

# **VDM® Alloy 926**

## **Cronifer 1925 hMo**

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VDM® Alloy 926 is an austenitic, special stainless steel that was developed by VDM Metals on the basis of the many times proven VDM® Alloy 904 L (1.4539). Due to its 6.5 % higher molybdenum concentration, VDM® Alloy 926 has a generally improved corrosion resistance and resistance against pitting corrosion and crevice corrosion compared to VDM® Alloy 904 L. This also has a positive effect on the resistance against stress corrosion that is induced by pitting corrosion.

VDM® Alloy 926 is characterized by:

- very good resistance against chloride-induced stress corrosion,
- increased resistance against stress corrosion in comparison to other austenitic stainless steels,
- excellent general corrosion resistance when in contact with oxidizing and reducing media,
- higher strength than VDM® Alloy 904 L (1.4539),
- low propensity to form inter-metallic phases,
- Approval for pressure vessels in the temperature range from -196 to 400 °C (-272.2 to 752 °F).
- Approval from building supervisory authorities for components and joining elements made of stainless steels, Deutsches Institut für Bautechnik [German Centre of Competence for Construction], September '98

### Designations

Standard	Material Designation
EN	1.4529 X1 NiCrMoCuN25-20-7
UNS	N08926

### Standards

Product form	DIN	VdTÜV	ASTM	ASME	EN	others
Sheet	EN10088-2 EN10028-7	502	A 240			
Strip	EN 10028 EN 10088-2	502	A 240 B 625	SA 240 SB 625		API 5LD
Bar	EN10088-3	502 502	B 649	SB 649	10222	NACE 0175/ISO15156
Wire	EN 10088-2					

Table 1- Designations and standards

# Chemical composition

	<b>C</b>	<b>S</b>	<b>N</b>	<b>Cr</b>	<b>Ni</b>	<b>Mn</b>	<b>Si</b>	<b>Mo</b>	<b>Cu</b>	<b>P</b>
Min.			0.15	20.0	24.0			6.0	0.5	
Max.	0.02	0.010	0.25	21.0	26.0	1.0	0.5	7.0	1.5	0.03

Overall analysis corresponds to VdTÜV sheet 502  
 Due to technical reasons the alloy may contain additional elements

Table 2 – Chemical composition (%)

# Physical properties

Density	Melting range	Relative magnetic permeability at 20 °C (68 °F)
8.1 g/m <sup>3</sup> bei 20 °C 506 lb/ft <sup>3</sup> at 68 °F	1,320 - 1,390 °C (2,408 - 2,534 °F)	1.001

Temperature		Specific heat capacity		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{J}{Kg \cdot K}$	$\frac{Btu}{lb \cdot ^\circ F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in}{sq. ft \cdot h \cdot ^\circ F}$	$\mu\Omega \cdot cm$	GPa	10 <sup>6</sup> psi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{^\circ F}$
20	68	415	0.0991	12.0	6.93	96	193	28.0	-	-
100	212	435	0.104	12.9	7.45	99	186	27.0	15.0	8.33
200	392	470	0.112	14.4	8.32	104	179	26.0	15.7	8.72
300	572	495	0.118	16.5	9.53	108	173	25.1	16.1	8.94
400	752	510	0.122	18.5	10.7	112	168	24.0	164	9.11

Table 3 – Typical physical properties at room- and elevated temperatures

# Microstructural properties

VDM® Alloy 926 has a cubic, face-centered crystal structure.

# Mechanical properties

The following properties at room and elevated temperatures apply to VDM® Alloy 926 in the solution-annealed condition and for the specified dimensions. The properties for larger dimensions must be agreed separately. The values are valid for longitudinal and traverse test samples.

