Nicorros® – alloy 400

Material Data Sheet No. 4010
December 2002 Edition

Corrosion-resistant alloy

A company of
ThyssenKrupp
Stainless

ThyssenKrupp VDM

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Nicorros® – alloy 400

Nicorros is a single-phase solid-solution nickel-copper alloy with excellent corrosion resistance to a wide range of media.

Nicorros is characterized by:

- corrosion resistance in a wide range of marine and chemical environments
- freedom from chloride induced stress-corrosion cracking
- good mechanical properties from sub-zero temperatures up to about 550 °C (1020 °F)
- approved for pressure vessels with wall temperatures from -10 to 425 °C (14 to 800 °F) according to VdTÜV-Wbl. 263 and up to 900 °F (480 °C) according to ASME Boiler and Pressure Vessel Code.
- good workability and weldability

Designations 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. 2.4360** NiCu30Fe	 17743 263	 17751 263		 17750 263	 17752 263	 17750	 17753	 17754 263
F AFNOR	NU 30								
UK BS	NA 12		3074		3072	3076	3073	3075	
USA ASTM ASME SAE/AMS QQ-N-281	UNS N04400	 Table 1	 B 163/165 SB 163/165 4574		 B 127 SB 127 4544 Form 4,6	 B 164 SB 164 4675 Form 1	 B 127 SB 127 4544 Form 5	 4730 Form 7	 B 564 SB 564 4675 Form 2
ISO	NiCu30	9722	6207		6208	9723	6208	9724	9725

Table 1 – Designations and standards.

Chemical composition

	Ni	Fe	C	Mn	Si	Cu	Al	S
min.	63.0	1.0				28.0		
max.		2.5	0.16	2.00	0.50	34.0	0.50	0.02
Some compositional limits of other specifications may vary slightly								

Table 2 – Chemical composition (wt.-%) according to VdTÜV 263.

Physical properties

Density	8.8 g/cm³	0.32 lb/in.³
Melting range	1300 – 1350 °C	2370 – 2460 °F

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
-130	-200			22	130					11.5	6.4
-75	-100			24	140					12.1	6.7
20	**68**	430	0.102	26	150	51.3	310	182	26.4		
93	**200**		0.105		170		330		26.1		7.7
100	212	445		29.5		54		180		13.9	
200	392	465		33		55.5		177		15.5	
204	**400**		0.110		190		335		25.7		8.6
300	572	478		36.5		57.5		170		15.8	
316	**600**		0.114		215		345		24.5		8.8
400	752	490		40		58.5		165		16.0	
427	**800**				240		360		23.2		8.9
500	932			44		60		150		16.3	
538	**1000**				265		370		20.9		9.1
600	1112			48.5		61.8				16.6	
649	**1200**				290		380				9.3
700	1292			52		63.5				17.0	
760	**1400**				315		390				9.6
800	1472			56		65.5				17.4	
871	**1600**				340		400				9.8
900	1652			58		67.5				17.5	
982	**1800**										
1000	1832										

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

Nicorros® – alloy 400

Mechanical properties

The following properties are applicable to Nicorros in the stated conditions and specifications as well as the indicated size ranges. Specified properties of material outside these size ranges are subject to special enquiry.

Condition	Specification	Tensile strength R_m		Yield strength $R_{p0.2}$		Yield strength $R_{p1.0}$		Elongation A_5	Brinell hardness
		N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB
Soft annealed	DIN, VdTÜV-Wbl.	450	65	180	26	210	30	30	≤ 150
	ASTM, ASME, QQ-N, BS	480	70	195	28	220*		35	
Stress relieved	DIN	550	80	300	44			25	~170
	VdTÜV-Wbl.	580	84	400	58			18	
	ASTM, ASME, BS	550 – 600	80 – 87	275 – 415	40 – 60			20	
Hard	DIN	700	102	650	94			3	~210
	ASTM, ASME, QQ-N	690 – 760	100 – 110	620	90			2	
*BS only									

Table 4 – Minimum mechanical properties at room temperature.

	Yield strength, $R_{p0.2}$					Tensile strength, R_m				
Temperature, °C	100	200	300	400	425	100	200	300	400	425
N/mm²	150	135	130	130	130	420	390	380	370	360

Temperature, °F	200	400	600	800	200	400	600	800
ksi	21.9	19.6	18.9	18.9	61	56	55	52

Table 5 – Minimum mechanical properties of originally soft-annealed material at elevated temperatures according to VdTÜV-Wbl. 263.

