VDM Metals

VDM® Alloy B-2
Nimofer 6928

Material Data Sheet No. 4022
March 2002 Edition

Nimofer® 6928 – alloy B-2

Nimofer 6928 is a corrosion-resistant, solid-solution nickel-molybdenum alloy.

Nimofer 6928 is characterized by:

- controlled chemistry with a minimum iron and chromium content to retard the formation of ordered β-phase Ni_4Mo
- significant corrosion resistance to reducing environments
- excellent resistance to medium-concentrated sulphuric acid and a number of non-oxidizing acids
- good resistance to chloride-induced stress-corrosion cracking (SCC)
- good resistance to a wide range of organic acids.

Designation and standards

Country National standards	Material designation	Specification							
		Chemical composition	Tube and pipe seamless	Tube and pipe welded	Sheet and plate	Rod and bar	Strip	Wire	Forgings
D DIN VdTÜV	**W.-Nr. 2.4617** NiMo28	17744 436	17751	17751	17750 436	17752 436	17750		436
F AFNOR	NiMo28								
UK BS									
USA ASTM ASME	UNS N10665		B 622 SB 622	B 619 B 626 SB 619 SB 626	B 333 SB 333	B 335 SB 335	B 333 SB 333		
ISO	NiMo28	9722	6207		6208	9723	6208	9724	9725

Table 1 – Designation and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Mo	Co	P	S
min.	bal.	0.4	1.6					26.0			
max.		1.0	2.0	0.01	1.0	0.08	0.5	30.0	1.0	0.02	0.010

Table 2 – Chemical composition (wt.-%).

Physical properties

Density	9.2 g/cm³	0.332 lb/in.³
Melting range	1330-1380 °C	2430-2520 °F
Permeability at 20 °C/68 °F (RT)	≤ 1.001	

Temperature (T)		Specific heat		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	J/(kg K)	Btu/(lb °F)	W/(m K)	Btu in./(ft² h °F)	μ Ω cm	Ω circ mil/ft	kN/mm²	10³ ksi	10⁻⁶/K	10⁻⁶/°F
0	32	373	0.089			137	824	218	31.6		
20	**68**	377	0.090	11.1	77	137	825	217	31.4		
93	**200**		0.092		84		829		30.8		5.7
100	212	389		12.2		138		213		10.3	
200	392	406		13.4		138		208		10.8	
204	**400**		0.097		94		832		30.1		6.0
300	572	423		14.6		139		203		11.1	
316	**600**		0.101		104		836		29.3		6.2
400	752	431		16.0		139		197		11.4	
427	**800**		0.104		114		838		28.4		6.4
500	932	444		17.3		141		191		11.6	
538	**1000**		0.107		124		858		27.4		6.5
600	1112	456		18.7		146		184		11.8	
649	**1200**		0.110		134		900		26.1		6.6
700	1292							176			

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

Mechanical properties

The following properties are applicable to Nimofer 6928 in the solution-treated condition and the indicated size ranges (see availability). Specified properties of material outside these size ranges are subject to special enquiry.

Product	Dimensions		Yield strength $R_{p0.2}$		Yield strength $R_{p1.0}$		Tensile strength R_m		Elongation A_5/A_{50}	Brinell hardness	Grain size max.	
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB	µm	ASTM No.
Sheet and strip cold rolled	≤ 5	≤ 3/16	340	49	380	55	755	109	40	250	127	3.0
Plate hot rolled	5–65	3/16–2 1/2									214	1.5
Rod and bar			325	47	370	54	745	108		–	–	–
Tube and pipe			340	49	360	52	755	109		–	–	–
All (according to ASTM)			350	51	–	–	760	110		241	see above	

Table 4 – Minimum mechanical properties at room temperature (according to DIN/ASTM).

Product	Yield strength, $R_{p0.2}$ N/mm²				Yield strength, $R_{p1.0}$ N/mm²			
Temperature, °C	100	200	300	400	100	200	300	400
Sheet and plate Tube and pipe	315	285	270	255	355	325	310	295
Rod, bar, forgings	300	275	255	240	340	315	300	285

	ksi				ksi			
Temperature, °F	200	400	600	800	200	400	600	800
Sheet and plate Tube and pipe	46	41	39	(36)	52	47	45	(42)
Rod, bar, forgings	44	40	37	(34)	50	46	43	(41)

Table 5 – Minimum mechanical properties at elevated temperatures according to VdTÜV data sheet 436.

