VDM Metals

VDM® Alloy 36
Pernifer 36

Material Data Sheet No. 7101 **Revision 01**
March 2020

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Pernifer 36

VDM® Alloy 36 is a binary iron-nickel alloy with a particularly low heat expansion coefficient, whereby the levels of carbon and manganese as well as freedom of impurities are significant. Cold forming also reduces the heat expansion. Artificial aging with gradual heat treatment stabilizes the expansion coefficients in a selected temperature range.

VDM® Alloy 36 is characterized by:

- an extremely low expansion coefficient between -250 °C (-418 °F) and +200 °C (392 °F)
- good ductility and toughness.

Designations

Standard	Material designation
EN	1.3912 Ni36
UNS	K93600 (for thermostates) K93601 (for pressure vessels) K93602 (for chip removing process) K93603 (for alloys with low heat expansion)
AFNOR	Fe-Ni36

Standards

Produkt form	ASTM	DIN	SEW
Sheet, plate	F1684	17745	385
Strip	B603	17470	
Rod, bar	F1684	17745	385
Wire	B603	17470	

Table 1 – Designations and standards

Chemical composition

	Ni	Cr	Fe	Co	Mn	Si	C	S	P
Min.	35								
Max.	37	0.25	bal.	0.5	0.6	0.4	0.05	0.015	0.015
Due to technical reasons the alloy may contain additional elements									

Table 2 – Chemical composition (%)

Physical properties

Density	Melting range	Curie temperature
8,1 g/m³ at 20 °C 506 lb/ft² at 68 °F	1,430 °C 2,610 °F	230 °C 446 °F

Temperature		Specific heat capacity		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	10^3 ksi	10^{-6}/K	10^{-6}/°F
-250	-418			2	13.9		133	19.3	1.3-2-2	0.722-1.22
-200	-328			6	41.3		135	19.6	1.2-2.1	0.667-1.17
-180	-292					49				
-150	-238					52				
-100	-148			10	69.3	59	138	20.0	1-1.6	0.556-0.889
-60	-76	440	0.105							
-50	-58	450	0.107							
20	68	486	0.117	12.8	88.7	78	143	20.7		
100	212	518	0.124	14.0	97.1	87	142	20.6	0.6-2.1	0.333-1.17
200	392	545	0.13	15.1	105	95	141	20.5	1.6-3.6	0.889-2.0
300	572	523	0.125	16.1	112	100	140	20.3	4.4-5.5	2.44-3.06
400	752	524	0.125	17.0	118	104	138	20.0	7.4-8.4	4.11-4.67
500	932	529	0.126	18.1	125	107	130	18.9	8.9-9.7	4.94-5.39
600	1,112	545	0.13	19.5	135	110	120	17.4	10-10.7	5.56-5.94

Table 3 – Typical physical properties (at low, room and elevated temperatures)

Microstructural properties

In the soft annealed condition, VDM® Alloy 36 has a cubic face-centered crystal structure.

Mechanical properties

The following mechanical properties apply to VDM® Alloy 36 in the soft annealed condition.

Temperature		**Yield strength** $R_{p\ 0.2}$		**Tensile strength** R_m		**Elongation** A
°C	**°F**	**MPa**	**ksi**	**MPa**	**ksi**	**%**
0	32	310	45	520	75.4	40
20	68	270	39.2	490	71.1	40
100	212	180	26.1	435	63.1	45
200	392	115	16.7	430	62.4	45
300	572	95	13.8	410	59.5	50
400	752	90	13.1	350	50.8	55
500	932	90	13.1	290	42.1	60
600	1,112	75	10.9	210	30.5	70

Table 4 – Typical mechanical properties in the soft- annealed condition

Corrosion resistance

In a dry atmosphere, VDM® Alloy 36 is corrosion-resistant at room temperature. In unfavorable conditions, for example a humid atmosphere, corrosion may occur on the surface.

