VDM Metals

VDM® Alloy C-4

Nicrofer 6616 hMo

Material Data Sheet No. 4124

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VDM® Alloy C-4 is an austenitic nickel-molybdenum-chromium alloy with a low carbon, silicon, and iron content.
This alloy has a significantly lower tendency to form precipitation in the temperature range between 650 and 1,040 °C (1,202 - 1,904 °F), improving its resistance to inter-crystalline corrosion. When machined perfectly, no knife line attack occurs in the heat-affected zones of a welding edge.

VDM® Alloy C-4 is characterized by:

- Very good resistance in a broad field of corrosive media, in particular under strongly oxidizing conditions.
- Excellent resistance to pitting, crevice and stress corrosion.
- Approval for pressure vessels in the temperature range from -196 to 400 °C (-320 to 752 °F) in acc. w. VdTÜV Materials Sheet 424.

Designations

Standard	Material designation
EN	2.4610 NiMo16Cr16Ti
IISO	NiMo16Cr16Ti
UNS	N06455

Standards

Product form	ASTM	ASME	DIN	VdTÜV	NACE	sonstige
Sheet, plate	B 575	SB 575	17744 17751	424	MR 0175/ISO 15156 MR 0103/ISO 17945	
Strip						SAE AMS 5608
Rod, bar						AFNOR AIR 9165 AFNOR AIR 9161 SAE AMS 5772
Wire						SAE AMS 5801

Table 1 – Designations and standards

Chemical composition

	Cr	Mo	Ni	Fe	C	S	Mn	Si	Ti	P	Co
Min.	14.50	14.00	Bal.								
Max.	17.50	17.00		3.00	0.009	0.010	1.00	0.050	0.70	0.020	2.00
Due to technical reasons the alloy may contain more elements than listed											

Table 2 – Typical chemical composition (%)

Physical properties

Density	Melting Range
8.6 g/ cm³ at 20 °C 537 lb/ft³ at 68 °F	1,335-1,380 °C (2,430-2,520 °F)

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	10^6 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
0	32	406	0.097							
20	68	408	0.0974	10,1	70	124	211	30.6		
100	212	426	0.102	11,4	79	125	207	30	10,9	6.06
200	392	448	0.107	13,2	91.5	126	202	29.3	11,9	6.61
300	572	465	0.111	15,0	104	127	195	28.3	12,5	6.94
400	752	477	0.114	16,7	116	128	188	27.3	12,9	7.17
500	932	490	0.117	18,4	128	129	181	26.3	13,2	7.33
600	1,112	502	0.12	20,5	142	132	175	25.4	13,6	7.56
700	1,292	512	0.122	22,5	156	135	168	24.4	14,0	7.78
800	1,472	522	0.125	24,8	172	138	158	22.9	14,5	8.06

Table 3 – Typical physical properties at room and increased temperatures

Microstructural properties

VDM® Alloy C-4 has a cubic face-centered cubic lattice. Based on its special chemical composition, the alloy shows good structural stability and resistance to sensitization

Mechanical properties

The following mechanical properties at room and increased temperatures apply to VDM® Alloy C-4 in the solution-annealed condition for longitudinal and traverse test samples of the specified dimensions. The properties for larger dimensions must be agreed upon separately.

Temperature		Yield strength $R_{p\ 0.2}$		Yield strength $R_{p\ 1,0}$		Tensile strength R_m		Elongation at fracture A
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	300	43.5	330	47.9	700-900	102-131	40
100	212	270	39.2	305	44.2			
200	392	245	35.5	208	40.6			
300	572	220	31.9	255	37.0			
400	752	205	29.7	240	34.8			

Table 4 – Mechanical properties at room and increased temperatures. Minimum values acc. to VdTÜV 424

