VDM Metals

A company of ACERINOX

VDM® Alloy 33
Nicrofer 3033

Material Data Sheet No. 4142 Revision 01
November 2020

VDM® Alloy 33

Nicrofer 3033

VDM® Alloy 33 is an austenitic alloy that has an excellent resistance against common corrosion and pitting corrosion in media containing chloride due to its well-balanced analysis and extraordinarily high chrome concentration. Also because of its very high strength and good workability, VDM® Alloy 33 is a material that can be used for many applications in the chemical processing industry.

VDM® Alloy 33 is characterized by:

- excellent resistance against pitting corrosion in media containing chloride and against general corrosion in hot mineral acids, mixed acids and alkalis as well as seawater and brackish water,
- high strength and high ductility even in high temperatures,
- good workability and welding characteristics,
- ASME approval for pressure vessels in the temperature range from -196 °C to 450 °C (-320 to 842 °F).

Designations

Designation	Material name
EN	1.4591 X1CrNiMoCuN33-32-1
UNS	R20033

Standards

Product form	DIN	VdTÜV	ASTM	ASME	others
Plate and sheet	EN 10029	516	B 625	SB 625	SEW 400
Strip		516	B 625	SB 625	SEW 400
Rod		516	B 649	SB 649	
Wire: Only used as welding wire VDM® FM 33					

Table 1 – Designations and standards

Chemical composition

	Ni	Cr	Fe	C	S	N	Mn	Si	Mo	Cu	P
Min.	30,0	31,0	Bal.			0,35			0,5	0,3	
Max.	33,0	35,0		0,015	0,010	0,6	2,0	0,5	2,0	1,2	0,02
For technical reasons this alloy may contain more elements then listed.											

Table 2 – Typical chemical composition (%)

Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
7,9 g/cm³ at 20 °C 493 lb/ft³ at 68 °F	1.330 – 1.370 °C (2,430 – 2,498 °F)	1,01

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	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	68	446 1)	0.107	13.4	7.74	104	195	28.3		
100	212	466	0.111	14.6	8.44	107	185	26.8	14.5	8.06
200	392	486	0.116	16.0	9.24	109	176	25.5	15.3	8.5
300	572	503	0.120	17.5	10.1	112	170	24.7	15.3	8.5
400	762	520	0.124	19.0	11.0	114	163	23.6	15.7	8.72
500	932	538	0.128	20.4	11.8	116	159	23.1	16.1	8.94
1) at 25 °C (77 °F)										

Table 3 – Typical physical properties at room and elevated temperatures

Microstructural properties

VDM® Alloy 33 has a cubic face-centered crystal structure. The content of approx. 0.4% nitrogen together with 31% nickel stabilizes the austenitic crystal structure and reduces the dispersion speed of intermetallic sigma phases.

Mechanical properties

The following minimum values at room and increased temperatures apply to VDM® Alloy 33 in the solution-annealed condition for longitudinal and traverse test samples of the specified dimensions. The properties for other dimensions must be agreed separately.

Temperature		Yield strength $R_{p\ 0.2}$		Yield strength $R_{p\ 1,0}$		Tensile strength R_m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	380	55.1	420	60.9	720-920	104-133	40
100	212	320	46.4	350	50.8			
200	392	270	39.2	300	43.5			
300	572	240	34.8	270	39.2			
400	752	220	31.9	250	36.3			
500	932	210	30.5	240	34.8			

Table 4 – Mechanical properties at room and elevated temperature. Minimum values according to TÜV material data sheet 516

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	≤ 50	≤ 1.97	≥ 380	≥ 55.1	≥ 420	≥ 60.9	720-920	104-133	≥ 40
Bar	≤ 150	≤ 5.91	≥ 380	≥ 55.1	≥ 420	≥ 60.9	720-920	104-133	≥ 40

Table 5 – Mechanical properties at room temperature according to ASTM B 625 (strip, sheet), B649 (rod, wire)

ISO V impact value

	ISO-V impact strength Ak (mean value) in J/m²	ISO-V notch impact energy Kv in J
Sheet	≥ 188	≥ 150 J (111 ft* lbf)
Bar/ forging	≥ 150	≥ 120 J

Table 6- V-Probe according to DIN EN 10045-1 at 20 °C (68 °F) mean value of three samples longitudinal/transverse

Hardness of Brinell HBW

Brinell hardness ≤240

For sheet ≤ 50 mm (1.968 in), strip ≤ 3 mm (0.118 in), rod ≤ 150 mm (5.90 in)

Corrosion resistance

The austenitic material VDM® Alloy 33 has an extremely high chrome concentration of 33% and therefore offers the basis for the excellent corrosion resistance in oxidizing media. The low addition of molybdenum and copper improves resistance in phosphorus acid and simplifies passivation in sulfuric acid. Besides the excellent resistance against nitric acid/hydro-fluoric acid mixture, the material also has great corrosion resistance against all alkali media. Furthermore, the resistance against pitting corrosion in media containing chloride is also excellent. Optimal corrosion resistance can only be assured if the material is used in clean, metallic bright condition.

