Nicrofer® 7016 TiAl – alloy 751

Material Data Sheet No. 4047
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Superalloy

A company of
ThyssenKrupp
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Nicrofer® 7016 TiAl – alloy 751

Nicrofer 7016 TiAl is a precipitation hardenable nickel-chromium-iron alloy containing titanium, niobium and aluminium, exhibiting good corrosion resistance at high and low temperatures and high strength up to 820 °C (1510 °F). It is similar to Nicrofer 7016 TiNb - alloy X - 750, except that its slightly modified composition imparts increased stress-rupture properties at 870 °C (1600 °F).

It can be delivered in the solution-treated or precipitation-hardened condition.

Nicrofer 7016 TiAl is characterized by:

- high tensile strength up to 600 °C (1110 °F)
- high creep and rupture strength up to 820 °C (1510 °F)
- high oxidation resistance up to 980 °C (1795 °F)
- excellent mechanical properties in cryogenic environments
- good corrosion resistance at high and low temperatures and high resistance to stress-corrosion cracking
- good weldability by resistance and fusion processes

Designations 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 SEW	**W.-Nr. 2.4694** NiCr16Fe7TiAl								
USA ASTM ASME SAE AMS	UNS N07751								

Table 1 – Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Ti	Nb	Al	S
min.	70.0	14.0	5.0					2.00	0.70	0.90	
max.		17.0	9.0	0.08	1.00	0.50	0.50	2.50	1.20	1.50	0.010

Table 2 – Chemical composition (wt.-%)

Physical properties

Density	8.2 g/cm³	0.296 lb/in.³
Melting range	1390 – 1430 °C	2540 – 2600 °F
Permeability at 20 °C/68 °F (RT)	1.0035	
Curie temperature (age-hardened)	-223 °C	-369 °F

Temperature (T)		Specific heat		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	$\frac{J}{kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in.}{ft^2 \cdot h \cdot °F}$	μΩ · cm	$\frac{\Omega \cdot circ\ mil}{ft}$	$\frac{kN}{mm^2}$	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	**68**	431	0.103	10.5	73	123	743	213	30.6		
93	**200**		0.109		81		751				7.3
100	212	460	0.110	11.8		125				13.2	
200	392	480	0.115	13.4		127		189	27.4	13.5	
204	**400**		0.115		93		765				7.5
300	572	500	0.119	15.0		128				13.7	
316	**600**		0.120		105		776				7.6
400	752	520	0.124	16.5		130		194	28.1	13.9	
427	**800**		0.125		117		785				7.7
500	932	535	0.128	18.0		131				14.2	
538	**1000**		0.131		130		788				7.9
600	1112	560	0.134	19.8		130		180	26.1	14.8	
649	**1200**		0.137		143		783				8.3
700	1292	600	0.143	21.5		129		172	24.9	15.2	
760	**1400**		0.150		157		780				8.6
800	1472	660	0.158	23.3		129		161	23.4	15.8	
871	**1600**		0.171		170		774				9.0
900	1652	750	0.179	25.2		127		144	20.9	16.5	
982	**1800**				186		760				9.5
1000	1832			27.2		126				17.3	

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

Mechanical properties

The following properties are typical for Nicrofer 7016 TiAl rod and bar products in the hot and cold formed and solution-treated or solution-treated and precipitation-hardened conditions respectively.

Condition	Temperature		Tensile strength R_m		0.2 % Yield strength $R_{p\,0.2}$		Elongation A_5
	°C	°F	N/mm²	ksi	N/mm²	ksi	%
Solution-treated at 1200 °C (2190 °F) for 2 hours and water quenched	20	68	782	113	391	57	42
	100	212					
	200	392	700	102	380	55	44
	300	572					
	400	752	640	93	371	54	47
	500	932					
	600	1112	600	87	360	52	47
	700	1292	593	86	350	51	17
	800	1472	577	84	340	49	7
	900	1652	316	46	243	35	34
	1000	1832	78	11	73	11	100
Solution-treated as above + precipitation-hardened at 780 °C (1435 °F) for 4 hours and air cooled	20	68	1075	156	716	104	24
	100	212					
	200	392	1021	148	670	97	27
	300	572					
	400	752	983	143	652	95	30
	500	932					
	600	1112	912	132	660	96	25
	700	1292	861	125	660	96	14
	800	1472	637	92	534	77	12
	900	1652	35	5	271	39	29

Table 4 – Typical short-time mechanical properties for rod and bar products in the solution-treated and solution-treated and age-hardened conditions at room and elevated temperatures.

