VDM Metals

VDM® Alloy 31

Nicrofer 3127 hMo

Material Data Sheet No. 4131

November 2016

VDM® Alloy 31

Nicrofer 3127 hMo

VDM® Alloy 31 is an iron-nickel-chromium-molybdenum alloy with the addition of nitrogen. The alloy developed by VDM Metals closes the gap between high alloyed austenitic special stainless steels and nickel alloys. VDM® Alloy 31 has proven itself to be suitable particularly in the chemical and petrochemical industries, in ore digestion plants, in environmental and marine engineering as well as in oil and gas extraction.

VDM® Alloy 31 is characterized by:

- Outstanding corrosion resistance in alkaline and acidic halide-containing media
- Excellent resistance to sulfuric acid, even in highly concentrated form
- Excellent resistance to corrosion and erosion in phosphoric acid media
- Outstanding resistance to surface corrosion and local corrosion in chlorine dioxide bleaching plants in paper production
- Excellent resistance in reducing and oxidizing media as well as in boiling azeotropic nitric acid
- Good workability and weldability
- VdTÜV-certification for pressure vessels with operating temperatures from -196 to 550 °C (-320.8 to 1,022 °F)
- Certification according to ISO 15156/NACE MR 0175 up to level VI for acid gas applications in the oil and gas industry
- ASME approval for pressure vessels up to 800 °F (427 °C)

The material is included in the list of the German Federal Institute for Materials Research and Testing (BAM) for transport and storage containers for hazardous goods.

Designations and standards

Standard	Material designation
D	1.4562 - X1NiCrMoCu32-28-7
ISO	NACE MR0175/ISO 15156:2003
UNS	N08031

Product form	VdTÜV	ASTM	ASME	SEW	Others
Sheet, plate	509	B 625	SB 625	400	
Strip	509	B 625	SB 625	400	API 5LD
Rod, bar	509	B 581 B 649	SB 581 SB 649	400	
Wire		B 649 B 564	SB 649	400	

Table 1 – Designations and standards

Chemical composition

	Ni	Cr	Fe	S	Si	Mn	P	Mo	Cu	N	C
Min.	30.0	26.0	balance					6.0	1.0	0.15	
Max.	32.0	28.0		0.010	0.3	2.0	0.020	7.0	1.4	0.25	0.015

Table 2 – Chemical composition (%) according to UNS N08031

Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
8.05 g/cm³ (0.29 lb/in³) at 20 °C (68 °F)	1,330-1,370 °C (2,426-2,498 °F)	1.001

Temperature		Thermal conductivity[1)]		Electrical resistivity	Modulus of elasticity[1)]		Coefficient of thermal expansion[1)]	
°C	°F	W / m · K	Btu · in / sq. ft · h · °F	µΩ · cm	GPa	10^3 ksi	10^{-6} / K	10^{-6} / °F
20	68	11.7	81.2	104	198	28.7		
100	212	13.2	91.6	107	189	27.4	14.3	7.94
200	392	15	104.1	110	183	26.5	14.7	8.17
300	572	16.8	116.6	113	176	25.5	15.1	8.39
400	762	18.5	128.4	116	170	24.7	15.5	8.61
500	932	20.2	140.1	118	163	23.6	15.7	8.72
600	1,112	21.9[2)]	151.9	120	158	22.9	15.9	8.83

1) values according to VdTÜV material data sheet 509
2) extrapolated value

Table 3 – Typical physical properties of VDM® Alloy 31 at room temperature and elevated temperatures

Microstructural properties

VDM® Alloy 31 has a face-centered cubic lattice. The 0.2% nitrogen content stabilizes the austenite and reduces the precipitation rate of intermetallic sigma phases.

Mechanical properties

The following mechanical properties apply to VDM® Alloy 31 in the solution-annealed and quenched condition and in the stated semi-finished forms and dimensions.

