VDM Metals

VDM® Alloy 600/600 H
Nicrofer 7216

Material Data Sheet No. 4107
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VDM® Alloy 600 and the solution-annealed variant 600 H are nickel-chromium-iron alloys.

They are characterized by:
- good resistance against oxidation, carbonization and nitriding,
- good resistance to stress corrosion in room and increased temperatures,
- good resistance against dry chlorine and hydrogen chloride,
- good mechanical properties at both low and high temperatures.

Due to its improved creep resistance, VDM® Alloy 600 H is preferred for use at temperatures above 700 °C (1,292 °F).

Designations

Standards	Material designation
EN	2.4816 – NiCr15Fe
ISO	NiCr15Fe8
UNS	N0660
UK	NA 14
AFNOR	NC15Fe

Standards

Product form	DIN	DIN EN	VdTÜV	ASTM	ASME	NACE	Others
Plate and sheet	17750 17742	10095	305	B 168	SB 168	MR 0175/ISO 15156 MR 0103	SAE AMS 5540 ISO 6208 ISO 9722
Strip	17742	10095	305	B 168	SB 168		SEW 470 SAE AMS 5540 ISO 6208
Bar	17752 17742	10095	305	B 166 B 564	SB 166 SB 564	MR0175/ISO 15156 MR 0103	

Table 1 – Designations and standards

Chemical composition

	Fe	Cr	Ni	C	S	Mn	Si	Ti	Cu	P	Al
Min.	6.0	14.0	Bal.	0.05							
Max.	10.0	17.0		0.15	0.015	1.0	0.5	0.3	0.5	0.02	0.3
Due to technical reasons the alloy may contain more elements than listed											
Analysis limit values in other specifications can differ slightly in some elements, e.g. according to UNS N06600 the C-content is 0.15% max.; according to VdTÜV data sheet 305: P-content 0.015% max.											
On request C-content from 0.025%; P-content: 0.015% max.											

Table 2 – Chemical composition (%) according to DIN EN 10095

Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
8.5 g/cm³ at 20 °C 531 lb/ft³ at 68 °F	1,370 – 1,425 °C (2,500 – 2,600 °F)	1.005 (max)

Temperature		Specific heat capacity		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{J}{Kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in}{h \cdot ft^2 \cdot °F}$	µΩ · cm	GPa	10^3 psi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	68	455	0.109	14.8	102.7	103	214	31.0	-	-
100	212	475	0.113	15.8	109.6	104	209	30.3	13.7	7.61
200	392	495	0.118	17.0	117.9	106	205	29.7	14.1	7.83
300	572	508	0.121	18.4	127.7	107	200	29.0	14.4	8.0
400	752	525	0.125	20.0	138.8	108	194	28.1	14.8	8.22
500	932	550	0.131	22.0	152.6	111	187	27.1	15.1	8.39
600	1,112	572	0.137	24.0	166.5	112	180	26.1	15.4	8.56
700	1,292	602	0.144	25.7	178.3	112	172	24.9	15.8	8.78
800	1,472	620	0.148	27.5	190.8	112	163	23.6	16.1	8.94
900	1,652	630	0.15	29.4	204	113	153	22.2	16.4	9.11
1,000	1,832	635	0.152	31.2	216.5	114	143	20.7	16.9	9.39

Table 3 – Typical physical properties at room- and elevated temperatures

Microstructural properties

VDM® Alloy 600 and VDM® Alloy 600 H have a cubic face-centered crystal structure.

Mechanical properties

The following mechanical properties apply to VDM® Alloy 600 and VDM® Alloy 600 H in the annealed or solution-annealed condition and in the specified semi-finished forms and dimensions. The properties for larger dimensions must be agreed separately.