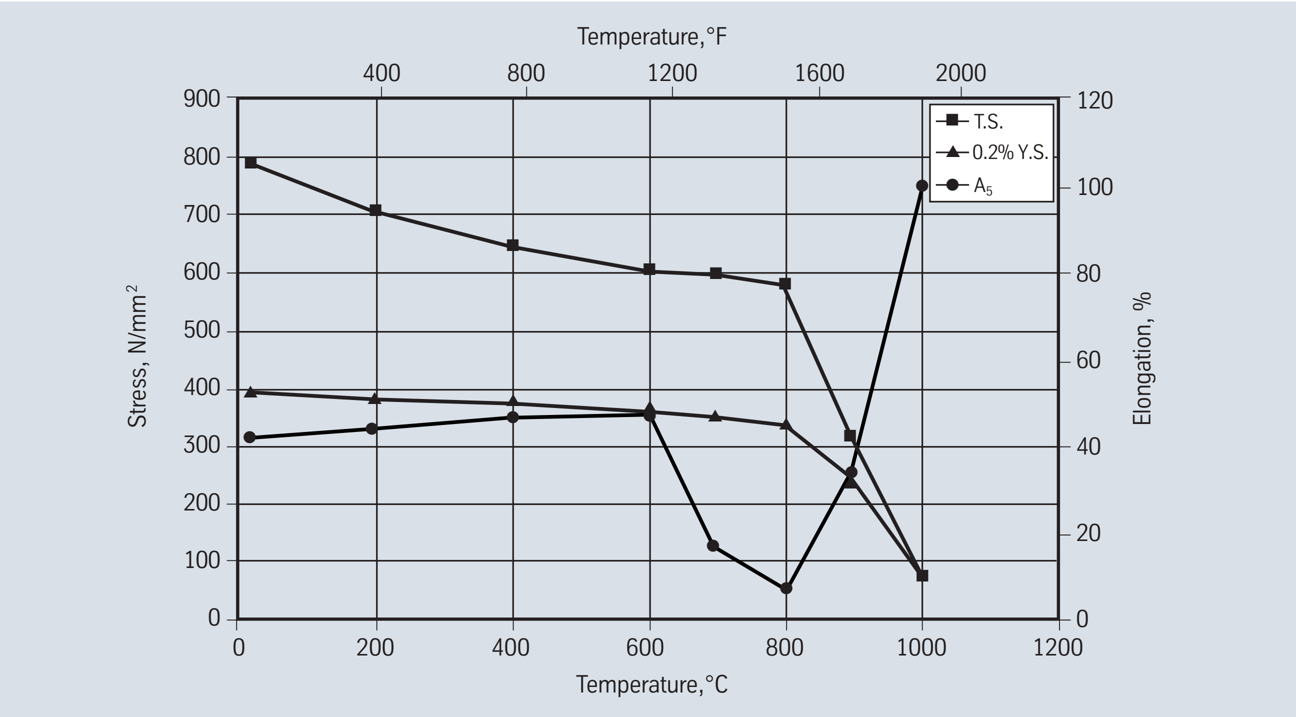

Fig. 1 – Typical short-time properties of solution-treated Nicrofer 7016 TiAl rod and bar products at room and elevated temperatures.