Temperature		Yield strength[1)] $R_{p\ 0.2}$		Tensile strength[1)] R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
20	68	280	40.6	650	94.3	40
100	212	210	30.5	630	91.4	40
200	392	180	26.1	580	84.1	40
300	572	165	23.9	530	76.9	40
400	762	150	21.8	500	72.5	40
500	932	135	19.6	470	68.2	40
550	1,022	125	18.1	450	65.3	40

1) values according to VdTÜV material data sheet 509

Table 4 – Typical short-term properties at room temperature and elevated temperatures for sheet products

Product form	Dimensions		Yield strength $R_{p\ 0.2}$		Yield strength $R_{p\ 1.0}$		Tensile strength R_m		Elongation A
	mm	in	MPa	ksi	MPa	ksi	MPa	ksi	%
Sheet, plate	≤ 50	≤ 1.97	≥ 280	≥ 40.6	≥ 310	≥ 45.0	≥ 650	≥ 94.3	≥ 40
Strip	≤ 3	≤ 0.12							
Rod, bar	≤ 300	≤ 11.81							
Wire	≤ 12	≤ 0.47							

Table 5 – Mechanical properties at room temperature according to ASTM B625 (plate, sheet and strip), B649 (bar and wire)

ISO V-notch impact toughness

Average value, room temperature: ≥ 185 J/cm²

Average value, -196 °C (-320.8 °F): ≥ 140 J/cm²

Minimum impact values at room temperature for sheet products according to VdTÜV material data sheet 509.

Corrosion resistance

Optimal corrosion resistance is only ensured if the material is used in a solution annealed, clean and metallic bright condition. The chemical composition of VDM® Alloy 31 is designed to enable the achievement of a high corrosion resistance in halide-containing media. At the same time, the material has excellent resistance in pure and contaminated sulfuric acid over a broad range of concentrations and temperatures up to 80 °C (176 °F). Figure 1 shows the ISO corrosion diagram of VDM® Alloy 31 in lightly aerated sulfuric acid of technical purity, determined in immersion tests of at least 120 h.

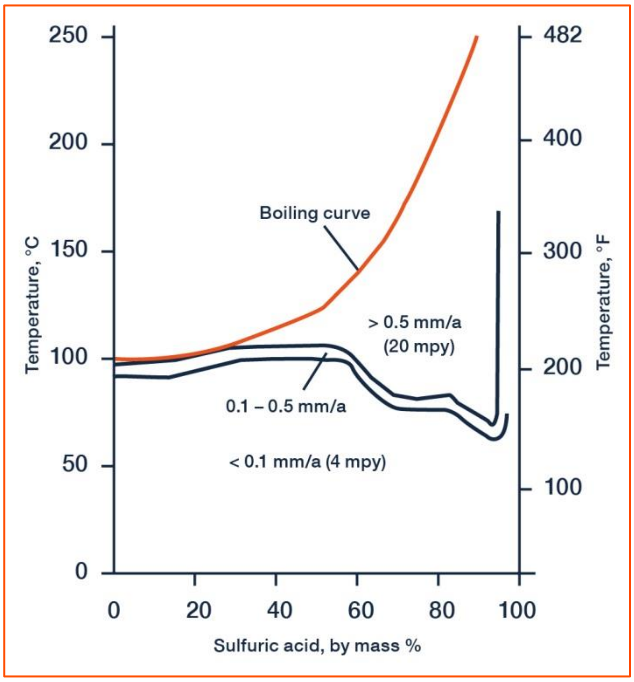

Figure 1 – ISO corrosion diagram of VDM® Alloy 31 in weakly aerated sulfuric acid of technical purity, determined in immersion tests of at least 120 h

Under heavy stress from erosion corrosion in the wet digestion process in the production of phosphoric acid, VDM® Alloy 31 has proven to be a true alternative to nickel alloys. Tests in chlorine dioxide bleaching plants in the pulp and paper industry have shown that VDM® Alloy 31 withstands the harshest operating conditions.