Temperature		Yield strength $R_{p0.2}$		Yield strength $R_{p1.0}$	
°C	°F	MPa	ksi	MPa	ksi
20	68	300	43.5	340	49.3
100	212	230	33.4	270	39.2
200	392	190	27.6	225	32.6
300	572	170	24.7	205	29.7
400	762	160	32.2	190	27.6
500	932	120	17.4	150	21.8
550	1022	105	15.2	135	19.6

Table 4 – Mechanical properties at elevated temperatures, min. values according to VdTÜV material data sheet 502

Productform	Dimensions		Yield stress $R_{p0.2}$		Yield stress $R_{p1.0}$		Tensile strength $R_m$		Elongation at fracture <sup>1)</sup> A
	mm	in	MPa	ksi	MPa	ksi	MPa	ksi	%
Sheet	≤ 50	≤ 1.97	≥ 300	≥ 43.5	≥ 340	≥ 49.3	600 – 800	87 – 116	≥ 40
Strip	≤ 3	≤ 1.18	≥ 300	≥ 43.5	≥ 340	≥ 49.3	600 – 800	87 – 116	≥ 40
bar	≤ 300	≤ 11.8	≥ 300	≥ 43.5	≥ 340	≥ 49.3	600 – 800	87 – 116	≥ 40

1) Elongation at fracture: for flat products < 3mm (0.01 in) with lengthwise minimum values reduced by 5% - points

Table 5 – Mechanical properties at room temperature

## ISO – V notch impact toughness

Temperature	Notched-bar impact strength (J/cm <sup>2</sup> )
-196 °C (-321 °F)	≥125
20 °C (68 °F)	≥150

Table 6 – The results of the notched-bar impact-bending test at the V-trial according to DIN EN ISO 148 -1 minimum average value of three trials (min. single value must not be less than 105 J/cm<sup>2</sup> at 20°C resp. 88 J/cm<sup>2</sup> at -196 °C).

# Corrosion resistance

VDM® Alloy 926 is an austenitic, special stainless steel with largely the same chemical composition as VDM® Alloy 904 L, while the nitrogen content was raised to 0.2 % and the molybdenum concentration to about 6.5 %. At the same time, the resistance against stress crack corrosion induced by pitting corrosion is improved. The nitrogen concentration raised to rounded 0.2 % improve the austenite stability and lowers the propensity to form inter-metallic phases. VDM® Alloy 926 is a good pick for media such as diluted sulfuric and phosphorus acids that are contaminated with chlorides, and also for salt concentrations and crystallizations against which the material proves a higher resistance against wear and tear. Due to its good corrosion resistance in seawater, VDM® Alloy 926 is also used for facilities on offshore platforms. The optimal corrosion behavior is only given if the material is used in clean, passivated condition.

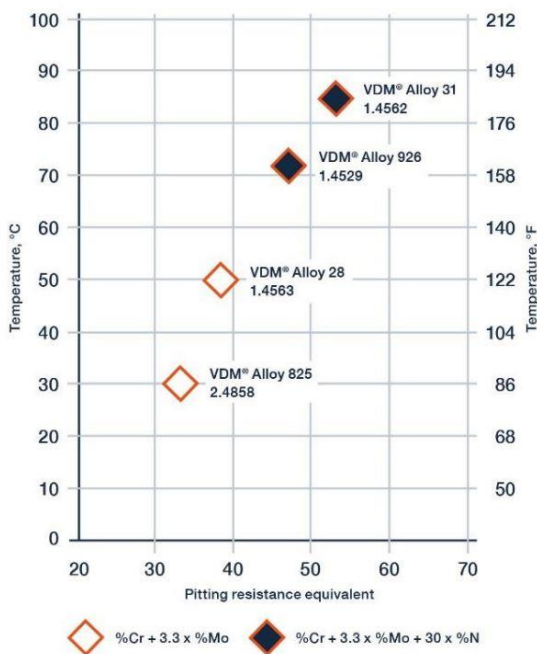


Fig. 1 – Critical pitting corrosion temperature in 10 % FeCl3 x6H2O solution as a function of the effective sum in comparison to some stainless steels and nickel alloys.