Applications

VDM® Alloy 36 was developed for applications requiring the lowest possible heat expansion.

Typical applications are:

- Manufacturing, storage and transport of liquefied gases
- Components for OLED screens
- Measuring and control devices for temperatures below 200 °C (392 °F), e.g. for thermostats
- Bushings for screw or rivet joints between various metals
- Bi-metal components and thermostatic bi-metals, where VDM® Alloy 36 is the passive component
- Forms for the production of carbon-fiber reinforced plastic (CFP), especially for the aerospace industry
- Frameworks for electronic control units in satellites and space travel down to -200 °C (-328 °F)
- Support elements for electro-magnetic lenses in laser control units
- Pendulum
- Components for the automotive industry
- Overhead power lines in an alloyed, age-hardenable variant

Fabrication and heat treatment

VDM® Alloy 36 can be easily formed both hot and cold and can also be machined. The workability is comparable to that of austenitic stainless steels.

Heating

Workpieces must be 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 36. This type of contamination can also be contained in marking and temperature display paints or pins, 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% in weight of sulfur. Heating oil with a sulfur content of maximum 0.5% in weight is suitable. Heat treatment should preferably be carried out in electric furnaces under vacuum or shielding gas due to the precise temperature control and freedom of impurities. Heat treatment in air or in gas-heated furnaces are also acceptable, as long as impurities are at a low level so that a neutral and easily oxidizing furnace temperature can be set. A furnace temperature which alternates between oxidizing and reducing should be avoided. The workpieces should not be contacted directly by flames.

Hot forming

VDM® Alloy 36 can be hot-formed in a temperature range between 1,050 and 800 °C (1,950-1,472 °F) with subsequent rapid cooling down in water or air. For heating up, workpieces should be placed in a furnace which has been heated up to the maximum hot forming temperature of 1,050 °C (1,922 °F). The workpiece should be retained in the furnace for around 60 minutes per 100 mm of thickness once the furnace has reached its temperature again. Deformation must take place immediately, whereby reheating is required should the temperature reach the lower limit. Heat treatment after hot forming is recommended in order to achieve optimal properties.

Cold forming

For cold forming, the workpiece should be in the annealed condition. VDM® Alloy 36 has a similar work hardening rate to austenitic stainless steels. This should be taken into account when selecting forming equipment and planning forming processes. Intermediate annealing is necessary for major cold forming work. Under certain circumstances, a cold-formed microstructure is advantageous because it can reduce the heat expansion coefficient slightly. However, this condition is not stable, in particular when used at high temperatures.

Cold forming	**0,2 % yield strength $R_{p\,0,2}$**		**Elongation at fracture A_5**
%	**MPa**	**ksi**	**%**
0	292	42.4	40
23	645	93.5	15
39	679	89.5	13
53	702	102	12

Table 5 – Typical mechanical properties of soft-annealed rods following cold forming at room temperature

Heat treatment

The annealing should be performed at temperatures of 820 to 900 °C (1,580-1,652 °F), followed by air cooling.
Compared with air cooling, water cooling following annealing results in a lower heat expansion coefficient. However, the resulting microstructure is not stable. Following cold forming of less than 10%, the annealing temperature should not exceed 860 °C (1,580 °F).
Stress relief annealing is performed at temperatures of approx. 700 °C (1,292 °F).

The lowest heat expansion values at 100 °C (212 °F) are achieved in 3 steps with heat treatment:
1) Approx. 30 minutes of annealing at 830 °C (1,526 °F) with subsequent water quenching.
2) Heating to 300 °C (572 °F); maintaining the temperature for 1 hour; air cooling.
3) Re-heating to 100 °C (212 °F); maintaining the temperature for 30 minutes; furnace cooling to room temperature for 48 hours.