The resistance to inter-crystalline corrosion (IC) was determined both according to ASTM G 28, method A, and according to SEP 1877 II. Figure 2 shows, that VDM® Alloy 31 becomes sensitized only after prolonged exposure. The resistance to pitting was determined via potential measurements and through testing according to ASTM G 48 under staged temperature increases and the use of the same samples. Figure 3 shows the results in comparison with other materials. Even in other corrosive media, VDM® Alloy 31 demonstrates significant advantages compared with other alloys.

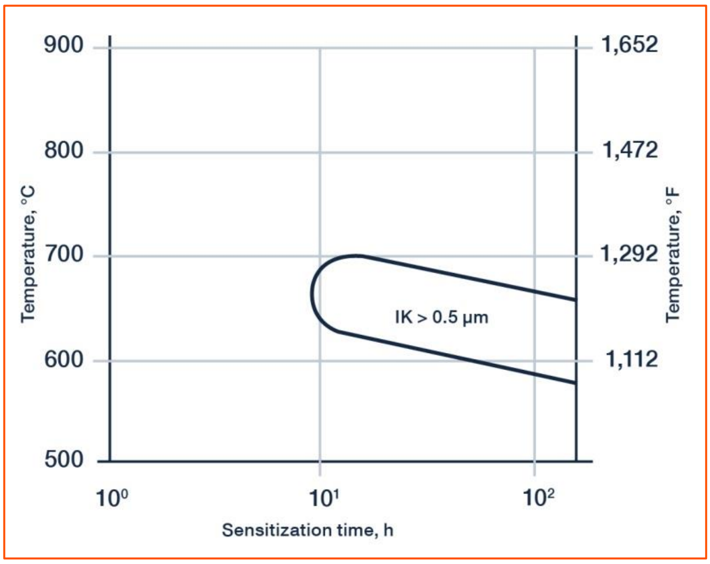

Figure 2 – Time-temperature sensitization diagram (TTS), IC attack based on testing according to ASTM G 28, method A

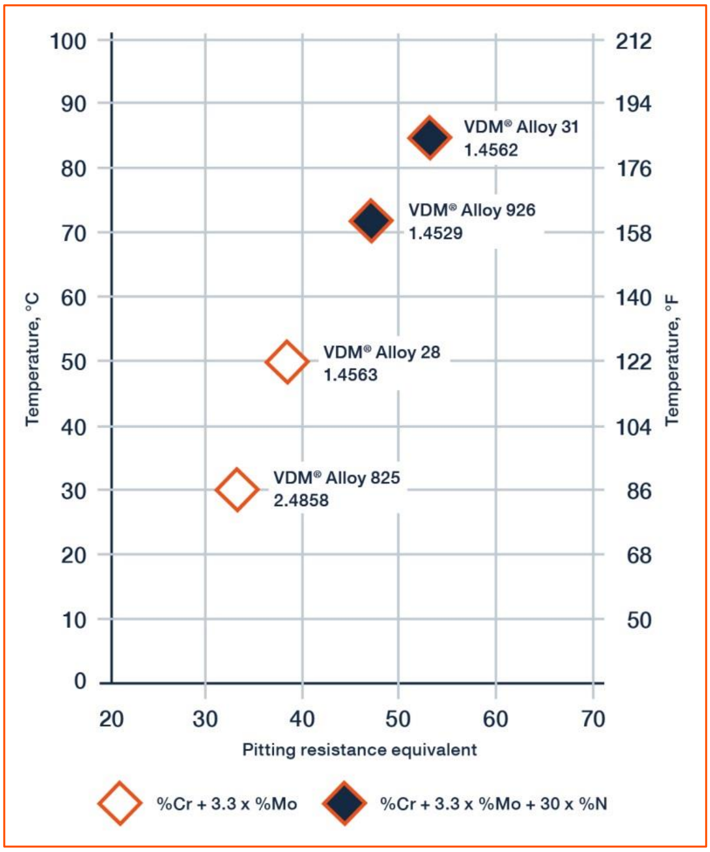

Figure 3 – Critical pitting temperature (CPT) in 10% $FeCl_3$ x 6 H_2O as a function of the corresponding pitting resistance equivalents; determination with staged temperature increases using the same samples

