VDM Metals
A company of ACERINOX

VDM® Alloy C-276
Nicrofer 5716 hMoW

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VDM® Alloy C-276

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VDM® Alloy C-276 is a nickel-chrome-molybdenum alloy with tungsten. It is characterized by:

- Extraordinary resistance across a wide range of corrosive, watery media; in particular oxidizing and reducing acids
- Particularly high resistance against chloride-induced crevice, pitting and stress corrosion

Designations and standards

Standard	Material designation
EN	2.4819 - NiMo16Cr15W
ISO	NiMo16Cr15Fe6W4
UNS	N10276
AFNOR	NC17D

Table 1a – Designations and standards

Designations and standards

Product form	DIN	VdTÜV	ISO	ASTM	ASME	NACE	Others
Sheet, plate	17744	400	6208	B 575	SB 575	MR 0175/ISO 15156	
Strip	17744	400	6208	B 575	SB 575	MR 0175/ISO 15156	API 5LD
Rod, bar, forging	17744 17752	400	9725	B 574 B 564	SB 574 SB 564	MR 0103 MR 0175/ISO 15156	
Wire	17744 17753						

Table 1b – Designations and standards

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	W	Mo	Co	V	P	S
Min.	51	15	4				3	15				
Max.	63	16.5	7	0.01	1	0.08	4.5	17	2.5	0.3	0.02	0.01

Table 2 – Chemical composition (wt.-%)

Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
8.9 g/cm³ (0.32 lb/in³) at 20 °C (68 °F)	1,325-1,370 °C (2,417-2,498 °F)	1,001 (Maximum)

Temperature		Specific heat capacity		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{J}{Kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in}{sq.\ ft \cdot h \cdot °F}$	μΩ · cm	GPa	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	68	426	0.102	10.2	70.8	125	208	30.2	12.1	6.72
100	212	438	0.105	11.6	80.5	127	204	29.6	12.4	6.89
200	392	453	0.108	13.4	93.0	128.5	200	29.0	12.8	7.11
300	572	469	0.112	15.1	104.8	129	195	28.3	13.1	7.28
400	762	483	0.115	16.7	115.9	129.5	188	27.3	13.4	7.44
500	932	493	0.118	18.1	125.6	129	182	26.4	13.4	7.44
600	1,112	515	0.123	20.2	140.1	128.5	175	25.4	13.5	7.50
700	1,292	609	0.145	25.7	178.3	128	168	24.4	14.0	7.78
800	1,472	605	0.145	25.8	179.0	126.5	160	23.2	14.6	8.11
900	1,652	609	0.145	25.9	179.7	126	151	21.9	15.1	8.39
1,000	1,832	605	0.145	27.2	188.7	125.5	143	20.7	15.6	8.67

Table 3 – Typical physical properties of VDM® Alloy C-276 at room temperature and elevated temperatures

Microstructural properties

VDM® Alloy C-276 has a cubic, face-centered microstructure. In the temperature range of 600 to 1,100 °C (1,112 to 2,012 °F), inter-metallic phases can form during longer exposure times or when cooling is too slow. In addition, carbides can dissipate on the grain boundaries, which reduce resistance against inter-crystalline corrosion.

Mechanical properties

The following minimum values at room and increased temperatures apply to the solution-annealed condition for longitudinal and traverse test samples of the specified dimensions. The properties for larger dimensions must be agreed separately.

