Nicrofer® 4221 – alloy 825

Material Data Sheet No. 4001
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Corrosion-resistant alloy

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ThyssenKrupp

Nicrofer® 4221 – alloy 825

Nicrofer 4221 is a titanium-stabilized fully austenitic nickel-iron-chromium alloy with additions of copper and molybdenum.

Nicrofer 4221 is characterized by:

- good resistance to stress-corrosion cracking
- satisfactory resistance to pitting and crevice corrosion
- good resistance to oxidizing and non-oxidizing hot acids
- good mechanical properties at both room and elevated temperatures, up to approximately 550 °C (1020 °F)
- approval for pressure vessels with wall temperatures up to 450 °C (842 °F)

Designation and standards

Country National standards	Material designation	Specification						
		Chemical composition	Tube and pipe		Sheet and plate	Rod and bar	Strip	Wire	Forgings
			seamless	welded					
D DIN VdTÜV	**W.-Nr. 2.4858** NiCr21Mo	17744 432	17751 432/2		17750 432/1	17752 432/3	17750 432/1		17754 432/3
F AFNOR	NC21FeDU								
UK BS	NA 16		3074		3072	3076	3073		
USA ASTM ASME AMS	UNS N08825		B 423 SB 423	B 163 B 704/705 SB 163	B 424 SB 424	B 425 SB 425	B 424 SB 424		
ISO	NiFe30Cr21Mo3								

Table 1 – Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Mo	Al	Ti	P	S
min.	38.0	19.5	bal.				1.5	2.5		0.6		
max.	46.0	23.5		0.025	1.0	0.5	3.0	3.5	0.2	1.2	0.020	0.010

Table 2 – Chemical composition (wt.-%) according to VdTÜV 432.

Note: Some compositional limits of other specifications may vary slightly.

Physical properties

Density	8.1 g/cm³	0.293 lb/in.³
Melting range	1370-1400 °C	2500-2550 °F
Permeability at 20 °C/68 °F (RT)	1.004	

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			10.5	73	112	677				
20	68	440	0.105	10.8	75	112	678	195	28.3		
93	200		0.110		85		687		27.4		7.8
100	212	462		12.4		114		190		14.1	
200	392	488		14.1		118		185		14.9	
204	400		0.117		98		710		26.8		8.3
300	572	514		15.6		120		179		15.2	
316	600		0.123		110		728		25.8		8.5
400	762	540		16.9		124		174		15.6	
427	800		0.131		120		751		25.0		8.7
500	932	565		18.3		126		168		15.8	
538	1000		0.137		131		761		23.8		8.8
600	1112	590		19.6		126		161		16.0	
649	1200		0.144		142		762		22.7		9.1
700	1292	615		21.0		127		154		16.7	
760	1400		0.153		155		765		21.2		9.5
800	1472	655		23.2		128		142		17.2	
871	1600		0.160		172		775		19.4		9.7
900	1652	680		25.7		129		130		17.6	
982	1800		0.167		192		782		17.3		9.9
1000	1832	710		28.1		130		119		17.9	

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

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Mechanical properties

The following properties are applicable to Nicrofer 4221 in the soft-annealed (stabilizing annealed) condition and indicated size ranges.

Specified properties of material outside these size ranges with agreed properties are subject to special enquiry.

Product		Dimensions		Yield strength $R_{p0.2}$		Yield strength $R_{p1.0}$		Tensile strength R_m		Elongation A_{50}	Brinell hardness
		mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB
Sheet, strip	cr	0.5– 6.4	0.018–0.25	240	35	265	38	585	85	30	≤ 200
Plate	hr	5 –100	3/16 –4								135–165
Rod, bar	cf	1.6– 64	1/16 –2 1/2								
	hf	25 –100	1 –4								
		> 100 –240	> 4 –9 1/2	220	32	250	36	550	80	35	
Tube, pipe	hf	64 –240	2 1/2–9 1/2	180	25	–	–	530	75	30	
	cf	5 –100	3/16 –4	240	35	265	38	585	85	30	
Condenser and heat exch. tube		16 – 76	5/8 –3								

Table 4 – Minimum mechanical properties at room temperature according to ASTM.

Product	Yield strength , $R_{p0.2}$ N/mm²					Yield strength, $R_{p1.0}$ N/mm²				
Temperature, °C	100	200	300	400	450	100	200	300	400	450
Sheet, strip, plate, tube	205	180	170	160	155	235	205	195	185	180
Rod, bar	190	165	155	145	140	220	190	180	170	165

	ksi					ksi				
Temperature, °F	200	400	600	800	–	200	400	600	800	–
Sheet, strip, plate, tube	30.5	26.1	26.4	22.6	–	34.8	29.7	28.0	26.3	–
Rod, bar	28.3	23.9	22.2	20.4	–	31.2	27.6	25.8	24.1	–

Table 5 – Minimum short-time mechanical properties in the soft-annealed condition at elevated temperatures according to VdTÜV Material Data Sheet 432.

