VDM Metals

VDM® Alloy 36
Pernifer 36

Material Data Sheet No. 7001
March 2004 Edition

Pernifer® 36 - alloy 36

Pernifer 36 is an austenitic binary iron-nickel alloy with a particularly low coefficient of expansion. Control of carbon and manganese contents as well as impurities is important.

It is ferromagnetic at temperatures below the Curie temperature and non-magnetic at temperatures above.

Cold deformation reduces the thermal expansion.

A 3-step ageing treatment stabilizes the coefficient of expansion within a selected temperature range.

Pernifer 36 is characterized by:

- extremely low coefficient of thermal expansion between -250 and +200°C (-418 and 392°F)
- good ductility and toughness
- good fatigue and mechanical properties at cryogenic temperature

Designations and standards

Country National standards	Material designation	Specification				
		Chemical composition	Sheet and plate	Rod and bar	Strip	Wire
D DIN SEW	**W.-Nr. 1.3912** Ni36	 17745 385	385	385	385	385
F AFNOR	Fe-Ni36	A 54-301	A 54-301		A 54-301	A 54-301
UK BS EN						
USA ASTM	UNS K93600 for thermostat alloy	B 388 B 753 (T-36)	B 388 B 753 (T-36)		B 388 B 753 (T-36)	
	UNS K93601 for pressure vessels					
	UNS K93602 free cutting grade					
	UNS K93603 low expansion alloy	F 1684	F 1684		F 1684	
AMS		I-23011				

Table 1 – Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Co	P	S
min.	35.0		bal.						
max.	37.0	0.25		0.15	0.60	0.40	0.50	0.025	0.025
Various other Pernifer 36 grades with slightly modified chemical composition and/or lower thermal expansion are available on request for specialized applications mainly in the electronic field.									

Table 2 – Chemical composition (wt.-%), according to ASTM B 753 (T-36).

Physical properties

Density	8.1 g/cm³	0.293 lb/in.³
Melting point	1430 °C	2606 °F
Curie temperature	approx. 280 °C	approx. 535 °F
Specific heat	515 J/kg·K	0.123 Btu/lb·°F

Temperature (T)		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	$\frac{W}{m\,K}$	$\frac{Btu\ in.}{ft^2\ h\ °F}$	μ Ω cm	$\frac{\Omega\ circ\ mil}{ft}$	$\frac{kN}{mm^2}$	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
-250	-418	2.0	14			133	19.3	1.3 - 2.2	0.72 - 1.22
-200	-328	6.0	42			135	19.6	1.2 - 2.1	0.67 - 1.17
-100	-148	10.0	69			138	19.0	1.0 - 1.6	0.56 - 0.89
20	68	12.8	89	76	457	143	20.7		
100	212	14.0	97	85	511	142	20.6	0.6 - 1.4	0.33 - 0.78
200	392	15.1	105	92	553	141	20.5	1.6 - 2.5	0.56 - 1.39
300	572	16.1	112	100	602	140	20.3	4.4 - 5.5	2.4 - 3.1
400	752	17.0	118	105	632	138	19.0	7.4 - 8.4	4.1 - 4.7
500	932	18.1	126	109	656	130	18.9	8.9 - 9.7	4.9 - 5.0
600	1112	19.5	135	113	680	120	17.4	10.0 - 10.7	5.6 - 5.9

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

Metallurgical structure
In the annealed condition Pernifer 36 exhibits an austenitic structure.

Corrosion resistance
Pernifer 36 is corrosion resistant in dry atmospheres at room temperature. Under unfavourable conditions, i.e., in humid or moist atmospheres, corrosion can occur in the form of rust.

Applications
Pernifer 36 was developed for applications requiring the lowest possible thermal expansion.

Typical applications are:

