRENT TIG PROCESS:** with 1.6 mm diameter tungsten electrode and ER 308L filler rod with 2.4 mm diameter
- **PROPOSED MIG/MAG PULSED PROCESS:** with solid wire ER 308LSi, Ø1.0 mm

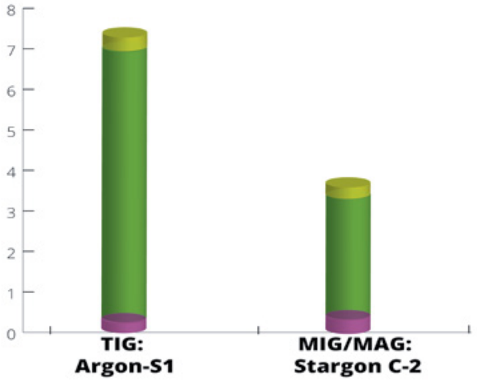
WELDING PROCEDURE	**CURRENT TIG**	**SUGGESTED: MIG/MAG**	**Notes:**
SHIELDING GAS	ARGON S1	STARGON C-2	
SUPPLY METHOD	CYLINDER	CYLINDER	
A - GAS PRICE (€/m³)	10	6	Purchases Dept.
B - GAS FLOW (l/min)	6	14	Data taken from process (1))
C - WELDING RATE (cm/min)	24	24	Data taken from process (2)
Total cost of shielding gas (€/m)	0.25	0.35	$\frac{A(€/m^3) \times B(l/min)}{C(cm/min) \times 10}$
TOTAL %	3.31%	9.40%	
LABOUR			
A - LABOUR + GENERAL EXPENSES (€/h)	25	20	Manufacturing Dept.
B - ARC TIME (%)	25	45	Data taken from process(3)
C - WELDING RATE (cm/min)	24	24	Data taken from process(2)
Total cost of labour (€/m)	6.94	3.09	$\frac{A(€/h) \times 100}{(B(\%)/100) \times C(cm/min) \times 60}$
TOTAL %	92.05%	82.92%	
CONSUMABLES			
A - CONSUMABLES PRICE (€/kg)	10	8	Purchases Dept
B - DEPOSITION EFFICIENCY (%)	100	98	Data taken from process (4)
C - WELDED METAL (kg/m)	0.035	0.035	Data taken from process(5)
Total cost of consumables(€/m)	0.35	0.29	$\frac{C(kg/m) \times A(€/kg)}{B(\%)/100}$
TOTAL %	4.64	7.68	







PROCESS	**CURRENT TIG**	**PROPOSES MIG/MAG**
	ARGON S1	**STARGON C-2**
SHIELDING GAS	0.25	0.35
LABOUR	6.94	3.09
CONSUMABLES	0.35	0.29
TOTAL COST (€/m)	**7.54**	**3.72**



(1)

SHIELDING GAS: The following values should be considered as guidelines. As it may be seen, the processes with the highest deposition rate (kg/h) use higher gas flow.

AVERAGE CONSUMPTION DATA SHIELDING GAS	GAS FLOW (l/min)
GMAW (MIG/MAG) Solid wire	12-14
GMAW (MIG/MAG) Tubular metal cored wire (without slag)	14-16
GMAW (MIG/MAG) Tubular flux cored wire (with slag)	16-18
GTAW (TIG)	5-8

(2)

WELDING RATE (cm/min): for approximate data, consult tables of welding parameters of each process.

(3)

ARC TIME (%): this is the percentage of time per welder (with arc) in relation to the total time including the time spent on welding cleaning, removal of slag, change of electrode, etc.

ARC TIME (%)	
MIG Pulsed arc	45
MIG Spray arc	45
MIG Ar-CO2 + solid wire	40
MIG CO2 + tubular wire	35
Coated Electrode	20
TIG	25
SUBMERGED ARC	50-90

(4)

DEPOSITION EFFICIENCY (%): this is the ratio in % between the weight of the material deposited and the weight of the consumable used. It may be calculated, the weight of the piece before welding is known (A), after welding once the spatters and slags have been cleaned (B) and that of the consumable used (C).

$$\text{Deposition efficiency} = \frac{\text{Weight B - Weight A}}{\text{Weight C}} \times 100$$

DEPOSITION EFFICIENCY (%)	
MIG Pulsed Arc (Ar base mixtures)	96
MIG Spray Arc (Ar base mixtures)	97
MIG CO_2 + solid wire	88
MIG CO_2 + tubular wire	85
Electrode	60
TIG	100
SUBMERGED ARC	95

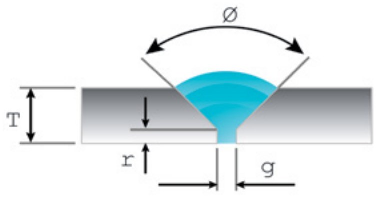
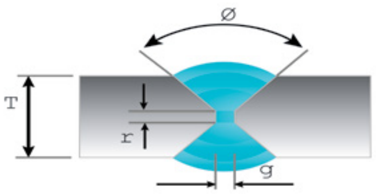
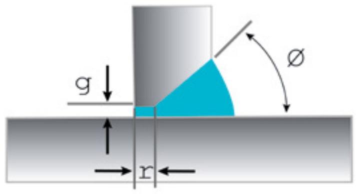
(5)

WELDED METAL (kg/m): is the amount of welded metal is needed per metre of welding.

It may be calculated, if possible per weight and mathematically:

Per weight, if possible, checking the difference between the weight of the piece before welding and after welding, spatters and slags have been cleaned.

Mathematically, by calculating:
1° The area of the cross section.
2° The volume per metre.
3° The weight per metre (volume x density).

Joint		Area
V-butt		$A=g \times T + t^2 \times \tan(\varnothing/2)$ g=Root separation T=Thickness t=(T-r) r=Root face Ø=V angle
X-butt		$A=g \times T + 2 \times t^2 \times \tan(\varnothing/2)$ g=Root separation T=Thickness t=(T-r)/2 r=Root face Ø=V angle
T with V preparation		$A=g \times T + 0{,}5 \times t^2 \times \tan \varnothing$ g=Root separation T=Thickness t=(T-r) r=Root face Ø=V angle

Conclusions

The example of a change in the proposed welding method results in the following:

Shielding gas: an **increase in cost of 0.10 €/m**. This is because a higher gas flow is required, although this gas has lower cost. The rate for both processes has been considered similar, although in general the rate of the proposed MIG / MAG process is usually higher than that of the TIG.

Labour: **savings of 3.85 €/m** in welder's labour and general expenses. However, in this case, the improvement is a 20% increase in arc time, which increases from 25% to 45%. This cost difference would be equally significant even though we could have considered the same labour cost for both processes

Consumables: the price of the MIG/MAG wire is lower than the Price of the TIG rod and although the deposition efficiency is 98% compared to 100% of TIG, they achieve the same volume per metre of welded metal which results in a saving of **0.06 €/m** in this case.

In general, it is possible to make improvements in shielding gas, optimising the type of gas, flow and supply method and/or in the consumable by selecting the type and diameter, but the reduction will be small, although never negligible. Costs may be significantly reduced by making the changes implied a reduction in welder labour (including general expenses) that is the heaviest item, although in order to achieve this we have to increase gas or consumable costs instead of reducing them.

15 Treatment of welded joints

The treatments that are generally applied to the surfaces of the products manufactured with stainless steel, after manufacturing or repair processes, to achieve or recover the conditions required to resist corrosion during the service life are the following:

Descaling

This process is usually applied in the steel mill after rolling or when it has been heat treated at high temperatures, to remove a thick oxide surface layer that is dark grey in colour. In welding applications. It is not generally necessary to use this, because shielding gas is applied or slag is formed to protect the bead during cooling and/or the nearby zone that may be affected by heat.

Pickling ▶ more info

It is applied to eliminate defects in a stainless steel surface and restore its initial corrosion resistance condition. Therefore, the oxidised upper layer and the immediately lower and finer layer are removed from the surface. This oxidation may be caused by heat during a thermal treatment, or by the heat input of the weld during production, which cause colourations or thermo colourations in the heat affected zone. This pickling treatment may also be required as part of a repair during the service life of the product. The main ways of applying pickling are:

Mechanical means

There may be areas, which have been subjected to high temperatures with light scale that may not be removed using a chemical process, requiring a mechanical process such as brushing or grinding, which allows pickling to be effective and then a correct passivation.

Brushing: with stainless steel brush and not used on carbon steel to avoid contamination. With brushing, slag residues, light scale are eliminated together with the surface coloration or thermo coloration layer, with the help of the appropriate paste or gel without causing excessive roughness. But the elimination of the lower layer of low chromium concentration is not guaranteed.

Grinding: is generally used to eliminate defects that have a certain depth, where brushing may not be effective, such as deep scratches, undercuts and excessive weld metal. The disks and the appropriate disk sequence should be used to leave the surface with the appropriate grain and to avoid heating the surface by applying the correct pressure.

Shot blasting: may be used to remove the colouration or thermo-colouration layer, but it should be ensured that the erosive medium has not been used on carbon steel and also renew it regularly. With this process it is necessary to take into account the roughness it generates, glass balls may be used, which do not increase the roughness as much as other means, and which do not eliminate the lower layer of low chromium content.

Chemical means

The main components of the stripping mixture are nitric acid and hydrofluoric acid. Regardless of the method chosen for the pickling, it is necessary to take into account:

- The type of steel and surface condition and define three variables, the concentration of each acid, the time and the temperature.
- The acid should be completely removed from the surfaces, to avoid marking by overexposure.

The product may be in the form of:

Paste, is usually used when the beads and the surface to be treated is not very large. It is applied with brush or roller and brush, it is necessary to be careful so they do not contaminate.

Gel, has higher density than paste, it may be used with a brush and with a spray, it may be applied to larger surfaces than with the paste and the finish is more uniform.

Liquid, although it may be applied with a brush or spray, its main application is in a tank, with the immersion of the piece, so the entire surface is equally treated.

There are commercial products in the market for each type of application, with instructions for each type of stainless steel and advice on temperature and time. If you prefer to prepare the mixture starting from the acid components, as an example, to prepare 1000 litres of nitric acid and hydrofluoric acid mixture, the concentrations are as follows:

Nitric and hydrofluoric acid concentrations /1000 l		
Products	Unstabilised austenitic steels, martensitic and ferritic steels	Stabilised austenitic steels
Nitric acid 53%	235 litres	235 litres
Potassium fluoride	20 Kg	40 kg
Water	765 litres	765 litres

Considering the handling of hydrofluoric acid has more risks to health and the working environment, the use of potassium fluoride for the formation of hydrofluoric acid directly in the bath is advisable. The pool temperature should be 50ºC and for 15 minutes. In case of using room temperature, not lower than 20ºC, the immersion time increases to more than 1 hour.

Electrochemical cleaning, by applying direct current and an appropriate electrolyte, a thin layer is removed from the stainless steel surface. With this treatment, the thickness of the layer to be removed is better controlled and the resulting roughness with the acid treatment, which tends to increase the roughness of the surface. In order to achieve certain roughness, the application of a mechanical treatment first may be beneficial, if surface particles remain, they may be eliminated in the electrochemical treatment stage, preventing future problems. A termination with low roughness favours cleaning, less adherence of polluting substances and better corrosion resistance.

Electrochemical treatment is usually carried out by immersion, which is not always possible due to size or complicated shapes. For these cases and for localised applications, such as welding beads, portable hand-held equipment may be used, which provides the direct current, the electrolytic solution and the applicator which may have various shapes depending on access to the area to be treated.

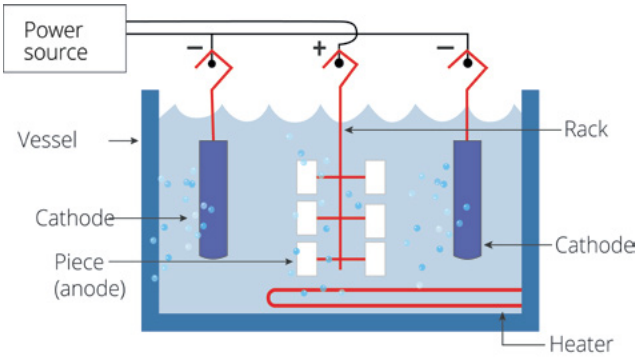
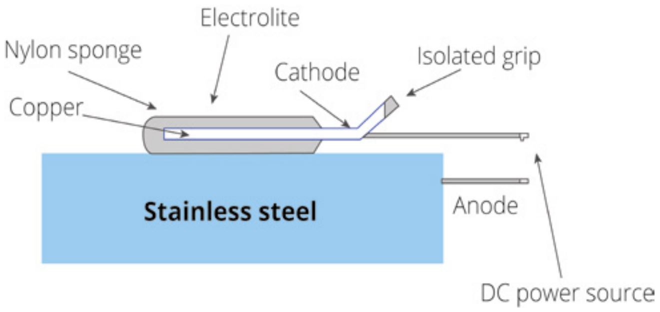


Fig. 125 - Diagram of electrochemical treatment in pool.



Procedure:

- The unit is connected to the direct current.
- Positive pole (anode) to the piece and negative pole (cathode) to the applicator.
- Selection of current range.
- Allow the electrolyte solution to moisten the applicator
- Pass the applicator through the area to be treated with gentle pressure.
- The electrochemical action will remove stains. The applicator should always have enough electrolyte.

Passivation

It may take place spontaneously and naturally on stainless steel surfaces by the action of oxygen from the air, which regenerates the chromium oxide layer on the surface. As this process is slow, when it is necessary to advance to put into service the products, the passivation may be encouraged with treatment using oxidising acid: nitric acid or citric acid are generally used. With passivation, unlike pickling, no surface layer is removed.

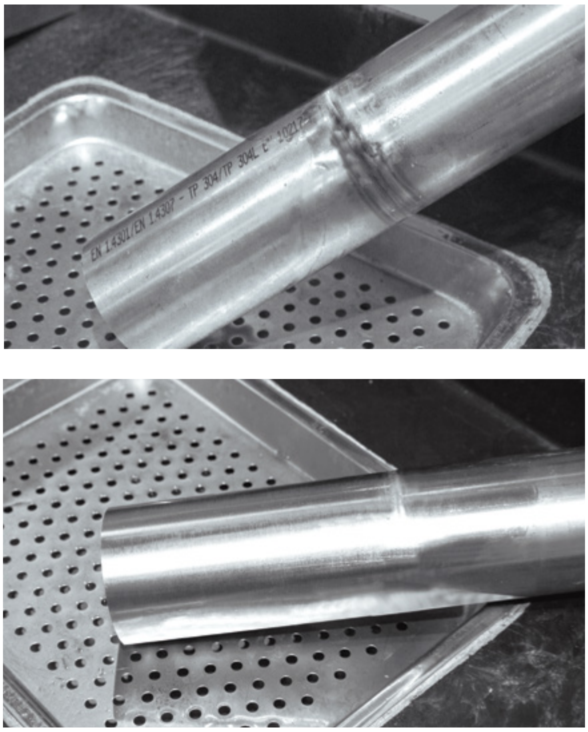


Fig. 126 - Appearance of the piece before and after the pickling treatment.

Removal of colouration or thermo-colouration caused by welding

It is produced by the welding heat input which facilitates the oxidation of the chromium on the surface layer, which has higher avidity to react with oxygen than iron. As a consequence of this oxidation, the thickness of the layer grows and chromium migration takes place from the layer immediately below, reducing its chromium content and therefore decreasing its corrosion resistance.

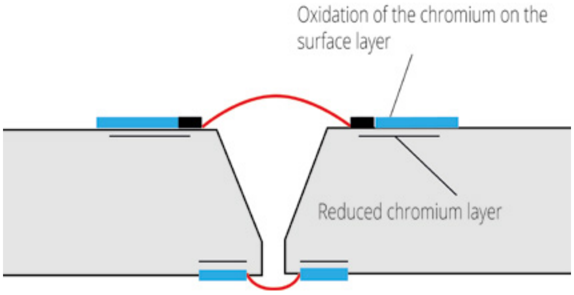


Fig. 127 - Thermo-colouration elimination.

The layer with colouration or thermo-colouration will have a thickness that will depend on the welding process, parameters, if shielding gas is used, quality and flow, parameters and welding position, consumables, etc.