ISO V-notch impact toughness

Average values:
≥ 150 J/cm² at RT
≥ 120 J/cm² at -196 °C (-320 °F)

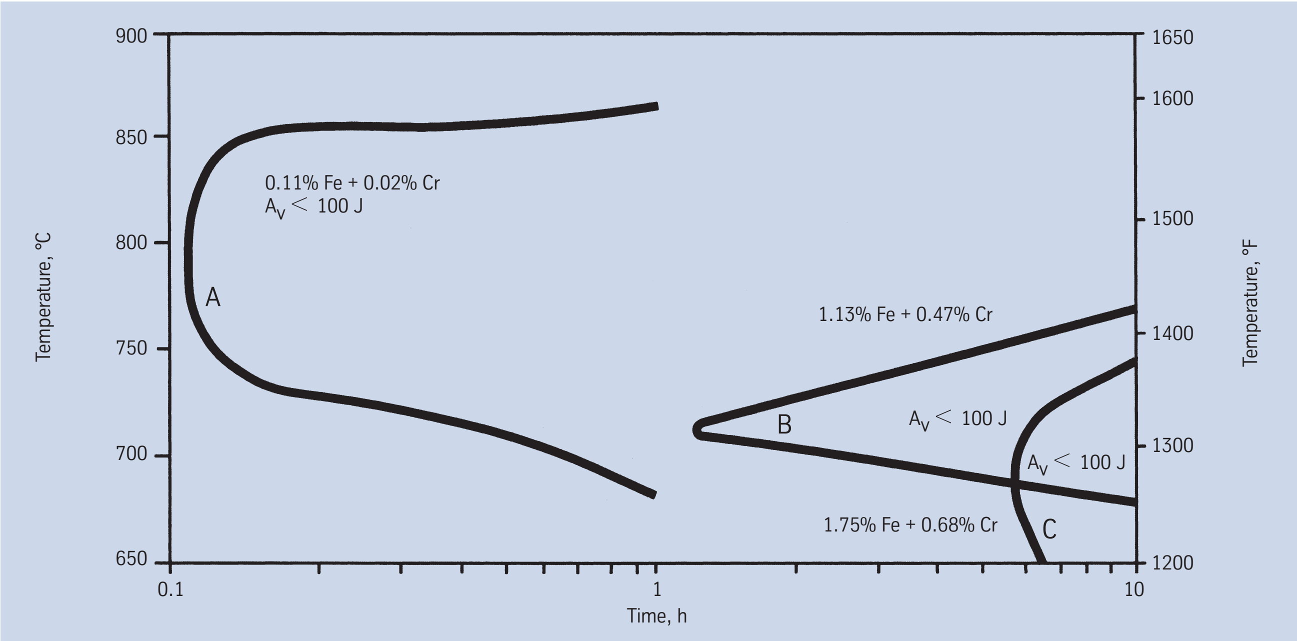

Fig. 1 – Time-temperature-impact diagram (ISO V-notch) for Nimofer 6928 in relation to Fe and Cr content for heats A, B and C.

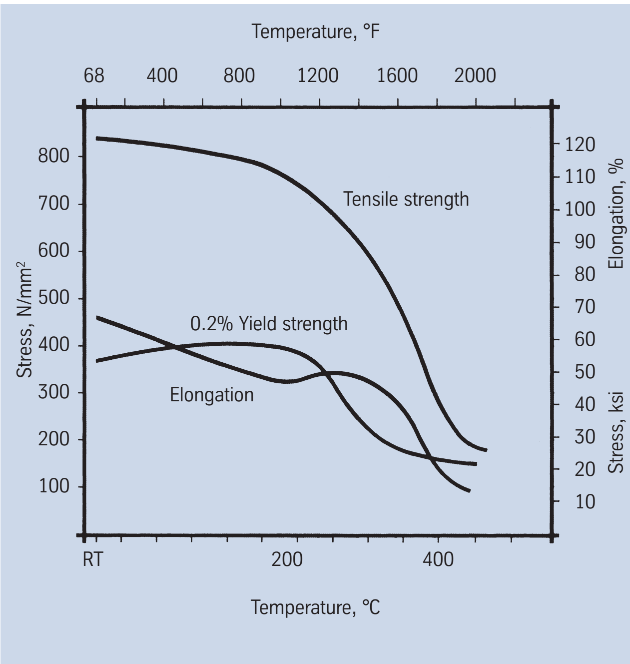

Fig. 2 – Typical short-time mechanical properties of solution-treated Nimofer 6928 (1080 °C/1980 °F/WQ) at elevated temperatures.