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

Descaling and pickling

Oxides of VDM® Alloy 36 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. Heat tints must be avoided. Before pickling in hydrochloric acid mixtures, which should be done in close observation of the pickling time and temperature, the oxide layers must be destroyed by blasting or fine sanding or pre-treated in a salt bath. A 20% hydrochloric acid mixture at 70 °C (158 °F) is particularly effective. Pickling solutions based on nitric acid/hydrofluoric acid should be avoided since they are generally too aggressive for pickling VDM® Alloy 36. To prevent over-pickling, we recommending performing pickling tests on samples beforehand.

Machining

VDM® Alloy 36 is preferably processed in the annealed condition. The machined characteristics of VDM® Alloy 36 are similar to those of austenitic stainless steels. Thanks to its high ductility, the chips resulting during machining tend to be string-like and tough, and can therefore result in fast wear to the cutting tool edge guides. The tool should be engaged at all times. A relatively low cutting speed should be used with a feed speed that is not too high. An adequate chip depth is important in order to cut below a previously formed work-hardened zone. This prevents excessive heat development and minimizes its impact on the material's expansion characteristics. Tools made of high speed steel (HSS) or carbide should be used. The cutting edges must be kept sharp. Generally, two types of lubricant are used when machining VDM® Alloy 36: Sulfochloride oils due to their ability to prevent fretting, and emulsions due to their higher cooling capacity. For most machining steps, sulfochloride cutting oils are required.

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 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 planing. 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 1 – have to be provided for butt welds.

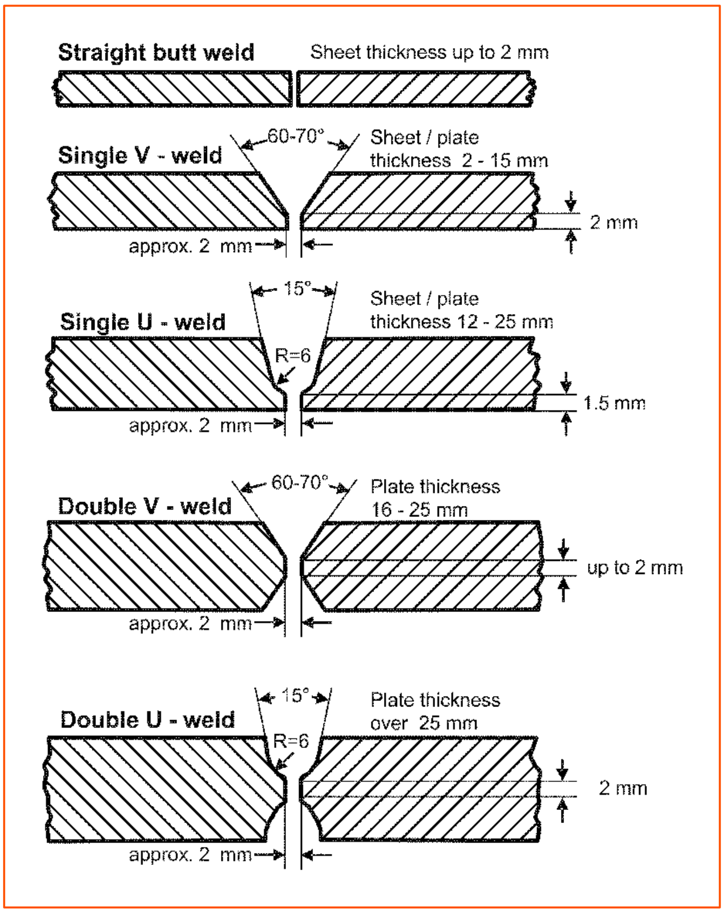

Figure 1 – Seam preparation for welding nickel alloys and special stainless steels

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 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.

Section energy E can be calculated as follows:

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

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

Welding filler

GTAW/GMAW
- VDM® FM 36 - material no. 1.3912

- VDM® FM 36 M - material no. 1.3990
Filler materials with optimized welding properties among other things for the MSG welding of thick sheets, e.g. for CFRP mold construction. VDM® FM 36 M is not suitable for use in low-temperature applications.