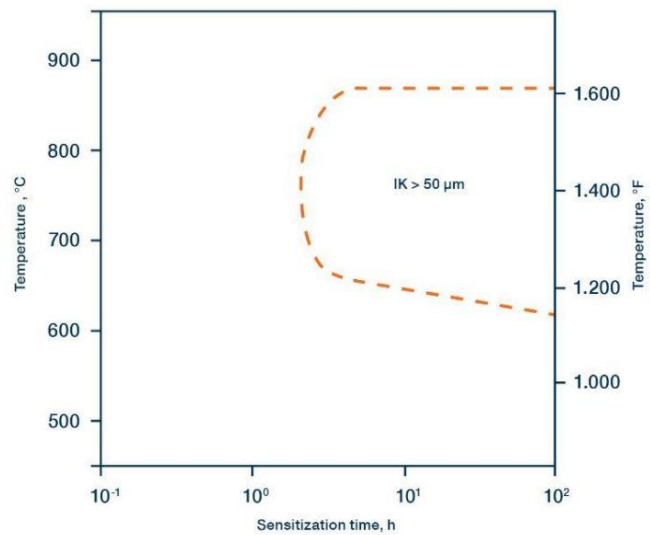


Fig. 2 – Time-temperature sensitization diagram (ZTS) of VDM® Alloy 926

# Applications

Typical applications for VDM® Alloy 926 are:

- Vaporizers, heat exchangers, tank housings, etc. in phosphorus acid production
- Facilities and pipework in the use of diluted sulfuric and phosphorus acid, even if these are contaminated with Chlorides
- Distributor systems and coolers for sulfuric acid plants
- Concentration and crystallization plants in salt extraction by vaporization
- Fire extinguishing systems, sea water filtration, hydraulics and injection systems of off-shore engineering
- Pump frames of oil extraction pumps
- Pump lines and couplings, wire lines in oil and gas extraction
- Condenser pipes and pipework systems in power plants with heavily contaminated cooling water
- Parts for flue gas desulfurization that are exposed to modest corrosion strain
- Facilities and parts for the bleaching phase of the pulp industry
- Flexible pipes in the off-shore industry
- Tanks for storing and transport of aggressive chemical substances

# Fabrication and heat treatment

VDM® Alloy 926 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 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 in direct contact with flames.

## Hot forming

VDM® Alloy 926 can be hot-formed in a temperature range between 1,200 and 900 °C (2,192 and 1,652 °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 1,200 °C (2,192 °F). Heat treatment after hot forming is recommended for achieving optimal corrosion behavior.

## Cold forming

The workpieces should be in the annealed condition for cold forming. Due to its high molybdenum concentration, VDM® Alloy 926 has a 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 during the planning of forming processes. Intermediate annealing is necessary for major cold forming work. For cold forming above 15%, a final solution annealing must be conducted.

## Heat treatment

Solution annealing should take place at temperatures between 1,150 to -1,200 °C (2,102 to -2,192 °F) and preferably at 1,180 °C (2,156 °F). The retention time during annealing depends on the semi-finished product thickness and can be calculated as follows:

- For thicknesses of  $d \leq 10$  mm (0.39 in), the retention time is  $t = d \cdot 3$  min / mm
- For thicknesses of  $d = 10$  to 20 mm (0.39 in to 0.79 in), the retention time  $t = 30$  min +  $(d - 10)$  mm · 2 min/mm
- For thicknesses of  $d > 20$  mm (0.79 in), the retention time  $t = 50$  min +  $(d - 20)$  mm · 1 min / mm

The retention time starts with material temperature equalization; 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 of less than approx. 1.5 mm. The material must be placed in a furnace that has been heated up to the maximum annealing temperature before any heat treatment. 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.

## Descaling and pickling

Oxides of VDM® Alloy 926 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 fine grinding, or pre-treated in salt baths. The pickling baths used should be carefully monitored with regard to concentration and temperature.