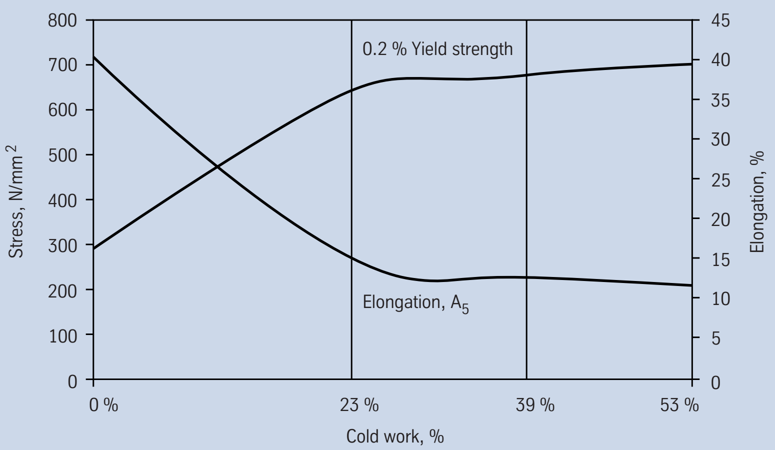
- Production, storage and transportation of liquefied gases
- Equipment to indicate and control temperatures below 200°C (392°F), i.e., thermostats
- Bushings for screw or bolt connections between different metals
- Bimetallic components and thermostat metals, where Pernifer 36 constitutes the passive component
- Diaphragm frames
- TV shadow masks
- Molds for the production of carbon fiber reinforced plastic (CFRP) components
- Frames for electronic control units for satellites and space crafts at temperatures down to -200°C (-328°F)
- Mountings for electromagnetic lens systems in laser control devices
- Clock pendulums
- Components in automotive applications

Pernifer® 36 - alloy 36

Mechanical properties

Temperature °C	Temperature °F	0.2 % Yield strength $R_{p\ 0.2}$ N/mm²	0.2 % Yield strength $R_{p\ 0.2}$ ksi	Tensile strength R_m N/mm²	Tensile strength R_m ksi	Elongation A_5 %	ISO V-notch impact toughness J/cm²
-250	-418	880	128	1000	145	40	
-240	**-400**	850	123	980	142	40	
-200	-328	700	102	870	126	40	85
-184	**-300**	670	97	840	122	40	
-129	**-200**	540	78	720	104	40	
-100	-148	500	73	670	97	40	100
-73	**-100**	430	62	630	91	40	
-18	0	330	48	540	78	40	
0	32	310	45	520	75	40	
20	68	270	34	490	71	40	132
93	**200**	180	26	435	63	45	
100	212	180	26	435	63	45	140
200	392	115	17	430	62	45	
204	**400**	115	17	430	62	45	
300	572	95	14	410	60	50	
316	**600**	95	14	405	59	50	
400	752	90	13	350	51	55	
427	**800**	90	13	340	49	55	
500	932	90	13	290	42	60	
538	**1000**	85	12	260	38	60	
600	1112	75	11	210	30	70	

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



Cold work %	0.2% Yield strength $R_{p\ 0.2}$ N/mm²	0.2% Yield strength $R_{p\ 0.2}$ ksi	Elongation A_5 %
0	292	42.4	40
23	645	93.5	15
39	679	98.5	13
53	702	101.8	12

Fig. 1 – Typical mechanical properties at room temperature of soft-annealed rods after cold forming.

Fabrication and heat treatment
Pernifer 36 can readily be hot and cold worked and machined. Working characteristics are similar to those of austenitic stainless steel.

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

Pernifer 36 may become embrittled if heated in the presence of contaminants such as sulfur, phosphorus, lead and other low-melting-point metals. Sources of such contaminants include marking and temperature-indicating paints and crayons, lubricating grease, fluids and fuels.

Fuels must be as low in sulfur as possible. Natural gas should contain less than 0.1 wt.-% sulfur. Fuel oils with a sulfur 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.

Hot working
Pernifer 36 may be hot-worked in the temperature range 1050 to 800°C (1920 to 1470°F), followed by water quenching or rapid air cooling.

For heating up, workpieces may be charged into the furnace at maximum working temperature. When the furnace has returned to temperature, the workpieces should be soaked for 60 minutes per 100 mm (4 in.) of thickness. At the end of this period it should be withdrawn immediately and worked within the above temperature range.

Heat treatment after hot working is recommended in order to achieve optimum properties.

Cold working
For cold working the material should be in the annealed condition. Pernifer 36 has a work-hardening rate similar to austenitic stainless steels. This should be taken into account when selecting forming equipment.