Temperature		**Yield strength** $R_{p\,0.2}$		**Tensile strength** R_m	
°C	**°F**	**MPa**	**ksi**	**MPa**	**ksi**
20	68	310	45.0	700	101.5
100	212	280	40.6	660	95.7
200	392	240	34.8	630	91.4
300	572	220	31.9	600	87.0
400	752	195	28.3	570	82.7
450	842	150	21.8	530	76.9

Table 4 – Minimum values at room temperatures in acc. w. VdTÜV Materials Sheet 400

Product form	**Dimensions**		**Yield strength** $R_{p\,0.2}$		**Tensile strength** R_m		**Elongation** A	**Brinell hardness** HB
	mm	**in**	**MPa**	**ksi**	**MPa**	**ksi**	**%**	
Sheet	≤ 5	0.20	≥ 310	≥ 45.0	≥ 730	≥ 105.9	≥ 30	≤ 240
Sheet	5-25	0.20-0.98	≥ 280	≥ 40.6	≥ 700	≥ 101.5	≥ 25	≤ 240
Strip	0.1-3	0.004-0.12	≥ 310	≥ 45.0	≥ 730	≥ 105.9	≥ 30	≤ 240
Rod, bar	≤ 100	≤ 3.94	≥ 280	≥ 40.6	≥ 730	≥ 105.9	≥ 30	≤ 240

Table 5 – Minimum values at room temperatures in acc. w. VdTÜV Materials Sheet 400

ISO V-notch impact toughness

Average value, room temperature, longitudinal: 120 J/cm^2

Corrosion resistance

VDM® Alloy C-276 can be used in many chemical processes with both oxidizing as well as reducing media. The high chrome and molybdenum concentrations make the alloy resistant to chloride ion attacks. The tungsten content further increases this resistance. VDM® Alloy C-276 is one of the few materials that are resistant against chlorine gas, hypochlorite and chlorine dioxide solutions. The alloy is characterized by excellent resistance against concentrated solutions of oxidizing salts (such as iron III and copper chloride).

Alloy	KPT in °C (°F)	CCT in °C (°F)
VDM® Alloy C-276	115-120 (239-248)	105 (221)
VDM® Alloy 59	≥ 120 (248)	≥ 110 (230)
VDM® Alloy 625	100 (212)	85-95 (185-203)
VDM Alloy 2120 MoN	145 (293)	130 (266)

Table 6 – Critical pitting temperature (CPT) and crevice corrosion temperature (CCT) in the "Green Death" solution: 7% H2SO4 + 3% HCl + 1% CuCl2 + 1% FeCl3 x 6H2O after 24 h evacuation time and per 5°C temperature increase.

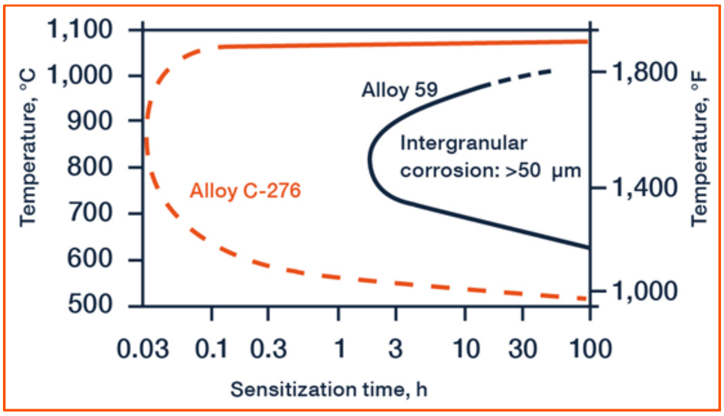

Figure 1 – Time-temperature sensitization diagram for solution annealed material according to the Streicher test (ASTM G-28, Method A)

Fields of application

VDM® Alloy C-276 has a broad field of application in the chemicals and petrochemicals industry, for components in organic processes containing chlorides, and for catalytic systems. The material can be used especially in cases where hot, contaminated mineral acids, solutions or organic acids (such as formic acid and acetic acid) and sea water occur.

Examples of fields of application:

- Paper and pulp industry, e.g. for digestion and bleaching tanks
- Washers, agitators and wet ventilators in flue gas desulfurization systems
- Equipment and components for acid gas applications
- Reactors for acetic acid production
- Sulfuric acid coolers
- Methylene diphenyl isocyanate (MDI)
- Manufacturing and processing of contaminated phosphoric acid

Fabrication and Heat treatment

VDM® Alloy C-276 is ideally suited for processing by means of common industrial processing techniques.