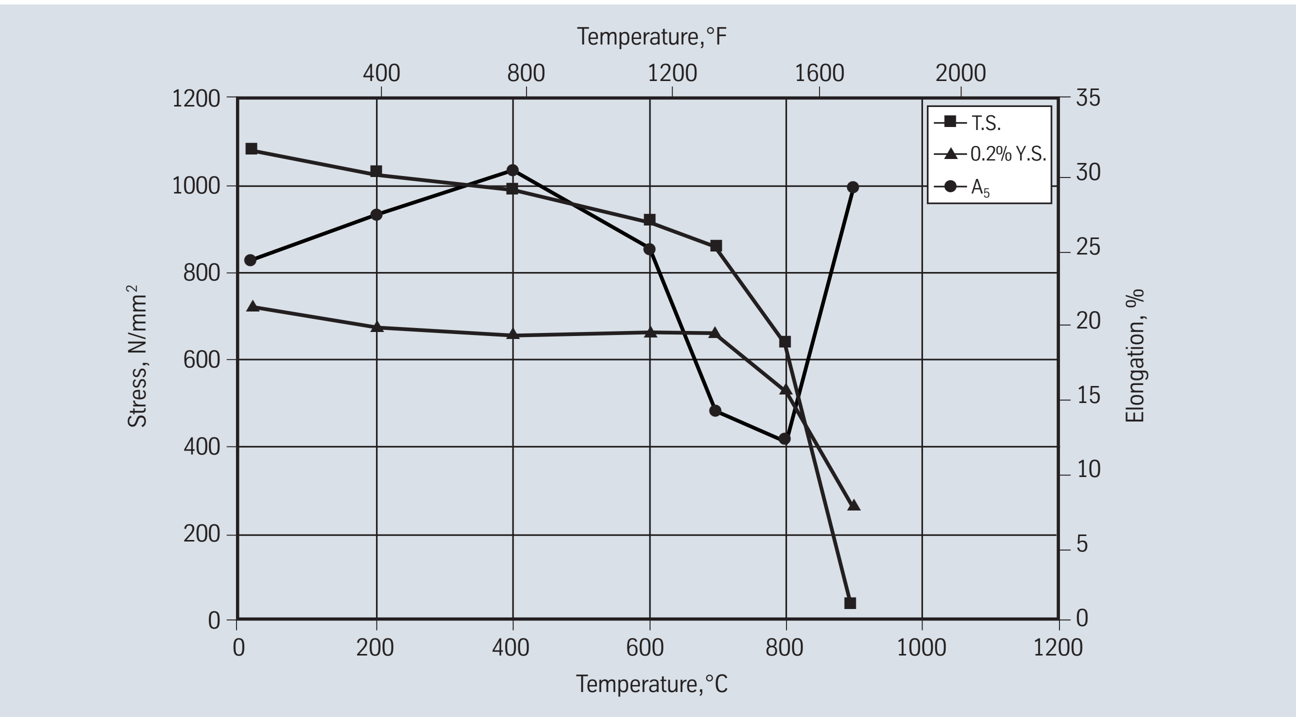

Fig. 2 – Typical short-time properties of solution-treated and age-hardened Nicrofer 7016 TiAl rod and bar products at room and elevated temperatures.

Temperature		Creep-rupture strength $R_{m/10^5 h}$	
°C	°F	N/mm²	ksi
649	**1200**	469	68
700	1292	(331)	(48)
732	**1350**	262	38
800	1472	(148)	(21.5)
816	**1500**	128	18.5
850	1562	(90)	(13)
871	**1600**	69	10
900	1652	(48)	(7)
927	**1700**	29	4.2
Values in brackets determined from a graph			

Table 5 – Typical creep-rupture strength of solution-treated and precipitation-hardened Nicrofer 7016 TiAl.

Metallurgical structure
Nicrofer 7016 TiAl has an austenitic structure. The excellent mechanical strenght results from precipitation hardening of the matrix gamma phase (γ) by formation of gamma prime phase (γ′) together with some carbides. By a double ageing heat treatment a duplex gamma prime (γ′) structure is formed.

Corrosion resistance
Nicrofer 7016 TiAl shows excellent general corrosion resistance at high and low temperatures and high resistance to stress-corrosion cracking. Oxidation resistance up to 980 °C (1800 °F) is remarkably high.

Applications
Due to its high temperature strength up to 820 °C (1510 °F) and its excellent corrosion resistance, Nicrofer 7016 TiAl finds a wide range of applications. For example combustion engine exhaust valves represent a typical application.

Fabrication and heat treatment
Nicrofer 7016 TiAl can be hot- and cold worked, fabricated and machined. Suitable equipment and procedures must be selected that will be appropriate for its high strenghth and characteristic strain-hardening rates. Forming should preferably be carried out in the solution-treated condition.

Heating
Workpieces must be clean and free from all kinds of contaminants before and during heating.

Nicrofer 7016 TiAl 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 and fluids, and fuels.

Fuels must be as low in sulfur as possible. Natural gas should contain less than 0.1 wt.-% sulfur and town gas 0.25 g/m³ maximum of 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 reducing 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 7016 TiAl may be hot worked in the temperature range 980 to 1200 °C (1800 to 2190 °F), followed by water quenching or rapid air cooling.