Temperature		Maximum allowable stress			
°C	°F	N/mm² 1)	1) 2)	ksi	2)
38	100			27.5	27.5
93	200			27.5	27.5
100	212	190	190		
149	300			27.5	27.5
200	392	190	190		
204	400			27.5	27.5
260	500			27.5	27.5
300	572	188	188		
316	600			27.2	27.2
371	700			26.6	27.1
400	752	180	180		
427	800			25.6	26.8

1) metric values determined by interpolation
2) conditional stress values (see below)

Table 6 – Maximum allowable stress values in tension according to ASME UNF-23.3, SB 333.

Nimofer® 6928 – alloy B-2

Conditional stress values
The higher conditional stress values of up to 90% of the yield strength at temperature may be used for applications in which slightly greater deformation is acceptable. These stresses may result in dimensional changes due to permanent strain and are not recommended for flanges of gasketed joints or other applications where slight amounts of distortions can cause leakage or malfunction.

Metallurgical structure
Nimofer 6928 has a face-centered-cubic structure.
The alloy's controlled chemistry with minimum iron and chromium content reduces the risks of embrittlement occurring during fabrication, as this retards precipitation of Ni_4Mo phase in the temperature range 700-870 °C (1290-1600 °F).

Corrosion resistance
The extremely low carbon and silicon content of Nimofer 6928 reduces precipitation of carbides and other phases in the heat-affected zone of welds and ensures adequate corrosion resistance even in the welded condition.

Nimofer 6928 exhibits excellent corrosion resistance in aggressive reducing media such as hydrochloric acid in a wide range of temperatures and concentrations, as well as in medium-concentrated sulphuric acid even with limited chloride contamination. It can also be used in acetic and phosphoric acids.

Optimum corrosion resistance can be obtained only if the material is in the correct metallurgical condition and exibits a clean structure.

The newly developed material Nimofer 6629 shows improved resistance to stress-corrosion cracking compared with alloy B-2 while retaining the same resistance to general corrosion and to intergranular corrosion. Resistance to sensitization is also improved.

For more details refer to the Nimofer 6629 data sheet No. 4041.

Applications
Nimofer 6928 is used in a wide range of applications in the chemical process industry, especially for processes involving sulphuric, hydrochloric, phosphoric and acetic acid. Spezial requirements should be referred to the material supplier.

Fabrication and heat treatment
Nimofer 6928 - alloy B-2 can readily be hot- and cold-worked and machined.

Heating
Workpieces must be clean and free from all kinds of contaminants before and during any heat treatment.

Nimofer 6928 may become impaired if heated in the presence of contaminants such as sulphur, phosphorus, lead and other low-melting-point metals. Sources of such contaminants include marking and temperature-indicating paints and crayons, lubricating grease and fluids, and fuels.

Fuels must be as low in sulphur as possible. Natural gas should contain less than 0.1 wt.-% sulphur. Fuel oils with a sulphur content not exceeding 0.5 wt.-% are suitable.

Due to their close control of temperature and freedom from contamination, thermal treatments in electric furnaces under vacuum or an inert gas atmosphere are to be preferred. Treatments in an air atmosphere and alternatively in gas-fired furnaces are acceptable though, if contaminants are at low levels so that a neutral or slightly oxidizing furnace atmosphere is attained. A furnace atmosphere fluctuating between oxidizing and reducing must be avoided as well as direct flame impingement on the metal.

Heating to the required temperature should always be as fast as possible.

Hot working
Nimofer 6928 may be hot-worked in the temperature range 1160 to 900 °C (2120 to 1650 °F). Cooling after hot working should be by water quenching.

