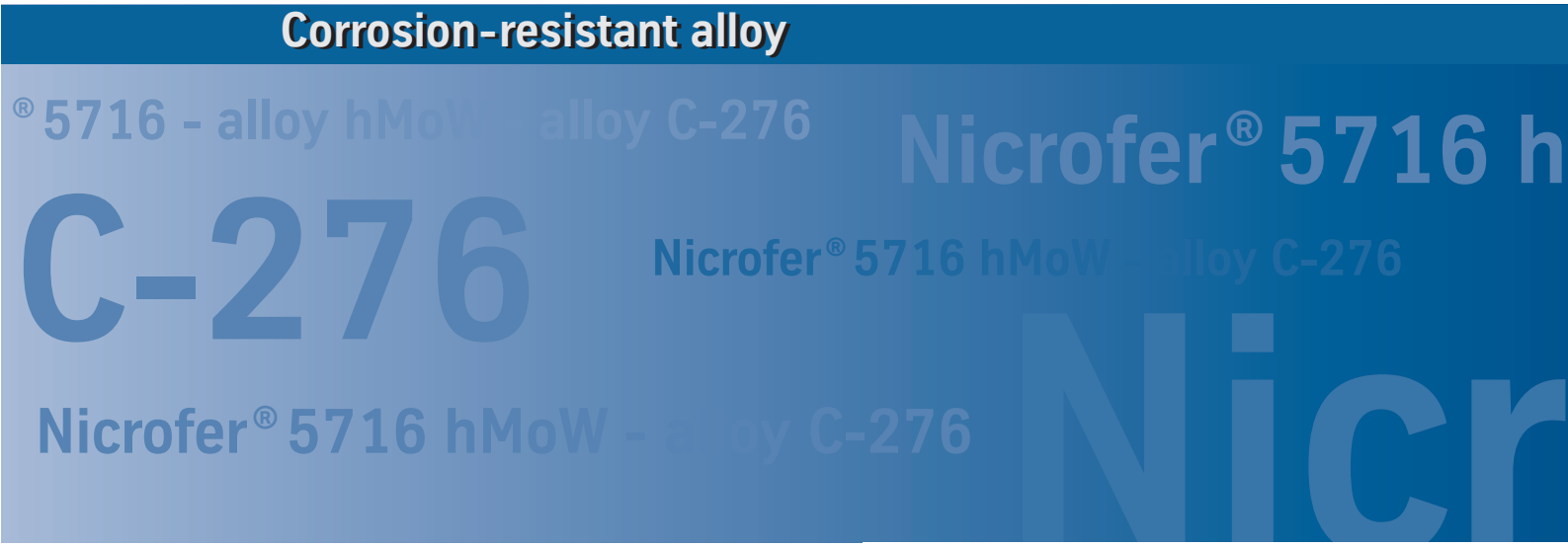
Nicrofer® 5716 hMoW - alloy C-276

Material Data Sheet No. 4015
May 2002 Edition

Corrosion-resistant alloy



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Nicrofer® 5716 hMoW - alloy C-276

Nicrofer 5716 hMoW is a nickel-chromium-molybdenum alloy containing tungsten and extremely low carbon and silicon contents.
Nicrofer 5716 hMoW is characterised by:

- excellent resistance to a wide range of corrosive media, under oxidizing and reducing conditions
- excellent resistance to pitting, crevice corrosion, and stress corrosion cracking.

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 EN	**W.-Nr. 2.4819** NiMo16Cr15W	17744 [1] 400	17751		17750 400	17752 400	17750		400
F AFNOR	NC17D								
UK BS EN									
USA ASTM ASME ASME Code Case	UNS N10276		B 622 SB 622 1924	B 619/626 SB 619/626 1924	B 575 SB 575 1924	B 574 SB 574* 1924	B 575 SB 575 1924		B 564 SB 564
ISO	NiMo16Cr15Fe6W4	9722	6207		6208	9723	6208	9724	9725
*rod only		[1]draft dated May 1998							

Table 1 – Designation and standards

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Mo	W	Co	V	P	S
min.	bal.	14.5	4.0				15.0	3.0				
max.		16.5	7.0	0.010	1.0	0.08	17.0	4.5	2.5	0.35	0.025	0.010
Some compositional limits of other specifications may vary slightly.												

