VDM® Alloy 400
Nicorros

Material Data Sheet No. 4110
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VDM® Alloy 400

Nicorros

VDM® Alloy 400 is a single-phase, solid solution, nickel-copper alloy with excellent corrosion resistance in a wide range of corrosive media.

VDM® Alloy 400 is characterized by:

- resistance against chloride-induced stress corrosion
- excellent strength even at low application temperatures
- easy processing compared to other high-alloy materials
- approved for pressure vessels from -10 to 425 °C (14 to 797 °F) pursuant to VdTÜV Material Sheet 263 and up to 480 °C (896 °F) in accordance with ASME Boiler and Pressure Vessel Code.

Designations and standards

Standard	Material designation
EN	2.4360 - NiCu30Fe
ISO	NiCu30
UNS	N04400
AFNOR	NU 30
BS	NA 13

Table 1a – Designations and standards

Designations and standards

Product form	DIN	VdTÜV	ISO	ASTM	ASME	SAE AMS	NACE	Others
Sheet, plate	17743 17750	263	6208	B 127	SB 127	4544	MR 0175/ISO 15156 MR 0103	QQ-N-281, Form 4, 6
Strip	17743		6208	B 127	SB 127	4544	MR 0175/ISO 15156	API 5LD QQ-N-281, Form 5
Rod, bar, forging	17743 17752 17754	263	9723	B 164 B 564	SB 164	4675	MR 0175/ISO 15156 MR 0103	QQ-N-281, Form 1, 2
Wire	17743			B 164				

Table 1b – Designations and standards

Chemical composition

	Ni	Fe	C	Mn	Si	Al	Cu
Min.	63	1					28
Max.		2.5	0.15	2	0.5	0.5	34

Table 2 – Chemical composition (%)

Physical properties

Density	Melting range	Curie temperature
8.82 g/cm³ (0.32 lb/in³) at 20 °C (68 °F)	1,300-1,350 °C (2,372-2,462 °F)	20-50 °C (68-122 °F)

Temperature		Specific heat		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	J / Kg · K	Btu / lb · °F	W / m · K	Btu · in / sq. ft · h · °F	μΩ · cm	GPa	10³ ksi	10^{-6} / K	10^{-6} / °F
20	68	452	0.108	23.0	160.0	51.3	182	26.4		
100	212	461	0.110	25.4	176.2	54.0	180	26.1	13.8	7.67
200	392	473	0.113	28.7	199.1	55.5	177	25.7	14.5	8.06
300	572	484	0.116	31.9	221.3	57.5	170	24.7	14.9	8.28
400	762	495	0.118	34.7	240.8	58.5	165	23.9	15.2	8.44
500	932	523	0.125	38.4	266.4	60.0	150	21.8	15.6	8.67
600	1,112	544	0.130	41.2	285.9	61.8			16.0	8.89
700	1,292	555	0.133	43.1	299.0	63.5			16.4	9.11
800	1,472	566	0.135	45.1	312.9	65.5			16.8	9.33
900	1,652	577	0.138	47.5	329.6	67.5			17.3	9.61
1,000	1,832	587	0.140	50.0	346.9					
1,150	2,102	603	0.144	52.9	367.0					

Table 3 – Typical physical properties of VDM® Alloy 400 at below, room and increased temperatures

Microstructural properties

VDM® Alloy 400 is a binary nickel-copper alloy with a face-centered cubic microstructure.

Mechanical properties

The following mechanical properties of VDM® Alloy 400 apply to the described conditions and specifications in the specified semi-fabricated forms and dimensions (ref. chapter on ‘Availability’). The properties for larger dimensions have to be agreed upon separately.

Temperature		Yield strength $R_{p\,0.2}$		Tensile strength R_m	
°C	°F	MPa	ksi	MPa	ksi
20	68	175	25.4	450	65.3
100	212	150	21.8	420	60.9
200	392	135	19.6	390	56.6
300	572	130	18.9	380	55.1
400	762	130	18.9	370	53.7
425	797	130	18.9	370	53.7

Table 4 – Mechanical properties at room temperature and increased temperature according to VdTÜV Material Sheet 263