Medium	**Temperature in °C (°F)**	**Corrosion rate in (mm/a) (inch/a)**
H_2SO_4 98%	100 (212)	0,04 (0.0015)
	150 (302)	0,08 (0.003)
	200 (392)	0,04 (0.0015)
H_3PO_4 85%	100 (212)	0,08** (0.003)
	154 (309.2)	1,07 (0.042)
NaOH 25%	75 (167)	< 0,01 (0.0003)
	104 (boiling) (219.2)	< 0,01 (0.0003)
50%	75 (167)	< 0,01 (0.0003)
	100 (212)	< 0,01 (0.0003)
	156 (boiling) (312.8)	< 0,01 (0.0003)
HNO_3 12%	90 (194)	< 0,01 (0.0003)
HNO_3 12% + HF 0,9%		0,24 (0.0094)
HNO_3 12% + HF 3,5%		1,19 (0.04)
HNO_3 32% + HF 0,4%		0,27 (0.01)
HNO_3 45% + HF 0,4%		0,67 (0.02)
HNO_3 56% + HF 0,4%		1,66 (0.06)
HNO_3 68% + HF 0,4%		3,08 (0.12)

** Testing time: 7 days (0,2mm/a after one day// 0.007 in/a)

Table 7 – Corrosion rate of VDM® Alloy 33 in different media depending on concentration and temperature

Applications

Typical applications for VDM® Alloy 33 are:

- Heat recovery and distribution systems in the sulfuric acid production
- Pipes and heat exchangers for sulfuric acids contaminated with chlorides
- Vessels for storage and transport of nitric acid/hydrofluoric acid mixtures
- Seawater conducting pipes, condensers, coolers, etc. with excellent resistance against pitting corrosion
- Production and use of NaOH and KOH up to 70 wt.-% and max. 170 °C (338 °F)
- Urea solutions in the concentration range from 5 to 90 wt.-%
- Components for the pulp and paper industry
- Vessels and pipes in purified terephthalic acid (PTA) ülants

Fabrication and heat treatment

VDM® Alloy 33 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 cause damage during the heat treatment of VDM® Alloy 33. This type of contamination is also contained in marking and temperature-indicating paints or pens, and also in lubricating greases, 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 because of the precise temperature control and lack of contaminants 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 33 should be hot-formed in a temperature range between 1,200 and 1,000 °C (2,192-1,832° 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 urgently recommended for achieving optimal corrosion behavior.

Cold forming

The workpieces should be in the annealed condition for cold forming. VDM® Alloy 33 has a higher work hardening than other austenitic stainless steels. This must be taken into account in the design and selection of forming tools and equipment, and in the planning of forming processes. Intermediate annealing is necessary for heavy-duty 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 1,100 and 1,150 °C (2,012-2,102 °F), preferably at 1,120 °C (2,048 °F). The retention time during annealing depends on the semi-finished product thickness and it can be calculated as follows:

- For thicknesses d < 10 mm (0.393 in), the retention time is t = d · 3 min/mm
- For thicknesses d = 10 to 20 mm (0.393-0.787 in), the retention time t = 30 min + (d – 10 mm) · 2 min/mm
- For thicknesses d > 20 mm (0.787), the retention time t = 50 min + (d – 20 mm) · 1 min/mm

The retention time commences with the temperature equalization of the workpiece; 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 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 under "Heating" must be observed.

Descaling and pickling

Oxides of VDM® Alloy 33 and heat tint in the area around welds adhere more strongly than in other 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 they should be pre-treated in salt baths. The pickling baths used should be monitored carefully with regard to concentration and temperature.

Machining
Machining of VDM® Alloy 33 should take place in an annealed condition. Since the alloy is prone to strong work hardening, a low cutting speed should be selected 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 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:

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

Workplace
A workplace must be provided, which is arranged in a separated location and clearly set apart from areas in which C steel is prepared. 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.

Edge preparation
The edge preparation should be carried out preferably using mechanical methods such as lathing, milling or planing. Abrasive waterjet cutting or plasma cutting is also permissible. In case of the latter, however, the cut edge (seam flank) must be cleanly reworked. 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 or web spacings (1 to 3 mm) are required to take these properties into account. 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.