ISO V-notch impact toughness

Average values at RT: longitudinal ≥ 150 J/cm²
transverse ≥ 100 J/cm²

Temperature		Maximum allowable stress			
°C	°F	N/mm² 1)	1) 2)	ksi	2)
38	100			21.2	21.2
93	200			21.2	21.2
100	212	146	146		
149	300			20.4	21.2
200	392	132	146		
204	400			19.2	21.2
260	500			18.3	21.2
300	572	124	146		
316	600			17.8	21.2
371	700			17.3	21.0
400	752	119	146		
427	800			17.1	20.8
482	900			16.8	20.5
500	932	115	138		
538	1000			16.6	19.7

1) metric values determined by interpolation
2) conditional stress values

Table 6 – Maximum allowable stress values in tension according to ASME UNF-23.3, SB 424.

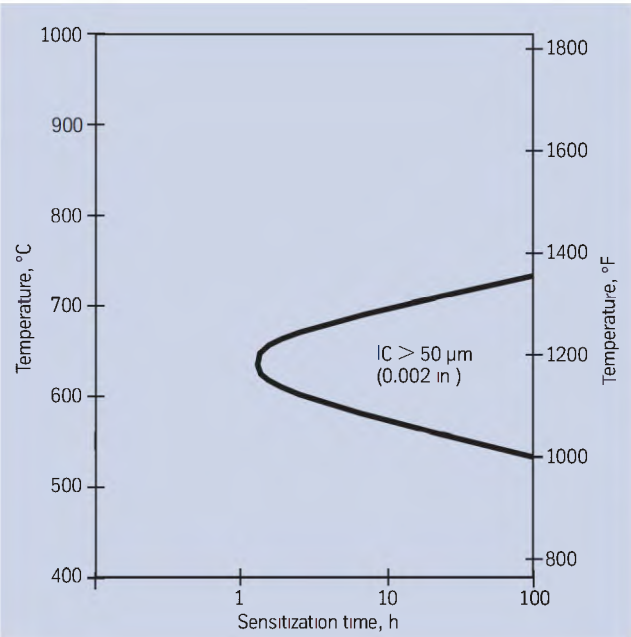

Fig. 1 – Time-temperature-sensitization (TTS) diagram for Nicrofer 4221 sheet (C=0.010%) after Streicher test, according to ASTM G-28, method A.

Conditional stress values
The higher conditional stress values of up to 90% of the yield strengh 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.

Metallurgical structure
Nicrofer 4221 has a stable face-centered-cubic structure. The chemical composition and optimized thermal treatment ensure that corrosion resistance is not impaired by sensitization.

Corrosion resistance
Nicrofer 4221 is a versatile general engineering alloy with resistance to corrosion in acids and alkalis under both oxidizing and reducing conditions.

High nickel content gives the alloy virtual immunity to stress corrosion cracking.
Corrosion resistance is good in media as diverse as sulphuric, sulphurous, phosphoric, nitric and organic acids, alkalis such as sodium or potassium hydroxide, and acidic chloride solutions.
The versatility of Nicrofer 4221 is illustrated by its use in nuclear fuel element dissolvers where a variety of corrosive media, e. g. sulphuric and nitric acids and sodium hydroxide, are handled in the same equipment.

Applications
Nicrofer 4221 is used in a wide variety of applications up to a temperature of approximately 550 °C (1020 °F).

Typical examples are:
- components such as heating coils, tanks, crates, baskets and chains in sulphuric acid pickling plants
- fuel element dissolvers
- sea-water-cooled heat exchangers, offshore product piping systems; tubes and components in sour gas service
- heat exchangers, evaporators, scrubbers, dip pipes etc. in phosphoric acid production
- air-cooled heat exchangers in petroleum refineries
- food processing
- chemical plant
- combustion-resistant alloy for high pressure O_2 applications

Fabrication and heat treatment
Nicrofer 4221 can readily be hot- and cold-worked and machined.

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Heating
Temperature control is important to ensure that the corrosion resistance of the alloy is not impaired by sensitization. Workpieces must be clean and free from all kinds of contaminants before and during any heat treatment.

Nicrofer 4221 may become embrittled 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 containing no more than 0.5 wt.-% sulphur 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
Nicrofer 4221 may be hot-worked in the temperature range 1150 to 900 °C (2100 to 1650 °F). Cooling after hot working should be by water quenching or rapid air cooling.

For hot working the material may be charged into the furnace at working temperature. When the furnace has returned to temperature the work piece 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. If the metal temperature falls below the minimum hot working temperature, it must be reheated. Annealing is required after hot working to ensure maximum corrosion resistance and optimum grain micro-structure.

Cold working
Cold working should be carried out on annealed material. Nicrofer 4221 has a work-hardening rate similar to that of austenitic stainless steels. This should be taken into account when selecting the forming equipment.

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

After final cold-working with more than 15% deformation a stabilizing anneal is required.