To restore corrosion resistance, it is necessary to eliminate both layers, the colouration or thermo colouration layer and the immediately lower layer. The previously described mechanical or chemical processes may be used to eliminate them.

Removal of contamination due to rust stains by "iron contamination"

This contamination may easily produce if the workshop is shared for the manufacture of carbon steel products, but it may also be easily removed, if detected at an early stage, before putting into service. If during the subsequent inspections carried out between the stages of the cleaning plan or during the final inspection, possible contamination is detected, before more costly elimination treatment, it is advisable to make the test with he greenish "ferroxyl" solution test and depending contamination it turns into an intense light blue colour in the presence of iron (test according to ASTM A380).

- Distilled water: 1000 cm^3
- HNO_3 80-87%: 20 cm^3
- Potassium Ferro cyanide: 30 gr

If the test is positive, the contamination should be eliminated with a solution of:

- Water: 750 cm^3
- Nitric acid 80-87%: 250 cm^3
- Room temperature

The duration of this treatment may be extended without the risk of modifying the surface because nitric acid is an oxidizing acid, the surface passivation is improved at the same time. After the acid treatment, the test should be repeated with "ferroxyl" until the test is negative.

TYPE OF SURFACE	RESULT APPLICATION FERROXYL SOLUTION
Clean stainless steel	It does not turn blue after 1 hour
Ferric chloride particles	It turns bright blue quickly
Stainless steel scratched with a carbon steel nail or on the automatic cutting table, shared with carbon steel cutting	Intense blue on scratches
TIG welding contaminated with iron particles, due to the use of a disk contaminated with carbon steel for the edge preparation	Intense blue in the Iron contaminated bead points
MIG weld bead and nearby area brushed with a brush for carbon steel	Intense blue on scratches
Shot blasting with carbon steel balls	Intense blue in a few seconds
Iron powder on stainless steel due to grinding next to carbon steel plate	Immediately intense blue
Iron oxides (Fe_2O_3 and Fe_3O_4)	Light blue in 10 minutes

Cleaning before treatments

For these pickling and passivation treatments with acids to be effective, it is necessary to previously eliminate contaminating oils and liquids from the manufacturing processes, since otherwise the treatments would be rapidly consumed and would not achieve the objective. Therefore, degreasing and pre-cleaning may be necessary to prepare surfaces properly.

Degreasing may be performed:

- By using organic solvents, preferably non-halogenated, to avoid pitting risks due to hydrochloric acid from decomposition.
- With aqueous degreasing agents by chemical processes.

▸*More information: "Cleaning of stainless steels"*

All rinses are important and should remove all traces of the acids used in pickling or passivation. Depending on the size and geometry of the pieces, it is advisable to first rinse by immersion in the tank, followed by a spray rinse and finally with pressurised water not exceeding chlorine content of 100 mg/l to avoid possible pitting corrosion or future stress corrosion problems.

In case of any doubt regarding the available water, it is advisable to use demineralized water for the final rinse to avoid deposits of potential contaminants. It is advisable to dry quickly with hot air, with the precaution that the air does not drag oil from the compressor.

Applicable regulations

UNE-EN-2516 (30/09/1997)

Passivation of corrosion resistant steels and decontamination of nickel-based alloys.

ASTM A380 (27/12/2016)

Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems.

ASTM A967 (27/12/2016)

Standard specification for Chemical Passivation for Stainless Steel Parts.

ASME BPE

Bioprocessing Equipment (2016)

Cleaning plan

Depending on the manufacturing, the type of stainless steel and the welding and cutting processes, each company has to design a cleaning plan with the treatments that guarantee that any possible contamination may be eliminated to restore the stainless steel to the finishing required by the product design and delivered by the steelworks through the storeholder.

- Considering toxic substances are handled in the treatments, the plan should include the means to guarantee the safety measures to comply with health and safety regulations.
- If there are subcontract manufacturing processes that include cleaning, they should be included in the proposal and within the cleaning plan.
- To avoid responsibilities in case of inspection, if an external company is responsible for carrying out the cleaning plan, whether partially or totally, it should include eliminating the waste generated within the proposal.

An example of a cleaning plan includes:

- Inspect how stainless steel affects the welding and cutting processes.
- Cleaning by mechanical processes (brushing, grinding).
- Degreasing.
- Degreasing rinse.
- Pickling.
- Pickling rinse.
- Rinse.
- Decontamination.
- Rinse.
- Passivation.
- Passivation rinse.
- Final drying.
- Final inspection.

Precautions during manufacturing to avoid contamination

The treatments that we have previously seen provide various possible solutions to restore the prescribed finish in the design, which guarantees corrosion resistance in the working area of the product after any contamination during the manufacturing processes, including welding.

For this treatment to be sufficient, the thermal effect caused by welding should be taken in consideration, and any contamination in the preparation stages before and during welding should also be considered.

BEFORE WELDING:

1. The elimination of the packing and the protective plastic film that covers stainless steel from the steel mill or warehouse protects the stainless steel from any contaminants and it should not be eliminated until the manufacturing processes begin.
2. When cutting and preparing edges for the joint:
    - Mechanical cutting, such as punching, guillotine or using a saw and abrasive, may leave greases or cutting liquid residue, which will have to be removed before welding, to avoid contamination.

- Plasma cutting: depending on the stainless steel, the type of plasma and the cutting gases used (air, nitrogen and Ar-H_2mixtures) it may be necessary to grind the edges to eliminate the remains of oxides that may have formed. Do not forget that in the case of stainless steel, any oxides of chromium and nickel formed melt at a temperature higher than that of metal.

Metal	**T fusion (ºC)**	**Metallic oxide**	**T fusion (ºC)**
Iron	1537	Fe_2O_3	1565
Nickel	1454	NiO	1982
AISI 304	1400-1454	Cr_2O_3	2266

Table 57. Melting temperatures of metals and their oxides.

3. When sharing manufacturing with other metals. If in the workshop only stainless steel is used for manufacturing, the tools and mechanical means are selected for that purpose and in general there are no contamination problems but if the workshop also uses carbon steel for manufacturing , it is convenient to create a physical separation to avoid contamination:
   - Use of automatic plasma or laser cutting tables. If they are interchangeably used for stainless steel and carbon, scratches may be made on the cutting table that embed carbon steel particles in the stainless steel. The same metallic dust generated in the cutting systems, if not eliminated, may cause carbon contamination. If cutting is subcontracted to cutting centres, consider in the proposal if there are machines exclusively intended for cutting stainless steel.
   - Shared tools: stainless steel brushes, picks, cutting and grinding discs should be suitable for stainless steel and not shared with carbon steel.
   - Shot blasting should not be shared with carbon steel.
   - Welding equipment: in the GMAW process (MIG/MAG), the spiral conduits (wires) should be changed if they have been used to weld carbon steel, since they would leave significant amounts of dust that would be subsequently dragged by the stainless steel wire and deposited in the weld. Even ground cables must be cleaned if they have been previously used for carbon steel.
   - Shielding gas: if carbon steel has been welded, the shielding gas should be changed, in addition to using the appropriate gas. Before welding, the gas remaining in hoses and pipes should be purged.
   - Tooling, turning plates and positioners: if they have been used for carbon steel, they should be blown and cleaned to avoid leaving carbon steel marks in the stainless steel.
   - Dust in the working environment: if a warehouse is shared by stainless steel and carbon welding, it is very difficult to avoid the carbon steel metallic particles being deposited on the stainless steel through the air. It is important to take this into account in the preliminary stainless steel cleaning before starting to weld.
   - Greases, paints, glue or solvent debris not eliminated, that in the cutting or welding process, may contaminate the weld, for example increasing the carbon content.

DURING WELDING:

The various welding processes will have different heat inputs and thermal efficiencies. They may be with or without shielding gas and may or may not generate slag. It must be considered that the proposed treatment is appropriate for each joint. For example, colouration or thermo-colouration in the heat affected zone may be lower if the welding process is TIG instead of MIG / MAG and therefore, although both joints have to be treated, those produced by TIG will need a lower treatment.

PROCESS	WASTE TO BE REMOVED	CLEANING PRIOR TO PICKLING
SMAW Coated electrode	• With slag, but if the joint and technique are correct, the slag should be easily separated. • Bead with good appearance for cooling under slag. • Spatters, in quantity depending on the technique. • Colouring in area close to the bead.	• Slag removal, brushing and grinding. • Mechanical removal of points of any spatter corrosion.
MIG/MAG (GMAW) with short arc	• Small slag areas depending on the shielding gas. • The bead appearance will depend on the shielding gas, but will be worse than that of the electrode-coated welding. • Spatters that leave small affected spots on the stainless steel surface and which should be removed. • Colouring in the area close to the bead.	• Brushing and grinding. • Mechanical removal of points of any spatter corrosion.
MIG/MAG (GMAW) with spray arc	• Small slag areas depending on the shielding gas. • The bead appearance will depend on the shielding gas, but will be worse than that of the electrode-coated welding. • Greater colouration in area close to the bead than with short arc.	• Brushing and grinding.
MIG/MAG (GMAW) with pulsed arc	• Small slag areas depending on the shielding gas. • High quality beads may be produced, with appearance depending on the shieldinge gas and which will be better than with MIG / MAG process with short and spray arc. • Higher colouration near the bead than with a short arc but less than with spray arc.	• Brushing and grinding.
MIG/MAG (FCAW)	• With slag, but if the joint and technique are correct, the slag should be easily separated. • Bead with good appearance due to cooling under slag. • Spatters, the quantity depending on the technique. • Colouring in the area close to the bead.	• Slag removal, brushing and grinding. • Mechanical removal of points of any spatter corrosion.
TIG (GTAW)	• Good bead appearance. • Small colouration zone.	• Grinding if possible due to thickness.
SAW Submerged arc	• With slag, but if the joint and technique are correct, the slag should be easily separated. • Bead with good appearance due to cooling under slag. • Colouring in the area close to the bead which will depend on flux[2] parameters and protection.	• Slag removal, brushing and grinding.

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[2] Author's note Appendix 3, page 260.

When all the joints are made by the same manufacturer, treatments to cover all the joints may be established taking into account the cost. But if there are several manufacturers welding the various components and then assembling them, it is necessary to have good coordination to avoid duplicate treatments or when assembling the components, to avoid leaving any joint without treatment.

In the same way depending on the importance and quality of the welded product, it is necessary to make a written welding protocol, there should be a procedure with the cleaning, degreasing processes and treatments for edges and bead preparation and the heat affected zone with colourations or thermo-colourations.

Summary:

Points which should be included in a purchase request or subcontracts, to avoid contamination.

1. All surfaces in contact with manufacturing processes, such as welding and cutting, should be free of oil, grease, paints, tapes, and other substances which contain organic material. In compliance with the test in ASTM A380.
2. All surfaces should be free from iron contamination. Water and ferroxyl tests set forth in the ASTM A380 standard will be required.
3. Welds should be free of colouration or thermo-colouration, spatters, stripping debris and areas stained by brushing and polishing. To eliminate them, the appropriate mechanical, chemical or electrochemical treatment will be required.
4. All the defects from poor bad welding practice such as lack of penetration, cracks, undercuts, should be repaired, duly cleaned and repaired by welding again.
5. The finished product will be inspected to accept the delivery.

COURTESY OF VDM METALS

16 Main welding defects and their causes

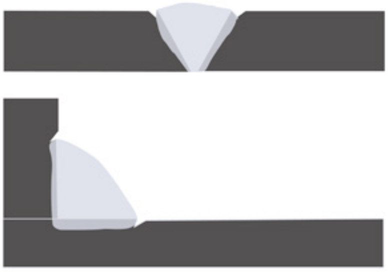
These do not refer to slags, colourations or thermo-colourations and spatters, which are inherent to welding; they refer to those caused by poor practice, such as lack of penetration, undercuts, cracking, overflow or excess metal, pores, slag inclusions, etc.

These defects have a negative impact on the mechanical properties and the corrosion resistance, as it is difficult to maintain a clean surface. They should be removed or cleaned, usually by grinding and repaired by welding.

This information summarises the main welding defects and the reasons that may cause them. As each welding process has its own characteristics that will facilitate the possibility of causing certain defects, when this is repeated once the possible causes have been reviewed, it may be advisable to change the process. For example:

1. **Cracking:** welding with MIG/MAG (GMAW) process with solid wire could be a solution, welding with MIG/MAG (FCAW) with basic tubular wire or with basic coated electrode (SMAW).
2. **Lack of penetration:** welding with MIG / MAG (GMAW) with solid wire, one of the solutions could be welding with TIG (GTAW), counting on the economic considerations due to reducing the deposition rate.

DEFECT	**CAUSES**
Lack of penetration 	Low welding current. Excessive welding rate. Very small root separation Bevel angle too small. Root bead too high. Misalignment between pieces.
Excessive penetration 	Excessive current in the root bead. Very low welding rate. Excessive edges separation.

DEFECT	**CAUSES**
Cracking 	• Welding with excessive degree of restraint[1]. • Welding with excessive current. • Fast cooling of the welding. • Inadequate consumable. • Poor welding sequence which causes excessive strains. • Base metal with difficult weldability. • Residual stressses in the base metal due to previous manufacturing processes. • Poor completion of the weld bead, leaving cracks in the final crater. • Inadequate bead shape without the required effective throat.
Undercuts 	• Excessive current. • Voltage too high. • Incorrect inclination of the electrode or the torch. • Faulty movement of the electrode. • Consumable diameter too thick. • High displacement rate with lack of retention at the ends.
Slag 	• Lack of slag cleaning, in multi pass welding. • Poor preparation of the joint with little edge separation and bevel with reduced angle. • Poor protection of the welding pool, which favours the appearance of oxides.

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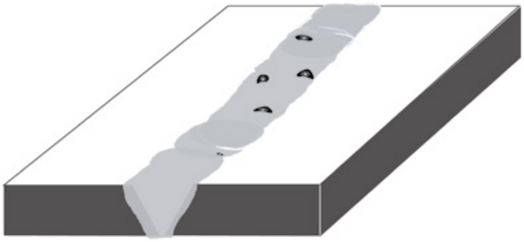
[1] Author's note Appendix 3, page 258.

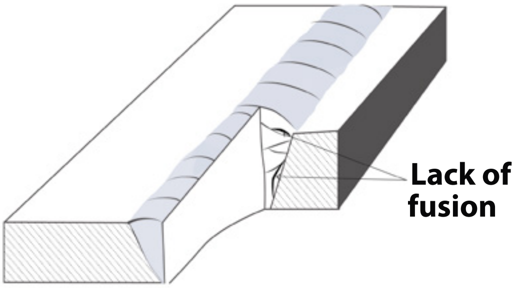
DEFECT **CAUSES**

Porosity

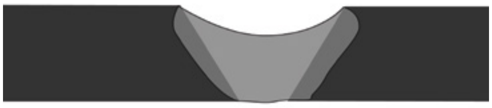


- Lack of cleaning in the joint edges, paint or grease.
- Excessive current.
- Unfavourable atmospheric conditions, excessive wind or air flows.
- Inadequate or contaminated shielding gas, with moisture, or with insufficient flow.
- Gas circuit in poor condition, hoses, flow metre regulator, connections which allow the entry of air.
- Broken refrigerated torch leaving water.
- Poor operating technique, welding with the arc too long or a too large angle, which introduces air from the weld pool instead of protecting it.
- Use of rusted solid wires or rusted tubular wires or with moisture.
- Coated electrodes with moist coating or poorly dried.
- Excessive welding rate, cooling the weld pool too fast and not allowing the gases to escape.

Lack of fusion



- Low current.
- Arc too long.
- Excessive welding rate.
- Defective preparation of edges, for example, bevel with very small angle, very small separation between sheets to be joined or misalignment between the pieces.
- Incorrect wire position not centred with respect to the edges of the joint.
- Welding over a bead with extra thickness.
- Defective connections.
- Incorrect torch oscillation.
- Inadequate welding parameters, such as the wire length (stick out), torch angle, etc.

