

# Nicrofer® 6023/6023 H – alloys 601/601 H

Material Data Sheet No. 4003  
February 1995 Edition

## High-temperature alloys

Nicrofer® 6023/6023 H – alloys 601/601 H Nicrofer® 6023/6

Nicrofer® 6023/6023 H – alloys 601/601 H

Nicrofer® 6023/6023 H – all

Nicrofer® 6023/6023 H – alloys

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Stainless

**ThyssenKrupp VDM**

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ThyssenKrupp

Nicrofer 6023 and 6023 H are nickel-chromium-iron alloys with additions of aluminium and titanium.

They are characterised by:

- outstanding resistance to oxidation at high-temperatures
- good resistance to carburising conditions
- good resistance in oxidising sulphur-bearing atmospheres
- good mechanical properties at both room and elevated temperatures
- good resistance to stress-corrosion cracking

Nicrofer 6023 H is specifically recommended for service above 500 °C (930 °F) because of higher creep-rupture properties, resulting from controlled carbon content and coarse grain size.

### Designations and standards

Country	Material designation	Specification							
		Chemical composition	Tube and pipe		Sheet and plate	Rod and bar	Strip	Wire	Forgings
seamless	welded								
D DIN	W.-Nr. 2.4851 NiCr23Fe	17742	17751		17750	17752	17750		
F AFNOR	NC23FeA								
UK BS									
USA ASTM ASME Code Case AMS	UNS N06601		1500	1500	1500 5870	1500 5715	1500 5870		1500 5717
ISO	NiCr23Fe15Al	9722	6207		6208	9723	6208	9724	9725

Table 1 – Designations and standards.

### Chemical composition

Alloy		Ni	Cr	Fe	C	Mn	Si	Cu	Al	Ti	Zr	Al	Fe
Nicrofer 6023	min	58.0	22.0	bal	0.03				1.1	0.1			
	max	63.0	24.0		0.08	0.8	0.5	0.5	1.6	0.4		0.020	0.010
Nicrofer 6023 H	min	58.0	22.0	bal					1.1	0.3			
	max	63.0	24.0		0.10	0.6	0.5	0.5	1.6	0.6	0.03	0.020	0.010

Table 2 – Chemical composition (wt.-%).

### Physical properties

Density	8.1 g/cm <sup>3</sup>	0.293 lb/in. <sup>3</sup>
Melting range	1320 – 1370 °C	2410 – 2500 °F
Permeability at 20 °C/68 °F (RT)	≤ 1.01	

Temperature (T)		Specific heat		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	$\frac{\text{J}}{\text{kg K}}$	$\frac{\text{Btu}}{\text{lb } ^\circ\text{F}}$	$\frac{\text{W}}{\text{m K}}$	$\frac{\text{Btu in.}}{\text{ft}^2 \text{ h } ^\circ\text{F}}$	$\mu \Omega \text{ cm}$	$\frac{\Omega \text{ circ mil}}{\text{ft}}$	$\frac{\text{kN}}{\text{mm}^2}$	10 <sup>3</sup> ksi	$\frac{10^{-6}}{\text{K}}$	$\frac{10^{-6}}{^\circ\text{F}}$
0	32										
20	68	450	0.107	11.3	78	119	716	207	30.0		
93	200		0.112		87		722		29.3		7.6
100	212	470		12.7		120		201		13.8	
200	392	500		14.4		122		196		14.4	
204	400		0.119		100		737		28.4		8.0
300	572	525		16.0		124		191		14.6	
316	600		0.126		112		749		27.6		8.1
400	752	550		17.6		125		186		14.8	
427	800		0.133		126		752		26.7		8.3
500	932	580		19.2		125		180		15.3	
538	1000		0.141		139		755		25.4		8.5
600	1112	600		20.6		126		171		15.7	
649	1200		0.148		148		758		24.1		8.9
700	1292	630		22.2		126		161		16.3	
760	1400		0.155		165		761		22.5		9.1
800	1472	660		24.5		127		150		16.7	
871	1600		0.162		178		767		20.6		9.5
900	1652	690		26.1		128		138		17.2	
982	1800		0.169		190		775		18.4		9.8
1000	1832	710		27.7		129		124		17.7	
1093	2000		0.176		203		782		16.1		10.1
1100	2012	740		29.3		130		110		18.3	

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

# Nicrofer<sup>®</sup> 6023/6023 H – alloys 601/601 H

## Mechanical properties

The following properties are applicable to Nicrofer 6023 and 6023 H in the indicated forms and size ranges, and in the annealed and solution-treated conditions respectively. Specified properties of material outside these size ranges are subject to special enquiry.