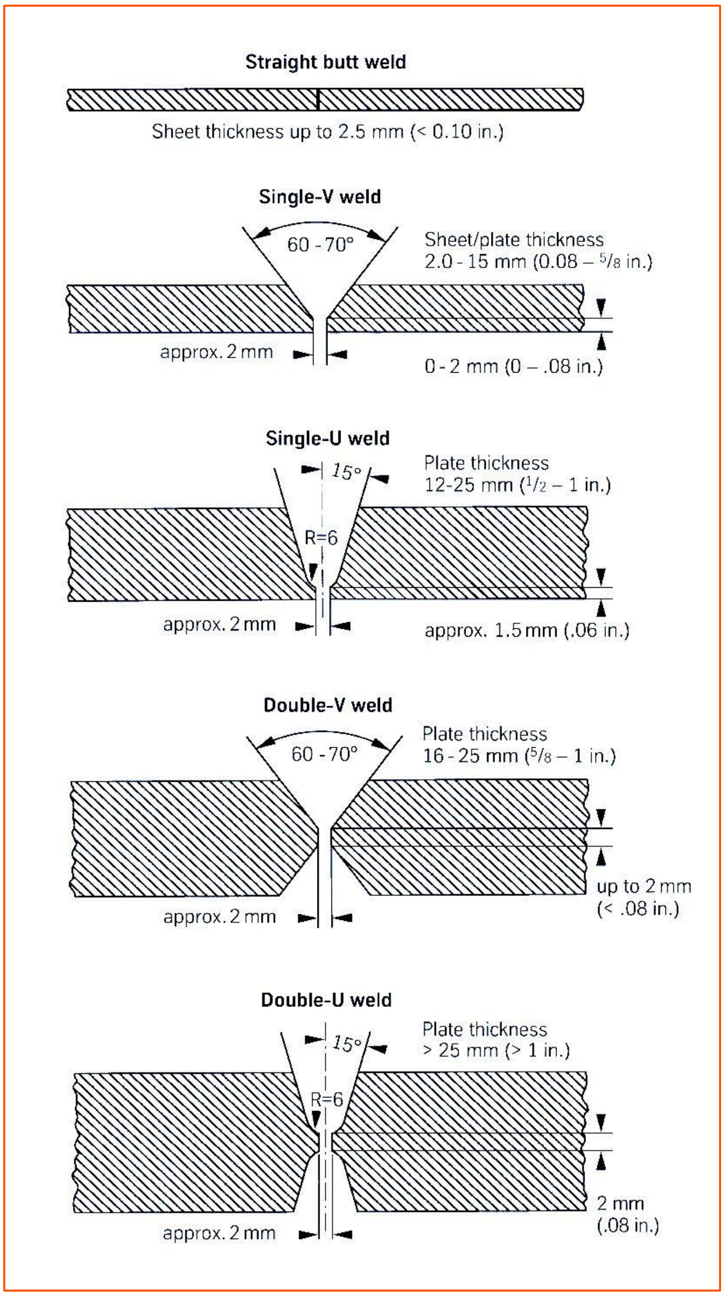

Figure 1 – Edge preparations for welding nickel alloys and special stainless steels

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

For welding, VDM® Alloy 33 must be in a solution-annealed condition and free of scale, grease and markings. VDM® Alloy 33 is weldable in the same way as the filler material tested for suitability for welding, VDM® FM 33 TIG, (TÜV engineering specifications no. 07528). When welding the root, care should be taken to achieve best quality root protection (min. Ar 4.6) and the welding edge must be largely free of oxides after welding. Any heat tints must be removed. As shielding gas, argon with max. 5% hydrogen should be used.

Welding filler
As welding filler, the following is recommended:
VDM® FM 33 (material no. 1.4591)
ISO 14343-A S Z 33 32 1 Cu N L,
AWS A5.9 ER33-31
(UNS R20033)

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 must not exceed 100°C. The stringer bead technique is recommended. In this context, also the right choice of wire and bar diameters should be pointed out. Due to the high nitrogen concentration in the material, the thinnest beads possible should be used (little weld metal, multi-bead technique). This allows the liquefied material in the weld pool to degas whereby pore formation is minimized. Residues at the seam flanks that cannot be removed by brushing must be removed by milling after each bead (beveling is not permissible).
From wall thicknesses of about 20 mm, the filler beads should be welded with the welding consumable VDM® FM 28 (material no. 1.4563) and be covered with at least two layers of VDM® FM 33, which is a welding consumable of the same kind. Corresponding section energy per unit length result from the aforementioned notes, which are shown as examples in Table 8. In principle, checking of welding parameters is necessary and it is therefore required to observe the section energy that is suitable for the material. For all weld constructions, the particularities of this material must be taken into consideration early on.