VDM® Alloy 31 is suitable only for applications in organic chemistry and for processes in which hydrochloric acid occurs only in low concentrations below 5% and this only at room temperature or slightly elevated temperatures. This is clearly shown by the ISO corrosion diagram in hydrochloric acid in Figure 4 and by other investigations at room temperature as well as with acid concentrations in the range of 10 to 30%, which yielded erosive corrosion rates of up to 0.5 mm/year (0.02 in/year).

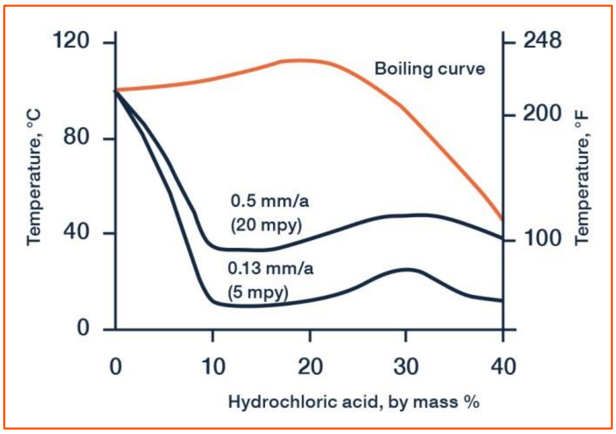

Figure 4 – ISO corrosion diagram of VDM® Alloy 31 in hydrochloric acid, determined via static immersion tests

Fields of application

Typical fields of application for VDM® Alloy 31 are:

- Components for flue gas desulfurization plants
- Plants for the production of phosphoric acid via the wet digestion process
- Pipes and heat exchangers for sulfuric acids contaminated with chlorides
- Pipes containing ocean water and brackish water, condensers and chillers
- Pickling plants for sulfuric acid as well as nitric-hydrofluoric acid
- Treatment of sulfuric acids from waste
- Evaporation and crystallization of salts
- Components for the cellulose and paper industry
- Digestion of ores, e.g. in HIPAL (high-pressure acid leach) plants for the digestion of laterite ores
- Mineral oil production and refineries
- Organic acids and ester synthesis
- Fine chemicals
- Strain-hardened transport and feed pipes as well as slicklines, wirelines and flowlines in the transport of oil and gas

Fabrication and heat treatment

VDM® Alloy 31 can be easily formed both hot and cold and can also be machined.

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 the material. This type of contamination is also contained in marking and temperature-indicating paints or pens as well as 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% by weight of sulfur. Heating oil with a maximum sulfur content of 0.5% by weight is also suitable. Electric 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 must not come in direct contact with flames.

Hot forming

VDM® Alloy 31 should be hot-formed in a temperature range of 1,200 to 1,050 °C (2,192 to 1,922 °F) with subsequent rapid cooling in water or in air. For heating up, workpieces should be placed in a furnace that has been heated up to the maximum hot-forming temperature (solution annealing temperature). Once the furnace has reached its temperature again, the workpieces should remain in the furnace for around 60 minutes per 100 mm (3.94 in) of thickness. After this, they should be removed from the furnace immediately and formed within the temperature range stated above, with reheating necessary once the temperature reaches 1,050 °C (1,922 °F). 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 31 has a significantly higher work hardening rate than other widely used austenitic stainless steels. This must be taken into account during 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

Solution annealing should take place at temperatures between 1,150 and 1,180 °C (2,102 and 2,156 °F). The retention time during annealing depends on the semi-finished product thickness and can be calculated as follows:

- For thickness d <= 10 mm (0.39 in), the retention time is t = d * 3 min/mm
- For thickness d = 10 to 20 mm (0.39-0.79 in), the retention time is
  t = 30 min + (d – 10 mm) * 2 min/mm
- For thickness d > 20 mm (0.79 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.