Heating
It is important that the workpieces are clean and free of any contaminants before and during heat treatment. Sulfur, phosphorus, lead and other low-melting-point metals can result in damage during the heat treatment of VDM® Alloy C-276. This type of contamination is also contained in marking and temperature-indicating paints or paints, and also in lubricating grease, oils, fuels and similar materials. Fuels must have as low a sulfur content as possible. Natural gas should contain less than 0.1% by weight of sulfur. Heating oil with a maximum sulfur content of 0.5% by weight is also suitable. Electrical furnaces are to be preferred due to precise temperature control and lack of contaminants due to fuel. The furnace temperature should be set between neutral and slightly oxidizing, and should not change between oxidizing and reducing. The workpieces may not come in direct contact with flames.

Hot forming
VDM® Alloy C-276 should be hot-formed in a temperature range of 950 to 1,200 °C (1,742 to 2,192 °F) with subsequent rapid cooling in water or in air. Heat treatment after hot-working is recommended in order to achieve optimal corrosion behavior. For heating up, workpieces should be placed in a furnace that is already heated up to the target value.

Cold forming
The workpieces should be in the annealed condition for cold working. VDM® Alloy C-276 has significantly higher cold forming properties than the widely used austenitic stainless steels. This must be taken into account during design and selection of forming tools and equipment and during the planning of forming processes. Intermediate annealing is necessary for major cold-working treatment. When cold forming of > 15 %, final solution annealing must be conducted.

Heat treatment
Solution annealing should take place at temperatures of between 1,100 and 1,160 °C (2,012 and 2,120 °F). The retention time during annealing depends on the semi-finished product thickness and can be calculated as follows:

- For thicknesses d < 10 mm (0.4 in), the retention time is t = d · 3 min/mm
- For thicknesses d = 10 to 20 mm (0.4-0.8 in), the retention time is t = 30 min + (d – 10 mm) · 2 min/mm
- For thicknesses of d = 20 mm (0.8 in), the retention time is t = 50 min + (d – 20 mm) · 1 min/mm

The retention time commences with material temperature equalization; longer times are generally considerably less critical than retention times that are too short.

Cooling down should be accelerated with water to achieve optimum properties. Fast air cooling can also be carried out at thicknesses of less than approx. 1.5 mm (0.059 in). In the process, the cooling must take place within 2 minutes between 1,000 and 600 °C (1,832 and 1,112 °F). The material must be placed in a furnace that has been heated up to the maximum annealing temperature before any heat treatment. For strip and wire products, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the material thickness. The cleanliness requirements listed in the Section 'Heating' have to be observed.

Descaling and pickling

Oxides of VDM® Alloy C-276 and discoloration adjacent to welds are more adherent than on stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. Care should be taken to prevent tarnishing. Before pickling in saltpeter hydrofluoric acid mixtures, the oxide layers should be broken up by abrasive blasting or fine grinding, or pre-treated in in a fused salt bath. The pickling baths used should be carefully monitored with regard to concentration and temperature.

Machining

VDM® Alloy C-276 should be machined in the heat-treated condition. For reasons of the considerably increased tendency to work hardening in comparison to austenitic stainless steels, a low cut speed at a feed level that is not too high should be selected and the cutting tool should be engaged at all times. An adequate depth of cut is important in order to cut below the previously formed strain-hardened zone. Optimum heat dissipation through the use of large quantities of suitable, preferably aqueous, lubricants has considerable influence on a stable machining process.

Welding information

When welding nickel-base alloys, the following instructions should be adhered to:

Workplace

A separately located workplace, which is specifically separated from areas in which C steel is being processed, must be provided. Considerable cleanliness is required and draughts must be avoided during gas-shielded welding.

Auxiliary equipment and clothing

Clean fine leather gloves and clean working clothes must be used.