Product-form	Dimensions		Yield stress $R_{p\ 0,2}$		Yield stress $R_{p\ 1,0}$		Tensile strength R_m		Elongation at fracture A
	mm	in	MPa	ksi	MPa	ksi	MPa	ksi	%
Sheet/ Plate	≤ 5	≤ 0.197	≥ 305	≥ 44.2	≥ 340	≥ 49.3	700 – 900	102-131	≥ 40
Strip	≤ 5	≤ 0.197	≥ 305	≥ 44.2	≥ 340	≥ 49.3	700 – 900	102-131	≥ 40
Sheet/Plate	5-20	0.197-0.787	≥ 300	≥ 43.5	≥ 330	≥ 47.9	700 – 900	102-131	≥ 40
Sheet/Plate	20-65	0.787-2.56	≥ 280	≥ 40.6	≥ 315	≥ 45.7	700 – 900	102-131	≥ 40
Bar	≤ 250	≤ 9.84	≥ 280	≥ 40.6	≥ 315	≥ 45.7	700 - 900	102-131	≥ 40

Table 5 – Mechanical properties at room temperature, minimum values acc. to VdTÜV 424

ISO V-notch impact toughness KV_2

Minimum	Minimum
20 °C (68 °F)	-196 °C (-122 °F)
96 J (70.8 ft/lbf)	80 J

Average value from 3 samples. Only one value may fall below the minimum average value, and by no more than 30%. The values also apply for the heat affected zones in welded joints.

Corrosion resistance

Due to the combination of chromium with a high molybdenum concentration, VDM® Alloy C-4 has an extraordinary resistance to a number of chemical media: e.g. contaminated, reducing mineral acids. Due to its high nickel concentration, VDM® Alloy C-4 is practically insensitive to chloride-induced stress corrosion, including in hot chloride solutions.

Applications

Typical applications for VDM® Alloy C-4 are:
VDM® Alloy C-4 is used in a field of chemical process technology, including at higher temperatures.
Special applications are:

- Pickling bath regeneration in production companies
- Components in acetic acid production and for the production of chemical fertilizers and pesticides

Fabrication and heat treatment

VDM® Alloy C-4 can be easily formed both hot and cold and can also be machined. VDM® Alloy C-4 is ideally suited for processing by means of common industrial processing techniques. However, machines which take account of the high mechanical properties are necessary for any processing work.

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 into direct contact with flames.

Hot forming

The material can be hot-formed in a temperature range between 1,080 and 900 °C (1,976 and 1,652 °F) with subsequent rapid cooling down in water or air. Heat treatment after hot forming is required in order to achieve optimal properties. For heating up, workpieces should be placed in a furnace that is already heated up to the target value.

Cold forming

VDM® Alloy C-4 has a significantly higher work hardening rate than other austenitic stainless steels. This must be taken into account for the design and selection of forming tools and equipment, and for the planning of forming processes. The workpiece should be in the solution-annealed condition. Intermediate annealing is necessary for major cold forming work. For cold forming of > 15%, new solution annealing must be conducted.

Heat treatment

Solution annealing should take place at temperatures of 1,120 °C (2,048 °F). Cooling down should be accelerated with water to achieve optimum corrosion properties. Fast air cooling can also be carried out at thicknesses of less than approx. 1.5 mm. In each heat treatment, the aforementioned cleanliness requirements must be observed.

Descaling and pickling

Oxides of VDM® Alloy C-4 and heat tint in the area around welds adhere more strongly than in stainless steels. Grinding using extremely fine abrasive belts or grinding discs is recommended. It is imperative that grinding burns be avoided. Before pickling in nitric-hydrofluoric acid mixtures, the oxide layers should be destroyed by abrasive blasting, or pretreated in salt baths.

Machining

Machining of VDM® Alloy C-4 should take place in a solution-annealed condition. Because of the considerably elevated tendency toward work hardening rate in comparison with low-alloy austenitic stainless steels, a low cutting speed and a feed level that is not too high should be selected and the cutting tool should be engaged at all times. An adequate chip depth is important in order to cut below the previously formed strain-hardened zone.

Welding information

When welding nickel alloys and special stainless steels, the following information should be taken into account:

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

Workplace
A workplace arranged separately must be provided that is specifically cordoned off from areas where C steel is being processed. 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 from iron particles being pressed in, 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 root gaps (1 to 3 mm) are required to meet 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 (such as a welding rod) should be carried out using acetone.