DEFECT	CAUSES
Excessive over thickness 	• Low welding rate. • Low edge separation in butt joints. • Electrode diameter too thick. • Poor welding planning with excessive chamfer filling the penultimate pass.
Lack of thickness or welding metal 	• Lack of material, insufficient filling of the chamfer. • Very high edge separation. Excessive welding rate.
Irregular bead 	• Irregular advance movement. • Incorrect, excessive or insufficient current • Very long arc. • Inadequate inclination of the electrode. Irregular transversal movement

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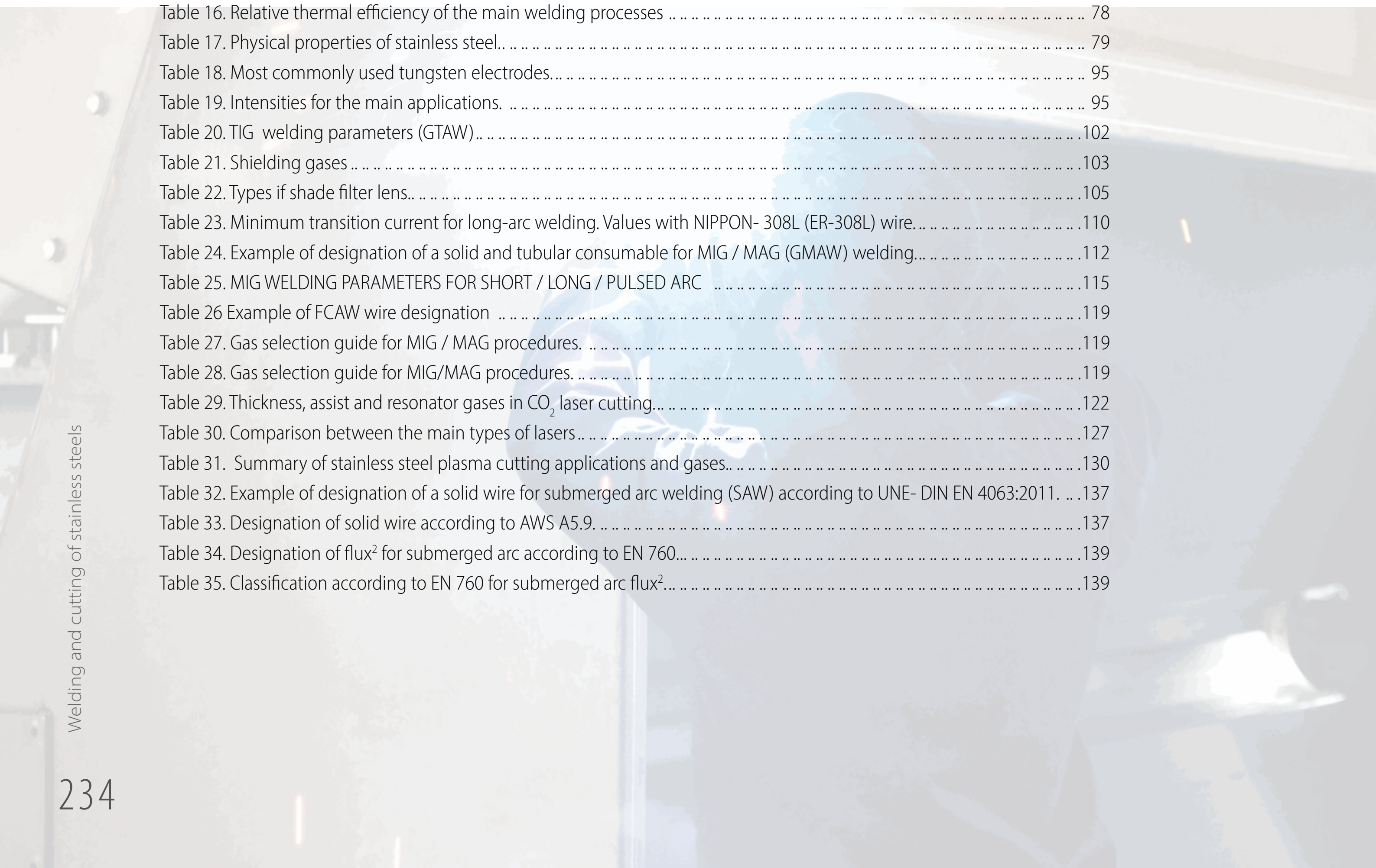
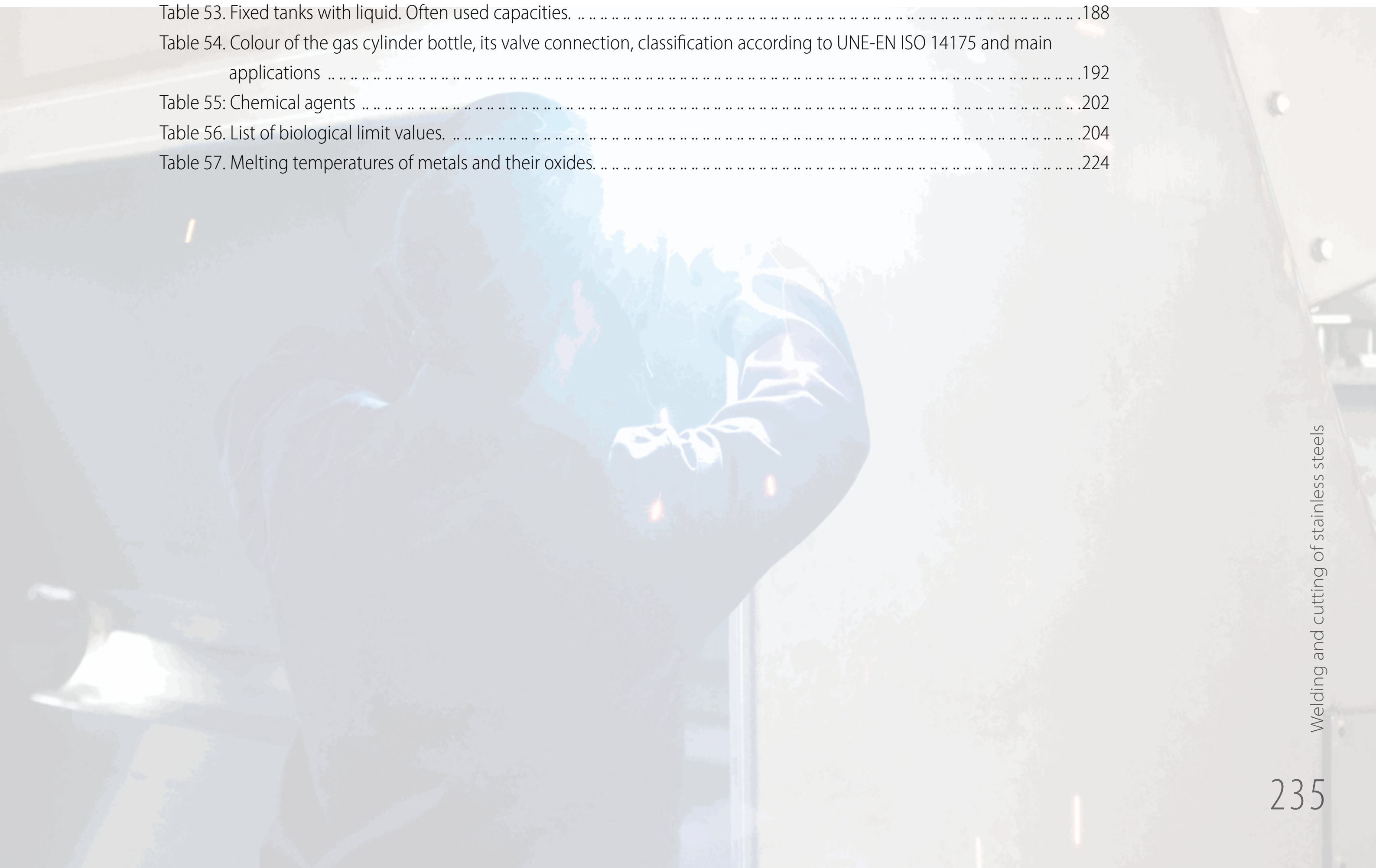
Índice de Tablas





Índice de Figuras

Appendices

SAFETY DATA SHEET

(in accordance with Regulation (EU) 2015/830)

MIG-316L

PRAXAIR
Making our planet more productive

Version: 2
Revision date: 19/01/2018

Page 1 of 11
Print date: 19/10/2018

SECTION 1: IDENTIFICATION OF THE MIXTURE AND OF THE COMPANY/UNDERTAKING.

1.1 Product identifier.

Product Name: MIG-316L

1.2 Relevant identified uses of the mixture and uses advised against.

Welding cable. Only for welding processes.

Uses advised against:
Uses other than those recommended.

1.3 Details of the supplier of the safety data sheet.

Company: **PRAXAIR ESPAÑA, S.L.U.**
Address: Calle de Orense, 11 - 5ª Planta
City: 28020 Madrid
Province: Madrid
Telephone: (+34) 914 533 000
E-mail: contact_espana@praxair.com
Web: www.praxair.es

1.4 Emergency telephone number: (+34) 914 533 000 (Available 24 hours)

SECTION 2: HAZARDS IDENTIFICATION.

2.1 Classification of the mixture.

In accordance with Regulation (EU) No 1272/2008:
Carc. 2 : Suspected of causing cancer.
Repr. 2 : Suspected of damaging fertility or the unborn child.
Skin Sens. 1 : May cause an allergic skin reaction.
STOT RE 1 : Causes damage to organs through prolonged or repeated exposure.

2.2 Label elements.

Labelling in accordance with Regulation (EU) No 1272/2008:
Pictograms:

Signal Word:
Danger

H statements:

H317	May cause an allergic skin reaction.
H351	Suspected of causing cancer.
H361	Suspected of damaging fertility or the unborn child.
H372	Causes damage to organs through prolonged or repeated exposure.

P statements:

P201	Obtain special instructions before use.
P260	Do not breathe dust/fume/gas/mist/vapours/spray.
P280	Wear protective gloves/protective clothing/eye protection/face protection.
P321	Specific treatment (see ... on this label).
P333+P313	If skin irritation or rash occurs: Get medical advice/attention.
P362+P364	Take off contaminated clothing and wash it before reuse.
P501	Dispose of contents / container through an authorized waste manager, according to current regulations.

-Continued on next page.-

EUH statements:
EUH208 Contains cobalt. May produce an allergic reaction.

Contains:
nickel
molybdenum

2.3 Other hazards.
The product may have the following additional risks:
Formation of air contaminants during hardening or processing.

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS.

3.1 Substances.
Not Applicable.

3.2 Mixtures.
Substances posing a danger to health or the environment in accordance with the Regulation (EC) No. 1272/2008, assigned a Community exposure limit in the workplace, and classified as PBT/vPvB or included in the Candidate List:

Identifiers	Name	Concentrate	(*)Classification - Regulation (EC) No 1272/2008	
			Classification	specific concentration limit
Index No: 028-002-00-7 CAS No: 7440-02-0 EC No: 231-111-4 Registration No: 01-2119438727-29-XXXX	nickel	10 - 50 %	Carc. 2, H351 - Skin Sens. 1, H317 - STOT RE 1, H372**	-
CAS No: 7440-47-3 EC No: 231-157-5 Registration No: 01-2119485652-31-XXXX	[1] chromium	10 - 25 %	-	-
CAS No: 7439-96-5 EC No: 231-105-1 Registration No: 01-2119449803-34-XXXX	[1] manganese	1 - 10 %	Acute Tox. 4, H332	-
CAS No: 7439-98-7 EC No: 231-107-2 Registration No: 01-2119472304-43-XXXX	molybdenum	3 - 25 %	Flam. Sol. 1, H228 - Repr. 2, H361	-
CAS No: 7440-21-3 EC No: 231-130-8 Registration No: 01-2119480401-47-XXXX	[1] silicon	1 - 10 %	Eye Irrit. 2, H319 - Flam. Sol. 2, H228	-
CAS No: 7440-44-0 EC No: 231-153-3	[1] carbon	0 - 2.5 %	-	-
CAS No: 7440-50-8 EC No: 231-159-6 Registration No: 01-2119480154-42-XXXX	[1] copper	0 - 2.5 %	-	-
Index No: 015-002-00-7 CAS No: 7723-14-0 EC No: 231-768-7 Registration No: 01-2119448009-39-XXXX	[1] red phosphorus	0 - 25 %	Aquatic Chronic 3, H412 - Flam. Sol. 1, H228	-

-Continued on next page.-

Index No: 027-001-00-9 CAS No: 7440-48-4 EC No: 231-158-0 Registration No: 01-2119517392-44-XXXX	cobalt	0.1 - 1 %	Aquatic Chronic 4, H413 - Resp. Sens. 1, H334 - Skin Sens. 1, H317	-
Index No: 013-002-00-1 CAS No: 7429-90-5 EC No: 231-072-3 Registration No: 01-2119529243-45-XXXX	[1] aluminium powder (stabilised)	0 - 25 %	Flam. Sol. 1, H228 - Water-react. 2, H261	-

(*)*The complete text of the H phrases is given in section 16 of this Safety Data Sheet.*
*** See Regulation (EC) No. 1272/2008, Annex VI, section 1.2.*
[1] Substance with a Community workplace exposure limit (see section 8.1).

SECTION 4: FIRST AID MEASURES.

4.1 Description of first aid measures.

Delayed effects may occur after the exposure to the product.

Inhalation.
Take the victim into open air; keep them warm and calm. If breathing is irregular or stops, perform artificial respiration.

Eye contact.
Remove contact lenses, if present and if it is easy to do. Wash eyes with plenty of clean and cool water for at least 10 minutes while pulling eyelids up, and seek medical assistance.

Skin contact.
Remove contaminated clothing. Wash skin vigorously with water and soap or a suitable skin cleaner. NEVER use solvents or thinners.

Ingestion.
If accidentally ingested, seek immediate medical attention. Keep calm. NEVER induce vomiting.

4.2 Most important symptoms and effects, both acute and delayed.

Long-term chronic exposure may result in injury to certain organs or tissues.
It may cause an allergic reaction, dermatitis, redness or inflammation of the skin.

4.3 Indication of any immediate medical attention and special treatment needed.

In case of doubt or when symptoms of feeling unwell persist, get medical attention. Never administer anything orally to persons who are unconscious. Keep the person comfortable. Turn him/her over to the left side and stay there while waiting for medical care.

SECTION 5: FIREFIGHTING MEASURES.

The product does not present any particular risk in case of fire.

5.1 Extinguishing media.

Suitable extinguishing media:
Extinguisher powder or CO2. In case of more serious fires, also alcohol-resistant foam and water spray.

Unsuitable extinguishing media:
Do not use a direct stream of water to extinguish. In the presence of electrical voltage, you cannot use water or foam as extinguishing media.

5.2 Special hazards arising from the mixture.

Special risks.
Fire can cause thick, black smoke. As a result of thermal decomposition, dangerous products can form: carbon monoxide, carbon dioxide. Exposure to combustion or decomposition products can be harmful to your health.

-Continued on next page.-

5.3 Advice for firefighters.
Use water to cool tanks, cisterns, or containers close to the heat source or fire. Take wind direction into account. Prevent the products used to fight the fire from going into drains, sewers, or waterways.

Fire protection equipment.
According to the size of the fire, it may be necessary to use protective suits against the heat, individual breathing equipment, gloves, protective goggles or facemasks, and boots.

SECTION 6: ACCIDENTAL RELEASE MEASURES.

6.1 Personal precautions, protective equipment and emergency procedures.
For exposure control and individual protection measures, see section 8.

6.2 Environmental precautions.
Prevent the contamination of drains, surface or subterranean waters, and the ground.

6.3 Methods and material for containment and cleaning up.
The contaminated area should be immediately cleaned with an appropriate de-contaminator. Pour the decontaminator on the remains in an opened container and let it act various days until no further reaction is produced.

6.4 Reference to other sections.
For exposure control and individual protection measures, see section 8.
For later elimination of waste, follow the recommendations under section 13.

SECTION 7: HANDLING AND STORAGE.

7.1 Precautions for safe handling.
For personal protection, see section 8.
In the application area, smoking, eating, and drinking must be prohibited.
Follow legislation on occupational health and safety.
Never use pressure to empty the containers. They are not pressure-resistant containers. Keep the product in containers made of a material identical to the original.

