Nicrofer® 5621 hMoW - alloy 22

Material Data Sheet No. 4021
March 2004 Edition

Corrosion-resistant alloy

A company of
ThyssenKrupp
Stainless

ThyssenKrupp VDM

ThyssenKrupp

Nicrofer® 5621 hMoW - alloy 22

Nicrofer 5621 hMoW is a nickel-chromium-molybdenum alloy containing tungsten and extremely low carbon and silicon contents.

Nicrofer 5621 hMoW is characterized by:

- outstanding 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 seamless	Tube and pipe welded	Sheet and plate	Rod and bar	Strip	Wire	Forgings	Pipe Fittings
D DIN VdTÜV	**W.-Nr. 2.4602** NiCr21Mo14W	17744 [479]1)	17751	17751	17750 [479]1)	17752 [479]1)	17750 [479]1)	17753 [479]1)	[479]1)	
F AFNOR										
UK BS EN										
USA ASTM ASME ASME Code Case	UNS N06022		B 622 SB-622 2226, N-621	B 619/626 SB-619/626 2226, N-621	B 575 SB-575 2226, N-621	B 574* SB-574* 2226, N-621	B 575 SB-575 2226, N-621		B 564 SB-564 2226, N-621	B 366 SB-366 2226, N-621
ISO	NiCr21Mo14W3									
*rod only	1)not necessarily applicable to product forms from ThyssenKrupp VDM manufacture									

Table 1 – Designation and standards

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Mo	W	Co	V	P	S
min.	bal.	20.0	2.0				12.5	2.5				
max.		22.5	6.0	0.010	0.50	0.08	14.5	3.5	2.5	0.35	0.025	0.015
Some compositional limits of other specifications may vary slightly.												

Table 2 – Chemical composition (wt.-%), according to DIN 17744

Physical properties

Density	8.7 g/cm³	0.314 lb/in.³
Melting range	1355–1400 ° C	2470–2550° F

Temperature (T)		Specific heat		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	$\frac{J}{kg\,K}$	$\frac{Btu}{lb\,°F}$	$\frac{W}{mK}$	$\frac{Btu\,in.}{ft^2\,h\,°F}$	$\mu\,\Omega\,cm$	$\frac{\Omega\,circ\,mil}{ft}$	$\frac{kN}{mm^2}$	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
0	32	402	0.096					207	30.0		
20	68	406	0.097	9.4	65	114	686	206	29.9		
93	**200**		0.101	11.0	76		734	203	29.4		6.9
100	212	423		11.1	77	123		202	29.3	12.4	
200	392	444		13.4	93	124		197	28.6	12.4	
204	**400**		0.106	13.6	94		746	196	28.4		6.9
300	572	460		15.5	107	125		190	27.6	12.5	
316	**600**		0.110	16.0	111		753	190	27.6		7.0
400	752	476		17.5	121	126		185	26.2	13.1	
427	**800**		0.114	18.9	131		759	183	26.2		7.4
500	932	495		19.5	135	127		178	25.8	13.7	
538	**1000**		0.117	20.2	140		767	177	25.7		7.7
600	1112	514		21.3	148	128		173	25.1	14.3	
649	**1200**		0.125	22.5	156		774	171	24.8		8.1
700	1292	533		23.2	160	129		167	24.2	14.9	
760	**1400**							163	23.6		8.5
800	1472							159	23.1	15.5	
871	**1600**							154	22.3		8.8
900	1652							150	21.8	15.8	
982	**1800**							145	21.0		9.0
1000	1832							143	20.7	16.2	

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

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 A_{50}	Brinell hardness
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB
Sheet & plate	≤ 50	≤ 2.0	310	45	335	49	690	100	45	240 max. (For information only)
Strip	≤ 3.0	≤ 0.120								
Rod	≤ 90	≤ 3.5								

Table 4 – Minimum mechanical properties at room temperature.

Thickness		ASTM	Average Grain Diameter	
mm	inches	Grain Size	µm	inches
≤ 3.2	≤ 0.125	3.0 or finer	127	.0050
> 3.2	> 0.125	1.5 or finer	214	.0084

Table 5 – Grain size for solution annealed sheet and strip.