For maximum corrosion resistance, the workpieces must be quickly cooled from the annealing temperature of at least 1,100 to 500 °C (2,012 to 932 °F) with a cooling rate of >150 °C/min (>302 °F/min). The material must be placed in a furnace that has been heated up to the maximum annealing temperature before any heat treatment. The cleanliness requirements listed under "Heating" must be observed. For strip products, the heat treatment can be performed in a continuous furnace at a speed and temperature that is adapted to the strip thickness.

Descaling and pickling

Oxides of VDM® Alloy 31 and discoloration adjacent to welds are more adherent than on 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 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 31 should be machined in the heat-treated condition. Because of the considerably elevated tendency toward work hardening 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 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 alloys and special stainless steels, the following information should be taken into account:

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. 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 planning. 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 special stainless steels exhibit 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 5 – have to be provided for butt welds.

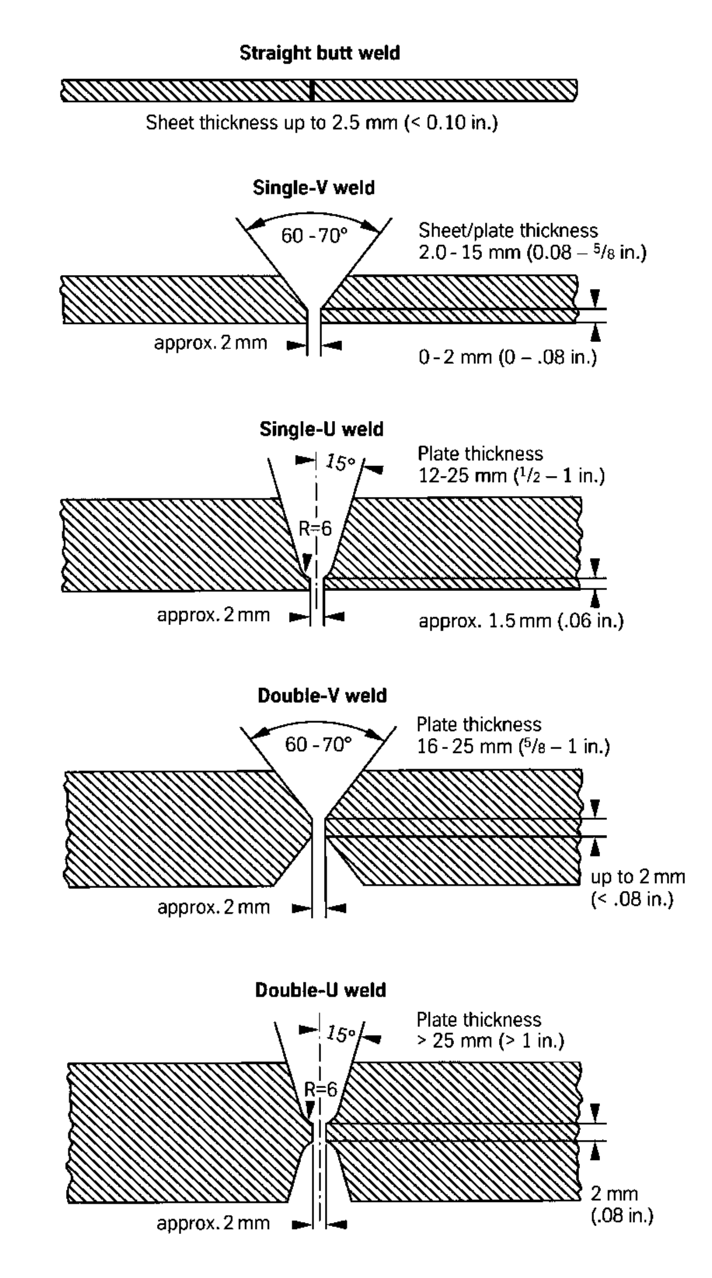

Figure 5 – Seam preparation for welding nickel alloys and special stainless steels