ISO V-notch impact toughness

Average values at RT:

soft annealed > 150 J/cm²

stress relieved > 100 J/cm²

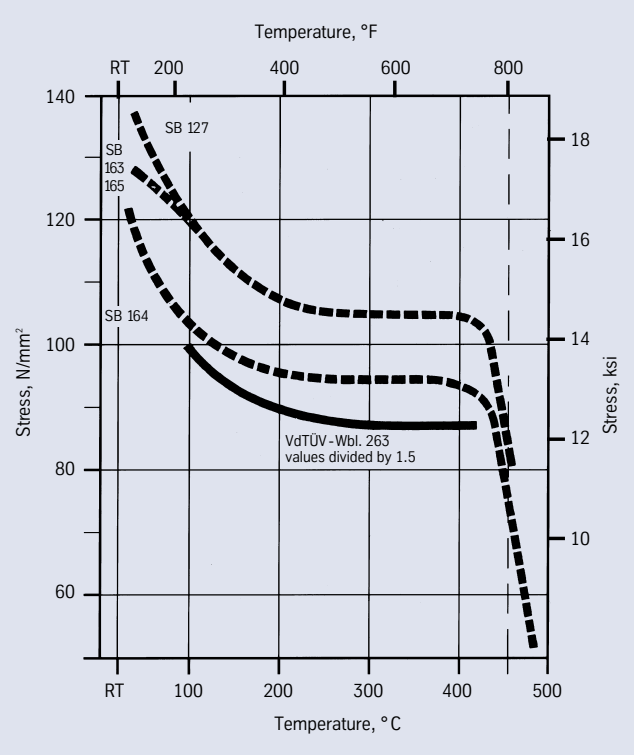

Fig. 1 – Comparison of maximum allowable stress values in tension for pressure vessels according to ASME SB 127, 163, 164, 165 (soft-annealed condition)
VdTÜV-Wbl. 263 values divided by safety factor 1.5.

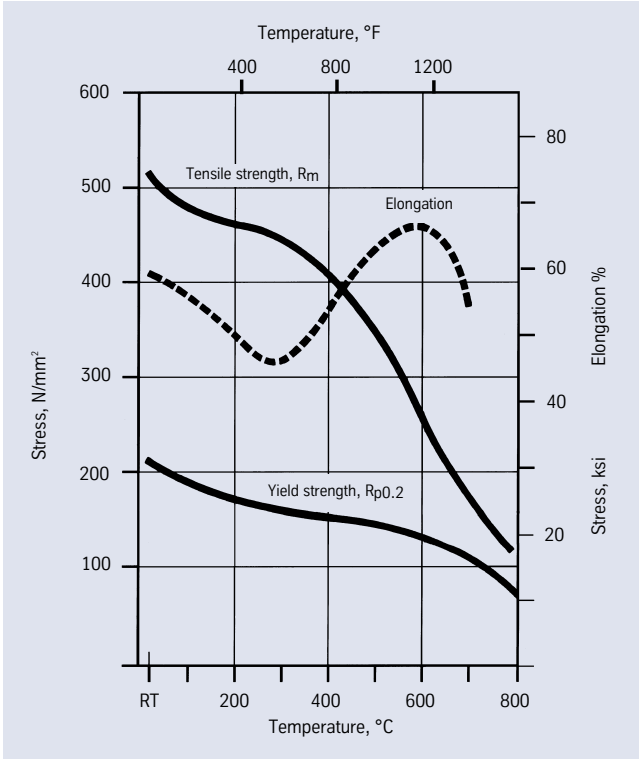

Fig. 2 – Typical short-time properties at elevated temperatures of hot rolled and annealed Nicorros.

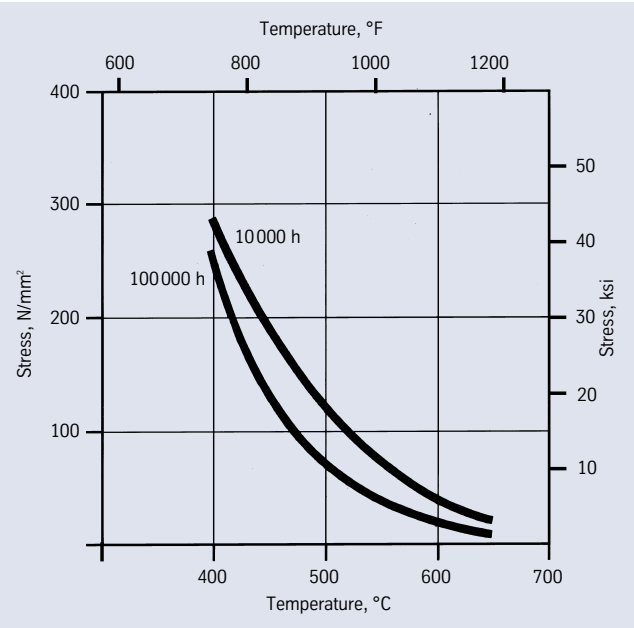

Fig. 3 – Typical long-time creep-rupture properties of cold formed and stress relieved Nicorros.