Temperature		Yield strength, $R_{p0.2}$		Yield strength, $R_{p1.0}$	
°C	°F	N/mm²	ksi	N/mm²	ksi
100	212	270	39	290	42
200	392	225	33	245	36
300	572	195	28	215	31
400	752	175	25	195	28

Table 6 – Minimum mechanical properties at elevated temperatures for sheet & plate (thickness: ≤ 50 mm), strip (thickness: ≤ 3.0 mm) and rod (diameter: ≤ 90 mm) according to VdTÜV data sheet 479.

ISO V-notch impact toughness

Average values at RT:
longitudinal/transverse ≥ 150 J/cm²
Average values at -196 °C (-320 °F):
longitudinal/transverse ≥ 120 J/cm²

One of the reasons primarily why nickel-base alloys are selected is for their performance under corrosive conditions. Though sometimes underestimated, characteristic design data frequently also plays an important role in selecting a particular alloy. As Fig. 1 shows, $R_{p0.2}$ yield strength data for Nicrofer 5621 hMoW is higher than that of Nicrofer 5716 hMoW. This allows for a reduction in wall thickness which may result in a more cost-effective design.

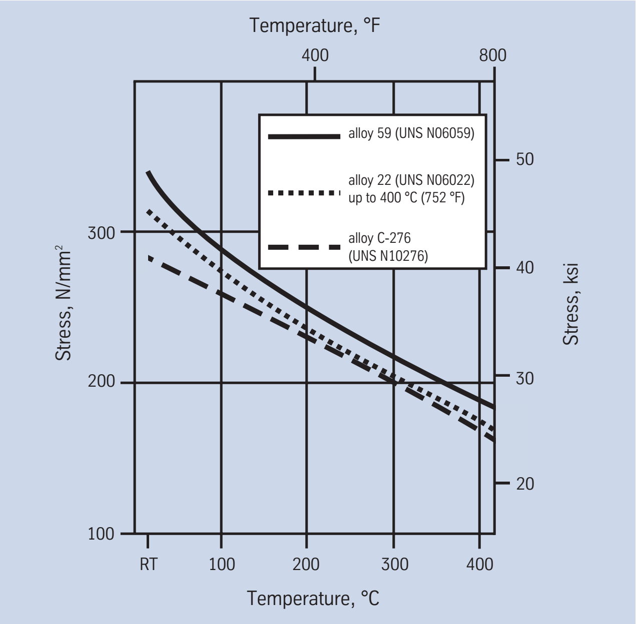

Fig. 1 – $R_{p0.2}$ yield strength for Nicrofer 5621 hMoW in comparison with other similar alloys.

Metallurgical structure
Nicrofer 5621 hMoW has a face-centered cubic structure.

Corrosion resistance
The chemical composition of Nicrofer 5621 hMoW has been designed to give it outstanding corrosion resistance in as wide a range of media as possible, both oxidizing and reducing. The high chromiurn content of the alloy makes it particularly suitable for oxidizing conditions, including wet chlorine gas, hypochlorite solutions or oxidizing acids. It is remarkably resistant to localized attack by halide ions, even under severe conditions of low pH and high temperatures. It resists attack in media contaminated by oxidizing chlorides such as ferric chloride or cupric chloride.

Nicrofer 5621 hMoW is also resistant to many reducing media. As a result it can be used for equipment in polyvalent chemical plant where widely varying conditions may be encountered. The very low carbon content of Nicrofer 5621 hMoW, together with its balanced composition, reduce the tendency to formation of grain-boundary precipitates in the heat-affected zone during welding, thus making it suitable in the as-welded condition for many applications in the chemical process industry.

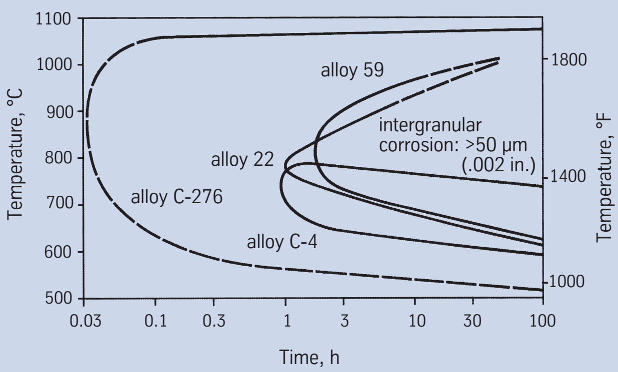

Fig. 2 – Time-temperature-sensitization (TTS) diagrams of nickel-chromium-molybdenum alloys tested according to ASTM G-28 A.