Tools and machines

Tools that have been used for other materials may not be used for nickel alloys and stainless steels. Only stainless steel brushes may be used. Processing and treatment machines such as shears, punches or rollers must be fitted (felt, cardboard, films) so that the workpiece surfaces cannot be damaged by the pressing in of iron particles through such equipment, as this can lead to corrosion.

Edge preparation

Welding seam preparation should preferably be carried out using mechanical methods through lathing, milling or planing. Abrasive waterjet cutting or plasma cutting is also possible. In the latter case, however, the cut edge (seam flank) must be cleanly reworked. Careful grinding without overheating is also permissible.

Striking the arc

The arc should only be struck in the seam area, such as on the weld edges or on an outlet piece, and not on the component surface. Scaling areas are areas in which corrosion more easily occurs.

Included angle

Compared to C-steels, nickel alloys and specialty stainless steels have a lower heat conductivity and greater heat expansion. These properties must be taken into account by larger root openings or root gaps (1 to 3 mm, 0.039 to 0.118 in). Due to the viscosity of the welding material (compared to standard austenites) and the tendency to shrink, opening angles of 60 to 70° – as shown in Figure 2 – have to be provided for butt welds.

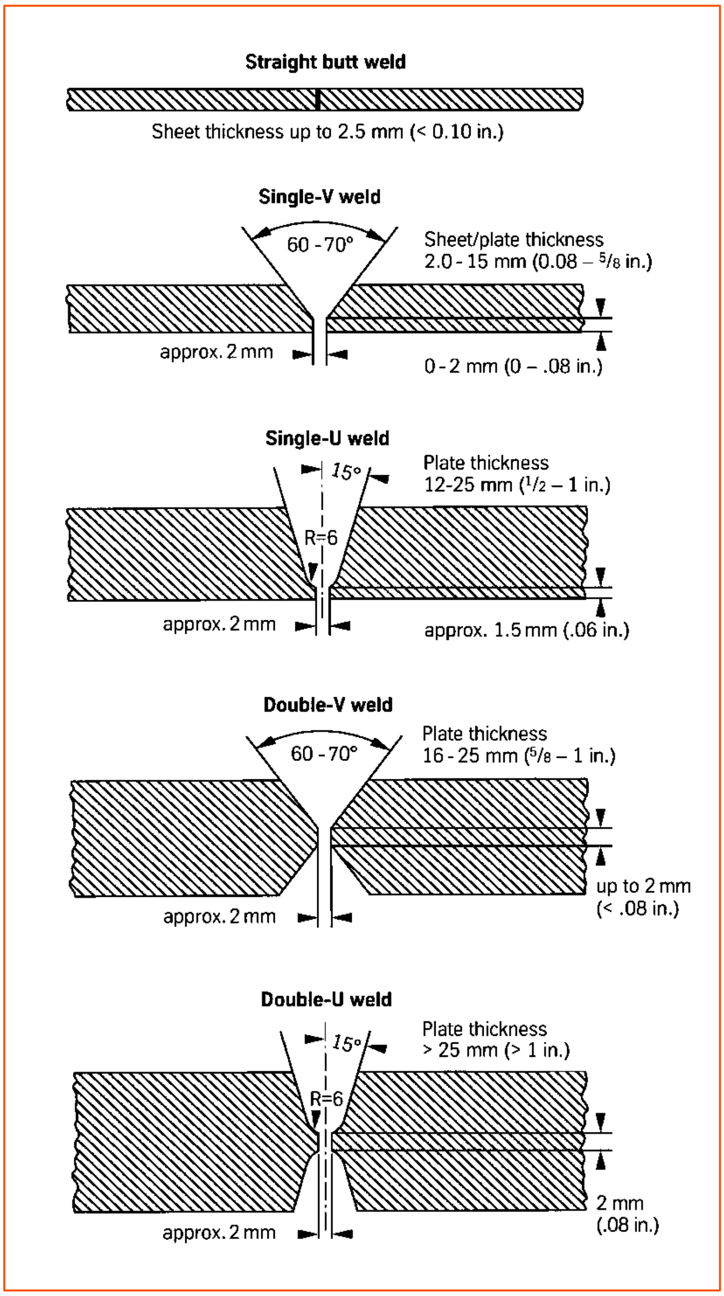

Figure 2 – Seam preparation for welding nickel alloys and special stainless steels

Cleaning

Cleaning of the basic material in the seam area (both sides) and the welding consumable (e.g. welding rod) should be carried out using acetone.