**Machining**

VDM® Alloy 926 is preferably processed in annealed condition. Since the alloy is prone to 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 work-hardened zone. An optimal heat dissipation by using large quantities of suitable, preferably aqueous, cold forming 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 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. 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 due to pressed-in iron particles 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 web spacing 1-3 mm (0.04 in to 0.12 in) are required to live up to 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 3 – have to be provided for butt welds.



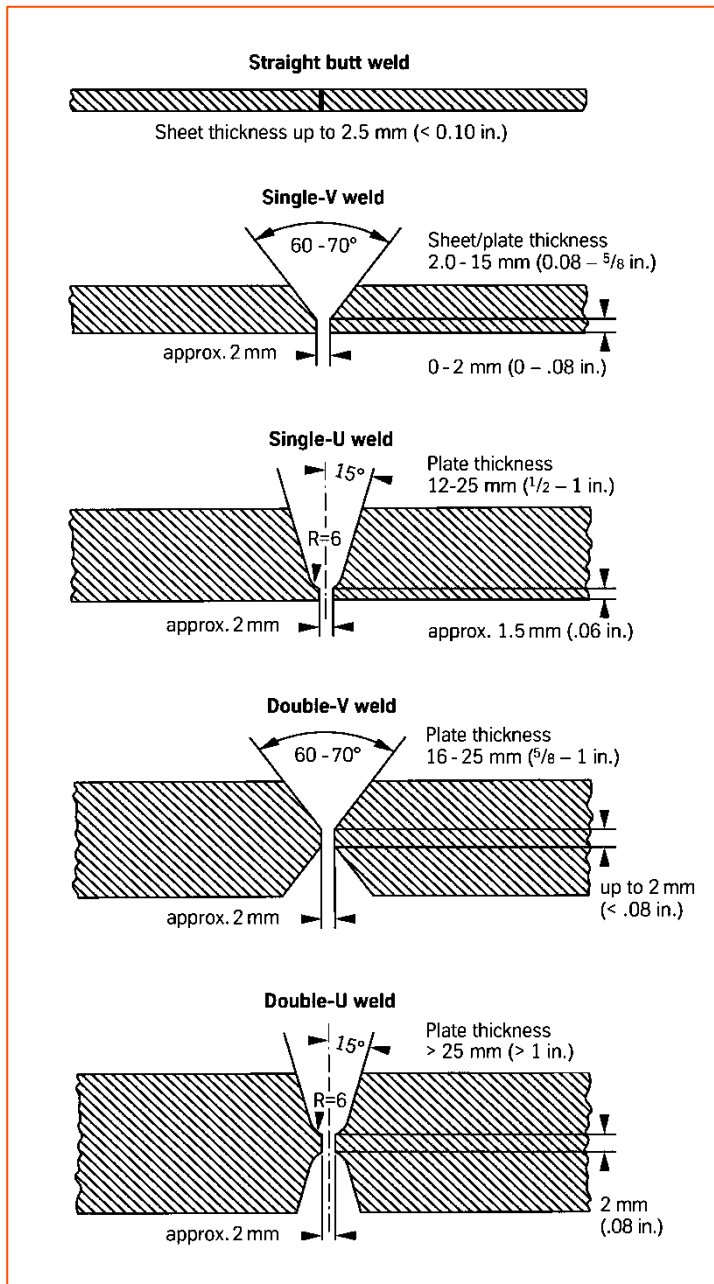


Figure 1 – Seam preparation for welding nickel alloys and special stainless steels

### 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 filler

As welding fillers, VDM® FM 59 (preferred) or VDM® FM 625 are recommended:

VDM® FM 59 (mat. no. 2.4607)

ISO 18274 - S Ni 6059 (NiCr23Mo16), AWS A5.14 ERNiCrMo-13

VDM® FM 625 (W.-no. 2.4831)

ISO 18274 - S Ni 6625 (NiCr22Mo9Nb), AWS A5.14 ERNiCrMo-3

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 as listed in Table 7 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 and it is therefore required to observe the section energy that is suitable for the material.