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 technique

VDM® Alloy 31 can be welded using conventional processes with metals of the same type as well as many other metals. This includes GTAW (TIG), GMAW (MIG/MAG) and plasma welding. Pulsed arc welding is preferred for gas-shielded welding processes. The use of a multi-component shielding gas (Ar + He + H_2 + CO_2) is recommended for the MAG processes. For welding, VDM® Alloy 31 should be in a solution-annealed condition and free of scale, grease and markings. When welding the root, care should be taken to achieve best quality root protection using pure argon (argon 4.6) so that the welding edge is free of oxides after welding the root. Root protection is also recommended for the first and, in certain cases depending on the welded construction, also for the second intermediate layer weld after root welding. Any tempering colors must be removed while the welding edge is still hot, preferably using a stainless steel brush.

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

Welding rods and wire electrodes:

VDM® FM 59 (material no. 2.4607)
UNS N06059 AWS A5.14: ERNiCrMo-13
DIN EN ISO 18274: S Ni 6059 (NiCr23Mo16)

or

VDM® FM 31 (material no. 1.4562)
UNS N08031
DIN EN ISO 18274: X1 NiCrMoCu32-28-7

The use of coated electrodes is possible.

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 (248 °F). 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/min

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.

Stabilizing annealing should be carried out on semi-finished products that have already been used at temperatures of between 600 and 650 °C (1,112 and 1,202 °F) before they are used in this critical temperature range again after a repair welding.

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	15	I1, R1 mit max. 3% H2	8-10
6	manual TIG	2-2.4	-	100-110	10	120-140	12	14-16	I1, R1 mit max. 3% H2	8-10
8	manual TIG	2.4	-	100-110	11	130-140	12	14-16	I1, R1 mit max. 3% H2	8-10
10	manual TIG	2.4	-	100-110	11	130-140	12	14-16	I1, R1 mit max. 3% H2	8-10
3	autom. TIG[2)]	1.2	1.2	-	-	150	11	25	I1, R1 mit max. 3% H2	12-14
5	autom. TIG[2)]	1.2	1.4	-	-	180	12	25	I1, R1 mit max. 3% H2	12-14
2	autom. TIG HD[2)]	1	-	-	-	180	11	80	I1, R1 mit max. 3% H2	12-14
10	autom. TIG HD[2)]	1.2	-	-	-	220	12	40	I1, R1 mit max. 3% H2	12-14
4	Plasma [3)]	1.2	1	180	25	-	-	30	I1, R1 mit max. 3% H2	30
6	Plasma [3)]	1.2	1	200-220	26	-	-	26	I1, R1 mit max. 3% H2	30
8	GMAW[4]	1	6-7	-	-	130-140	23-27	24-30	I1	18
10	GMAW[4]	1.2	6-7	-	-	130-140	23-27	25-30	I1	18

[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:
autom. TIG HD max. 6; manual TIG, GMAW manual, autom. max. 8; Plasma max. 10

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

Table 6 – Welding parameters

Availability

VDM® Alloy 31 is available in the following standard semi-finished forms:

Sheet

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*	3-60 (0.12-2.36)	≤ 2,500 (98.43)	≤ 12,500 (492.13)	≤ 1,650 (3,637.63)

* 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			
0.02-0.15 (0.0008-0.006)	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

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

Dimensions*	Outside diameter mm (in)	Length mm (in)
General dimensions	6-800 (0.24-31.50)	1,500-12,000 (59.06-472.44)
Material specific dimensions	10-400 (0.39-15.75)	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)

Publications

The following technical literature has been published about the material VDM® Alloy 31:

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Legal notice

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