Heat treatment after hot working is recommended to ensure maximum corrosion resistance.

For heating up, workpieces should be charged into the furnace at maximum working temperature (solution annealing temperature).

Cold working
For cold working the material should be in the solution-annealed condition. Nimofer 6928 has a higher work-hardening rate than austenitic stainless steels. This should be taken into account when selecting forming equipment.

Interstage annealing may be necessary with high degrees of cold forming.

After cold working with more than 15% deformation, solution annealing is required.

Heat treatment
Solution heat treatment should be carried out in the temperature range 1060 to 1080 °C (1940 to 1980 °F).

Water quenching or rapid air cooling for thicknesses above 1.5 mm (0.06 in.) is recommended and is essential for maximum corrosion resistance.

For any thermal treatment the material should be charged into the furnace at temperature. Also for any thermal treatment operation the precautions concerning cleanliness mentioned earlier under '**Heating**' must be observed.

Descaling and pickling
Oxides of Nimofer 6928 and discoloration adjacent to welds are more adherent than on stainless steels. Grinding with very fine abrasive belts or discs is recommended. Care should be taken to prevent tarnishing.

Before pickling, which may be performed in a nitric/hydrofluoric acid mixture with proper control of pickling time and temperature, the surface oxide layer must be broken up by abrasive blasting, by carefully performed grinding or by pretreatment in a fused salt bath.

Due to the alloy's sensitivity to oxidizing media, relatively high mass loss rates along with heavy formation of nitrous gases may be expected.

Machining
Nimofer 6928 should be machined in the heat-treated condition. As the alloy exhibits a high work-hardening rate only low cutting speeds should be used compared with low-alloyed standard austenitic stainless steels. Tools should be engaged at all times. An adequate depth of cut is important in order to cut below the previously formed work-hardened zone.

Welding
When welding nickel-base alloys, the following instructions should be adhered to:

Workplace
The workplace should be in a separate location, well away from areas where carbon steel fabrication takes place. Maximum cleanliness and avoidance of draughts are paramount.

Auxiliaries, clothing
Clean fine leather gloves and clean working clothes should be used.

Tools and machines
Tools used for nickel-base alloys and stainless steels must not be used for other materials. Brushes should be made of stainless materials.

Fabricating and working machinery such as shears, presses or rollers should be fitted with means (felt, cardboard, plastic sheeting) of avoiding contamination of the metal with ferrous particles, which can be pressed into the surface and thus lead to corrosion.

Cleaning
Cleaning of the base metal in the weld area (both sides) and of the filler metal (e.g. welding rod) should be carried out with ACETONE.

Trichlorethylene (TRI), perchlorethylene (PER) and carbon tetrachloride (TETRA) must not be used.