- VDM® FM 36 LT - in accordance with VdTÜV data sheet no. 11218.
VDM® FM 36 LT is optimized for applications requiring high ductility and strength at very low temperatures (e.g. in the liquefied natural gas (LNG) range).

If the lowest possible heat expansion is not required by the application, an alternative welding filler is available:
VDM® FM 82, material no. 2.4806
ISO 18274 - S Ni 6082 (NiCr20Mn3Nb);
AWS 5.14 ERNiCr-3

TIG/MIG
- VDM® FM 36 - material no. 1.3912

- VDM® FM 36 M - material no. 1.3990
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VDM® FM 82, material no. 2.4806
ISO 18274 - S Ni 6082 (NiCr20Mn3Nb)
AWS 5.14 ERNiCr-3

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.

Thickness	Welding technique	Filler material		Root pass[1]		Intermediate 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)
6 (0.236)	Plasma[3]	1,2 (0.0472)	0,5			220	26	26	I1, R1 mit max. 2% H2	30
8 (0.315)	Plasma[3]	1.2 (0.0472)	0,5			27	27	25	I1, R1 mit max. 2% H2	30
2 (0.0787)	m-WIG (manual TIG)	2,0 (0.0787)		70	9			15	I1, R1 mit max. 2% H2	8
6 (0.236)	m-WIG (manual TIG)	2,0 – 2,4 (0.0787-0.0945)	90	10	130	16	16		I1, R1 mit max. 2% H2	8
12 (0.472)	m-WIG (manual TIG)	2,4 (0.0945)		100	10	14	14	16	I1, R1 mit max. 2% H2	8
3 (0.118)	v-WIG[2] (autom. TIG)	1,2 (0.0472)	1			13	13	25	I1, R1 mit max. 2% H2	12-15
5 (0.197)	v-WIG[2] (autom. TIG)	1,2 (0.0472)	1,0			13	13	25	I1, R1 mit max. 2% H2	12-15
≥10 (0.394)	v-WIG[2] (autom. TIG)	1,2 (0.0472)	1,5			14	14	20-25	I1, R1 mit max. 2% H2	15

1) Root pass: for all inert gas welding processes, it must be ensured that there is sufficient root protection, for example using Ar 4.6.

2) autom. TIG: the root pass should be welded manually (see manual TIG parameters)

3) Plasma: recommended plasma gas Ar 4.6 / plasma gas quantity 3.0-3.5 l/min

Section energy kJ/cm: TIG, manual, mechanical max. ca. 8; plasma max. ca. 10

This information serves as guidance to simplify the setting of welding machines.

The table contains guideline parameters for VDM® FM 36 and VDM® FM 36 LT intended to simplify the setting of welding machines. However, VDM® FM 36 M is also a good candidate for MSG welding. Guideline parameters for this (and VDM® FM 82) can be found in the VDM welding consumables catalog.

Table 6 – Welding parameters

Availability

VDM® Alloy 36 is available in the following standard 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 Kg (lb)
Cold rolled	1-7 (0.039-0.275)	1,000-2,500 (39.4-98.42)	≤ 12,500 (492)	
Hot rolled	3-60 (0.11-3,15)	1,000- 2,500 (39.4-98.42)	≤ 12,500 (492)	≤ 3,850 (8,490)

Strip

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

Thickness mm (in)	Width mm (in)	Coil-inside diameter mm (in)			
0,002-0,2 (0.000787-0.00787)	4-230 (0.157-9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0,2-0.25 (0.00787-0.00984)	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)
2-3,5 (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 dimensions	6-800 (0.236-31.5)	1,500-12,000 (59.1 – 472)
Material specific dimensions	20-275 (0.787-10.8)	1,500-12.000 (59.1 - 472)
* 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 (0.006-0.04)	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.

Legal notice

26 March 2020

Publisher
VDM Metals International GmbH
Plettenberger Strasse 2
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