Welding technique

VDM® Alloy C-276 can be welded using all of the common welding processes, such as GTAW (TIG), GTAW (TIG) hot wire, plasma and GMAW (MIG/MAG).

Welding consumable

The following welding consumable is recommended:

VDM® FM 59 (mat. no. 2.4607)
Code SG-NiCr23Mo16
AWS A5.14 ENiCrMo-13

The use of bar electrodes in sleeves is possible.

Welding parameters and influences

It must be ensured that work is carried out using targeted heat application and low heat input. The interpass temperature should not exceed 120 °C (248 °F). The stringer bead technique is recommended. In this context, also the right choice of wire and bar electrode diameters should be pointed out. Corresponding energy inputs per unit length result from the aforementioned notes, which are shown as examples in Table 7. In principle, checking of welding parameters is necessary.

Heat input Q can be calculated as follows:

$$Q=\frac{U \cdot I \cdot 60}{v \cdot 1.000}\ \left(\frac{kJ}{cm}\right)$$

U = arc voltage, volts
I = welding current strength, amperes
v = welding speed, cm/minute

Post-treatment

Brushing with a stainless steel wire brush immediately after welding, i.e. while the metal is still warm generally results in removal of heat tint and produces the desired surface condition without additional pickling.
Pickling, if required or prescribed, however, would generally be the last operation performed on the weldment. Please also refer to the information on ‘Descaling and pickling. Neither pre- nor post weld heat treatments are normally required.

Thickness	Welding technique	Filler material		Root pass[1)]		Intermediate and final passes		Welding speed	Shielding gas	
(mm)		Diameter (mm)	Speed (m/min)	I in (A)	U in (V)	I in (A)	U in (V)	(cm/min)	Type	Rate (l/min)
3	manual TIG	2	-	90	10	110-120	11	10-15	I1, R1 mit max. 3% H2	8-10
6	manual TIG	2.,0-2.4	-	100-110	10	120-130	12	10-15	I1, R1 mit max. 3% H2	8-10
8	manual TIG	2.4	-	110-120	11	130-140	12	10-15	I1, R1 mit max. 3% H2	8-10
10	manual TIG	2.4	-	110-120	11	130-140	12	10-15	I1, R1 mit max. 3% H2	8-10
3	autom. TIG[2)]	0.8	0.5	-	-	150	10	25	I1, R1 mit max. 3% H2	15-20
5	autom. TIG[2)]	0.8	0.5	-	-	150	10	25	I1, R1 mit max. 3% H2	15-20
2	autom. TIG[2)]	1	0.3	-	-	180	10	80	I1, R1 mit max. 3% H2	-
10	autom. TIG[2)]	1.2	0.45	-	-	250	12	40	I1, R1 mit max. 3% H2	-
4	Plasma[3)]	0.8	0.5	165	25	-	-	25	I1, R1 mit max. 3% H2	30
6	Plasma[3)]	0.8	0.5	190-150	25	-	-	25	I1, R1 mit max. 3% H2	30
8	GMAW[4)]	1	8	-	-	130-140	23-27	24-30	I1, R1 mit max. 3% H2	18-20
10	GMAW[4)]	1.2	8	-	-	130-150	23-27	20-26	I1, R1 mit max. 3% H2	18-20

[1)] It must be ensured that there is sufficient root protection, for example using Ar 4.6, for all inert gas welding processes.