Product form	Heat treatment	Standard	Yield strength $R_{p\,0,2}$		Tensile strength Rm		Elongation A
			MPa	ksi	MPa	ksi	%
Sheet, plate / rod, bar	stress-relieved	ASTM, ASME	275-415	39.9-60.2	550-600	79.8-87.0	≥ 20
Sheet, plate / rod, bar	stress-relieved	DIN	≥ 300	≥ 43.5	≥ 550	≥ 79.8	≥ 25
Sheet, plate / rod, bar	annealed	ASTM, ASME, QQN	≥ 195	≥ 28.3	≥ 480	≥ 69.6	≥ 35
Sheet, plate / rod, bar	annealed	DIN, VdTÜV[1)]	≥ 175	≥ 25.4	≥ 450	≥ 65.3	≥ 30

[1)] VdTÜV values apply to the following dimensions: max. thickness sheet = 50 mm (1.97 in), max. diameter rod and bar = 200 mm (7.87 in)

Table 5 – Mechanical properties at room temperature, minimum values

ISO V-notch impact toughness

Average value, room temperature, annealed: 150 J/cm^2
Average value, room temperature, stress-relieved: > 100 J/cm^2

Source: VdTÜV Material Sheet 263

Rockwell hardness HRB

Stress-relieved, room temperature, DIN: ≥ 170
Annealed, room temperature, DIN, VdTÜV: ≤ 150

Corrosion resistance

VDM® Alloy 400 has excellent resistance to neutral and alkaline salts and has long been the standard material for salt production systems. VDM® Alloy 400 is one of the few materials which can be used in contact with fluorine, hydrofluoric acid and hydrogen fluoride or their compounds. The material has a very high resistance to alkaline media. Its behavior in seawater is also excellent compared to copper-based alloys with an increased resistance to cavitation. VDM® Alloy 400 can be used in contact with highly diluted mineral acids, such as sulfuric and hydrochloric acid, provided that they are not ventilated.

Since the alloy does not contain chromium, the corrosion rates can increase significantly under oxidizing conditions. While VDM® Alloy 400 is resistant to stress corrosion cracking, it can display stress cracks in the presence of mercury or in moist, aerated HF vapors. Stress relief annealing is necessary in these conditions.

Fields of application

Common applications of VDM® Alloy 400 are:

- Feedwater and steam generator tubes in power plants
- Brine heater and recompression evaporator in saltworks
- Sulfuric and hydrofluoric acid alkylation
- Heat exchangers in the chemical industry
- Plating components for mineral oil distillation plants
- Splash zone lining on offshore platforms
- Impellers and pump shafts in marine technology
- Refining plants for the production of nuclear fuel
- Pumps and valves in production lines for tetrachlorethylene (perchlorethylene) and chlorinated plastics
- Heating tubes for monoethanolamine (MEA)
- Sour-gas resistant components for oil and gas production

Processing and Heat treatment

VDM® Alloy 400 is easy to process by the conventional method in the industry.

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 400. This type of contamination is also contained in marking and temperature display paints or pens, 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 wt.-% of sulfur. Heating oil with a sulfur content of maximum 0.5 wt.-% 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 be contacted directly by flames.

Hot forming
VDM® Alloy 400 can be hot formed in the temperature range of 800 to 1,200 °C (1,472 to 2,192 °F), but only slight deformations should occur at 925 °C (1,697 °F). Hot bending is performed from 1,200 to 1,025 °C (2,192 to 1,877 °F). For preheating, the workpieces may be placed in the furnace which has already been preheated to the maximum hot forming temperature. The workpieces should remain in the furnace for around 60 minutes per 100 mm (3.94 in) of thickness once the furnace has reached its temperature again. After this, the workpiece should be removed from the furnace immediately and formed within the temperature interval stated above. Heat treatment after hot forming is recommended for the achievement of optimal mechanical properties and corrosion resistance.

Cold forming
VDM® Alloy 400 is easily cold-shaped. However, it has a slightly higher work-hardening than does carbon steel. 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 during cold working. The strength of VDM® Alloy 400 can be increased by hardening, though. Stress relief annealing is recommended in such cases, though, especially when used in media that can cause stress corrosion cracking in nickel-copper alloys, such as mercury and its compounds or fluorosilicic acid.

Heat treatment
The soft annealing should be performed at temperatures of 700 to 900 °C (1,292 to 1,652 °F), preferably at about 825 °C (1,517 °F).