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

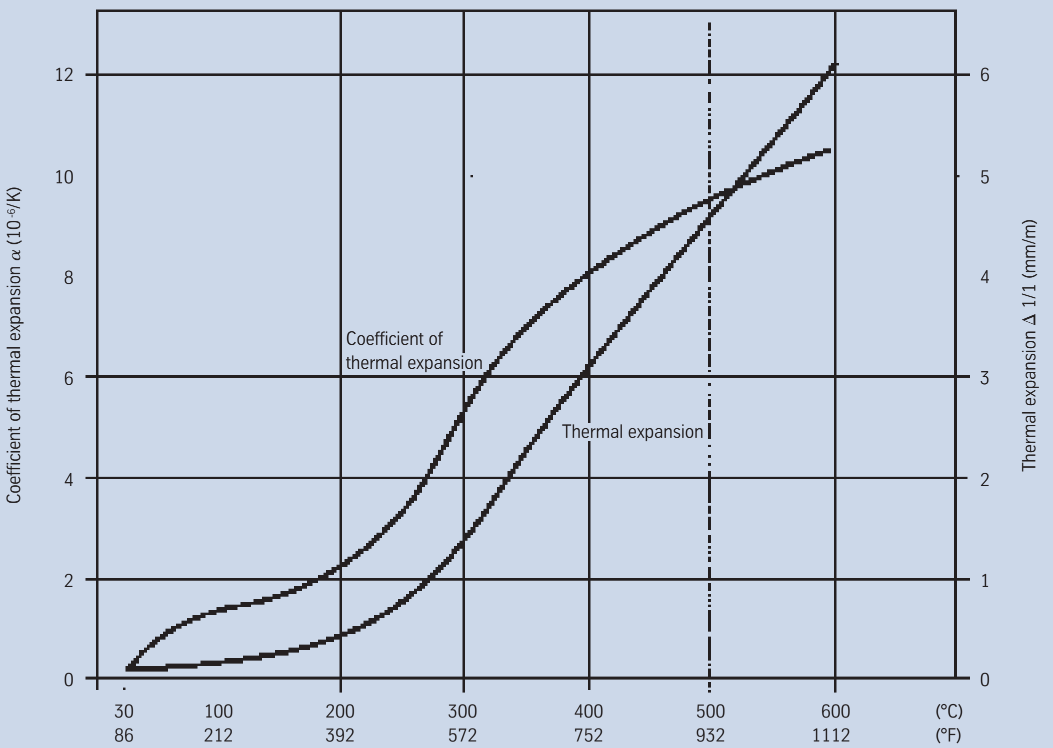


Fig. 2– Typical variation of coefficient of thermal expansion and thermal expansion with temperature.

A cold-worked structure is advantageous under certain circumstances as this reduces slightly the coefficient of thermal expansion. However, the cold-worked structure is not particularly stable, especially in applications at higher temperatures.

Heat treatment
Soft annealing is carried out in the temperature range 820 to 900°C (1510 to 1650°F) and generally followed by air cooling.

Though water quenching from the annealing temperature range leads to a slightly lower thermal expansion than air cooling, it again does not result in a particularly stable structure. For material which has been cold worked with less than 10 % deformation, an annealing temperature of close to, but not exceeding 860°C (1580°F) is recommended.

Stress-relief annealing may be performed at temperatures below 360°C (680°F) or more effectively above 650°C (1200°F).

The nominally low values of thermal expansion up to 100°C (212°F) are attained by using the following 3-step thermal treatment:

1) Thermal treatment at 830°C (1526°F) for approx. 30 min., followed by water quenching.

2) Reheating to 300°C (572°F); after holding at temperature for one hour, cooling in air.

3) Again reheating to 100°C (212°F); after holding at temperature for 30 min., furnace cool for 48 hours to room temperature.

For any thermal treatment the material should be charged into the furnace at maximum annealing temperature observing the precautions concerning cleanliness mentioned earlier under **'Heating'**.

Descaling and pickling
Oxides of Pernifer 36 and discoloration (heat tint) 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 is best done in hydrochloric acid solutions with proper control of pickling time and temperature, the surface oxide layer should be broken up by abrasive blasting or by carefully performed grinding or by pretreatment in a fused salt bath. A 20 % hydrochloric acid solution at 70°C (160°F) is particularly effective.

Pickling solutions consisting of nitric and hydrofluoric acid mixtures are generally considered to be too aggressive for Pernifer 36.

To avoid over-etching of the material it is recommended to first carry out pickling trials using samples.

Machining
Pernifer is tough and ductile and therefore somewhat difficult to machine. It should be machined in the annealed condition. The machining characteristics of Pernifer 36 are similar to austenitic stainless steels. Because of its high ductility, the chips formed during machining tend to be stringy and tough and may thus impose rapid wear on the cutting tool edges. In general, slow speeds and light feeds should be used to avoid excessive heat and minimize the possibility of the generated heat affecting the expansion characteristics. An adequate depth of cut is important, however, in order to cut below any previously formed work-hardend zone.