Table 2 – Chemical composition (wt.-%), according to DIN

Physical properties

Density	8.9 g/cm³	0.322 lb/in.³
Melting range	1325–1370 °C	2410–2500 °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 / mK	Btu in. / ft² h °F	μ Ω cm	Ω circ mil / ft	kN / mm²	10³ ksi	10⁻⁶ / K	10⁻⁶ / °F
0	32			10.2	71			209	30.3		
20	68	407	0.097	10.6	73	125	752	208	30.2		
93	**200**		0.102		82		764		29.7		6.5
100	212	430		12.0		127		204		11.7	
200	392	454		13.7		128.5		200		12.1	
204	**400**		0.108		95		773		29.0		6.7
300	572	474		15.4		129		195		12.8	
316	**600**		0.113		108		776		28.0		7.1
400	752	492		17.1		129.5		188		13.1	
427	**800**		0.118		122		779		27.0		7.3
500	932	503		18.7		129		182		13.5	
538	**1000**		0.121		134		776		26.0		7.6
600	1112	517		20.7		128.5		175		14.0	
649	**1200**		0.124		151		770		24.8		7.9
700	1292	527		22.6		128		168		14.7	
760	**1400**		0.127		164		764		23.5		8.4
800	1472	536		24.3		126.5		160		15.5	
871	**1600**		0.129		177		758		22.2		8.8
900	1652	545		26.2		126		151		16.0	
982	**1800**		0.131		191		755		21.0		9.1
1000	1832	551		28.0		125.5		143		16.5	

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

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Mechanical properties

The following minimum values at room and elevated temperatures apply to longitudinal and, where applicable, transverse specimens in the solution-treated condition and indicated size ranges.
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 A5*	Brinell hardness
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB
Sheet & plate		≤ 5	≤ 0.20	310	45	330	48	730	106	30
	> 5 – 25	> 0.20 – 1.00	280	41	300	44	700	102	25	≤ 240
Rod	≤ 100	≤ 4							35 (long.)	
Strip*	0.1 – 3	0.004 – 0.12	310	45	330	48	730	106	40	

* Elongation values for strip products are normally determined based on an initial gauge length of 50 mm (2 in.).
These values are lower, dependent on the alloy, than the corresponding A_5 values by an order of approx. 10 %.

Table 4 – Minimum mechanical properties at room temperature.

Product	Dimensions		Yield strength, $R_{p0.2}$ N/mm²					Yield strength, $R_{p1.0}$ N/mm²				
	mm	inches										
Temperature, °C			100	200	300	400	450	100	200	300	400	450
Sheet & plate	≤ 5	≤ 0.20	280	240	220	195	150	305	275	245	230	160
	> 5 – 25	> 0.20 – 1.00	280	240	220	195	150	305	275	245	230	160
Rod	≤ 100	≤ 4	255	225	200	170	150	275	245	215	200	160
Strip	0.1 – 3	0.004 – 0.12	280	240	220	195	150	305	275	245	230	160

			ksi					ksi				
Temperature, °C			200	400	600	800	850	200	400	600	800	850
Sheet & plate	≤ 5	≤ 0.20	41	35	31	27	22	44	39	35	33	23
	> 5 – 25	> 0.20 – 1.00	41	35	31	27	22	44	39	35	33	23
Rod	≤ 100	≤ 4	37	33	28	24	22	40	36	31	29	23
Strip	0.1 – 3	0.004 – 0.12	41	35	31	27	22	44	39	35	33	23

Table 5 – Minimum mechanical properties at elevated temperatures.

ISO V-notch impact toughness

Average values at RT: longitudinal ≥ 120 J/cm²
transverse ≥ 90 J/cm²

Metallurgical structure
Nicrofer 5716 hMoW has a face-centered-cubic structure.

Corrosion resistance
Nicrofer 5716 hMoW can be used in many chemical processes with oxidizing and with reducing media.

Its corrosion resistance in lightly aerated, technical grade sulphuric acid is shown in Fig. 2. Except for areas where a corrosion rate of > 0.5 mm/a is indicated the use of Nicrofer 5716 hMoW is considered suitable.

The high molybdenum and chromium contents render the alloy resistant to chloride ion attack. The tungsten content further increases this resistance.

Nicrofer 5716 hMoW is one of the few materials that is resistant to moist chlorine gas, hypochlorite and chlorine dioxide solutions.

The alloy exhibits excellent resistance to concentrated solutions of oxidizing salts (such as iron (III) chloride and copper chloride).