Alloy	Normal range of corrosion rates in mm/a according to ASTM G-28 A	ASTM G-28 B
Nicrofer 5923 hMo – alloy 59	0.6 - 1.0	0.08 - 0.15
Nicrofer 5621 hMoW – alloy 22	0.8 - 1.2	0.10 - 0.15
Nicrofer 5716 hMoW – alloy C-276	4.0 - 9.2	0.80 - 1.20

Table 7 – Comparison of typical corrosion rates in ASTM G-28 A and B standardized corrosion tests.

Alloy	CPT	CCT
Nicrofer 5923 hMo – alloy 59	> 120 °C / > 248 °F*	110 °C / 230 °F
Nicrofer 5621 hMoW – alloy 22	120 °C / 248 °F	105 °C / 221 °F
Nicrofer 5716 hMoW – alloy C-276	110 °C / 230 °F	105 °C / 221 °F
*Above 120 °C the “Green Death” solution chemically breaks down.		

Table 8 – Critical pitting temperature (CPT) and crevice corrosion temperature (CCT) in ‘Green Death’ test solution. (11.4% H_2SO_4 + 1.2% HCl + 1% $CuCl_2$ + 1% $FeCl_3$ x 6 H_2O after repeatedly heating for 24 hours using 5 °C (9 °F) temperature increments).

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Applications
The versatile nature of Nicrofer 5621 hMoW combined with its excellent mechanical properties mean that it can be used in a wide variety of applications, including:

- organic syntheses
- flue gas desulphurization
- electrolytic galvanizing
- plate heat exchangers
- fine chemicals production
- incineration plants
- pharmaceutical intermediates
- combustion-resistant alloy for high pressure oxygen applications

Fabrication and heat treatment
Nicrofer 5621 hMoW can readily be hot and cold worked and machined.

Heating
It is very important that the workpiece be clean and free from any contaminant before and during heating.

Nicrofer 5621 hMoW may become embrittled if heated in the presence of contaminants such as sulphur, phosphorus, lead and other low-melting-point metals. Sources of contamination include marking and temperature-indicating paints and crayons, lubricating grease and fluids, and fuels. Fuels must be low in sulphur; e. g. natural and liquefied petroleum gases should contain less than 0.1 % by mass and town gas 0.25 g/m^3 maximum of sulphur. Fuel oils containing no more than 0.5 % by mass of sulphor are satisfactory.

The furnace atmosphere should be neutral to slightly reducing and must not fluctuate between oxidising and reducing. Flame impingement on the metal must be avoided.

Hot working
Nicrofer 5621 hMoW may be hot-worked in the range 1100 to 900 °C (2010 to 1650 °F). Cooling should be by water quenching or fast air cooling.

Annealing is recommended after hot working to ensure maximum corrosion resistance.

For hot working, the material may be charged into the furnace at maximum working temperature.

Cold working
For cold working the material should be in the annealed condition. Nicrofer 5621 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 1400 °C (2010 to 2085 °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 5621 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 5621 hMoW should be machined in the solution-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 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 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; abraisive 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 – 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 5621 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 5621 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 UNS N06059 AWS A5.14: ERNiCrMo-13 SG-NiCr23Mo16 (W.-Nr. 2.4607)
Covered electrodes:	UNS W86059 AWS A5.11: ENiCrMo-13 EL-NiCr22Mo16 (W.-Nr. 2.4609)

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

Weld strip:	Nicrofer B 5923 – WS 59 UNS N06059 AWS A5.14: ERNiCrMo-13 UP-NiCr23Mo16 (W.-Nr. 2.4607)

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 10 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:

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

U = arc voltage, volts
I = welding current, amps
v = welding speed, cm/min.

Consultation with ThyssenKrupp VDM's Welding Laboratory is recommended.