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

- For semi-finished thicknesses of d ≤ 10 mm (0.39 in), the retention time is t = d * 3min/mm.
- For semi-finished thicknesses of d = 10-20 mm (0.39-0.79 in), the retention time t = 30 min + (d – 10 mm) * 2min/mm
- For semi-finished product thicknesses of d > 20 mm (0.79 in), the retention time t = 50 min + (d – 20 mm) * 1min/mm

The retention time commences with material temperature equalization of the workpiece. Cooling down should be accelerated with air to achieve optimum corrosion-protection properties. To form a fine grain structure, the observance of heat treatment temperature and time is very important. The values are to be set precisely. Under certain circumstances, an increase in strength by cold forming is advantageous. Stress-relief annealing at about 550 to 650 °C (1,022 to 1,202 °F) should then occur, in order to prevent stress corrosion cracking.

The material must be placed in a furnace which has been heated up to the maximum annealing temperature before any heat treatment. For the product form strip, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the band thickness. The cleanliness requirements listed under "Heating" have to be observed.

Descaling and pickling
Oxides on VDM® Alloy 400 and discolorations in the area of weld edges have to be removed before use. Before the pickling in hot sulfuric acid, blasting of the surfaces is helpful to shorten the pickling times. Pickling in saltpeter hydrofluoric acid mixtures leads to the formation of nitric gases damaging to health and the environment and it is not recommendable.

Machining processing
VDM® Alloy 400 can be easily machined in the soft annealed condition. Strain-hardened, stress relieved material is a more favorable processing behavior in most machining processes. Since the alloy has a tendency to hardening, a low cutting speed should be selected and the cutting tool should stay engaged at all times. An adequate depth of cut is important in order to cut below the previously formed work-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 alloys and special stainless steels, the following information should be taken into account:

Workplace
A separate workplace should be provided which is clearly separated from the areas where carbon steel is processed. Considerable cleanliness is required, and draughts 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. 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.

Weld preparation
Welding seam preparation should preferably be carried out using mechanical methods through lathing, milling or planning. Abrasive waterjet cutting or plasma cutting is also possible. In the latter case, however, the cutting edge (seam edge) has to be finished off cleanly. Careful grinding without overheating is also permissible.

Scaling
The scaling may only occur 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.

Opening angle

Compared to C-steels, nickel alloys and specialty stainless steels have a lower heat conductivity and greater heat expansion. These properties have to be taken into account by a larger root openings or root gaps (1 to 3 mm, 0.04 to 0.12 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 3 – have to be provided for butt welds.