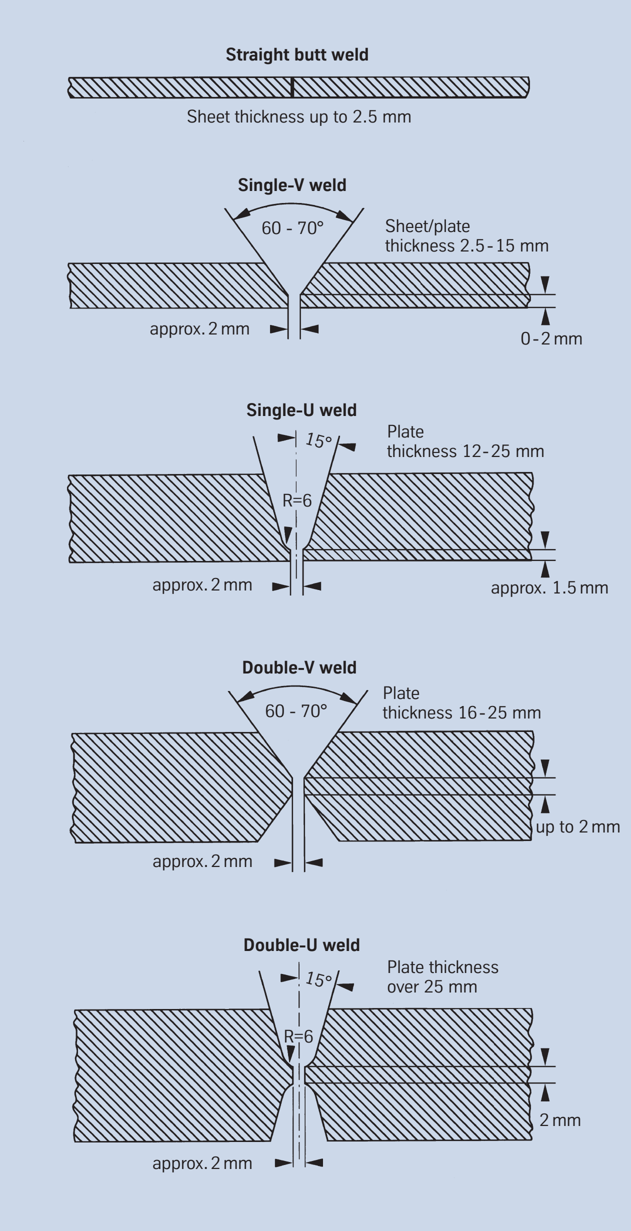

Fig. 3 – Edge preparation for welding of nickel-base alloys and special stainless steels.

Edge preparation
This should preferably be done by mechanical means by turning, milling or planing; plasma cutting is also possible. However, in the latter case the cut edge (the face to be welded) must be finished off cleanly. Careful grinding without overheating is permitted. Also a zone approximately 25 mm (1 in.) wide on each side of the joint should be ground to bright metal.

Included angle
The different physical characteristics of nickel-base alloys and special stainless steels compared with carbon steel generally manifest themselves in a lower thermal conductivity and a higher rate of thermal expansion.

This should be allowed for by means of, among other things, wider root gaps or openings (1-3 mm), while larger included angles (60-70°), as shown in Fig. 3, should be used for individual butt joints owing to the viscous nature of the molten weld metal and to counteract the pronounced shrinkage tendency.

Striking of the arc
The arc should only be struck in the weld area, e.g. on the faces to be welded or on a run-out piece. Striking marks lead to corrosion.

Welding processes
Nimofer 6928 can be joined to itself and to many other metals by conventional welding processes. These include GTAW (TIG), plasma arc, GMAW (MIG/MAG and MAG-Tandem) and SMAW (MMA). Pulsed arc welding is the preferred technique. For MAG processes the use of a multi-component shielding gas ($Ar+He+H_2+CO_2$) is recommended.

For welding, Nimofer 6928 should be in the annealed condition and be free from scale, grease and markings. When welding the root, care should be taken to achieve best-quality root backing (argon 99.99), so that the weld is free from oxides after welding the root. Any heat tint should be removed preferably by brushing with a stainless steel wire brush while the weld metal is still hot.

Filler metal
For the gas-shielded welding processes, filler metal with the same composition as the base metal is recommended:

Bare electrodes:	Nimofer S 6928 – FM B-2 Werkstoff-Nr. 2.4615 SG-NiMo 27 AWS A 5.14: ERNiMo-7
Covered electrodes:	Werkstoff-Nr. 2.4616 EL-NiMo 29 AWS A 5.11: ENiMo-7

Welding parameters and influences
(heat input/linear energy input per unit length of weld)

Care should be taken that the work is performed with a deliberately chosen, low heat input as indicated in Table 8 by way of example. Use of the stringer beat technique should be aimed at. Interpass temperature should be kept below 120 °C (250 °F).

The welding parameters should be monitored as a matter of principle.

The heat input Q may be calculated as follows:

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

U = arc voltage, volts
I = welding current, amps
v = welding speed, cm/min.

Consultation with ThyssenKrupp VDM's Welding Laboratory is recommended.

Postweld treatment
(brushing, pickling and thermal treatments)

Brushing with a stainless steel wire brush immediately after welding, i.e. while the metal is still hot 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. Also refer to the information on **'Descaling and pickling'**.

Neither pre- nor postweld thermal treatments are required.