7.2 Conditions for safe storage, including any incompatibilities.
Store according to local legislation. Observe indications on the label. Store the containers between 5 and 35º C, in a dry and well-ventilated place, far from sources of heat and direct solar light. Keep far away from ignition points. Keep away from oxidising agents and from highly acidic or alkaline materials. Do not smoke. Prevent the entry of non-authorised persons. Once the containers are open, they must be carefully closed and placed vertically to prevent spills.
The product is not affected by Directive 2012/18/EU (SEVESO III).
7.3 Specific end use(s).
Ninguno/a.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION.

8.1 Control parameters.

Work exposure limit for:

Name	CAS No.	Country	Limit value	ppm	mg/m^3
chromium	7440-47-3	European Union [1]	**Eight hours**		2
			Short term		
		United Kingdom [2]	**Eight hours**		0,5
			Short term		

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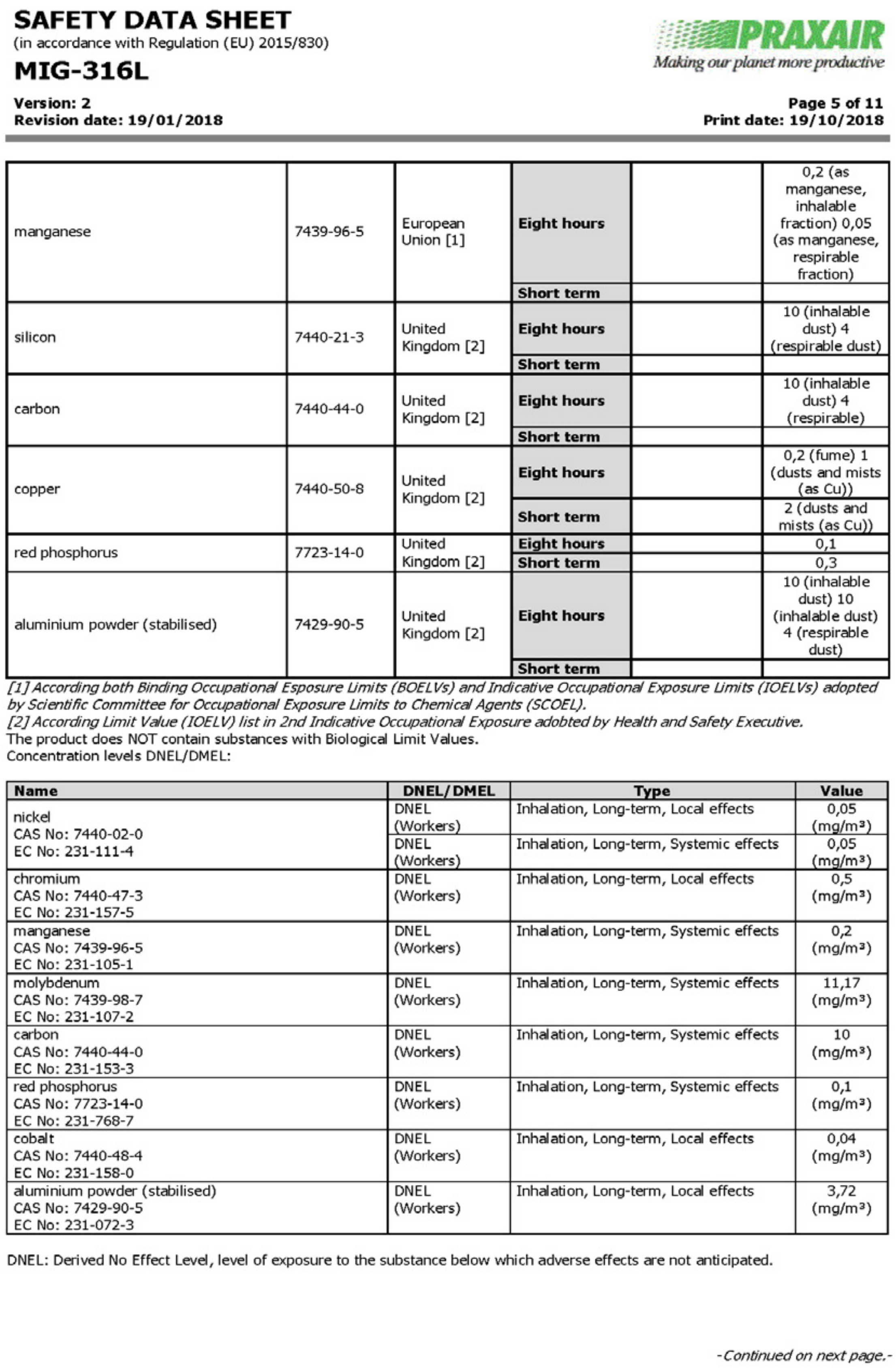

SAFETY DATA SHEET

(in accordance with Regulation (EU) 2015/830)

MIG-316L

Version: 2
Revision date: 19/01/2018

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Print date: 19/10/2018

manganese	7439-96-5	European Union [1]	**Eight hours**		0,2 (as manganese, inhalable fraction) 0,05 (as manganese, respirable fraction)
			Short term		
silicon	7440-21-3	United Kingdom [2]	**Eight hours**		10 (inhalable dust) 4 (respirable dust)
			Short term		
carbon	7440-44-0	United Kingdom [2]	**Eight hours**		10 (inhalable dust) 4 (respirable)
			Short term		
copper	7440-50-8	United Kingdom [2]	**Eight hours**		0,2 (fume) 1 (dusts and mists (as Cu))
			Short term		2 (dusts and mists (as Cu))
red phosphorus	7723-14-0	United Kingdom [2]	**Eight hours**		0,1
			Short term		0,3
aluminium powder (stabilised)	7429-90-5	United Kingdom [2]	**Eight hours**		10 (inhalable dust) 10 (inhalable dust) 4 (respirable dust)
			Short term		

[1] According both Binding Occupational Esposure Limits (BOELVs) and Indicative Occupational Exposure Limits (IOELVs) adopted by Scientific Committee for Occupational Exposure Limits to Chemical Agents (SCOEL).
[2] According Limit Value (IOELV) list in 2nd Indicative Occupational Exposure adobted by Health and Safety Executive.
The product does NOT contain substances with Biological Limit Values.
Concentration levels DNEL/DMEL:

Name	**DNEL/DMEL**	**Type**	**Value**
nickel CAS No: 7440-02-0 EC No: 231-111-4	DNEL (Workers)	Inhalation, Long-term, Local effects	0,05 (mg/m³)
	DNEL (Workers)	Inhalation, Long-term, Systemic effects	0,05 (mg/m³)
chromium CAS No: 7440-47-3 EC No: 231-157-5	DNEL (Workers)	Inhalation, Long-term, Local effects	0,5 (mg/m³)
manganese CAS No: 7439-96-5 EC No: 231-105-1	DNEL (Workers)	Inhalation, Long-term, Systemic effects	0,2 (mg/m³)
molybdenum CAS No: 7439-98-7 EC No: 231-107-2	DNEL (Workers)	Inhalation, Long-term, Systemic effects	11,17 (mg/m³)
carbon CAS No: 7440-44-0 EC No: 231-153-3	DNEL (Workers)	Inhalation, Long-term, Systemic effects	10 (mg/m³)
red phosphorus CAS No: 7723-14-0 EC No: 231-768-7	DNEL (Workers)	Inhalation, Long-term, Systemic effects	0,1 (mg/m³)
cobalt CAS No: 7440-48-4 EC No: 231-158-0	DNEL (Workers)	Inhalation, Long-term, Local effects	0,04 (mg/m³)
aluminium powder (stabilised) CAS No: 7429-90-5 EC No: 231-072-3	DNEL (Workers)	Inhalation, Long-term, Local effects	3,72 (mg/m³)

DNEL: Derived No Effect Level, level of exposure to the substance below which adverse effects are not anticipated.

-Continued on next page.-

Welding and cutting of stainless steels

DMEL: Derived Minimal Effect Level, exposure level corresponding to a low risk, that risk should be considered a tolerable minimum.

8.2 Exposure controls.

Measures of a technical nature:
Provide adequate ventilation, which can be achieved by using good local exhaust-ventilation and a good general exhaust system.

Concentration:	**100 %**				
Uses:	**Cable para soldadura. Sólo para procesos de soldadura.**				
Breathing protection:					
PPE:	Filter mask for protection against gases and particles.				
Characteristics:	«CE» marking, category III. The mask must have a wide field of vision and an anatomically designed form in order to be sealed and watertight.				
CEN standards:	EN 136, EN 140, EN 405				
Maintenance:	Should not be stored in places exposed to high temperatures and damp environments before use. Special attention should be paid to the state of the inhalation and exhalation valves in the face adaptor.				
Observations:	Read carefully the manufacturer's instructions regarding the equipment's use and maintenance. Attach the necessary filters to the equipment according to the specific nature of the risk (Particles and aerosols: P1-P2-P3, Gases and vapours: A-B-E-K-AX), changing them as advised by the manufacturer.				
Filter Type needed:	A2				
Hand protection:					
PPE:	Work gloves.				
Characteristics:	«CE» marking, category I.				
CEN standards:	EN 374-1, En 374-2, EN 374-3, EN 420				
Maintenance:	Keep in a dry place, away from any sources of heat, and avoid exposure to sunlight as much as possible. Do not make any changes to the gloves that may alter their resistance, or apply paints, solvents or adhesives.				
Observations:	Gloves should be of the appropriate size and fit the user's hand well, not being too loose or too tight. Always use with clean, dry hands.				
Material:	PVC (polyvinyl chloride)	Breakthrough time (min.):	> 480	Material thickness (mm):	0,35
Eye protection:					
PPE:	Protective goggles against particle impacts.				
Characteristics:	«CE» marking, category II. Eye protector against dust and smoke.				
CEN standards:	EN 165, EN 166, EN 167, EN 168				
Maintenance:	Visibility through lenses should be ideal. Therefore, these parts should be cleaned daily. Protectors should be disinfected periodically following the manufacturer's instructions.				
Observations:	Some signs of wear and tear include: yellow colouring of the lenses, superficial scratching of the lenses, scraping etc.				
Skin protection:					
PPE:	Protective clothing.				
Characteristics:	«CE» marking, category II. Protective clothing should not be too tight or loose in order not to obstruct the user's movements.				
CEN standards:	EN 340				
Maintenance:	In order to guarantee uniform protection, follow the washing and maintenance instructions provided by the manufacturer.				
Observations:	The protective clothing should offer a level of comfort in line with the level of protection provided in terms of the hazard against which it protects, bearing in mind environmental conditions, the user's level of activity and the expected time of use.				
PPE:	Work footwear.				
Characteristics:	«CE» marking, category II.				
CEN standards:	EN ISO 13287, EN 20347				
Maintenance:	This product adapts to the first user's foot shape. That is why, as well as for hygienic reasons, it should not be used by other people.				
Observations:	Work footwear for professional use includes protection elements aimed at protecting users against any injury resulting from an accident				

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES.

9.1 Information on basic physical and chemical properties.
Appearance: Bare stainless steel cable.

-Continued on next page.-

Colour: Steel with a shiny appearance or with a matt finish.
Odour: Odorless.
Odour threshold:N.A./N.A.
pH:N.A./N.A.
Melting point:1600 - 2100 ºC
Boiling Point: N.A./N.A.
Flash point: N.A./N.A.
Evaporation rate: N.A./N.A.
Inflammability (solid, gas): N.A./N.A.
Lower Explosive Limit: N.A./N.A.
Upper Explosive Limit: N.A./N.A.
Vapour pressure: N.A./N.A.
Vapour density:N.A./N.A.
Relative density:7,7 - 8,1
Solubility:N.A./N.A.
Liposolubility: N.A./N.A.
Hydrosolubility: N.A./N.A.
Partition coefficient (n-octanol/water): N.A./N.A.
Auto-ignition temperature: N.A./N.A.
Decomposition temperature: N.A./N.A.
Viscosity: N.A./N.A.
Explosive properties: N.A./N.A.
Oxidizing properties: N.A./N.A.
N.A./N.A.= Not Available/Not Applicable due to the nature of the product

9.2 Other information.

Dropping point: N.A./N.A.
Blink: N.A./N.A.
Kinematic viscosity: N.A./N.A.
N.A./N.A.= Not Available/Not Applicable due to the nature of the product

SECTION 10: STABILITY AND REACTIVITY.

10.1 Reactivity.

The product does not present hazards by their reactivity.

10.2 Chemical stability.

Stable under the recommended handling and storage conditions (see section 7).

10.3 Possibility of hazardous reactions.

The product does not present possibility of hazardous reactions.

10.4 Conditions to avoid.

Avoid any improper handling.

10.5 Incompatible materials.

Keep away from oxidising agents and from highly alkaline or acidic materials in order to prevent exothermic reactions.

10.6 Hazardous decomposition products.

No decomposition if used for the intended uses.

SECTION 11: TOXICOLOGICAL INFORMATION.

11.1 Information on toxicological effects.

Repeated or prolonged contact with the product can cause the elimination of oil from the skin, giving rise to non-allergic cont dermatitis and absorption of the product through the skin.
Splatters in the eyes can cause irritation and reversible damage.

Toxicological information about the substances present in the composition.

-Continued on next pag

Name	Acute toxicity			
	Type	**Test**	**Kind**	**Value**
silicon CAS No: 7440-21-3 EC No: 231-130-8	Oral	LD50	Rat	3160 mg/kg [1]
		[1] FAO Nutrition Meetings Report Series. Vol. 53A, Pg. 21, 1974.		
	Dermal			
	Inhalation			

a) acute toxicity;
Not conclusive data for classification.

b) skin corrosion/irritation;
Not conclusive data for classification.

c) serious eye damage/irritation;
Based on available data, the classification criteria are not met.

d) respiratory or skin sensitisation;
Product classified:
Skin sensitiser, Category 1: May cause an allergic skin reaction.

e) germ cell mutagenicity;
Not conclusive data for classification.

f) carcinogenicity;
Product classified:
Carcinogen, Category 2: Suspected of causing cancer.

g) reproductive toxicity;
Product classified:
Reproductive toxicant, Category 2: Suspected of damaging fertility or the unborn child.

h) STOT-single exposure;
Not conclusive data for classification.

i) STOT-repeated exposure;
Product classified:
Specific target organ toxicity following a repeated exposure, Category 1: Causes damage to organs through prolonged or repeated exposure.

j) aspiration hazard;
Not conclusive data for classification.

SECTION 12: ECOLOGICAL INFORMATION.

12.1 Toxicity.

Name	Ecotoxicity			
	Type	**Test**	**Kind**	**Value**
molybdenum CAS No: 7439-98-7 EC No: 231-107-2	Fish	LC50	Fish	1060 mg/l (96 h) [1]
		[1] Goettl, J.P.Jr., P.H. Davies, and J.R. Sinley 1976. Water Pollution Studies. In: D.B.Cope (Ed.), Colorado Fish.Res.Rev.1972-1975, DOW-R-R-F72-75, Colorado Div.of Wildl., Boulder, CO :68-75		
	Aquatic invertebrates			
	Aquatic plants			

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12.2 Persistence and degradability.

No information is available regarding the biodegradability of the substances present.
No information is available on the degradability of the substances present.
No information is available about persistence and degradability of the product.

12.3 Bioaccumulative potential.

No information is available regarding the bioaccumulation of the substances present.

12.4 Mobility in soil.

No information is available about the mobility in soil.
The product must not be allowed to go into sewers or waterways.
Prevent penetration into the ground.

12.5 Results of PBT and vPvB assessment.

No information is available about the results of PBT and vPvB assessment of the product.

12.6 Other adverse effects.

No information is available about other adverse effects for the environment.

SECTION 13 DISPOSAL CONSIDERATIONS.

13.1 Waste treatment methods.

Do not dump into sewers or waterways. Waste and empty containers must be handled and eliminated according to current, local/national legislation.
Follow the provisions of Directive 2008/98/EC regarding waste management.

Waste classification according to the European Waste Catalogue:
12 WASTES FROM SHAPING AND PHYSICAL AND MECHANICAL SURFACE TREATMENT OF METALS AND PLASTICS
12 01 wastes from shaping and physical and mechanical surface treatment of metals and plastics
12 01 02 ferrous metal dust and particles

Method of treatment according to Directive 2008/98/EC:
Recovery
R4 Recycling/reclamation of metals and metal compounds

SECTION 14: TRANSPORT INFORMATION.

Transportation is not dangerous. In case of road accident causing the product's spillage, proceed in accordance with point 6.