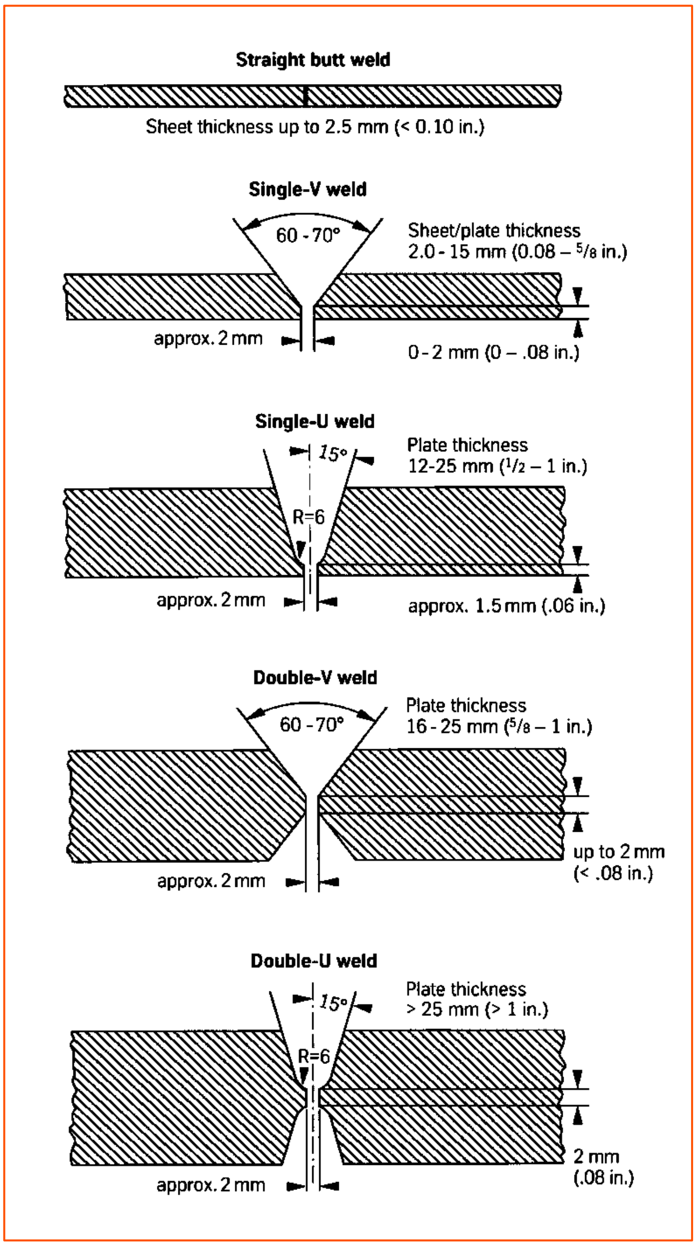

Figure 1 – Seam preparation for welding nickel alloys and special stainless steels

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

The material VDM® Alloy 400 is welded with the common welding processes, such as GTAW (TIG), GTAW (TIG) hot wire, plasma, GMAW (MIG/MAG) and submerged arc welding. The material should be in its annealed condition for welding and should be free of scale, grease and markings. During welding, everything has to be scrupulously clean.

Welding consumable
The following welding consumable is recommended:

VDM® FM 60 (W.-Nr. 2.4377) (WIG electrodes, Welding wire, Wire electrode)
VDM® WS 60 (W.-No. 2.4377) (strip for submerged arc welding or electrode slag welding)
SG-NiCu30MnTi
AWS A5.14: ERNiCu-7
ISO 18274: S Ni 4060, NiCu30Mn3Ti

The use of bar electrodes in sleeves is possible.

Welding parameters and influences
It has to be ensured that work is performed using targeted heat application and low heat input. The interpass temperature should not exceed 150 °C (302 °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 6. In principle, checking of welding parameters is necessary.

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.

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

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	-	9	10	110-120	11	10-15	I1, R1 with max. 3% H2	8-10
6	manual TIG	2-2.4	-	100-110	10	120-130	12	10-15	I1, R1 with max. 3% H2	8-10
8	manual TIG	2.4	-	100-110	11	130-140	12	10-15	I1, R1 with max. 3% H2	8-10
10	manual TIG	2.4	-	100-110	11	130-140	12	10-15	I1, R1 with max. 3% H2	8-10
3	autom. TIG HD[2)]	1.2	0.5	-	-	150	10	25	I1, R1 with max. 3% H2	15-20
5	autom. TIG HD[2)]	1.2	0.5	-	-	150	10	25	I1, R1 with max. 3% H2	15-20
4	Plasma[3)]	1.2	0.5	165	25	-	-	25	I1, R1 with max. 3% H2	30
6	Plasma[3)]	1.2	0.5	190-200	25	-	-	25	I1, R1 with max. 3% H2	30
8	GMAW (MIG/MAG)[4)]	1	8	-	-	130-140	23-27	24-30	I1, R1 with max. 3% H2	18-20
10	GMAW (MIG/MAG)[4)]	1.2	5	-	-	130-150	23-27	20-26	I1, R1 with max. 3% H2	18-20
12	Submerged arc welding	1.6	-	-	-	240-280	28	45-55	-	-
20	Submerged arc welding	1.6	-	-	-	240-280	28	45-55	-	-

[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:
manual TIG, autom. TIG max. 8; TIG hot wire max. 6; manual GMAW (MIG/MAG), autom. GMAW (MIG/MAG) max. 11; Plasma max. 10, submerged arc welding max. 7

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

Table 6 - Welding parameters

Availability

VDM® Alloy 400 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*	3-80 (0.12-3.15)	≤ 2,500 (98.43)	≤ 12,500 (492.13)	≤ 2,450 (5401.33)

* 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			
0,02-0,2 (0.0008-0.008)	4-230 (0.16-9.06)	300	400	500	–
0.2-0.25 (0.008-0.01)	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
2-3.5 (0.08-0.14)	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	12-500 (0.47-19.69)	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 spiders

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.

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