Annealing after hot working is recommended to obtain optimum properties and to ensure maximum corrosion resistance.

For heating up, workpieces should 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 they should be withdrawn immediately and worked within the above temperature range. If the metal temperature of a workpiece falls below 980 °C (1800 °F), it should be reheated.

During the final hot working with min. 20% reduction the temperature must not exceed 1100 °C (2000 °F) to ensure high mechanical properties.

Cold working
Cold working should be carried out on solution annealed material. Nicrofer 7016 TiAl has a much 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.

Heat treatment
Various solution and ageing treatments are used to produce the required properties. Long ageing times are necessary to develop optimum mechanical properties in Nicrofer 7016 TiAl.

For service up to 600 °C (1110 °F) with high tensile strength, direct ageing after forming or annealing is usual. For optimum long-term properties, high creep and rupture strength and good oxidation resistance, a solution treatment followed by double ageing is recommended.

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

Descaling and pickling
Oxides of Nicrofer 7016 TiAl 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/hydro-flouric acid mixture the surface oxide layer must be broken up by abrasive blasting, by carefully performed grinding or by pretreatment in a fused salt bath. Particular attention should be paid to the pickling time and temperature.

Machining
Nicrofer 7016 TiAl should be machined in the as-hot finished or annealed condition. As the alloy exhibits a high work-hardening rate, only low cutting speeds should be used compared to low-alloyed standard austenitic stainless steels. An adequate depth of cut is important in order to cut below the previously formed work-hardened zone. Tools should be engaged at all times.

Welding
When welding nickel alloys and high-alloyed special stainless steels, 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 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 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, i. e., by turning, milling or planing; abrasive water jet or plasma cutting is also suitable. 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 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 the arc
The arc should only be struck in the weld area, i. e., on the faces to be welded or on a run-out piece. Striking marks lead to corrosion.

Welding process
Nicrofer 7016 TiAl can be joined to itself and to many other metals by conventional welding processes. Though GTAW (TIG) is preferred for optimum corrosion resistance, SMAW (MMA) is also possible. Nicrofer 7016 TiAl can also be welded by resistance welding.

Nicrofer 7016 TiAl should be in the solution annealed condition and be free from scale, grease and markings prior to welding. Preheating is not required. 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. Root backing is also recommended for the first intermediate pass following the initial root pass and in some cases even for the second pass depending on the weld set-up. 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 7020 – FM 82 (W.-Nr. 2.4806)
UNS N06082
AWS A5.14: ERNiCr-3
DIN EN ISO 18274: S Ni 6082 (NiCr20Mn3Nb)

or

Nicrofer S 5520 – FM 617 (W.-Nr. 2.4627)
UNS N06617
AWS A5.14: ERNiCrCoMo-1
DIN EN ISO 18274: S Ni 6617 (NiCr22Co12Mo9)

Covered electrodes:
W.-Nr. 2.4648
DIN EN ISO 14172: E NI 6082 (NiCr20Mn3Nb)

or

W.-Nr. 2.4628
UNS W86117
AWS A5.11: ENiCrCoMo-1
DIN EN ISO 14172: E Ni 6617 (NiCr22Co12Mo)

It should be noted, that although the base metal can be age-hardened, this does not hold true for the weld metal in the welding zone as all the filler metals suggested above are not age-hardenable. Never-the-less the use of Nicrofer S 5520 or the corresponding covered electrode 2.4628 (E Ni 6617) will result in a weld with higher mechanical properties, though lower than those of the age-hardened base metal, than those which are obtainable when Nicrofer S 7020 or its correspon-ding covered electrode 2.4648 (E Ni 6082) is used as filler metal.

It is recommended that Technical Marketing is consulted for selecting the most suitable filler metal for a specific application.

Welding parameters and influences (heat input)

Care should be taken that the work is performed with a delibe-rately chosen, low heat input as indicated in Table 7 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.

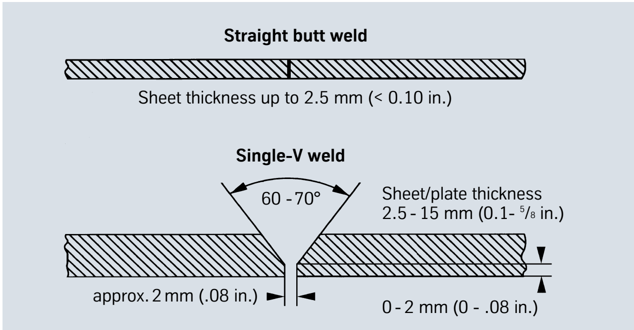

Fig. 3 – Edge preparation for welding of nickel alloys and special stainless steels.