Welding parameters and influences
It must be ensured that work is carried out using targeted heat application and low heat input as listed in Table 6 as an example. The stringer bead technique is recommended. The interpass temperature should not exceed 120°C. In principle, checking of welding parameters is necessary.

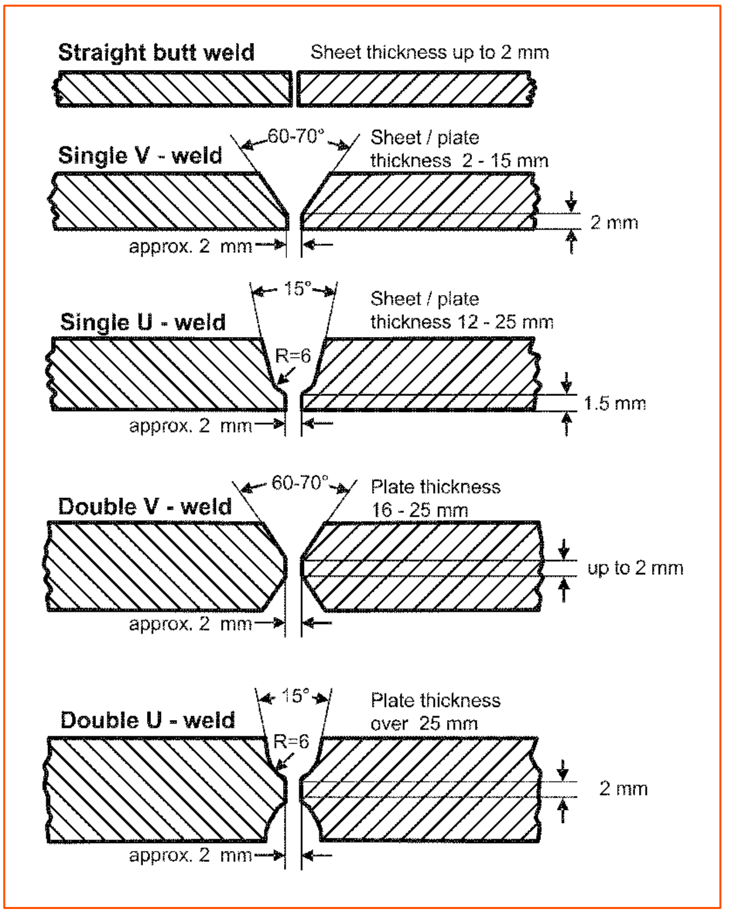

Figure 1 – Edge preparations for welding nickel alloys and special stainless steels

Welding filler

The use of the following fillers is recommended for gas-shielded welding methods:

Weld cladding
VDM® WS C-4
ISO 18274 - B Ni 6455 (NiCr16Mo16Ti)
Material No. 2.4611

TIG/MIG
VDM® FM 59
ISO 18274 - S Ni 6059 (NiCr23Mo16)
Material No. 2.4607

VDM® FM C-4;
ISO 18274 - S Ni 6455 (NiCr16Mo16Ti)
Material No. 2.4611

You will find examples for welding techniques and parameters in the VDM Metals welding filler catalogue.

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 tints can be removed completely. Pickling, if required or specified, should generally be the last work step in the welding process. The information contained in the section entitled "Descaling and pickling" must be observed. Heat treatments are normally neither required before nor after welding.

Availability

VDM® Alloy C-4 is available in the following semi-finished forms:

Sheet

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

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Piece Weight
Cold rolled	1-7 (0.039-0.275)	1,000-2,500 (39.4- 98.42)	≤ 12,500 (492)	
Hot rolled*	3-50 (0.118-1.97)	1,000-2,500 (39.4 -98.42)	≤ 12,500 (492)	≤ 2,100 kg (4,630 lb)

*2mm thickness on request

Strip

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

Thickness mm (in)	Width mm (in)	Coil-inside diameter mm (in)			
0,025-0,15 (0.000984-0.00591)	4-230 (0.157-9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0,15-0.25 (0.00591-0.00984)	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 -0.0394)	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, ground 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	12-550 (0.472-21.7)	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)
0.16-10 (0.006-0.04)	5.5-19 (0.22-0.75)

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

Legal notice

30 September 2018

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