Applications
Nicrofer 5716 hMoW finds wide application in the chemical and petrochemical industry, for components in organic processes containing chlorides, and for catalytic systems.

This material is especially suitable for use in situations where hot, contaminated mineral acids, solutions and organic acids (such as formic and acetic acid) as well as sea water are encountered.

It is also widely used in pollution control equipment in energy production and thermal waste treatment plants.

Thypical applications are:

- Pulp and paper industry, e.g. for digestion and bleaching vessels
- Scrubbers and special reheaters as well as wet-operating fans for combustion and flue gas desulphurisation systems
- Equipment and components for sour-gas service
- Reactors for acetic acid production
- Sulphuric acid coolers
- Methylene diphenyl isocyanate (MDI)
- Manufacture and processing of technically impure phosphoric acid
- Combustion-resistant alloy for high pressure oxygen applications

Alloy	CPT	CCT
Nicrofer 5716 hMoW – alloy C-276	115 – 120 °C (240 – 250 °F)	105 °C (220 °F)
Nicrofer 5923 hMo – alloy 59	> 120 °C (250 °F)	> 110 °C (230 °F)
Nicrofer 6020 hMo – alloy 625	100 °C (212 °F)	85 – 95 °C (185 – 205 °F)

Table 6 – Critical pitting temperature (CPT) and crevice corrosion temperature (CCT) in "Green Death" test solution. (7vol.% H_2SO_4 + 3vol.% HCl + 1% $CuCl_2$ + 1% $FeCl_3$ x 6 H_2O after repeatedly immersing and heating for 24 hours using 5 °C (9 °F) temperature increments).

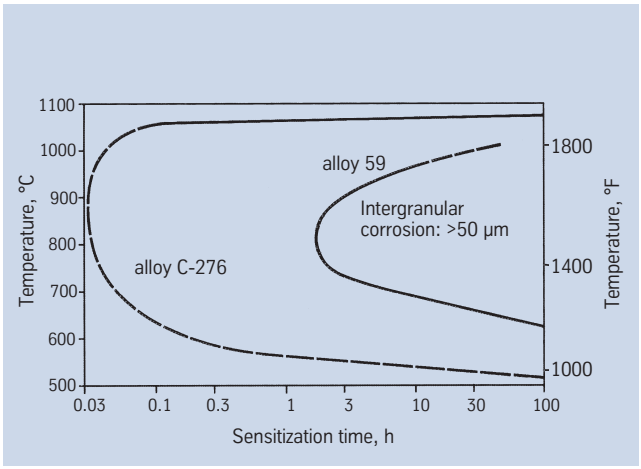

Fig. 1 – Time-temperature-sensitization (TTS) diagram for Nicrofer 5716 hMoW and Nicrofer 5923 hMo according to the Streicher test (ASTM G-28, Method A).

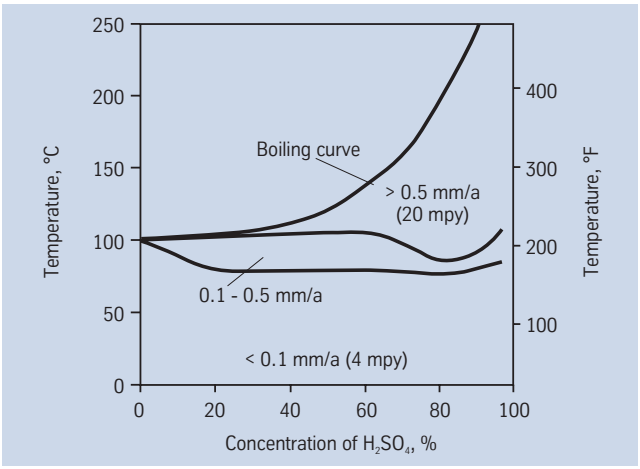

Fig. 2 – Isocorrosion diagram of Nicrofer 5716 hMoW-alloy C-276 in lightly aerated, technical grade sulphuric acid based on immersion test results over at least 120 h.

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Fabrication and heat treatment
Nicrofer 5716 hMoW 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.

Nicrofer 5716 hMoW 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.

Hot working
Nicrofer 5716 hMoW may be hot worked in the temperature range 1180 to 950 °C (2160 to 1740 °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 annealed condition. Nicrofer 5716 hMoW 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 before use.