Sheet/ plate thick-ness mm	Welding process	Filler metal diameter 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 cm/min.	Shielding gas Type & rate l/min.
3.0	Manual GTAW	2.0		90	10	110 – 120	11	approx. 15	Ar W2[1)] 8 – 10
6.0	Manual GTAW	2.0 – 2.4		100 – 110	10	120 – 140	12	14 – 16	Ar W2[1)] 8 – 10
8.0	Manual GTAW	2.4		100 – 110	11	130 – 140	12	14 – 16	Ar W2[1)] 8 – 10
10.0	Manual GTAW	2.4		100 – 110	11	130 – 140	12	14 – 16	Ar W2[1)] 8 – 10
3.0	Autom. GTAW	1.2	approx. 1.2	Manual GTAW		150	11	25	Ar W2[1)] 12 – 14
5.0	Autom. GTAW	1.2	approx. 1.4	Manual GTAW		180	12	25	Ar W2[1)] 12 – 14
6.0	SMAW (MMA)	2.5		40 – 70	approx. 21	40 – 70	approx. 21		
8.0	SMAW (MMA)	2.5 – 3.25		40 – 70	approx. 21	70 – 100	approx. 22		
16.0	SMAW (MMA)	4.0				90 – 130	approx. 22		

[1)] Argon or argon + max. 2 % hydrogen
In all gas-shielded welding operations, ensure adequate back shielding. Figures are for guidance only and are intended to facilitate setting of the welding machines.

Table 6 – Welding parameters (guide values).

Welding process	Heat input per unit length kJ/cm
GTAW, manual, fully mechanised	max. 8
SMAW, manual metal arc (MMA)	max. 7

Table 7 – 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 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 under **'Descaling and pickling'**.

A postweld heat treatment is required before age-hardening.

Availability
Nicrofer 7016 TiAl is available in the following standard product forms:

Rod & bar and billet
Conditions:
forged, rolled, drawn,
thermally treated (solution-treated or precipitation hardened), 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)	not standard
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)	not standard
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.

Discs and rings
Conditions:
Hot rolled or forged,
thermally treated (solution-treated or precipitation hardened), descaled or pickled, machined, peeled or ground.
Available up to a maximum piece weight of 6 t for discs and 3 t for rings in accordance to drawings and technical feasability.

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

Thickness mm	Width[3] mm	Coil I. D. mm			
0.02 – ≤ 0.10	4 – 200[4]	300	400		
> 0.10 – ≤ 0.20	4 – 350[4]	300	400	500	
> 0.20 – ≤ 0.25	4 – 700		400	500	600
> 0.25 – ≤ 0.60	6 – 700		400	500	600
> 0.60 – ≤ 1.0	8 – 700		400	500	600
> 1.0 – ≤ 2.0	15 – 700		400	500	600
> 2.0 – ≤ 3.0[2] – ≤ 3.5[2]	25 – 700		400	500	600

inches	inches	inches			
0.0008 – ≤ 0.004	0.16 – 8[4]	12	16		
> 0.004 – ≤ 0.008	0.16 – 14[4]	12	16	20	
> 0.008 – ≤ 0.010	0.16 – 28		16	20	24
> 0.010 – ≤ 0.024	0.24 – 28		16	20	24
> 0.024 – ≤ 0.040	0.32 – 28		16	20	24
> 0.040 – ≤ 0.080	0.60 – 28		16	20	24
> 0.080 – ≤ 0.120[2] – ≤ 0.140[2]	1.0 – 28		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 mm (0.120 in.),
cold rolled only - 3.5 mm (0.140 in.)
[3] Wider widths subject to special enquiry
[4] Wider widths up to 730 mm (29 in.) subject to special enquiry

Wire
Conditions:
bright drawn, $^{1}/_{4}$ hard to hard,
bright annealed

Dimensions:
0.1 – 12.0 mm (0.004 – 0.47 in.) diameter,
in coils, pay-off packs, on spools and spiders.

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

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Nicrofer

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