High speed steel or sintered carbide tools should be used and cutting edges should be kept sharp.

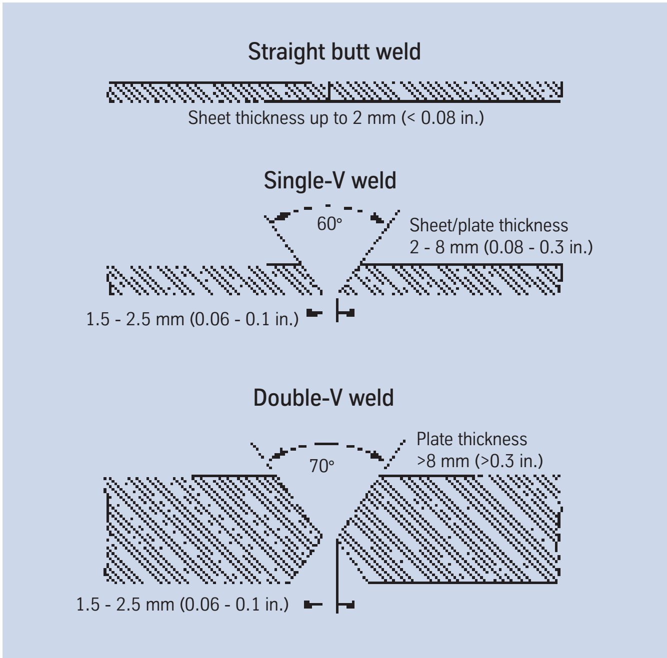


Fig. 3 - Edge preparation for GTAW of Pernifer 36.

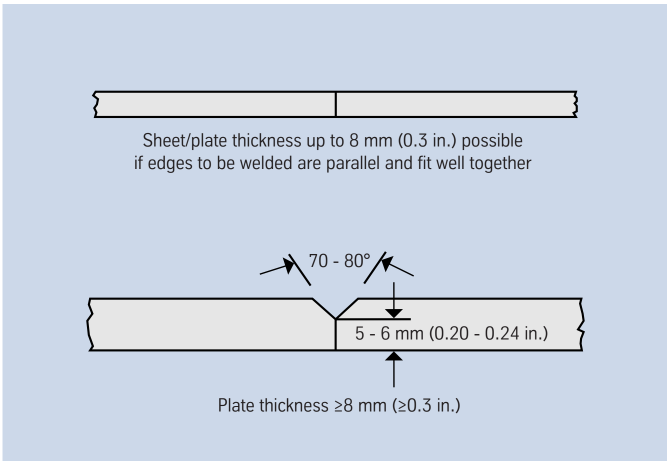


Fig. 4 - Edge preparation for plasma-keyhole welding of Pernifer 36.

Two types of cutting fluids are commonly used in machining Pernifer 36 alloy grades - sulfochlorinated oils recognized for their ability to prevent seizing, and emulsifiable fluids which have greater cooling capacity. Most machining operations require a sulfochlorinated oil.

Welding

When welding Pernifer 36, similar to nickel alloys, the following instructions should be adhered to:

Workplace

The workplace should be in a separate location, well away from the 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 machinery

Tools used for nickel alloys and stainless steels must not be used for other materials. Brushes should be made of stainless material. Fabricating and working machinery such as shears, presses or rollers should be fitted with means (felt, cardboard, plastic sheet) of avoiding contamination of the metal with ferrous particles, which can be pressed into the surface and thus damage the metal and may then constitute sites particularly prone 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.

Edge preparation

This should preferably be done by mechanical means, i.e., turning, milling or planing; abrasive water jet or 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 permissible.

Included angle

The different physical characteristics of nickel alloys and special stainless steels compared with carbon steel generally manifest themselves in lower thermal conductivity and higher rate of thermal expansion. This should be allowed for by means of, among other things, wider root gaps or openings (1.5 to 2.5 mm), while larger included angles (70 to 80˚), as shown in Figure 3 and 4, 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 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 are sites particularly prone to corrosion.

Welding processes

Pernifer 36 can be joined to itself and to many other metals by conventional welding processes. These include GTAW (TIG) and plasma keyhole. Pulsed arc welding is the preferred technique. The use of Ar + 2 % H_2 as shielding gas is recommended.