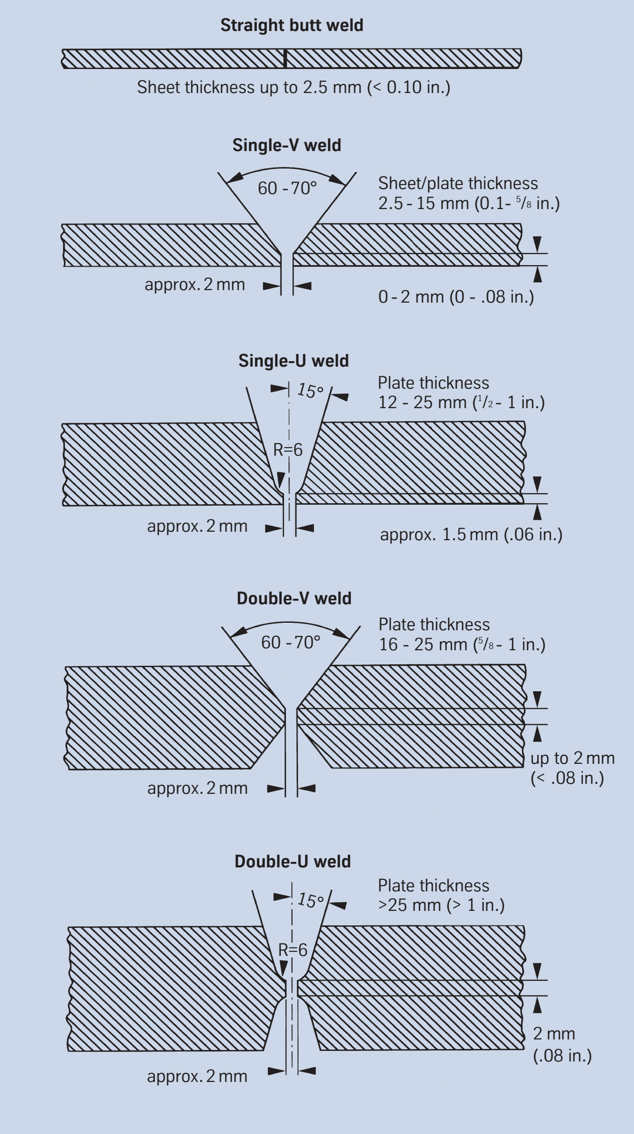

Fig. 3 – Edge preparation for welding of nickel alloys and special stainless steels.

Sheet/plate thickness mm	Welding process	Filler metal Diameter mm	Filler metal Speed m/min.	Welding parameters Root pass A	Root pass V	Intermediate and final passes A	Intermediate and final passes 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 9 – 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 mechanized	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 10 – 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 5621 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 – 60	12 – 50
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	$^{5}/_{16}$ – 2 $^{3}/_{8}$	$^{1}/_{2}$ – 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 mm	Coil I. D. mm			
0.04 – ≤ 0.10	4 – 200[3]	300	400		
> 0.10 – ≤ 0.20	4 – 350[3]	300	400	500	
> 0.20 – ≤ 0.25	4 – 700[4]		400	500	600
> 0.25 – ≤ 0.60	6 – 700[4]		400	500	600
> 0.60 – ≤ 1.0	8 – 700[4]		400	500	600
> 1.0 – ≤ 2.0	15 – 700[4]		400	500	600
> 2.0 – ≤ 3.0 (3.5)[2]	25 – 700[4]		400	500	600

inches	inches	inches			
0.0008 – ≤ 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 – 28[4]		16	20	24
> 0.010 – ≤ 0.024	0.24 – 28[4]		16	20	24
> 0.024 – ≤ 0.040	0.32 – 28[4]		16	20	24
> 0.040 – ≤ 0.080	0.60 – 28[4]		16	20	24
> 0.080 – ≤ 0.120[2] ≤ 0.140[2]	1.0 – 28[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 mm (0.120 in.), cold rolled only – 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:
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.

Technical publications
The following publications also referring to Nicrofer 5621 hMoW-alloy 22 may be obtained from ThyssenKrupp VDM GmbH:

U. Heubner, et al.:
Nickel alloys and high-alloy special stainless steels;
expert verlag, 3rd rev. edition 2003

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

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Nicrofer

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