14.1 UN number.

Transportation is not dangerous.

14.2 UN proper shipping name.

Description:
ADR: Transportation is not dangerous.
IMDG: Transportation is not dangerous.
ICAO/IATA: Transportation is not dangerous.

14.3 Transport hazard class(es).

Transportation is not dangerous.

14.4 Packing group.

Transportation is not dangerous.

14.5 Environmental hazards.

Transportation is not dangerous.

14.6 Special precautions for user.

Transportation is not dangerous.

-Continued on next page.-

14.7 Transport in bulk according to Annex II of MARPOL and the IBC Code.
Transportation is not dangerous.

SECTION 15: REGULATORY INFORMATION.

15.1 Safety, health and environmental regulations/legislation specific for the mixture.

The product is not affected by the Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 on substances that deplete the ozone layer.

The product is not affected by Directive 2012/18/EU (SEVESO III).
The product is not affected by Regulation (EU) No 528/2012 concerning the making available on the market and use of biocidal products.
The product is not affected by the procedure established Regulation (EU) No 649/2012, concerning the export and import of dangerous chemicals.
Restrictions on the manufacturing, placing on the market and use of certain dangerous substances, mixtures and articles:

Designation of the substance, of the group of substances or of the mixture	**Conditions of restriction**
27. Nickel CAS No 7440-02-0 EC No 231-111-4 and its compounds	1. Shall not be used: (a) in any post assemblies which are inserted into pierced ears and other pierced parts of the human body unless the rate of nickel release from such post assemblies is less than 0,2 µg/cm2/week (migration limit); (b) in articles intended to come into direct and prolonged contact with the skin such as: - earrings, - necklaces, bracelets and chains, anklets, finger rings, - wrist-watch cases, watch straps and tighteners, - rivet buttons, tighteners, rivets, zippers and metal marks, when these are used in garments, if the rate of nickel release from the parts of these articles coming into direct and prolonged contact with the skin is greater than 0,5 µg/cm2/week. (c) in articles referred to in point (b) where these have a non-nickel coating unless such coating is sufficient to ensure that the rate of nickel release from those parts of such articles coming into direct and prolonged contact with the skin will not exceed 0,5 µg/cm2/week for a period of at least two years of normal use of the article. 2. Articles which are the subject of paragraph 1 shall not be placed on the market unless they conform to the requirements set out in that paragraph. 3. The standards adopted by the European Committee for Standardisation (CEN) shall be used as the test methods for demonstrating the conformity of articles to paragraphs 1 and 2.

15.2 Chemical safety assessment.

No Chemical Safety Assessment has been carried out for this substance/mixture by the supplier.

SECTION 16: OTHER INFORMATION.

Complete text of the H phrases that appear in section 3:

H228	Flammable solid.
H261	In contact with water releases flammable gases.
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.
H332	Harmful if inhaled.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H351	Suspected of causing cancer.
H361	Suspected of damaging fertility or the unborn child.
H372	Causes damage to organs through prolonged or repeated exposure.
H412	Harmful to aquatic life with long lasting effects.
H413	May cause long lasting harmful effects to aquatic life.

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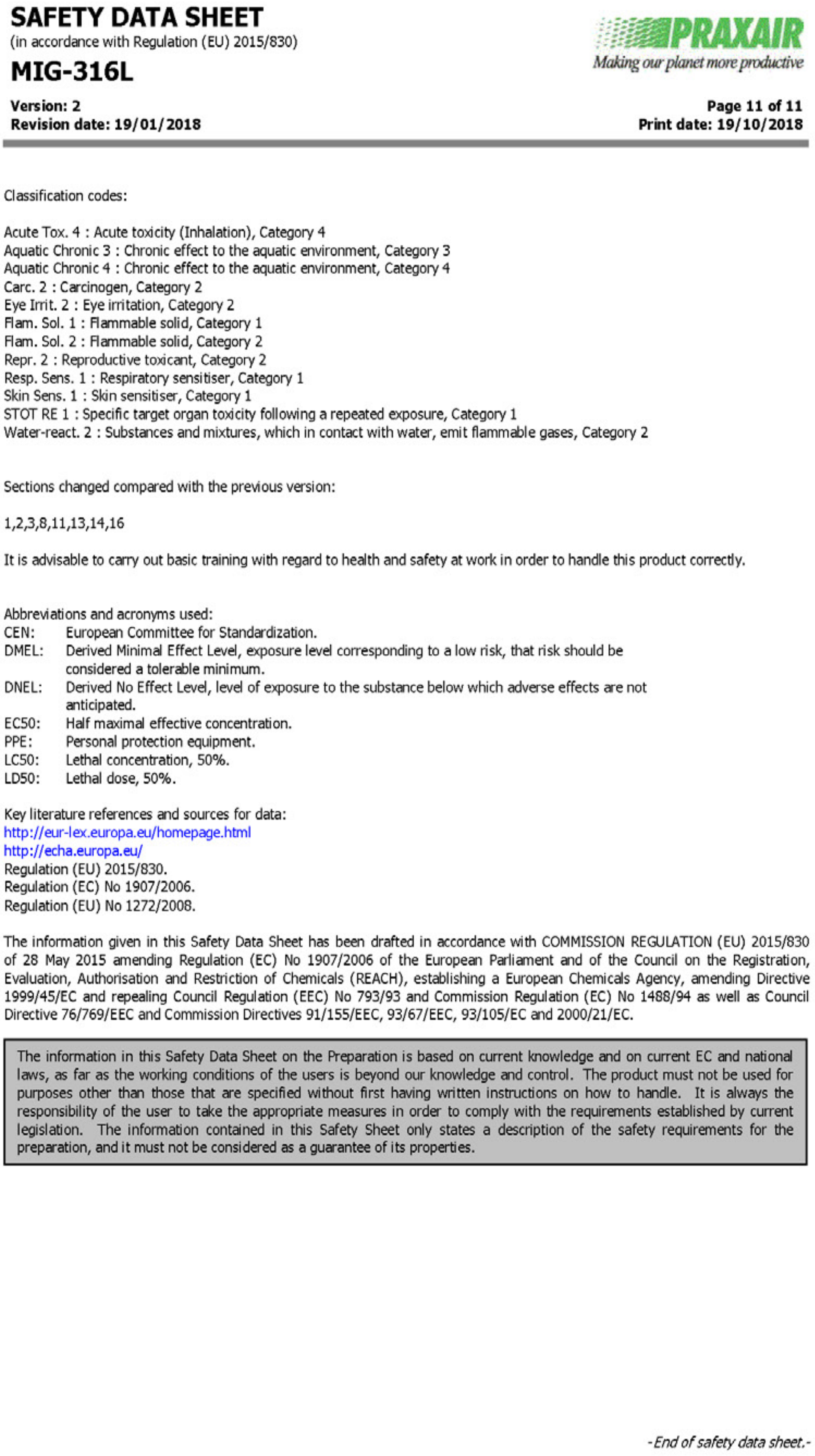


Classification codes:

Acute Tox. 4 : Acute toxicity (Inhalation), Category 4
Aquatic Chronic 3 : Chronic effect to the aquatic environment, Category 3
Aquatic Chronic 4 : Chronic effect to the aquatic environment, Category 4
Carc. 2 : Carcinogen, Category 2
Eye Irrit. 2 : Eye irritation, Category 2
Flam. Sol. 1 : Flammable solid, Category 1
Flam. Sol. 2 : Flammable solid, Category 2
Repr. 2 : Reproductive toxicant, Category 2
Resp. Sens. 1 : Respiratory sensitiser, Category 1
Skin Sens. 1 : Skin sensitiser, Category 1
STOT RE 1 : Specific target organ toxicity following a repeated exposure, Category 1
Water-react. 2 : Substances and mixtures, which in contact with water, emit flammable gases, Category 2

Sections changed compared with the previous version:

1,2,3,8,11,13,14,16

It is advisable to carry out basic training with regard to health and safety at work in order to handle this product correctly.

Abbreviations and acronyms used:

CEN:	European Committee for Standardization.
DMEL:	Derived Minimal Effect Level, exposure level corresponding to a low risk, that risk should be considered a tolerable minimum.
DNEL:	Derived No Effect Level, level of exposure to the substance below which adverse effects are not anticipated.
EC50:	Half maximal effective concentration.
PPE:	Personal protection equipment.
LC50:	Lethal concentration, 50%.
LD50:	Lethal dose, 50%.

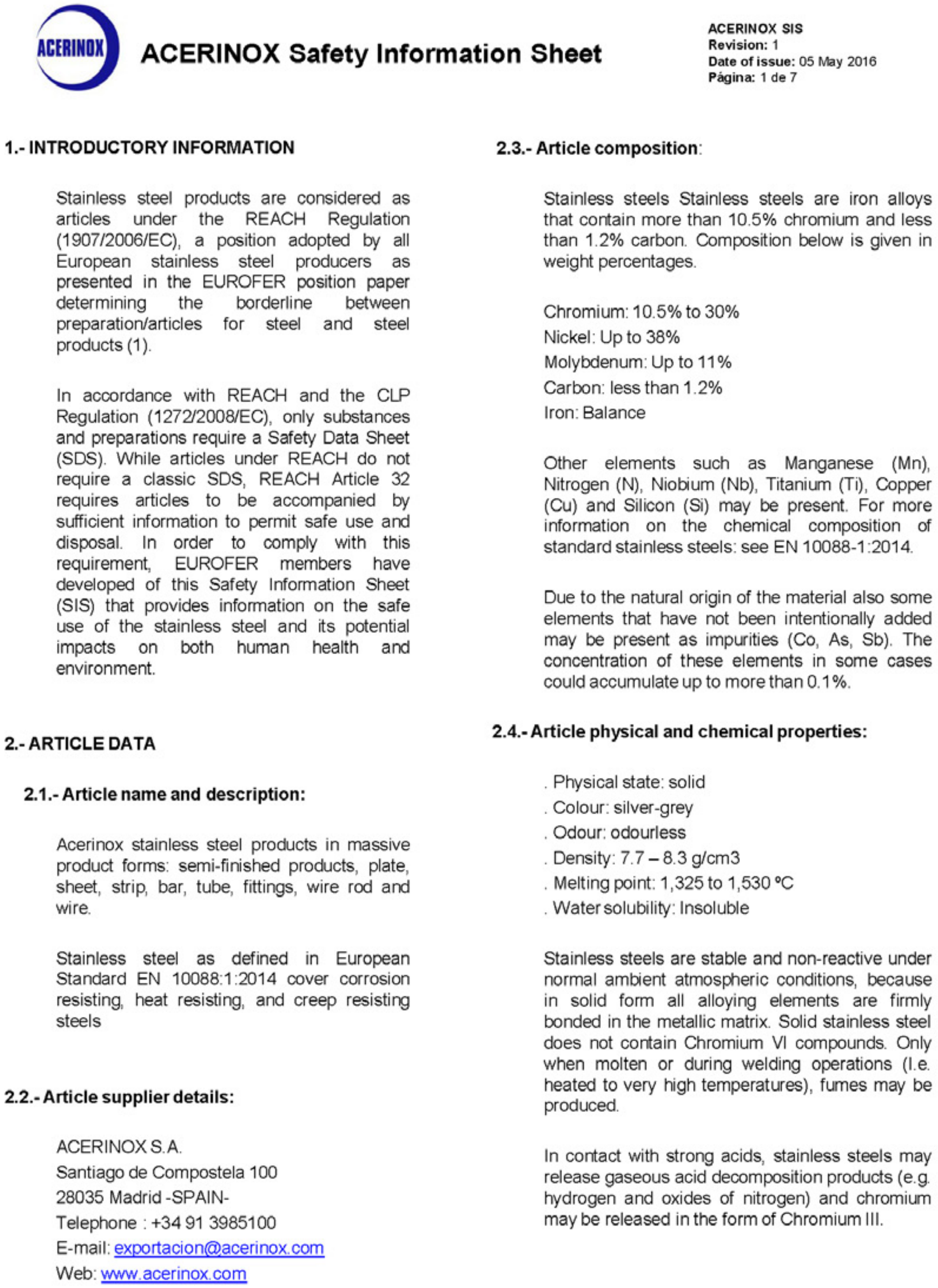
Key literature references and sources for data:
http://eur-lex.europa.eu/homepage.html
http://echa.europa.eu/
Regulation (EU) 2015/830.
Regulation (EC) No 1907/2006.
Regulation (EU) No 1272/2008.

The information given in this Safety Data Sheet has been drafted in accordance with COMMISSION REGULATION (EU) 2015/830 of 28 May 2015 amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

The information in this Safety Data Sheet on the Preparation is based on current knowledge and on current EC and national laws, as far as the working conditions of the users is beyond our knowledge and control. The product must not be used for purposes other than those that are specified without first having written instructions on how to handle. It is always the responsibility of the user to take the appropriate measures in order to comply with the requirements established by current legislation. The information contained in this Safety Sheet only states a description of the safety requirements for the preparation, and it must not be considered as a guarantee of its properties.

-End of safety data sheet.-

Appendix 2



ACERINOX Safety Information Sheet

ACERINOX SIS
Revision: 1
Date of issue: 05 May 2016
Página: 1 de 7

1.- INTRODUCTORY INFORMATION

Stainless steel products are considered as articles under the REACH Regulation (1907/2006/EC), a position adopted by all European stainless steel producers as presented in the EUROFER position paper determining the borderline between preparation/articles for steel and steel products (1).

In accordance with REACH and the CLP Regulation (1272/2008/EC), only substances and preparations require a Safety Data Sheet (SDS). While articles under REACH do not require a classic SDS, REACH Article 32 requires articles to be accompanied by sufficient information to permit safe use and disposal. In order to comply with this requirement, EUROFER members have developed of this Safety Information Sheet (SIS) that provides information on the safe use of the stainless steel and its potential impacts on both human health and environment.

2.- ARTICLE DATA

2.1.- Article name and description:

Acerinox stainless steel products in massive product forms: semi-finished products, plate, sheet, strip, bar, tube, fittings, wire rod and wire.

Stainless steel as defined in European Standard EN 10088:1:2014 cover corrosion resisting, heat resisting, and creep resisting steels

2.2.- Article supplier details:

ACERINOX S.A.
Santiago de Compostela 100
28035 Madrid -SPAIN-
Telephone : +34 91 3985100
E-mail: exportacion@acerinox.com
Web: www.acerinox.com

2.3.- Article composition:

Stainless steels Stainless steels are iron alloys that contain more than 10.5% chromium and less than 1.2% carbon. Composition below is given in weight percentages.

Chromium: 10.5% to 30%
Nickel: Up to 38%
Molybdenum: Up to 11%
Carbon: less than 1.2%
Iron: Balance

Other elements such as Manganese (Mn), Nitrogen (N), Niobium (Nb), Titanium (Ti), Copper (Cu) and Silicon (Si) may be present. For more information on the chemical composition of standard stainless steels: see EN 10088-1:2014.

Due to the natural origin of the material also some elements that have not been intentionally added may be present as impurities (Co, As, Sb). The concentration of these elements in some cases could accumulate up to more than 0.1%.