Metallurgical structure
Nicorros has a face-centered cubic structure.

Corrosion resistance
Nicorros has outstanding resistance to neutral and alkaline salt solutions. It has been a standard material for salt plants for many years.

This alloy is one of the few metallic materials which can be used in contact with fluorine, hydrofluoric acid, hydrogen fluoride or their derivatives.

Nicorros shows very high resistance to caustic alkalies. Behaviour in seawater is also excellent, with improved resistance to cavitation corrosion compared with copper-base alloys. It can be used in contact with dilute solutions of mineral acids such as sulphuric and hydrochloric acids, particularly if they are air-free. However, as the alloy contains no chromium, corrosion rates may increase significantly under oxidizing conditions.

Whilst Nicorros can be considered immune to chloride-ion stress cracking, it can stress crack in the presence of mercury or in moist aerated HF vapours. A stress-relieving heat treatment is applied in such cases.

Nicorros® – alloy 400

Applications
Typical applications include:

- feed-water and steam generator tubing in power plants
- brine heaters and evaporator bodies in seawater desalination plants
- sulphuric and hydrofluoric acid alkylation plants
- industrial heat exchangers
- cladding for crude oil distillation columns
- splash-zone sheathing in offshore structures
- propeller and pump shafts for seawater service
- plants for uranium refining and isotope separation in the production of nuclear fuel
- pumps and valves used in the manufacture of chlorinated hydrocarbons
- monoethanolamine (MEA) reboiler tubes
- valves and heat exchangers exposed to oxygen at higher temperatures, pressure and concentration of oxygen to avoid combustion and ignition through oxygen
- sour gas environment: Nicorros is listed in NACE Standard MR0175 ("Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment") as acceptable up to a maximum hardness value of 35 HRC

Fabrication and heat treatment
Nicorros 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.

Nicorros 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, 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.

Hot working
Nicorros may be hot worked in the range 1200 to 800 °C (2200 to 1470 °F), but only light hot working should be performed below about 925 °C (1700 °F). Hot bending is carried out between 1200 and 1000 °C (2200 to 1830 °F).

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 withdraw immediately and worked within the above temperature range. If the metal temperature falls below the minimum working temperature, it must be reheated.

Soft annealing after hot working is recommended in order to achieve optimum properties and to ensure maximum corrosion resistance.

Cold working
Cold working should be carried out on annealed material. Nicorros has a somewhat higher work-hardening rate than carbon steel and the forming equipment must be adapted accordingly.

Interstage annealing may be necessary with high degrees of cold forming. After cold working with more than 5 % deformation a stress relieve or soft annealing is required before use.

Cold reduction is sometimes used to improve the mechanical properties. Subsequent stress relieving is recommended for service under conditions where stress-corrosion cracking could occur, as in mercury or in moist aerated HF vapours.

Heat treatment
Soft annealing should be carried out in the temperature range 700 to 900 °C (1300 to 1650 °F), preferably at about 825 °C (1510 °F). Rapid air cooling is recommended for maximum corrosion resistance.

Temperature and time at temperature are important with regard to final grain size. They must therefore be carefully considered when determining the annealing parameters.

Under certain circumstances the enhanced strength produced by cold working may be used to advantage.

However, in such a case Nicorros should be stress relieved by heating between 550 and 650 °C (1020 to 1200 °F). This treatment applies mainly to tubes.

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

Descaling and pickling

Oxides of Nicorros 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 with proper control of pickling time and temperature, the surface oxide layer must be broken up by abrasive blasting or by carefully performed grinding or by pretreatment in a fused salt bath.

Machining

Nicorros should be machined in the soft-annealed condition. Cold formed, stress relieved material is more readily machinable. The alloy's high work-hardening rate should be considered; i.e. surface cutting speeds should be low compared with those used with carbon steel. 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 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-base 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 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. 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-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. 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, i. e. on the faces to be welded or on a run-out piece. Striking marks lead to corrosion.

Straightening

The need for straightening should be minimized by means of an optimum welding sequence. Flame straightening should be avoided, as it can cause precipitation in the base metal and hence a decrease in corrosion resistance.

Welding process

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

For welding, Nicorros should be in the soft-annealed or stress-relieved 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. 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.