[2)] The root pass should be welded manually (see manual TIG).

[3)] Recommended plasma gas Ar 4.6 / rate 3.0 to 3.5 l/min

[4)] For MAG welding the use of multicomponent inert gases is recommended.

Section energy kJ/cm:
TIG, manual, autom. max. 8; TIG hot wire max. 6; GMAW, manual, autom max.11; Plasma max. 10, arc welding max. 7

Figures are for guidance only and are intended to facilitate setting of the welding machines.

Table 7 - Welding parameters

Availability

VDM® Alloy C-276 is available in the following standard semi-fabricated forms:

Sheet and plate

Delivery condition: hot or cold-rolled, heat-treated, de-scaled or pickled

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece weight Kg (lb)
Cold rolled	1-7 (0.04-0.28)	≤ 2,500 (98.43)	≤ 12,500 (492.13)	
Hot rolled*	3-70 (0.12-2.76)	≤ 2,500 (98.43)	≤ 12,500 (492.13)	≤ 2,100 (4,630)

Sheets can be manufactured considering the minimum and maximum dimensions
* 2 mm (0.08 in) thickness on request

Strip

Delivery condition: cold rolled, heat treated, pickled or bright annealed

Thickness mm (in)	Width mm (in)	Coil - inside diameter mm			
0,025-0,15 (0.001-0.006)	4-230 (0.16-9.06)	300	400	500	–
0.15-0.25 (0.006-0.01)	4-720 (0.16-28.34)	300	400	500	–
0.25-0.6 (0.01-0.024)	6-750 (0.24-29.5)	–	400	500	600
0.6-1 (0.024-0.04)	8-750 (0.32-29.5)	–	400	500	600
1-2 (0.04-0.08)	15-750 (0.6-29.5)	–	400	500	600
2-3 (0.08-0.12)	25-750 (0.98-29.5)	–	400	500	600

Rolled sheet – separated from the coil – are available in lengths from 250 to 4,000 mm (9.84 to 157.48 in).

Rod and bar

Delivery condition: forged, rolled, drawn, heat-treated, oxidized, de-scaled or pickled, twisted, peeled, ground or polished.

Dimensions*	Delivery condition	Outside diameter mm (in)	Length mm (in)
General dimensions	Hot rolled	6-800 (0.24-31.50)	1,500-12,000 (59.06-472.44)
Material specific dimensions	Hot rolled	10-600 (0.39-23.62)	1,500-12,000 (59.06-472.44)

* Further dimensions on request

Wire

Delivery condition: drawn bright, ¼ hard to hard, bright annealed in rings, containers, on spools and headstocks

Drawn mm (in)	Hot rolled mm (in)
0.16-10 (0.006-0.4)	5.5-19 (0.22-0.75)

Other shapes and dimensions (such as discs, rings, seamless or longitudinally welded pipes and forgings) can be requested.

Publications

The following technical literature has been published about VDM® Alloy C-276:

”The use of Nicrofer 5716 hMoW – Alloy C-276“ (M. Rockel and W. Herda) Stainless Steel World, May 1996.

U. Heubner, J. Klöwer et al.: "Nickelwerkstoffe und hochlegierte Sonderedelstähle” [Nickel materials and high-alloy special stainless steels], 5th edition, Expert Verlag, Renningen-Malmsheim, 2012.

“Das Zeit-Temperatur- Ausscheidungs- und das Zeit-Temperatur-Sensibilisierungs-Verhalten von hochkorrosionsbeständigen Nickel-Chrom-Molybdän-Legierungen” [The time-temperature dissipation and time-temperature sensitization behavior of highly corrosion-resistant nickel-chrome-molybdenum alloys] (U. Heubner , M. Köhler) Werkstoffe und Korrosion [Materials and Corrosion] 43, 181–190 (1992).

”Behaviour of some metallic materials in sulphuric acid“ – August 1994 VDM Report No. 22

Legal notice

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