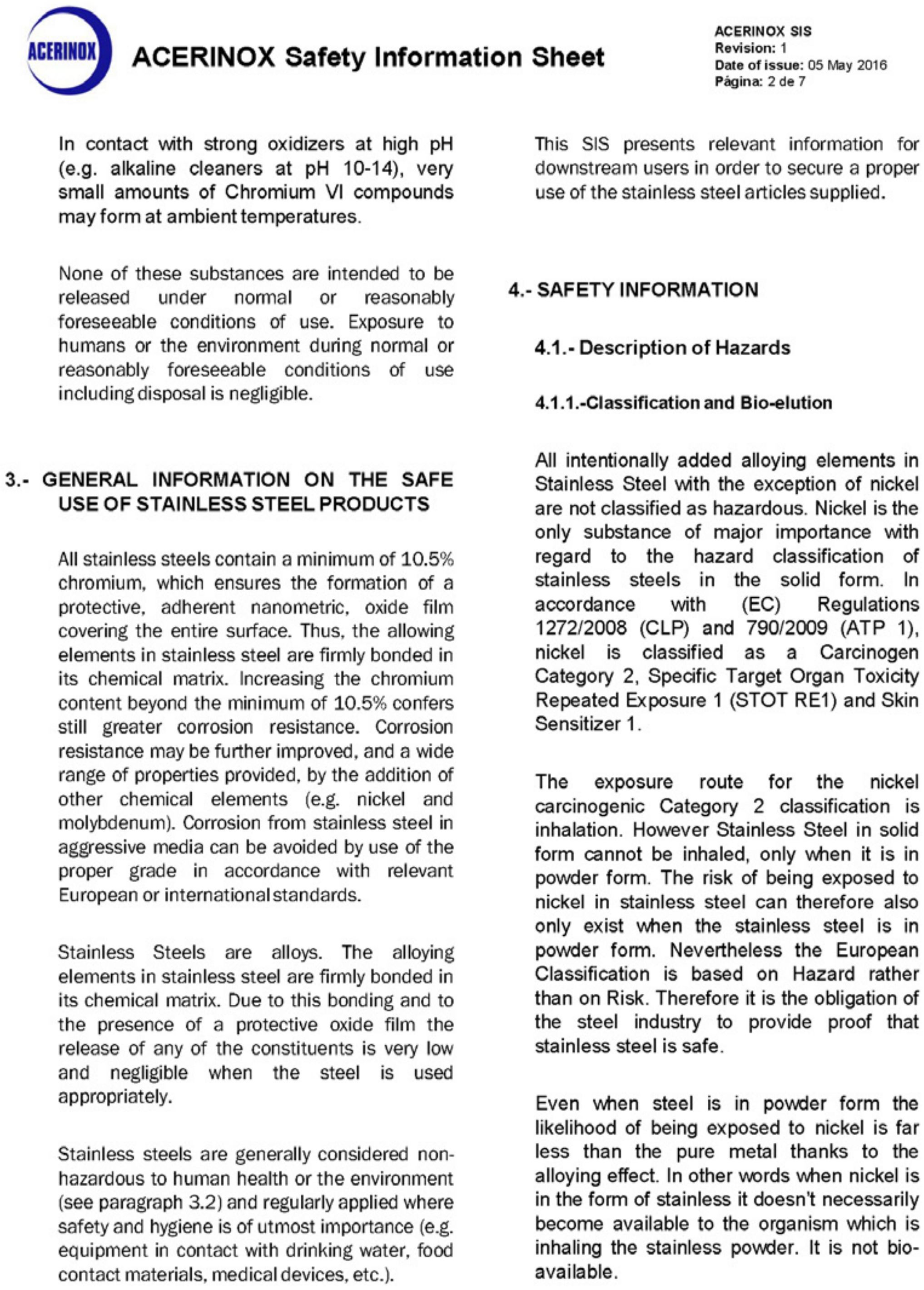
2.4.- Article physical and chemical properties:

. Physical state: solid
. Colour: silver-grey
. Odour: odourless
. Density: 7.7 – 8.3 g/cm3
. Melting point: 1,325 to 1,530 °C
. Water solubility: Insoluble

Stainless steels are stable and non-reactive under normal ambient atmospheric conditions, because in solid form all alloying elements are firmly bonded in the metallic matrix. Solid stainless steel does not contain Chromium VI compounds. Only when molten or during welding operations (I.e. heated to very high temperatures), fumes may be produced.

In contact with strong acids, stainless steels may release gaseous acid decomposition products (e.g. hydrogen and oxides of nitrogen) and chromium may be released in the form of Chromium III.

Welding and cutting of stainless steels



In contact with strong oxidizers at high pH (e.g. alkaline cleaners at pH 10-14), very small amounts of Chromium VI compounds may form at ambient temperatures.

None of these substances are intended to be released under normal or reasonably foreseeable conditions of use. Exposure to humans or the environment during normal or reasonably foreseeable conditions of use including disposal is negligible.

3.- GENERAL INFORMATION ON THE SAFE USE OF STAINLESS STEEL PRODUCTS

All stainless steels contain a minimum of 10.5% chromium, which ensures the formation of a protective, adherent nanometric, oxide film covering the entire surface. Thus, the allowing elements in stainless steel are firmly bonded in its chemical matrix. Increasing the chromium content beyond the minimum of 10.5% confers still greater corrosion resistance. Corrosion resistance may be further improved, and a wide range of properties provided, by the addition of other chemical elements (e.g. nickel and molybdenum). Corrosion from stainless steel in aggressive media can be avoided by use of the proper grade in accordance with relevant European or international standards.

Stainless Steels are alloys. The alloying elements in stainless steel are firmly bonded in its chemical matrix. Due to this bonding and to the presence of a protective oxide film the release of any of the constituents is very low and negligible when the steel is used appropriately.

Stainless steels are generally considered non-hazardous to human health or the environment (see paragraph 3.2) and regularly applied where safety and hygiene is of utmost importance (e.g. equipment in contact with drinking water, food contact materials, medical devices, etc.).

This SIS presents relevant information for downstream users in order to secure a proper use of the stainless steel articles supplied.

4.- SAFETY INFORMATION

4.1.- Description of Hazards

4.1.1.-Classification and Bio-elution

All intentionally added alloying elements in Stainless Steel with the exception of nickel are not classified as hazardous. Nickel is the only substance of major importance with regard to the hazard classification of stainless steels in the solid form. In accordance with (EC) Regulations 1272/2008 (CLP) and 790/2009 (ATP 1), nickel is classified as a Carcinogen Category 2, Specific Target Organ Toxicity Repeated Exposure 1 (STOT RE1) and Skin Sensitizer 1.

The exposure route for the nickel carcinogenic Category 2 classification is inhalation. However Stainless Steel in solid form cannot be inhaled, only when it is in powder form. The risk of being exposed to nickel in stainless steel can therefore also only exist when the stainless steel is in powder form. Nevertheless the European Classification is based on Hazard rather than on Risk. Therefore it is the obligation of the steel industry to provide proof that stainless steel is safe.

Even when steel is in powder form the likelihood of being exposed to nickel is far less than the pure metal thanks to the alloying effect. In other words when nickel is in the form of stainless it doesn't necessarily become available to the organism which is inhaling the stainless powder. It is not bio-available.

This bio-availability can only be proven by doing in vivo testing using test animals. There are two tests described in literature for in Vivo testing of stainless powder (2, 3, 4).

As industry is encouraged to find alternative ways to animal testing the non-ferrous metals industry in Europe is developing a testing methodology based on Bio-elution. This methodology is an in vitro methodology thus preventing the necessity of in vivo testing. In Bio-elution body fluids like saliva, gastric, lung and intestinal fluids are mimicked and the specific release of constituents is tested. In these tests the bio-accessibility is being established.

The European Steel Industry together with the European Non-ferrous industry strongly believe that bio-accessibility in vitro tests will become a good and sustainable alternative to animal testing and we believe that bio-accessibility data are a good predictor of bioavailability and toxicity for use in hazard assessment.

4.1.2.-Sensitization

According to REACH (5), alloys that contain Ni and that could come in frequent contact with skin, may be tested according to European standard EN1811 to determine the release rate of Ni. Tests conducted in accordance with this standard determined that stainless steels release nickel at levels significantly below the criteria set for classification as a skin sensitizer. Thus, stainless steels in general are suitable for use as piercing posts (where the maximum nickel release limits is 0.2 µg/cm2/week) and for those applications involving close and prolonged contact with the skin (where the maximum nickel release limits is 0.5 µg/cm2/week).

However, tests conducted in accordance with EN 1811 (6) have shown that the resulphurised free-machining stainless steels (containing 0.15 – 0.30 % sulphur) release nickel at levels close to, or above, the maximum nickel release limit 0.5 µg/cm2/week. Resulphurised free-machining stainless steels are, therefore, not suitable for use as piercing posts or for applications involving prolonged contact with the skin (i.e. jewellery, watch backs and watch straps, etc.).

Clinical studies did not reveal any risk of allergy among individual already sensitised to nickel. Thus, frequent intermittent contact with stainless steels of all types should not pose a problem to downstream users or consumers (7).

4.1.3.-Specific Target Organ Toxicity

In accordance with the CLP Regulation, stainless steels are considered to be mixtures (8, 9). This means that stainless steels containing more than 10% nickel should be classified as Specific Target Organ Toxicity Repeated Exposure 1 (STOT RE1) and stainless steels containing 1 - 10% nickel should be classified as STOT RE 2. Stainless steels containing less than 1% nickel are not classified.

However, a 28-day repeated inhalation study on rats with stainless steel in the powder form (2) clearly indicates a lack of toxicity (i.e. no adverse effects were seen, even at the highest concentration of stainless steel, which was 1.0 mg/L in the study), whereas the lowest nickel dose (0.004 mg/L) resulted in clear signs of toxicity in a 28-day nickel inhalation study (3, 4). No classification of stainless steel for STOT is proposed.

4.1.4.- Carcinogenicity

In accordance with the CLP Regulation, stainless steels are considered to be mixtures. This means that stainless steels containing more than 1% nickel should be classified as Carcinogen Category 2 when it is classified as a simple mixture. However, no carcinogenic effects resulting from exposure to stainless steels have been reported, either in epidemiological studies or in tests with animals (7). Therefore, it can be concluded that the weight of evidence supports the non-carcinogenicity of stainless steel.

In addition, IARC (International Agency for Research on Cancer) has concluded that stainless steel implants are not classifiable as to their carcinogenicity to humans (10). Several stainless steel grades are specifically designed for use in human implant parts (see ISO 5832).

Stainless steels containing less than 1% Ni are not classified.

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4.1.5.-Summary classification

According to CLP an alloy can be classified either on its constituents classification (simple mixture) or on the hazard properties the mixture if they have been tested. Based on studies on the stainless steel alloy (7) the steel industry proposes the following classification for stainless steel:

No classification for most stainless steel grades.

For re-sulphurised grades (0.15 – 0.30 % sulphur) Skin Sensitizer .

For a comparison between classification according to constituent and classification based on alloy testing, see Annex 1.

4.2.- Specific process and exposure controls

Dust and fume may be generated during processing e.g. in welding, cutting and grinding. If airborne concentrations of dust and fume are excessive, inhalation over long periods may affect workers' health, primarily of the lungs. Dust and fume quantity and composition depend on specific practice. Oxidized forms of the various alloying elements of stainless steel may be found in welding fumes.

Over long periods, inhalation of excessive airborne levels may have long term health effects, primarily affecting the lungs. Studies of workers exposed to nickel powder, and dust and fumes generated in the production of nickel alloys and stainless steels have not indicated a respiratory cancer hazard (7).

Chromium in stainless steel is in the metallic state (zero valence) and stainless steel does not contain hexavalent chromium. Welding and flame cutting fumes may contain hexavalent chromium compounds. Studies have shown that some hexavalent chromium compounds can cause cancer. However, epidemiological studies amongst welders indicate no extra increased risk of cancer when welding stainless steels, compared with the slightly increased risk when welding steels that do not contain chromium. IARC has defined the welding process and welding fumes as a risk, irrespectively of which metals that are involved (11).

The process of welding should only be performed by trained workers with the personal protective equipment in accordance with the laws of each Member State relating to safety. Guidance on the welding of metals and alloys is provided on the European Welding Association website (12). The guidance document will provide background information on health hazards posed by welding processes and appropriate Risk Management Measures.

There are no specific occupational exposure limits for stainless steel. However, specific occupational exposure limits have been established for some constituent elements and compounds. Users of this Safety Information Sheet are strongly advised to refer to the Occupational Exposure Limits set by their EU Member State for the substances in stainless steel and where relevant, welding fumes.

4.3.- First Aid Measures

There are no specific First Aid Measures developed for the stainless steel. Medical attention should be provided in case of an excessive inhalation of dust or a physical injury to the skin or to the eyes.

In case of eye injury note that austenitic stainless steel particles are non-magnetic or only slightly magnetic and may not respond to a magnet placed over the eye. In such cases seek hospital treatment.

4.4.- Handling and Storage

There are no special measures for handling stainless steels. Normal precautions should be taken to avoid physical injuries produced mainly by sharp edges. Personal protective equipment must be used e.g. special gloves and eye protection.

Stainless steels should be stored in manner that prevents iron contamination. Avoid placing or storing stainless steel in uncoated iron or steel racks and protect from iron emissions from cutting/grinding operations.

Care should be taken to avoid exposing fine process dust (e.g. from grinding and blasting operations) to high temperatures as it may present a potential fire hazard.

4.5.- Uses

Stainless steels are present in a wide variety of activities. Main use areas include industrial processes, architectural and building, house appliances and kitchenware, catering and transportation.

4.5.1.-Food Contact

Stainless steel has been in use for contact with food for many years and is present in various articles (kitchenware, bowls, and industrial kitchen appliances). Depending on the application (knives, blades, forks, spoons, bowls), different grades are selected and have been recognized as safe. The Council of Europe has published new technical test guideline to ensure the suitability and safety of finished articles of metals and alloys in food contact (13). The release of specific constituents has to be below certain specific release limits (SRL). Some national laws also give detailed information on the choice of grades that should be allowed for food contact.

4.5.2.- Medical devices and implants

In many cases stainless steel is the only material which can be used for medical devices and/or implants. Presently the Directive 90/385/EEC on Active Implantable Medical Devices and Directive 93/42/EEC on Medical Devices are being revised.

4.5.3 .-Drinking water

The four Member States Common Approach (agreed between Germany, France, the Netherlands and the United Kingdom) describes a procedure by which a material is approved. The list of "Metallic materials suitable for drinking water under hygienic aspects" includes those metallic materials, for which the hygienic suitability for drinking water has been demonstrated. This includes stainless steel.

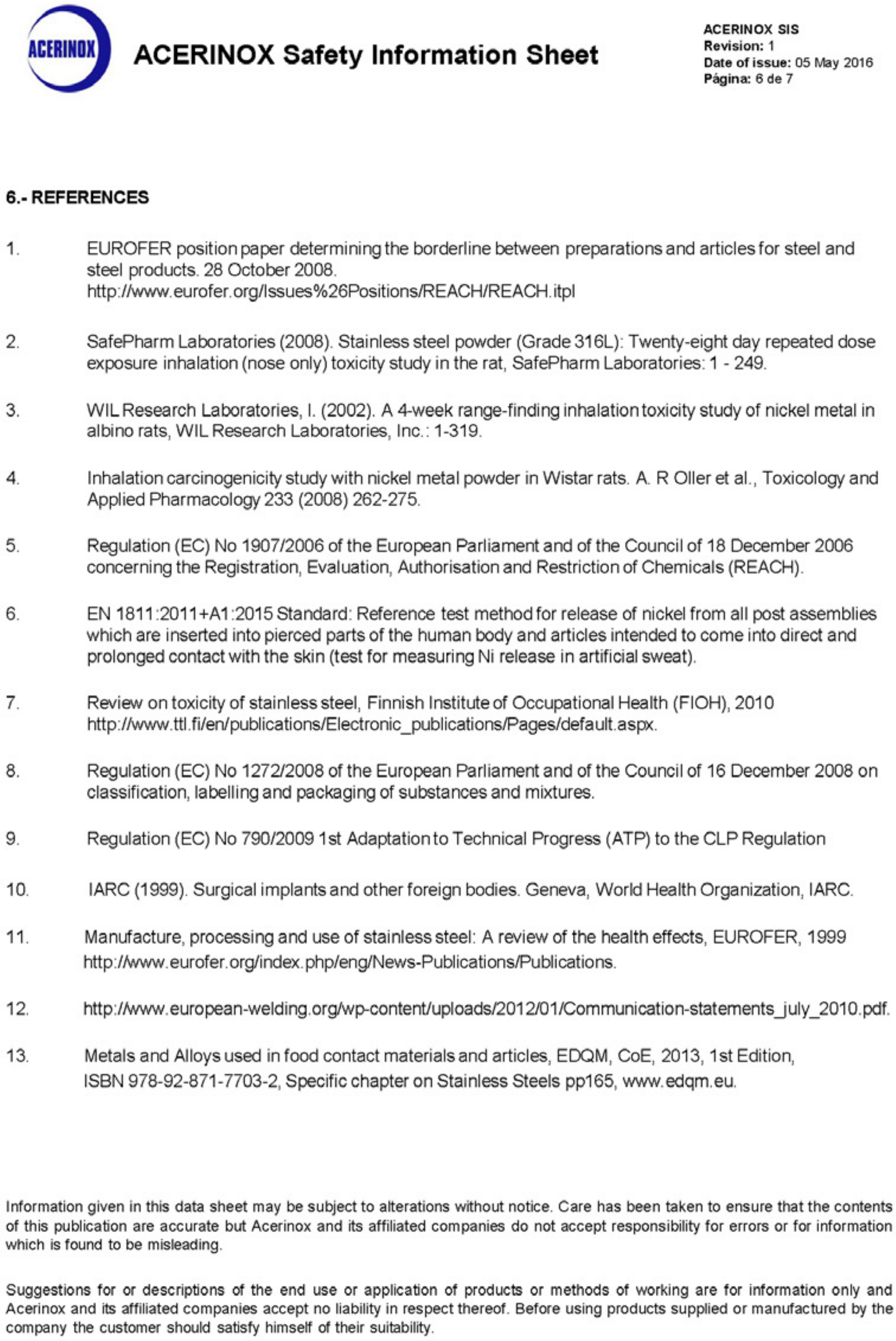
4.5.4.-Toys

Safe use of stainless steel in toys is recognized in European Directive 2009/48/EC.