Nicorros® – alloy 400

Filler metal
For the gas-shielded welding processes, the following filler metals are recommended:

Bare electrodes:	Nicorros S 6530 – FM 60 W.-Nr. 2.4377 SG-NiCu30MnTi AWS A5.14: ERNiCu-7 BS 2901 NA 35
	For applications under extreme corrosion conditions Nicrofer S 6020 – FM 625 W.-Nr. 2.4831 SG-NiCr21Mo9Nb, can be chosen
Covered electrodes:	W.-Nr. 2.4366 EL-NiCu30Mn AWS A5.15: ENiCu-7

For overlay welding by the electro-slag method (RES):

Weld strip:	Nicorros B 6530 – WS 60 W.-Nr. 2.4377 UP-NiCu30MnTi

Welding parameters and influences (heat input)
Care should be taken that the work is performed with a deliberately 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 150 °C (300 °F).

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

The heat input Q may be calculated as follows:

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

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 under **'Descaling and pickling'**.

Neither pre- nor postweld thermal treatments are normally required.

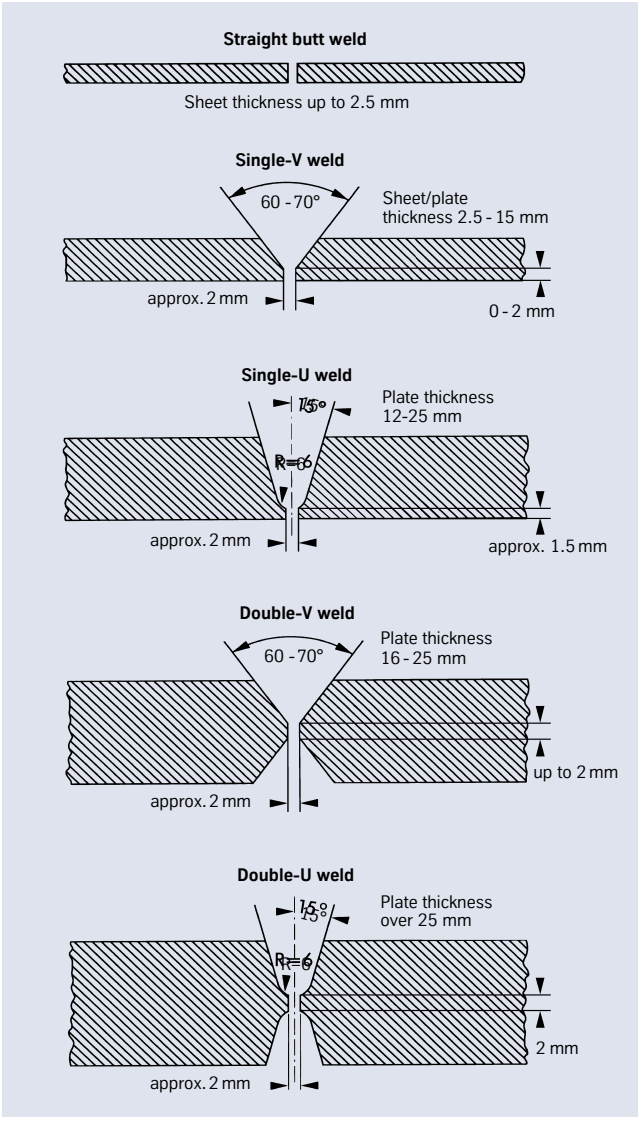

Fig. 4 – Edge preparation for welding of nickel alloys and special stainless steels.

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	aprrox. 22				
16.0	SMAW	4.0				90 – 130	approx. 22				

[1] Argon or argon + max. 3 % hydrogen
[2] For MAG welding 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 6 – 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. 8	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 7 – Heat input per unit length (guide values).

Nicorros® – alloy 400

Availability
Nicorros 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,
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	≤ 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

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 – 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 (3.5)[2)]	25 – 750		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 – 30		16	20	24
> 0.010 – ≤ 0.024	0.24 – 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: bright annealed – 3 mm (0.125 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:
0.01 – 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 SAS, Tour Neptune, F-92086 Paris, La Défense Cedex
(Fax: +33-1-4796 8141; Tel.: +33-1-4796 8140;
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.

December 2002 Edition.

This edition supersedes material data sheet no. 4010, dated December 1998.

Nicorros

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ThyssenKrupp VDM GmbH
Plettenberger Strasse 2
58791 Werdohl
P.O. Box 18 20
58778 Werdohl
Germany
Phone: +49 (23 92) 55-0
Fax: +49 (23 92) 55-22 17
E-Mail: info@tks-vdm.thyssenkrupp.com
www.thyssenkruppvdm.de