Temperature		Yield strength $R_{p\,0.2}$		Tensile strength R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	200	29.0	550	79.8	30
100	212	180	26.1	520	75.4	
200	392	165	23.9	500	72.5	
300	572	155	22.5	485	70.3	
400	752	150	21.8	480	69.6	
450	842	145	21.0	475	68.9	

Table 4a – Mechanical properties of VDM® Alloy 600 (annealed) at room- and elevated temperatures. Min. values according to VdTÜV material data sheet 305

Temperature		Yield strength $R_{p\,0.2}$		Tensile strength R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	180	26.1	500-700	72.5-102	35
100	212	170	24.7	480	69.6	
200	392	160	23.2	460	66.7	
300	572	150	21.8	445	64.5	
400	752	150	21.8	440	63.8	
500	932	145	21	435	63.1	

Table 4b – Mechanical properties of VDM® Alloy 600 H (solution annealed) at room- and elevated temperatures. Min. values according to VdTÜV material data sheet 305

Product form	Heat treatment	Dimensions		Yield stress $R_{p\ 1,0}$		Tensile strength R_m		Elongation A
		mm	in	MPa	ksi	MPa	ksi	%
Sheet	annealed			≥ 240	≥34.8	≥ 550	≥79.8	≥ 30
Strip	annealed			≥ 240	≥34.8	≥ 550	≥79.8	≥ 30
Bar	annealed			≥ 240	≥34.8	≥ 550	≥79.8	≥ 30
Forging	annealed			≥ 240	≥34.8	≥ 550	≥79.8	≥ 30
Wire	annealed	0.8	0.0315			≥ 600	≥87	≥ 30
Wire	annealed	0.3-0.8	0.0118-0.0315			≥ 600	≥87	≥ 15
Wire	annealed	0.1-0.3	0.00394-0.0118			≥ 600	≥87	≥ 10
Sheet	solution-annealed			≥ 180	≥26.1	≥ 500	≥72.5	≥ 35
Strip	solution-annealed			≥ 180	≥26.1	≥ 500	≥72.5	≥ 35
Bar	solution-annealed			≥ 180		≥ 500	≥72.5	≥ 30
Forging	solution-annealed			≥ 180		≥ 500	≥72.5	≥ 30

Table 5 – Typical mechanical properties at room temperature

Temperature		Creep limit $R_{p\ 1.0}/10^4$ h		Creep limit $R_{p\ 1.0}/10^5$ h		Creep strength $R_m/10^4$ h		Creep strength $R_m/10^5$ h	
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
500	932	153	22.2	126	18.3	297	43.1	215	31.2
600	1,112	91	13.2	66	9.57	138	20.0	97	14.1
700	1,292	43	6.24	28	4.06	63	9.14	42	6.09
800	1,472	18	2.61	12	1.74	29	4.21	17	2.47
850	1,562	11	1.60	6,7	0.972	17	2.47	9,2	1.33
900	1,652	8	1.16	4	0.58	13	1.89	7	1.02

Table 6 – Typical creep limit and creep strength of solution-annealed VDM® Alloy 600 H

ISO V-notch impact toughness

ISO-V- notch impact energy, longitudinally: 160 J (118 ft.lbf)
ISO-V-notch impact energy, cross: 120 J (88.5 ft.lbf)
The average value of three samples according to the VdTÜV Material Sheet 305. The minimum value may only be fallen below by a single value, notably at most by 30%.

Corrosion resistance

VDM® Alloy 600 and 600 H are resistant against a wide range of corrosive media. The chromium concentration provides the alloy with greater resistance under oxidizing conditions than VDM® Nickel 200 and VDM® Nickel 201. At the same time, the high nickel concentration results in good resistance under reducing conditions and in alkali solutions. The alloy is resistant to chloride stress corrosion cracking.

VDM® Alloy 600 and 600 H show good resistance against formic acid, acetic acid and other organic acids. Minor attack can occur at room and higher temperatures in dry gases such as chlorine or hydrogen chloride. In temperatures of up to 550°C (1,022 °F), it has been seen in these media that the alloy is the most resilient of all conventional alloys. VDM® Alloy 600 H proves good scaling resistance in high temperatures and simultaneously high strength. The alloy is furthermore resistant against atmospheres with ammoniac and resists nitriding and carburizing atmospheres. Under changing oxidizing and reducing conditions, the alloy can suffer selective oxidation (green rot).