5.- ENVIRONMENTAL INFORMATION

There are no hazards to the environment from stainless steel in the forms supplied.

Stainless steel is part of an integrated life cycle and it is a material that is 100% recyclable. Thus, surplus and scrap (waste) stainless steel is valuable and in demand for the production of prime new stainless steel. Recycling routes are well-established, and recycling is therefore the preferred disposal route. While disposal to landfill is not harmful to the environment, it is a waste of resources and therefore to be avoided for the benefit of recycling.



6.- REFERENCES

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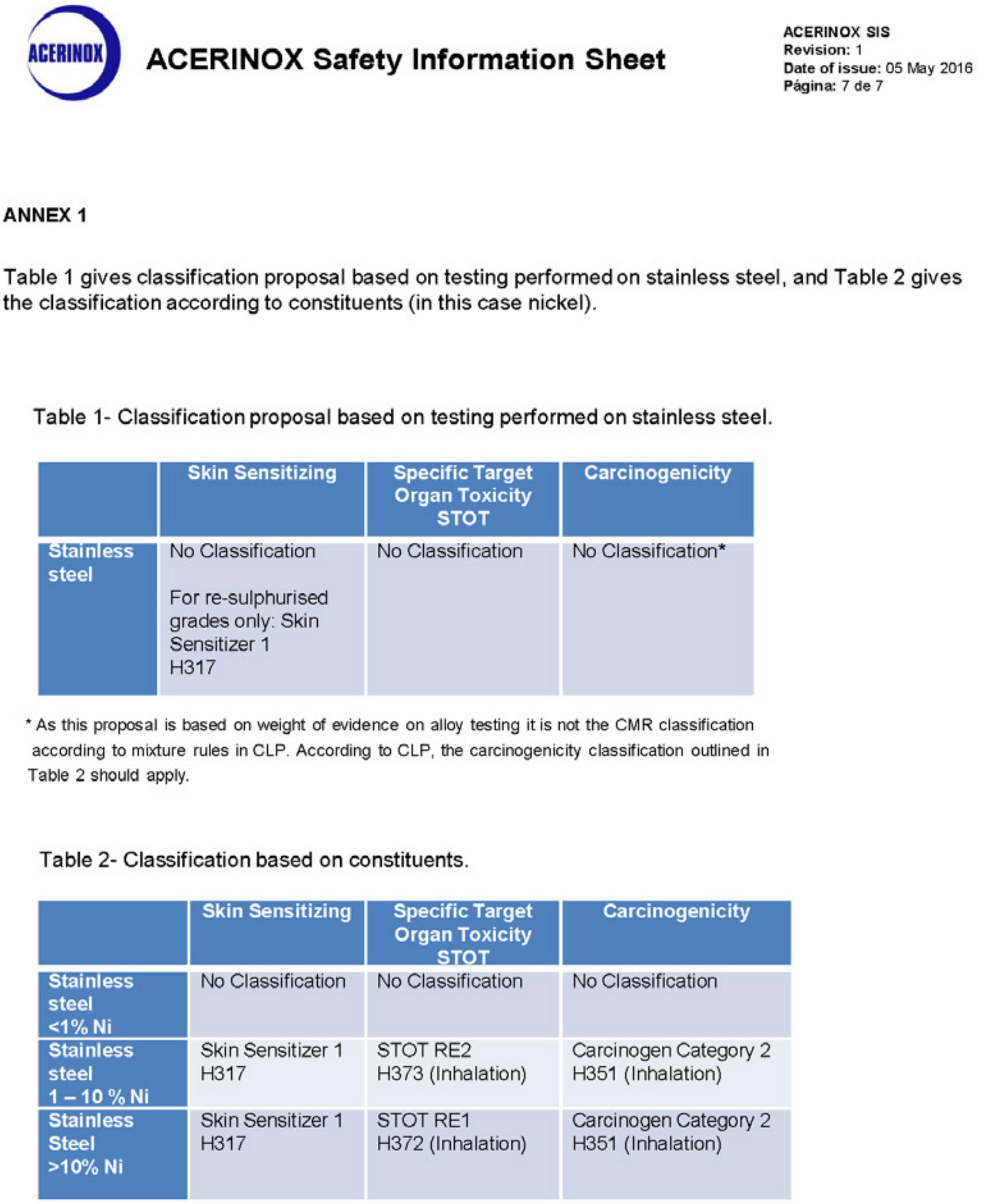

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ANNEX 1

Table 1 gives classification proposal based on testing performed on stainless steel, and Table 2 gives the classification according to constituents (in this case nickel).

Table 1- Classification proposal based on testing performed on stainless steel.

	Skin Sensitizing	Specific Target Organ Toxicity STOT	Carcinogenicity
Stainless steel	No Classification For re-sulphurised grades only: Skin Sensitizer 1 H317	No Classification	No Classification*

* As this proposal is based on weight of evidence on alloy testing it is not the CMR classification according to mixture rules in CLP. According to CLP, the carcinogenicity classification outlined in Table 2 should apply.

Table 2- Classification based on constituents.

	Skin Sensitizing	Specific Target Organ Toxicity STOT	Carcinogenicity
Stainless steel <1% Ni	No Classification	No Classification	No Classification
Stainless steel 1 – 10 % Ni	Skin Sensitizer 1 H317	STOT RE2 H373 (Inhalation)	Carcinogen Category 2 H351 (Inhalation)
Stainless Steel >10% Ni	Skin Sensitizer 1 H317	STOT RE1 H372 (Inhalation)	Carcinogen Category 2 H351 (Inhalation)

Appendix 3

1 Degree of restraint

It measures the degree of restriction to which a joint is subject. It is one of the variables that are taken into account to evaluate cracking susceptibility.

In the case of carbon steels, the variables to be estimated to evaluate whether a joint may be susceptible to cracking by martensite formation are:

- The carbon equivalent (CE) with the formula applicable to the type of carbon steel.
- Hydrogen level of the consumable.
- Thickness of the joint
- Three types are considered:
  - Low. When the joint is free or with certain freedom of movement
  - Medium. If the joint is part of a structure which reduces freedom of movement.
  - High. Where there is almost no freedom of movement. This case is the most frequent in repairs and with thick materials.
- Heat dissipation routes.

With the information about these variables, the preheating temperature required to reduce the cooling rate, the hardness reached and the possibility of cracking are estimated.

In the case of **stainless steels**, depending on the type and how cracking occurs, degree of restraint and the possibility of preheating will be taken into account.

For **austenitic** stainless steels, pre-heating is not applicable and may even be detrimental considering it increases distortion, favours intergranular corrosion and hot cracking

Which is produced when the austenite with melting point of 1450°C cools and the intergranular firm is still liquid because it has a melting point of 1100ºC. The stresses produced by this difference in temperature will cause cracking if the joint has a high degree of restraint. This cracking is avoided by choosing a suitable consumable so that a percentage of 5% delta ferrite is obtained in the bead with dilution.

In **duplex** steels, if the ferrite-austenite balance is broken due to fast cooling after welding and the ferrite content, with low ductility, rises above 60%, then if there is degree of restraint and thick materials, then cracking possibilities increase. The solution in the welding should be to choose a consumable that increases the ferrite content and in the heat affected zone preheating is required.

In **ferritic** steels, attention should be paid to type 430, which forms significant quantities of martensite in the grain edge during the weld cooling. In these cases it is advisable to take into account the degree of restraint and whether it is higher than 6 mm thick. To avoid cracking in the weld it is necessary to use an austenitic consumable and in the heat affected zone preheating is required.

Martensitic steels will increase their tendency to cracking with the increase of %C, with thickness and degree of restraint. In order to minimize cracking it is necessary to use austenitic consumables, to preheat and post weld heat treatment after welding.

2 Flux

A general definition from the metallurgical point of view is the mixture of products that reacts under welding heat and eliminates oxides of the metal to be welded, by forming slag that should be subsequently eliminated with the suitable means.

This is not the only function of flux and it may have other important functions, which are characteristic of the processes in which it takes part.

It is mentioned in three welding processes:

FCAW – Flux Cored Arc Welding (page 116),

SAW – Submerged Arc Welding (page 135),

Brazing and Soldering, (page 150).

In these last two welding processes, sometimes flux is also called deoxidizer.

Appendix 4

INOXFIL

INOXFIL

INOXFIL S.A. manufactures welding material with an optimal chemical composition and mechanical properties. The material can be delivered with dull or bright surface, suitable for each client in order to ensure high reliability and good arc stability in all welding processes such as semiautomatic and automatic. Inoxfil welding wire packages cover all possible needs of the clients.

Packaging

Welding	Packaging	Capacity (kg)
MIG/MAG (GMAW)	Plastic /metallic spool SD-300/BS300	15
	Plastic spool S-200	5
	Blue, Black metallic spool (BS 300)	15
	Metallic coil (4X) Wooden coil (4XM)	300 - 350
TIG (GTAW)	Tubes, 50 mm diameter	5
	Rectangular boxes	5
ELECTRODES	Coils	500 - 1000
SUBMERGED ARC	Metallic spool K-415 y K-435	25

Range of diameters

Welding	0.80	1.00	1.20	1.60	2.00	2.40	3.20	4.00
MIG/MAG (GMAW)	🟩	🟩	🟩	🟩				
TIG (GTAW)		🟩	🟩	🟩	🟩	🟩	🟩	
SUBMERGED ARC					🟩	🟩	🟩	🟩
ELECTRODES	1.60 - 5.00							

Tensile strength (Rm)

Welding		Rm N/mm^2
MIG/MAG (GMAW)	TIG (GTAW)	1000 - 1700
SUBMERGED ARC	ELECTRODES	800 - 1000

INOXFIL

Welding wire

AWS: A5.9	EN 14343-A	ACX	STEEL No	PROPERTIES
ER 308L	19 9 L	602	1.4316	It is a CrNi type , for submerged arc welding (SAW) and welding with rods (TIG). Its use for stainless steels 18Cr8Ni type is recommended. It is a low carbon wire welding providing good resistance to intergranular corrosion, eliminating the precipitation of chromium carbides. It is often used as small bar for coated electrodes.
ER 308L	19 9 L	603	1.4316	It is a CrNi type , for submerged arc welding (SAW) and welding with rods (TIG). Its use for stainless steels 18Cr8Ni type is recommended. It is a low carbon wire welding providing good resistance to intergranular corrosion, eliminating the precipitation of chromium carbides.
ER 308LSi	19 9 LSi	605	1.4316	It is a welding wire for MIG / MAG (GMAW) recommended for steels containing approximately 19Cr10Ni, such as AISI 304, 304L. The high silicon content improves arc stability, fluidity and appearance of the weld seam .Resistance of welding to hot crack sensitivity (hot cracking) is better with higher than with lower silicon content.
ER 316L	19 12 3 L	652	1.4430	It is a CrNiMo welding wire type, for submerged arc welding (SAW) and welding with rods (TIG) , recommended for welding AISI 316, AISI 316L types. Its low carbon eliminates the possibility of the formation of chromium carbides and increases the resistance to intergranular corrosion of the weld. It is often used as small bar for coated electrodes.
ER 316L	19 12 3 L	653	1.4430	It is a CrNiMo welding wire type, for submerged arc welding (SAW) and welding with rods (TIG) , recommended for welding AISI 316, AISI 316L types. Its low carbon eliminates the possibility of the formation of chromium carbides and increases the resistance to intergranular corrosion of the weld.
ER 316LSi	19 12 3 LSi	655	1.4430	It is recommended for MIG / MAG (GMAW) welding of corrosion resistant steels like 18Cr12Ni3Mo and other similar steels such as AISI types 316L. Resistance of welding to hot crack sensitivity (hot cracking) is better with higher than with lower silicon content. The high silicon content improves arc stability, fluidity and appearance of the weld seam.
"ER 307LSi"	18 8 Mn	682	1.4370	It is recommended for MIG / MAG (GMAW) welding of dissimilar steels such as 18-8 steel with carbon steel and for joining steels difficult to weld. This type of material is used mainly in the automotive industry in welded joints of exhaust systems. Manganese improves the characteristics of resistance to mechanical friction, provides excellent toughness and high impact strength, abrasion and corrosion resistances. It allows a good finish of the cord without projections.
"ER 430Nb"		525	1.4511	It is a welding wire of ferritic structure basically used in the automotive industry for welding exhaust system. Its use is recommended for ferritic stainless steels welding.
ER 309L	"23 12 L"	709	(1.4332)	It is commonly used for welding similar alloys, but in some cases it can be used to weld the type 18Cr8Ni to bases of the same or similar metal, where severe conditions of use exist, and corrosion problems may appear, thereby requiring high alloyed weld metal. This type can also be used to weld types 18Cr8Ni with carbon steel or low alloy steels, dissimilar metals.
ER 309LSi	"23 12 LSi"	732	(1.4332)	This type of steel is similar to ER 309L but with a higher silicon content in chemical composition. The high silicon content improves arc stability, fluidity and appearance of the weld seam. ER 309LSi can be used, as ER 309L, welding types 18Cr8Ni with carbon steel or low alloy steels, dissimilar metals.
ER 2209	22 9 3 N L	609	(1.4462)	I is is a highly alloyed wire with Cr and Mo , specially designed for carrying out welds of similar duplex types. The properties of the duplex types and in particular the Cr and Mo contents of this alloy provide in the welding seam an excellent high resistance to general, pitting and stress corrosion.
"ER 318Si"	19 12 3 Nb Si	618	1.4576	It is a stabilized type with Nb, used for MIG welding and welding with rods (TIG) It is a suitable wire for welding CrNiMo ,and CrNiMo with Ti or Nb materials, and it is recommended in environments where good resistance to corrosion is needed, as for food and chemical industries.
ER 310	25 20	610	1.4842	It is designed for welding similar austenitic refractory types 25Cr / 20Ni is used to resist corrosion and oxidation at high temperatures, it can withstand flacking up to 1000ºC and it can be used for MIG welding (GMAW), TIG (GTAW),and submerged arc welding (SAW).
ER 347Si	19 9 Nb Si	647	1.4551	It is stabilized with Nb, and designed for welding austenitic stainless steels 18Cr / 10Ni stabilized with Nb or Ti types, that can also be used to weld unstabilized types. It is indicated for places where you need an excellent resistance to intergranular corrosion, the Nb content gives this property.

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VDM Metals

Materials for the future.

VDM Metals, a company of Acerinox, is the world market leader for nickel alloys and high-alloyed special stainless steels. The company offers a wide product range of welding consumables - from wire electrodes up to welding strips. Materials are suitable for joint welding and overlay welding (cladding). The product range is rounded out by consulting services and training opportunities the company offers to customers in its welding centre

Please note that process parameters for welding nickel alloys differ from those for carbon steels or stainless steels. Most of the known welding processes are suitable for nickel alloys and high-alloyed special stainless steels. However, the welding parameters need to be customized for the special requirements of these materials.

Please check out VDM Metals' material data sheets and welding consumables catalogue for further information.

Product forms

- Wire electrodes and welding wires in diameters of 0.6 to 3.2 mm.
- Welding rods in diameters from 1.6 to 4 mm.
- Core wires in diameters from 2 to 5 mm.
- Welding strips for welded cladding, mostly 0.5 mm thick.
- Welding consumables are available as well in imperial sizes from either mill production or inventory in the US and outside the US.