Sheet/ plate thick-ness mm	Welding process	Filler metal Diameter mm	Speed m/min.	Welding parameters Root pass A	V	Intermediate and final passes A	V	Welding speed cm/min.	Flux/ shielding gas rate l/min.	Plasma-gas rate l/min.	Plasma/ nozzle diameter mm
2.0	Manual GTAW	2.0		90	10	110-120	11	10–15	Ar W3[1)] 8–10		
6.0	Manual GTAW	2.0–2.4		100–110	10	120-130	12	10–15	Ar W3[1)] 8–10		
8.0	Manual GTAW	2.4		110–120	11	130-140	12	10–15	Ar W3[1)] 8–10		
10.0	Manual GTAW	2.4		110–120	11	130-140	12	10–15	Ar W3[1)] 8–10		
3.0	Autom. GTAW	1.2	0.5	manual		150	10	25	Ar W3[1)] 15-20		
5.0	Autom. GTAW	1.2	0.5	manual		150	10	25	Ar W3[1)] 15-20		
2.0	Hot wire GTAW	1.0	0.3			180	10	80	Ar W3[1)] 15-20		
10.0	Hot wire GTAW	1.2	0.45	manual		250	12	40	Ar W3[1)] 15-20		
4.0	Plasma arc	1.2	0.5	165	25			25	Ar W3[1)] 30	Ar W3[1)] 3.0	3.2
6.0	Plasma arc	1.2	0.5	190–200	25			25	Ar W3[1)] 30	Ar W3[1)] 3.5	3.2
8.0	MIG/MAG GMAW	1.0	approx. 8	GTAW		130-140	23-27	24-30	MAG[2)] MIG: argon 18–20		
10.0	MIG/MAG GMAW	1.2	approx. 5	GTAW		130-150	23-27	20–26	MAG[2)] MIG: argon 18–20		
6.0	SMAW	2.5		40–70	approx. 21	40–70	approx. 21				
8.0	SMAW	2.5–3.25		40–70	approx. 21	70–100	approx. 22				
16.0	SMAW	4.0				90–130	approx. 22				

[1)] Argon or argon + max. 3 % hydrogen.
[2)] For MAG welding the use of the shielding gas Cronigon He30S or Argomag-Ni, for example, is recommended.
In all gas-shielded welding operations, ensure adequate back shielding.
These figures are only a guide and are intended to facilitate setting of the welding machines.
For guide settings for MAG-Tandem welding contact the ThyssenKrupp VDM Welding Laboratory.

Table 7 – Welding parameters (guide values)

Welding process	Heat input per unit length kJ/cm	Welding process	Heat input per unit length kJ/cm
GTAW, manual, fully mechanised	max. 10	MIG/MAG, manual, fully mechanised	max. 11
Hot wire GTAW	max. 6	Manual metal arc (SMAW)	max. 7
Plasma arc	max. 10		

Table 8 – Heat input per unit length (guide values)

Availability
Nimofer 6928 is available in the following standard product forms:

Sheet & plate
(for cut-to-length availability, refer to strip)

Conditions:
hot or cold rolled (hr, cr)
thermally treated and pickled

Thickness mm	hr / cr	Width 1) mm	Length 1) mm
1.10 – < 1.50	cr	2000	8000
1.50 – < 3.00	cr	2500	8000
3.00 – < 7.50	cr / hr	2500	8000
7.50 – ≤ 25.00	hr	2500	8000 2)
> 25.00 1)	hr	2500 2)	8000 2)

inches		inches	inches
0.043 – < 0.060	cr	80	320
0.060 – < 0.120	cr	100	320
0.120 – < 0.300	cr / hr	100	320
0.300 – ≤ 1.000	hr	100	320 2)
> 1.000 1)	hr	100 2)	320 2)

1) other sizes subject to special enquiry
2) depending on piece weight

Discs and rings
Conditions:
hot rolled or forged,
thermally treated,
pickled or machined

Product	Weight kg	Thickness mm	O.D. 1) mm	I.D. 1) mm
Disc	≤ 10000	≤ 300	≤ 3000	
Ring	≤ 3000	≤ 200	≤ 2500	on request

	lbs	inches	inches	inches
Disc	≤ 22000	≤ 12	≤ 120	
Ring	≤ 6600	≤ 8	≤ 100	on request

1) other sizes subject to special enquiry

Rod & bar
Conditions:
forged, rolled, drawn,
thermally treated,
pickled, machined, peeled or ground