Applications

Typical applications for VDM® Alloy 600 and 600 H are:

- Transport rollers, steel pipes, ventilators and other installations in industrial furnaces
- Industrial furnace muffles, in particular for heat treatment in N_2 atmospheres
- Thermal element protective conduits in nitriding and carburizing atmospheres
- Pipes for dichloroethylene pyrolysis
- Components in the production of uranium tetrafluoride from hydrofluoric acid
- Production of caustic alkalis, especially with the presence of sulfur bonds
- Reaction vessels and heat exchanger pipes in the production of vinyl chloride
- Plant parts for the production of chlorinated and fluorinated hydrocarbons
- Parts such as cladding tubes for control rods, reactor tanks and seals, steam dryers and separators in boiling water reactors
- Pipes in $TiCl_4$ evaporators in the production of TiO_2
- Vessels and piping used to contain caustic solutions
- For the automotive industry the alloy is used for high temperature sensors, rupture discs in airbag systems, electrodes for spark plugs and gaskets.

Due to its improved creep resistance, VDM® Alloy 600 H is preferred for use at temperatures above 700 °C (1,292 °F).

Fabrication and heat treatment

VDM® Alloy 600 and VDM® Alloy 600 H are ideally suited for processing by means of common industrial processing techniques.

Heating

It is important that the workpieces are clean and free of any contaminations before and during heat treatment. Sulfur, phosphorus, lead and other low-melting point metals can result in material damage during the heat treatment. This type of contamination is also contained in marking and temperature-indicating paints or pens, and also in lubricating grease, oils, fuels and similar materials. The sulfur content of fuels must be as low as possible. Natural gas should contain less than 0.1 wt.-% of sulfur. Heating oil with a maximum sulfur content of 0.5 wt.-% is also suitable. Electric furnaces are preferable for their precise temperature control and a lack of contaminations from fuels. The furnace temperature should be set between neutral and slightly oxidizing and it should not change between oxidizing and reducing. The workpieces must not come in direct contact with flames.

Hot forming

VDM® Alloy 600 and VDM® Alloy 600 H can be hot-formed in a temperature range between 1,200 and 900 °C (2,192 and 1,652 °F) with subsequent rapid cooling down in water or air. For heating up, workpieces should be placed in a furnace that is already heated up to the target value. Heat treatment after hot forming is recommended in order to achieve optimal properties.

Cold forming

The workpieces should be in the annealed condition for cold forming. VDM® Alloy 600 and VDM® Alloy 600 H have a significantly higher work hardening rate than austenitic stainless steels. This must be taken into account for the design and selection of forming tools and equipment and during the planning of forming processes. Intermediate annealing is necessary for major cold forming work. For cold forming of > 15%, a final solution annealing must be conducted.

Heat treatment

Soft annealing of VDM® Alloy 600 should take place in the temperature range between 920 and 1,000°C (1,688 and 1,832 °F).

Solution annealing of VDM® Alloy 600 H should take place at temperatures between 1,080 and 1,150°C (1,976 and 2,102 °F).

The retention time during annealing depends on the semi-finished product thickness and can be calculated as follows:

- For thicknesses d < 10 mm (0.39 in), the retention time t = d * 3 min/mm
- For thicknesses d = 10 - 20 mm (0.39 in to 0.79 in), the retention time t = 30 min + (d – 10 mm) * 2 min/mm
- For thicknesses d = 20 mm (0.79 in), the retention time t = 50 min + (d – 20 mm) * 1 min/mm

The retention time starts 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 below approx. 3 mm. For strips as the product form, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the strip thickness. In each heat treatment, the aforementioned cleanliness requirements must be observed.

Descaling and pickling

Oxides and discolorations in the area around welding seams have better bonding than in stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. The pickling times – as for all high-temperature materials – should be kept short because they can otherwise be subject to inter-crystalline attack. Furthermore, the temperature of the pickling line must be checked. Before pickling in nitric-hydrofluoric acid mixtures, the oxide layers should be destroyed by abrasive blasting or fine grinding, or pre-treated in salt baths.

Machining

VDM® Alloy 600 and VDM® Alloy 600H are preferably processed in annealed condition. Since the alloy is prone to work hardening, a low cutting speed should be used with a feed speed that is not too high and the cutting tool should stay engaged at all times. An adequate chip depth is important in order to cut below the previously formed work-hardened zone. An optimal heat dissipation by using large quantities of suitable, preferably aqueous, cold forming lubricants has considerable influence on a stable machining process.