Packaging options

- Welding wire is available on standardized spools, as special spools or in various barrel types.
- Electrodes/rods are delivered in storage tubes.
- Welding strip is available as coil.

Quality standards

- Narrow tolerance fluctuations in the alloying elements and in the dimensions.
- Setting of optimized cast and helix values for trouble-free wire transport in automated welding processes.
- Optimum preparation of raw stocks for clean and fault-free surfaces.
- All quality-relevant processing steps are carried out by VDM Metals.

Out of stock delivery

In addition to individually produced filler metals, VDM Metals' Service Centers hold a permanent stock of numerous materials in the form of solid wire and welding rods in order to ensure quick delivery.

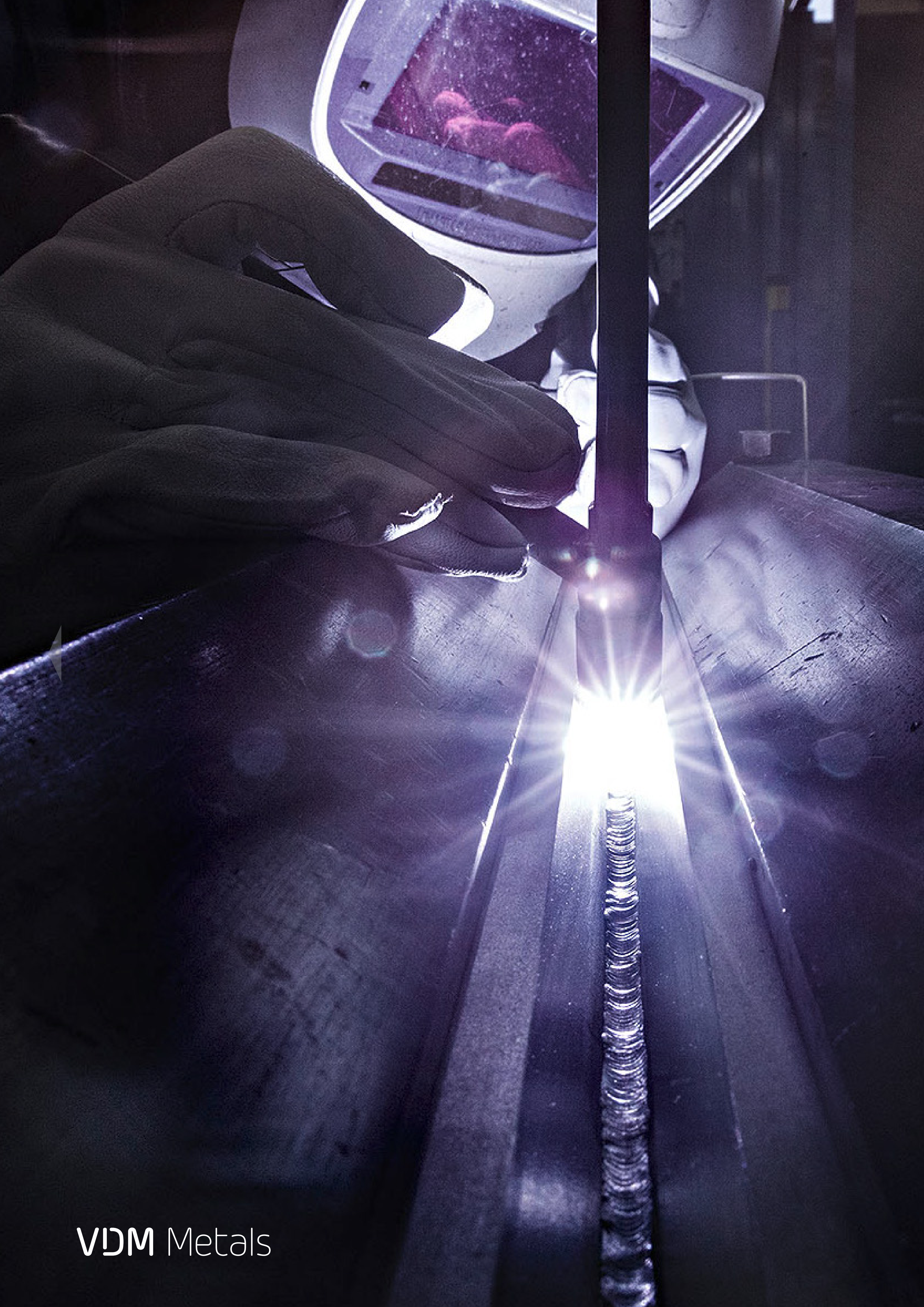
We can deliver our solid wire on basket coils (15 kg/33 lbs) or in barrels (250 kg/450 kg - 551lbs/992 lbs). We also supply welding rods for TIG welding in quivers (5 kg/11 lbs). Other formats are also available on demand. Please visit our webshop:

www.vdm-metals.com/shop

VDM Metals

AWS	VDM Name	Steel No.	Description
	VDM® FM 31 Plus	2.4692	VDM® FM 31 Plus has a high chromium and moderate molybdenum content and is well suited for oxidizing media. VDM® FM 31 Plus also has a very stable austenite microstructure, even in welding-induced iron admixtures or when a PWHT is carried out. VDM® FM 31 Plus is therefore particularly suitable as a corrosion-resistant welding filler for deposition welding.
AWS A5.9: ER33-31	**VDM® FM 33**	1.4591	VDM® FM 33 is a nickel-chromium-iron-molybdenum filler material that has been developed especially for welding VDM® Alloy 33. It possesses outstanding corrosion resistance in oxidizing acids and hot caustic soda and is used for corrosion-resistant weld cladding in large combustion plants.
	VDM® FM 36 M		VDM® FM 36 M is an iron-nickel filler material for welding VDM® Alloy 36 with a very low thermal expansion. Thanks to its alloy additives, it exhibits good welding behaviour.
	VDM® FM 36 LT		VDM® FM 36 LT is an iron-nickel filler material for welding VDM® Alloy 36. Its alloy additives make it particularly suitable for low-temperature applications in which a reduced coefficient of thermal expansion combined with increased stability of the weld metal is required.
AWS A5.14: ERNiCrFe-15	**VDM FM 52i®**		VDM FM 52i® is a nickel-chromium filler material with good workability and a low tendency to crack that is ideal for seam welding homogeneous and similar materials. In particular, this material has been developed for weld cladding and welding in Ni-Cr-Fe components in the reactor coolant systems of nuclear power plants. It is characterized by high resistance to stress corrosion cracking in this environment

AWS A5.15: ENiFe-CI	**VDM® FM 55**	2.4560	VDM® 55 is used for cast iron cold welding, e.g. for repairs and for joining large structural elements made of grey cast iron.
AWS A5.14: ERNiCrMo-13, ABS	**VDM® FM 59**	2.4607	VDM® FM 59 is a nickel-chromium-molybdenum filler material with a low carbon content for the over alloyed seam welding of high performance alloys in the area of wet chemistry. It possesses exceptionally high stability in hot acid and chloride-containing media and is frequently used in the chemical industry and environmental technologies.
AWS A5.14: ERNiCu-7, ABS	**VDM® FM 60**	2.4377	VDM® FM 60 is a cupronickel filler material for seam welding VDM® Alloy 400. It possesses good corrosion resistance in brine and alkaline salt solutions and is frequently used in offshore installations, ship building and the chemical industry.
AWS A5.14: ERNi–1, ABS	**VDM® FM 61**	2.4155	VDM® FM 61 is a pure nickel filler material with a titanium additive for seam welding nickel and weld cladding on steel, frequently as a buffer layer. Due to its high corrosion resistance in saline solutions and alkalis, it is often used in the chemical industry.
AWS A5.14: ERNiFeCr-1	**VDM® FM 65 Ni**	2.4858	VDM® FM 65 Ni is a nickel-chromium-molybdenum filler material for wet corrosion and acid gas applications. It is used primarily for the corrosion resistant weld cladding of pipes and valves for the oil and gas industry.
AWS A5.7: ERCuNi, ABS	**VDM® FM 67**	2.0837	VDM® FM 67 is a cupronickel filler material for seam welding cupronickel materials and the weld cladding of cupronickel materials on steel. It possesses good corrosion resistance in brine and is therefore frequently used in marine engineering.
AWS A5.14: ERNiCr-3	**VDM® FM 82**	2.4806	VDM® FM 82 is a versatile nickel-chromium filler material for the joint welding of high temperature and heat resistant chromium nickel steels and nickel alloys. It is frequently used in industrial oven construction and for steam generators.
AWS A5.14: ERNiCrFe-12	**VDM® FM 602 CA**	2.4649	VDM® FM 602 CA is a nickel-chromium-aluminum filler material with excellent high temperature stability and oxidation stability of more than 1,000 ºC (1,832 °F) and a high resistance to carburization and metal dusting. The main areas of application are syngas applications and high temperature applications up to 1,200 °C (2,192 °F).
AWS A5.14: ERNiCrCoMo-1	**VDM® FM 617**	2.4627	VDM® FM 617 is a highly heat-resistant nickel-chromium-cobalt filler material for seam welding in high temperature applications. It is primarily used in the power plant technology and industrial oven construction.



AWS A5.14: ERNiCrCoMo-1	**VDM® FM 617 B**	2.4627	VDM® FM 617 B was developed with the aim of providing enhanced weldability and increased creep rupture strength compared with FM 617. Its field of application is in highly stressed pipes and fittings for coal-fired power stations with extremely high steam temperatures.
AWS A5.14: ERNiCrMo-10	**VDM® FM 622**	2.4635	VDM® FM 622 is a nickel-chromium-molybdenum filler material with a low carbon content for the seam welding of homogeneous alloys in the area of wet corrosion applications. It is also used for the corrosion resistant weld cladding of steam generator pipes for various fuels.
AWS A5.14: ERNiCrMo-3, ABS	**VDM® FM 625**	2.4831	VDM® FM 625 is a versatile nickel-chromium-molybdenum filler material for seam welding homogeneous alloys in wet corrosion and high-temperature applications. It is also used for corrosion resistant weld cladding in piping and fittings in oil production and steam generator pipes.
AWS A5.14: ERNiCrMo-20	**VDM® FM 660**		VDM® FM 660 has a similar material concept to FM 625, but VDM® FM 660 uses the alloy element tungsten instead of niobium. Compared with FM 625, VDM® FM 660 offers improved weldability, higher welding material ductility and a higher thermal stability, in particular in case of post heat treatment of the substrate materials.
AWS A5.14: ERNiFeCr-2	**VDM® FM 718**	2.4667	VDM® FM 718 is a nickel-chromium-iron-molybdenum filler material for seam welding of the basic material VDM® Alloy 718 in a wide range of demanding applications. Based on its properties and good workability, VDM® FM 718 is used for seam welding and repair welding in stationary gas turbines, automotive applications, fastening elements and in pipework for the chemical processing industry.
AWS A5.14: ERNiCrMo-19	**VDM® FM 2120**	2.4700	VDM® FM 2120 is a nickel-chromium-molybdenum filler material with a low carbon content and controlled nitrogen addition for the over-alloyed seam welding of high-performance alloys in the area of wet chemistry. It offers extremely high corrosion resistance in both reducing and oxidizing conditions, in hot, acid, and chloride-containing media and excellent resistance to mineral acids such as sulfuric acid and hydrochloric acid. VDM® FM 2120 is frequently used in extremely corrosive media in the chemical industry and environmental engineering.
AWS A5.14: ERNiMo-7	**VDM® FM B-2**	2.4615	VDM® FM B-2 is a nickel-molybdenum filler material that has been developed especially for welding VDM® Alloy B-2. It possesses outstanding corrosion resistance in reducing acids.
AWS A5.14: ERNiCrMo-7	**VDM® FM C-4**	2.4611	VDM® FM C-4 is a nickel-chromium-molybdenum filler material with a low carbon content for seam welding homogeneous alloys in wet corrosion applications. It is frequently used in the chemical industry for applications involving hydrochloric acid.

	VDM® FM C-263	2.4650	VDM® FM C-263 is a nickel-chromium-cobalt filler material that has been developed especially for the homogeneous welding of superalloy VDM® Alloy C-263. The addition of titanium means that the weld metal can be hardened and thus achieves excellent creep resistance.
AWS A5.14: ERNiCrMo-4, ABS	**VDM® FM C-276**	2.4886	VDM® FM C-276 is a nickel-chromium-molybdenum filler material with a low carbon content for seam welding homogeneous alloys in wet corrosion applications. It is widely used in the chemical industry and environmental technologies.
AWS A5.15: ENiFe-CI	**VDM® CW 55**	2.4560	VDM® CW 55 is used for the production of coated nickel-iron stick electrodes. The filler material is used for so-called cast iron cold welding, e.g. for repairs and for joining large structural elements made of grey cast iron.
AWS A5.14: ERNiCu-7	**VDM® CW 60**	2.4377	VDM® CW 60 is used for the production of coated stick electrodes as per material no. 2.4377. The filler material is used for the joint welding of nickel-copper materials and for corrosion resistant weld cladding on steel. It is used for salt solutions and alkalis in the chemical industry and in marine engineering.
AWS A5.14: ERNiCr-3	**VDM® CW 182**	2.4620, 2.4648	VDM® CW 182 is used for the production of coated electrodes as per material no. 2.4648 or 2.4807. It is a widely used nickel-chromium filler material for the joint welding of high temperature and heat-resistant chromium-nickel steels and nickel alloys, also together with carbon steels, as well as low-temperature nickel steels. It is used in cryogenic engineering as well as for industrial oven construction and steam generators.
	VDM® CW Nickel	2.4066	VDM® CW Nickel is used for the production of coated stick electrodes with a core of commercially pure nickel. Typically, these coated stick electrodes are used for joint and repair welds of cast iron especially in order to meet highest demands on ductility and machinability.
AWS A5.14: EQNiCrFe-15	**VDM® WS 52i**		VDM® WS 52i is a nickel-chromium welding filler with good workability and a low tendency to crack that is ideal for seam welding homogeneous materials. In particular, this material was developed for weld cladding and welding in Ni-Cr-Fe components in the reactor coolant systems of nuclear power plants.
AWS A5.14: EQNiCrMo-13	**VDM® WS 59**	2.4607	VDM® WS 59 is a nickel-chromium-molybdenum filler material with a low carbon content for wet corrosion-resistant weld cladding on steel. It possesses exceptionally high stability in hot acid and chloride-containing media and is frequently used in the chemical industry and environmental technologies.

AWS A5.14: EQNiCr-3	**VDM® WS 82**	2.4806	VDM® WS 82 is a chromium-nickel filler material for corrosion and heat resistant weld cladding. It possesses good resistance to alkaline salt solutions as well as high temperature oxidation and chlorination. The main areas of use are in the chemical industry, oven construction and nuclear energy.
AWS A5.14: EQNiCrMo-3	**VDM® WS 625**	2.4831	VDM® WS 625 is a nickel-chromium-molybdenum filler material for wet corrosion and heat resistant applications. It is mainly used for corrosion resistant weld cladding in acid gas applications, e. g. piping and valves for the oil and gas industry and for the corrosion protection of boiler tubes in waste to energy plants.
AWS A5.14: EQNiCrMo-3	**VDM® WS 625 HS**	2.4831	VDM® WS 625 HS is a nickel-chromium-molybdenum filler material designed as a strip for electroslag weld cladding, especially at high speeds. It is mainly used on unalloyed or low-alloyed steel to achieve higher corrosion resistance to wet corrosion or at higher temperatures. Example applications include acid gas treatment plants and acid gas lines, for slug catchers in oil production and in intake gas separators.
AWS A5.14: EQNiCr-6 (exc. C; Ti)	**VDM® WS 8020**	2.4639	VDM® WS 8020 is a chromium-nickel filler material for heat-resistant weld cladding. It has good resistance to high-temperature oxidation and chlorination. Its main areas of use are in the chemical industry and oven construction. Titanium and Carbon contents deviate from the standards due to requirements in the field of core wire.
AWS A5.14: EQNiCrMo-4	**VDM® WS C-276**	2.4886	VDM® WS C-276 is a nickel-chromium-molybdenum filler material with a low carbon content for wet corrosion resistant weld cladding on steel. It is widely used in the chemical industry and environmental technologies.

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WELDING AND CUTTING OF
STAINLESS STEELS