Product	Forged 1) mm	Rolled 1) mm	Drawn 1) mm
Rod (o.d.)	≤ 600	8–100	12–65
Bar, square (a)	40–600	15–280	not standard
Bar, flat (a x b)	(40–80) x (200–600)	(5–20) x (120–600)	(10–20) x (30–80)
Bar, hexagonal (s)	40–80	13–41	≤ 50

	inches	inches	inches
Rod (o.d.)	≤ 24	5/16–4	1/2–2 1/2
Bar, square (a)	1 5/8–24	10/16–11	not standard
Bar, flat (a x b)	(1 5/8–3 1/8) x (8–24)	(3/16–3/4) x (4 3/4–24)	(3/8–3/4) x (1 1/4–3 1/8)
Bar, hexagonal (s)	1 5/8–3 1/8	1/2–1 5/8	≤ 2

1) other sizes and conditions subject to special enquiry

Forgings
Shapes other than discs, rings, rod and bar are subject to special enquiry. Flanges and hollow shafts may be available up to a piece weight of 10 t.

Strip[1)]
Conditions:
cold rolled,
thermally treated and pickled or bright annealed[2)]

Thickness mm	Width[3)] mm	Coil I.D. mm			
0.04–≤0.10	4–200	300	400		
>0.10–≤0.20	4–350	300	400	500	
>0.20–≤0.25	4–750		400	500	600
>0.25–≤0.60	6–750		400	500	600
>0.60–≤1.0	8–750		400	500	600
>1.0 –≤2.0	15–750		400	500	600
>2.0 –≤3.0	25–750		400	500	600

inches	inches	inches			
0.0016–≤0.004	0.16– 8	12	16		
>0.004 –≤0.008	0.16–14	12	16	20	
>0.008 –≤0.010	0.16–30		16	20	24
>0.010 –≤0.024	0.20–30		16	20	24
>0.024 –≤0.040	0.32–30		16	20	24
>0.040 –≤0.080	0.60–30		16	20	24
>0.080 –≤0.120	1.0 –30		16	20	24

1) Cut-to-length available in lengths from 250 to 4000 mm (10 to 158 in.)
2) Maximum thickness 3 mm (0.125 in.)
3) Wider widths subject to special enquiry

Wire
Conditions:
bright drawn, 1/4 hard to hard,
bright annealed

Dimensions:
0.01–12.0 mm (0.0004–0.47 in.) diameter,
in coils, pay-off packs, on spools and spiders

Welding filler metals
Suitable welding rods, wire, strip electrodes and electrode core wire are available in all standard sizes.

Seamless tube and pipe
Using ThyssenKrupp VDM cast materials seamless tubes and pipes are produced and available from DMV STAINLESS Int. Sales, Tour Neptune, F-92086 Paris, La Defence Cedex (Fax: +33-1-4796 8126; Tel.: +33-1-4796 8128).

Welded tube and pipe
Welded tubes and pipes are obtainable from qualified manufacturers using ThyssenKrupp VDM semi-fabricated products.

Technical publications
The following publications concerning Nimofer 6928 may be obtained from ThyssenKrupp VDM GmbH:

H.-J. Büth, M. Köhler:
The ductility loss of the highly corrosion resistant alloy NiMo28 (Alloy B-2) during manufacturing of components for chemical plants and precautions to prevent it,
Werkstoffe und Korrosion 43 (1992), pp. 421-425

D.C. Agarwal, U. Heubner, M. Köhler, W. Herda:
UNS N10629: A new Ni-28%Mo Alloy,
Materials Performance Vol. 33 (1994), No. 10, pp. 64-68

M. Köhler, U. Heubner:
Stress Corrosion Cracking Behavior of Ni28Mo-Alloys, Recent Research Data,
CORROSION '94, Paper No. 230, NACE International Houston, Texas, 1994

TEM-Investigations to evaluate the effect of iron content on the precipitation behavior of Ni28Mo type alloys,
Praktische Metallographie 33 (1996) 7, pp. 330-339

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Publisher
VDM Metals GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

VDM Metals GmbH
Plettenberger Straße 2
58791 Werdohl
Germany

Phone +49 (0) 2392 55-0
Fax +49 (0) 2392 55-2217

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