Due to the possibility of galling, carbon steel is not recommended for dies, which should be of alloy tool steel, tungsten carbide or cast iron.

Heat treatment
Soft or stabilizing anneals should be carried out in the temperature range 920 to 980 °C (1690 to 1800 °F) preferably at 940 ± 10 °C (1725 ± 15 °F). Water quenching or rapid air cooling is recommended for thicknesses above about 1.5 mm (0.06 in.), and is essential for maximum corrosion resistance. For any thermal treatment the material should be charged into the furnace at temperature observing the precautions concerning cleanliness mentioned earlier under '**Heating**'.

Descaling and pickling
Oxides of Nicrofer 4221 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 in a nitric/hydrofluoric acid mixture, the surface oxide layer must be broken up by abrasive blasting or grinding or by pretreatment in a fused salt bath. Particular attention should be paid to the pickling time.

Machining
Nicrofer 4221 should be machined in the annealed condition. As the alloy is prone to work-hardening low cutting speeds should be used and the tool should be engaged at all times. Heavy feeds are important in getting below the work-hardened surface layer.

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.

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 of 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. 2, 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

Nicrofer 4221 can be joined to itself and to many other metals by conventional welding processes. These include GTAW (TIG), plasma arc, GMAW (MIG/MAG) and SMAW (MMA). Pulsed arc welding is the preferred technique. For the MAG process the use of a multi-component shielding gas (Ar + He + H_2 + CO_2) is recommended.

For welding, Nicrofer 4221 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, the following filler metals are recommended:

Bare electrodes:	Nicrofer S 6020 – FM 625 Werkstoff-Nr. 2.4831 SG-NiCr 21 Mo 9 Nb AWS A 5.14: ERNiCrMo-3
Covered electrodes:	Werkstoff-Nr. 2.4621 EL-NiCr 20 Mo 9 Nb AWS A 5.11: ENiCrMo-3

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 bead 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.

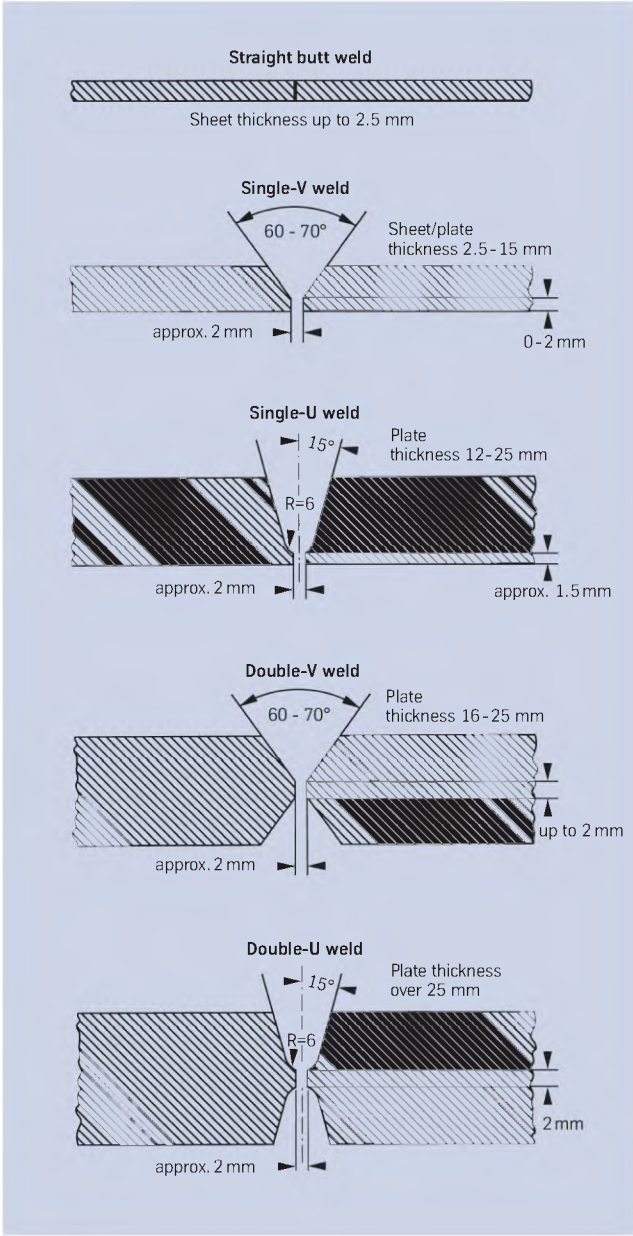

Fig. 2 – Edge preparation for welding of nickel-base alloys and special stainless steels.

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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
3.0	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.

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	GMAW, MIG/MAG, manual, fully mechanised	max. 11
Hot wire GTAW	max. 6	SMAW, manual metal arc (MMA)	max. 7
Plasma arc	max. 10		

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

Postweld treatment
(brushing, pickling and thermal treatments)

Brushing with a stainless steel wire brush immediately after welding, i.e. while the metal is still not 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.

Availability
Nicrofer 4221 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.

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