The section energy E can be calculated as follows:

$$E = U \times I \times 60 / v \times 1000 \text{ (kJ/cm)}$$

U = arc voltage, volts

I = welding current strength, amperes

v = welding speed, cm/minute

**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 tint can be removed completely. 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 (mm) / (in)	Welding process	Filler material		Root pass <sup>1)</sup>		Intermediate and final passes		Welding speed (cm/min.)	Shielding gas	
		Diameter (mm) (in)	Speed (m/min.)	I in (A)	U in (V)	I in (A)	U in (V)		Art	Quantity rate (l/min.)
1 (0.118)	Manual TIG	1.6-2.0 (0.063-0.079)	-	90	10	110-120	11	10-15	I1, R1 with max 3% H <sub>2</sub>	8-10
6 (0.236)	Manual TIG	2.0-2.4 (0.079-0.094)	-	100-110	10	120-130	12	10-15	I1, R1 with max 3% H <sub>2</sub>	8-10
8 (0.315)	Manual TIG	2.4-3.2 (0.094-0.126)	-	110-120	11	130-140	12	10-15	I1, R1 with max 3% H <sub>2</sub>	8-10
10 (0.394)	Manual TIG	2.4-3.2 (0.094-0.126)	-	110-120	11	130-140	12	10-15	I1, R1 with max 3% H <sub>2</sub>	8-10
3 (0.118)	autom.TIG <sup>2)</sup>	0.8 (0.0315)	0.5	-	-	140-160	10	25	I1, R1 with max 3% H <sub>2</sub>	15-20
5 (0.197)	autom.TIG <sup>2)</sup>	0.8 (0.031)	0.5	-	-	140-160	10	25	I1, R1 with max 3% H <sub>2</sub>	15-20
2 (0.0787)	Autom. TIG HD	1.0 (0.039)	0.3	-	-	180	10	80	I1, R1 with max 3% H <sub>2</sub>	15-20
10 (0.394)	Autom. TIG HD	1.2 (0.042)	0.45	-	-	250	12	40	I1, R1 with max 3% H <sub>2</sub>	15-20
4 (0.157)	Plasma	0.8-1.0 (0.0315-0.039)	0.5	165	25	-	-	25	I1, R1 with max 3% H <sub>2</sub>	30
6 (0.236)	Plasma	0.8-1.0 (0.0315-0.039)	0.5	190-200	25	-	-	25	I1, R1 with max 3% H <sub>2</sub>	30
8 (0.135)	GMAW (MIG/MAG) <sup>3)</sup>	1.0 (0.039)	7-10	-	-	130-140	23-27	24-30	I1, R1 (max 3% H <sub>2</sub> , Z- Gas with max. 0,12% CO <sub>2</sub> )	18-20
10 (0.394)	MIG/MAG <sup>3)</sup>	1.2 (0.047)	5-7	-	-	130-150	23-27	20-26	I1, R1 (max 3% H <sub>2</sub> , Z- Gas with max. 0,12% CO <sub>2</sub> )	18-20
12 (0.472)	UP	1.6 (0.063)	-	-	-	240-280	258	45-55	-	-
20 (0.787)	UP	1.6 (0.063)	-	-	-	24-280	258	45-55	-	-

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

<sup>2)</sup> Autom. TIG: the root pass should be welded manually (see manual TIG parameters)

<sup>3)</sup> Autom. TIG: the root pass should be welded manually (see manual TIG parameters)

Max. section energy kJ/cm: TIG, GMAW manual or automated, PAW (Plasma), SAW ca. 8 to 11.

The values are intended as guidance to simplify the setting of welding machines.