For welding, Pernifer 36 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

If the low coefficient of thermal expansion is the primary criterion for use of a component, which is welded by gas-shielded welding, then only filler metal with the same composition as the base metal must be used.

If, however, the coefficient of thermal expansion is not of primary concern, the use of conventional gas-shielded welding processes employing Nicrofer S 7020 - FM 82 filler metal is also possible.

Bare electrodes:	For lowest thermal expansion up to 200°C (392°F): Pernifer S 6436 W.-Nr. 1.3912 Possible alternative, if lowest thermal expansion is not required: Nicrofer S 7020 - FM 82 W.-Nr. 2.4806 SG-NiCr20Nb AWS A5.14: ERNiCr-3

Welding parameters and influences (heat input)

Care should be taken to ensure that the work is performed with a deliberately chosen, low heat input as indicated in Table 5 by way of example. Use of the stringer bead technique should be aimed at. Interpass temperature should be kept below 130°C (266°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 normally required.

Sheet/plate thickness mm	Sheet/plate thickness in.	Welding process	Filler metal Dia-meter mm	Filler metal Speed m/min.	Welding parameters Root pass I A	Root pass U V	Intermediate and final passes I A	Intermediate and final passes U V	Welding speed approx. cm/min.	Shielding gas rate l/min.	Heat input per unit length max. kJ/cm
2.0	0.08	Manual GTAW	2.0		70	9			15	Ar W2[1)]8	3.5
6.0	0.24	Manual GTAW	2.0–2.4		90	10	130	13	16	Ar W2[1)] 8	6.5
12.0	0.5	Manual GTAW	2.4		100	10	140	14	16	Ar W2[1)] 8	6.5
3.0	0.12	Autom.[2)] GTAW	1.2	1.0	manual		150	13	25	Ar W2[1)] 12-15	7
5.0	0.2	Autom.[2)] GTAW	1.2	1.0	manual		150	13	25	Ar W2[1)] 12-15	7
≥10.0	≥0.4	Autom.[2)] GTAW	1.2	1.5	manual		200	14	20-25	Ar W2[1)] 15	7
6.0	0.24	Plasma keyhole	1.2	0.5			220	26	26	Ar W2[1)] 30	
8.0	0.3	Plasma keyhole	1.2	0.5			240	27	25	Ar W2[1)] 30	

[1)] Argon or argon + max. 2 % hydrogen
[2)] Hot wire GTAW is also possible.

In all gas-shielded welding operations, ensure adequate back shielding.
These figures are only for guidance to facilitate setting of welding machines.

Table 5 – Welding parameters (guide values).

Pernifer® 36 - alloy 36

Availability

Pernifer 36 is available in the following standard product forms.

Sheet and plate

(for cut-to-length availability, refer to strip)

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

Thickness mm		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	100	320
0.300 - ≤ 1.000	hr	100	320[2]
>1000[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,
descaled or 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	≤2200	≤12	≤120	
Ring	≤6600	≤ 8	≤100	on request

[1] other sizes subject to special enquiry

Rod and bar

Conditions:
forged, rolled, drawn,
thermally treated,
descaled or 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 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 mm	Coil I.D. mm			
0.02 - ≤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 - ≤3.5[2)]	25 - 750		400	500	600

inches	inches	inches			
0.008 - ≤0.004	0.16 - 8[3)]	12	16		
> 0.004 - ≤0.008	0.16 - 14[3)]	12	16	20	
> 0.008 - ≤0.010	0.16 - 30[4)]		16	20	24
> 0.010 - ≤0.024	0.20 - 30[4)]		16	20	24
> 0.024 - ≤0.040	0.32 - 30[4)]		16	20	24
> 0.040 - ≤0.080	0.60 - 30[4)]		16	20	24
> 0.080 - ≤0.140[2)]	1.0 - 30[4)]		16	20	24

1) Cut-to-length available in lengths from 250 to 4000 mm (10 to 158 in.)
2) Maximum thickness:
bright annealed - 3.5 mm (0.140 in.)
3) Wider widths up to 730 mm (29 in.) subject to special enquiry
4) Wider widths subject to special enquiry

Wire

Conditions:
dry or wet drawn, depending on dimension,
¼ 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 and 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 SAS, Tour Neptune, F-92086 Paris, La Défense Cedex
(Fax: +33 1 47 96 81 41; Tel.: +33 1 47 96 81 40;
E-mail: dmv-hq@dmv-stainless.com

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

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