The section energy E can be calculated as follows:

$$S = \frac{U \cdot I \cdot 60}{v \cdot 1{,}000} \left(\frac{kJ}{cm}\right)$$

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

Post-treatment
If the work is carried out in the optimal way, brushing directly after welding, meaning still in the warm condition will result in the desired surface condition without additional pickling, i.e. heat tints can be removed without residues. 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. Heat treatments are normally not required before or after welding.

Thickness	Welding process	Filler material		Root pass[1)]		Internediate and final passes		Welding speed	Shielding gas	
mm (in)		Diameter mm (in)	Speed (m/min.)	I in (A)	U in (V)	I in (A)	U in (V)	(cm/min.)	Type	Rate (l/min.)
2 (0.0787)	m-TIG	2 (0.0787)	-	70	9.0-10.0			15	I1, R1 with max 3% H_2	8
6 (0.236)	m-TIG	2-2,4 (0.0787-0.0945)	-	90	10	120	11	15	I1, R1 with max 3% H_2	8
12 (0.472)	m-TIG	2.4 (0.0945)	-	100	10	140	14	15	I1, R1 with max 3% H_2	8

Table 8 – Welding parameter

Availability

VDM® Alloy 33 is available in the following semi-finished forms:

Plate/Sheet

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	3-25 (0.118-0.984)	≤ 2,500 (98.42)	≤ 12,500 (492)	≤ 1.600 (3,530)

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).

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

Publications

The following technical literature of VDM Metals GmbH has been published about the material VDM® Alloy 33:

M. Köhler, U. Heubner, K.-W. Eichenhofer, M. Renner: Alloy 33, A New Corrosion-Resistant Austenitic Material for the Refinery Industry and Related Applications, Corrosion 95, Paper No. 338NACE International, Houston, Texas, 1995.

M. Köhler, U. Heubner, K.-W. Eichenhofer: Progress with Alloy 33. A New Corrosion-Resistant Chromium-Based Austenitic Material, Corrosion 96, Paper No. 428NACE International, Houston, Texas, 1996.

U. Heubner, M. Köhler, K.-W. Eichenhofer, M. Renner: Alloy 33. A New Nitrogen-Alloyed Chromium-Based Material for Many Corrosive Environments, Proc. Int. Conf. Stainless Steel '96,Verlag Stahleisen, Düsseldorf, 1996.

F.E. White, M. Köhler, K.-W. Eichendorfer, M. Renner: Alloy 33: An optimized material for sulphuric acid service, Sulphur 96, Vancouver, 20-23 October 1996.

D. C. Agarwal, M. Köhler: Alloy 33. A New Material Resisting Marine Corrosion, Corrosion '97, Paper No. 424, NACE International, Houston, Texas, 1997.

U. Heubner, M. Köhler, K.-W. Eichenhofer, M. Renner: Alloy 33. A New Material for Handling HNO3/HFMedia in Processing of Nuclear Fuel, Corrosion 97, Paper No. 115, NACE International, Houston, Texas, 1997.

C. Voigt, G. Riedel, H. Werner, M. Köhler: Kühlwasserseitige Korrosionsbeständigkeit von metallischen Werkstoffen zur Handhabung von Schwefelsäure [Corrosion Resistance of Metallic Materials on the Coolant Water Side for the Handling of Sulfuric Acid], Materials and Corrosion 49, 489-495, 1998.

D. C. Agarwal, Philip A. Anderson: Corrosion resistance of various high chromium alloys in simulated chemical processing nuclear plant waste solutions, Corrosion 98, Paper No. 164, Nace International, Houston, Texas, 1998.

Pedro D. Portella, M. Köhler, M. Renner: Investigation of microstructure and properties of a chromium-rich austenitic material with high nitrogen content, 5th International Conference on High Nitrogen Steels, Espoo/Stockholm, May 24-28, 1998.

Imprint

23.11.2020

Publisher
VDM Metals International GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

Disclaimer
All information contained in this data sheet is based on the results of research and development work carried out by VDM Metals International GmbH and the data contained in the specifications and standards listed available at the time of printing. The information does not represent a guarantee of specific properties. VDM Metals reserves the right to change information without notice. All information contained in this data sheet is compiled to the best of our knowledge and is provided without liability. Deliveries and services are subject exclusively to the relevant contractual conditions and the General Terms and Conditions issued by VDM Metals. Use of the most up-to-date version of this data sheet is the responsibility of the customer.

VDM Metals International GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

Phone +49 (0)2392 55 0
Fax +49 (0)2392 55 22 17

vdm@vdm-metals.com
www.vdm-metals.com