Welding information

Safety
The generally applicable safety recommendations, especially for avoiding dust and smoke exposure must be observed.

Welding information
VDM® Alloy 600 and VDM® Alloy 600 H can be welded using the customary and conventional arc techniques such as TIG or MIG impulse technology. The material should be in its annealed condition for welding. A low heat input and fast heat removal must be ensured. The maximum interpass temperature should be between 100 and 150 °C (212 and 302 °F). Usually neither pre-heating nor a subsequent heat treatment is necessary.

For TIG and MIG welding, a welding filler of the type
VDM® FM 82
material no. 2.4806
ISO 18274 - S Ni 6082 (NiCr20Mn3Nb)
is recommended. To achieve optimum corrosion properties, the TIG method is preferable. When using (VDM® Alloy 600 and) VDM® Alloy 600 H in higher temperatures (above approx. 900 °C (1,652 °F)), the welding filler material VDM® FM 625 is recommendable for TIG, MSG and submerged arc UP welding.

Workplace
A separately located workplace, which is specifically separated from areas in which C steel is being processed, must be provided. Maximum cleanliness is required, and drafts should 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. Machines such as shears, punches or rollers must be fitted (e.g. with felt, cardboard, films) so that the workpiece surfaces cannot be damaged by such equipment due to pressed-in iron particles as this can lead to corrosion.

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

Striking the arc
Striking the arc may only take place in the seam area, e.g. on the seam flanks or on an outlet piece, and not on the component surface. Scaling areas are places that may be more susceptible to corrosion.

Included angle
Compared to C-steels, nickel alloys and special stainless steels exhibit lower thermal conductivity and greater heat expansion. Larger root openings and web spacing (1 to 3 mm) are required to live up to these properties. Due to the viscosity of the welding material (compared to standard austenites) and the tendency to shrink, included angles of 60 to 70° – as shown in Figure 1 – have to be provided for butt welds.

Cleaning

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

Welding filler

Please find the information on the recommended welding fillers under “Welding information” complete with listed materials and recommended welding technique.

Post-treatment

If the work is performed optimally, brushing immediately after welding, i.e. while still warm, and without additional pickling, will result in the desired surface condition. In other words, heat tint can be removed completely. Pickling, if required or specified, should generally be the last operation in the welding process. The information contained in the section entitled "Descaling and pickling" must be observed.

Straightening (after welding or annealing)

The necessity of straightening the welded components should be minimized by a clever choice of edge preparation (for example, by means of an X-seam instead of a V-seam) and welding edge sequence. Flame straightening should be avoided, as this can lead to unwanted structural changes in the material.

Availability

VDM® Alloy 600 and VDM® Alloy 600 H are available in the following standard semi-finished forms:

Sheet/Plate

Delivery condition: hot or cold rolled, heat treated, descaled or pickled

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece Weight kg (lb)
Cold rolled	1-7 (0.039-0.275)	≤ 2,500 (98.42)	≤ 12,500 (492)	
Hot rolled	3-50 (0.118-1.97)	≤ 2,500 (98.42)	≤ 12,500 (492)	≤ 2,900 (6,390)

Strip

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

Thickness mm (in)	Width mm (in)	Coil - inside diameter mm (in)			
0.02-0.15 (0.00078-0.0059)	4-230 (0.157-9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.15-0.25 (0.0059-0,00984)	4-720 (0.157-28.3)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.25-0.6 (0.00984-0.0236)	6-750 (0.236-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
0.6-1 (0.0236-0.00394)	8-750 (0.315-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
1-2 (0.0394-0.0787)	15-750 (0.591-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
2-3 (0.0787-0.118)	25-750 (0.984-29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)

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

Rod

Delivery condition: forged, rolled, drawn, heat treated, oxidized, descaled or pickled, turned, peeled, scalped or polished

Dimensions	Outside diameter mm (in)	Length mm (in)
General	6-800 (0.236-31.5)	1,500-12,000 (59.1-472)
Material specific dimensions	12-500 (0.472-19.7)	1,500-12,000 (59.1-472)

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)
Outside diameter	0.16 – 10 (0.006-0.39)	5.5 – 19 (0.22-0.75)

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

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