Heat treatment
Solution heat treatment should be carried out in the temperature range 1100 to 1160 °C (2010 to 2120 °F), preferably at about 1120 °C (2050 °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 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 Nicrofer 5716 hMoW 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/hydroflouric 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
Nicrofer 5716 hMoW 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 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; 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. 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, e. g. on the faces to be welded or on a run-out piece. Striking marks lead to corrosion.

Welding process
Nicrofer 5716 hMoW 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 the MAG processes the use of a multi-component shielding gas (Ar+He+H_2+CO_2) is recommended.

For welding, Nicrofer 5716 hMoW 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 5923 – FM 59 W.-Nr. 2.4607 SG-NiCr23Mo16 AWS A5.14: ERNiCrMo-13
Covered electrodes:	W.-Nr. 2.4609 EL-NiCr22Mo16 AWS A5.11: ENiCrMo-13

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

Weld strip:	Nicrofer B 5923 – WS 59 W.-Nr. 2.4607 UP-NiCr23Mo16 AWS A5.14: ERNiCrMo-13

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 8 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.

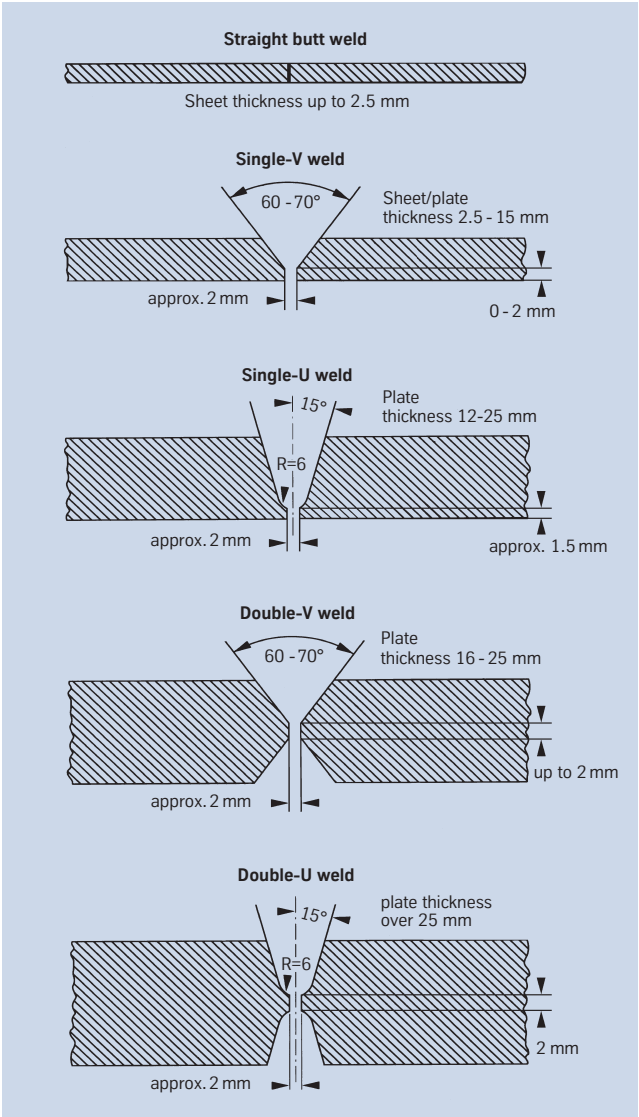

Fig. 3 – Edge preparation for welding of nickel-base alloys.

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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	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 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. 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 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 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.

Availability
Nicrofer 5716 hMoW 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,
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 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.

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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 or oxidized

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 Défense 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 Nicrofer 5716 hMoW-alloy C-276 may be obtained from ThyssenKrupp VDM GmbH:

M. Rockel, W. Herda
The use of Nicrofer 5716 hMoW-alloy C-276;
Stainless Steel World, May 1996

U. Heubner, et al.
Nickel alloys and high-alloy special stainless steels;
expert verlag, 1998

U. Heubner, M. Köhler:
Das Zeit - Temperatur - Ausscheidungs- und das Zeit - Temperatur - Sensibilisierungs - Verhalten von hochkorrosionsbeständigen Nickel - Chrom - Molybdän - Legierungen;
Werkstoffe und Korrosion 43 (1992), pp. 181-190

VDM Report No. 22:
Behaviour of some metallic materials in sulphuric acid;
August 1994

May 2002 Edition.

This edition supersedes material data sheet no. 4015, dated July 2000.

Nicrofer

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