Table 7 – Welding parameters

# Availability

VDM® Alloy 926 is available in the following semi-finished forms:

## Sheet/Plate

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

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)	Weight Kg (lb)
Cold rolled	1-7 (0.039-0.275)	≤ 2,500 (98.42)	≤ 12,500 (492)	
Hot rolled*	3-60 (0.118-2.36)	≤ 2,500 (98.42)	≤ 12,500 (492)	≤ 1,700 (3,750)

## 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)	–
0.15-2.5 (0.00591-0.0098)	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, twisted, 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	10-400 (0.394-15.7)	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 (0.0063-0.394)	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 has been published about the material VDM® Alloy 926:

Manfred B. Rockel, Wilfried R. Herda: "Die Oberflächenbehandlung von Schweißverbindungen hochkorrosionsbeständiger 6% Mo-Stähle und Nickel- Basislegierungen" [Surface Treatment of Weld Connections of Highly Corrosion Resistant 6% Mo Steels and Nickel Base Alloys], in WuK, issue 7, July 1992.

Manfred B. Rockel, Wilfried R. Herda: "Zwei neue hochlegierte austenitische Sonderstähle mit höherem Molybdängehalt und Stickstoffzusätzen" [Two New High Alloyed Austenitic Special Steels with Higher Molybdenum Concentration and Nitrogen Additions], in STAHL '92, issue 1, March 1992.

E. Altpeter, U. Heubner, M. B. Rockel: "Potential-Sonden-Messungen und Potential-Profil über Schweißverbindungen korrosionsbeständiger Nickel- Basis-Werkstoffe und Sonderstähle" [Potential Probe Measurements and Potential Profiles via Weld Connections of Corrosion Resistant Nickel Base Materials and Special Steels], in WuK, issue 3, March 1992.

G. K. Grossmann, M. B. Rockel: "Use of high alloy materials under dewpoint corrosion conditions in waste incineration", in METALL, issue 9, September 1991.

Wilfried R. Herda, Dr. Manfred B. Rockel: "Anwendungsentwicklung für Nickelbasislegierungen auf dem Gebiete der Umwelttechnik" [Application Development for Nickel Base Alloys in the Field of Environmental Engineering] in METALL, issue 10, 1990, p. 984.

Wilfried R. Herda, Manfred B. Rockel: "Nickelhaltige Legierungen und Sonderedelstähle in der Verfahrenstechnik" [Alloys Containing Nickel and Special Stainless Steels in Process Engineering] Chem.-Ing.-Tech. 62, 1990, No. 4, pp. 299-303.

R. Pleschko, R. Schimböck, E. M. Horn, P. Mattern, M. Renner und W. Heimann: "Walzplattierungen mit dem hochkorrosionsbeständigen nichtrostenden austenitischen Stahl X1NiCrMoCuN25 20 6, W.-Nr. 1.4529" [Roll Cladding with the Highly Corrosion Resistant Austenitic Stainless Steel X1NiCrMoCuN25 20 6, Material no. 1.4529] WuK, issue 41, 1990, pp. 563-570.

U. Heubner, M. B. Rockel, E. Wallis: "Das Ausscheidungsverhalten von hochlegierten austenitischen Stählen mit 6% Molybdän und sein Einfluß auf die Korrosionsbeständigkeit" [The Precipitation Behavior of High Alloyed Austenitic Steels with 6% Molybdenum and its Effect on Corrosion Resistance], WuK 40, 1989, pp. 459-466.

Dr. M. B. Rockel: "Korrosionsbeständigkeit von Schweißverbindungen hochlegierter Werkstoffe" [Corrosion resistance of Weld Connections with High Alloyed Materials] in METALL, issue 4, 42th year, 1988, p. 338.

H. Decking, W. R. Herda, M. Köhler: "Hochlegierte austenitische Sonderedelstähle für den Tunnelbau und tragende Bauteile: Superaustenite mit 6-7% Molybdän" [High Alloy Austenitic Special Stainless Steels for Tunnel Construction and Load-Bearing Components: super austenite with 6-7% molybdenum], Korrosionstagung, Pratteln, 1998.

# Imprint

10 April 2024

**Publisher**

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