Sheet and plate	up to 20 mm	0.75 in
Strip	up to 2.5 mm	0.10 in
Rod, bar, forgings	up to 100 mm	4 in
Tube wall thickness 0.5	up to 5 mm	0.02 to 0.2 in
Wire	up to 12.7 mm	0.5 in

Alloy and condition	Tensile strength		0.2% Yield strength		1.0% Yield strength		Elongation A5 %	Brinell hardness HB
	N/mm <sup>2</sup>	ksi	N/mm <sup>2</sup>	ksi	N/mm <sup>2</sup>	ksi		
Nicrofer 6023 annealed	650	94	300	44	330	48	30	–
Nicrofer 6023 H solution treated	600	87	240	35	270	39	30	≤ 220

Table 4 – Minimum mechanical properties at room temperature.

Bending requirements for sheet in the solution-treated condition, without cracking.

- Angle of 180° around a mandrel diameter of:
- 1 x sheet thickness up to 1.25 mm (0.05 in)
- 2 x sheet thickness > 1.25 to 6.35 mm (0.05 to 0.25 in)

Mechanical properties of solution-treated sheet and plate at elevated temperatures are represented graphically in figure 1 as well as table 5.

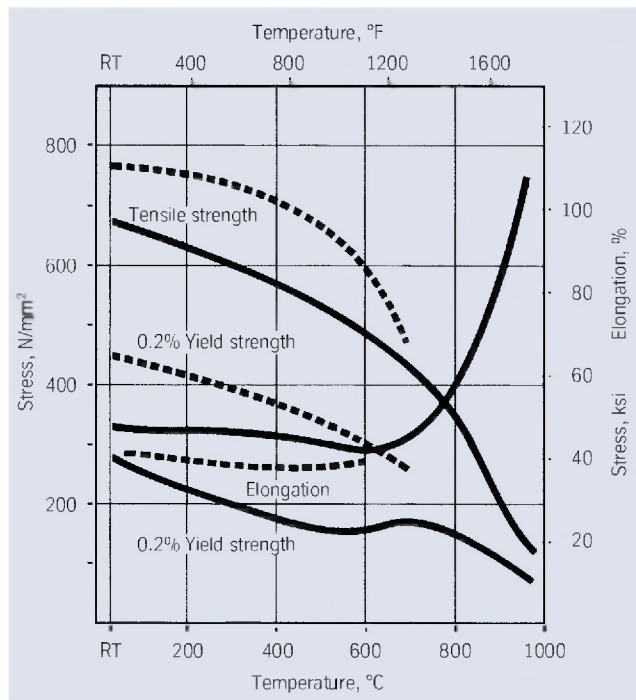


Fig. 1 – Typical short-time properties of annealed Nicrofer 6023 (---) and solution-treated Nicrofer 6023 H (—).

Temperature °C	Creep strength R <sub>p1.0</sub> N/mm <sup>2</sup>		Creep-rupture strength R <sub>m</sub> N/mm <sup>2</sup>	
	10 <sup>4</sup> hrs	10 <sup>5</sup> hrs	10 <sup>4</sup> hrs	10 <sup>5</sup> hrs
600	151	116	205	156
700	69	39	101	55
800	22	11.8	31	16.7
900	6.9	2.2	10.1	3.7

°F	ksi		ksi	
	10 <sup>4</sup> hrs	10 <sup>5</sup> hrs	10 <sup>4</sup> hrs	10 <sup>5</sup> hrs
1000	28.3	23.9		31.2
1200	15.4	9.9	21.8	14.5
1400	5.1	2.9	7.3	3.9
1600	1.45	0.44	1.9	0.87

Table 5 – Typical creep-rupture properties of Nicrofer 6023 H, solution treated.

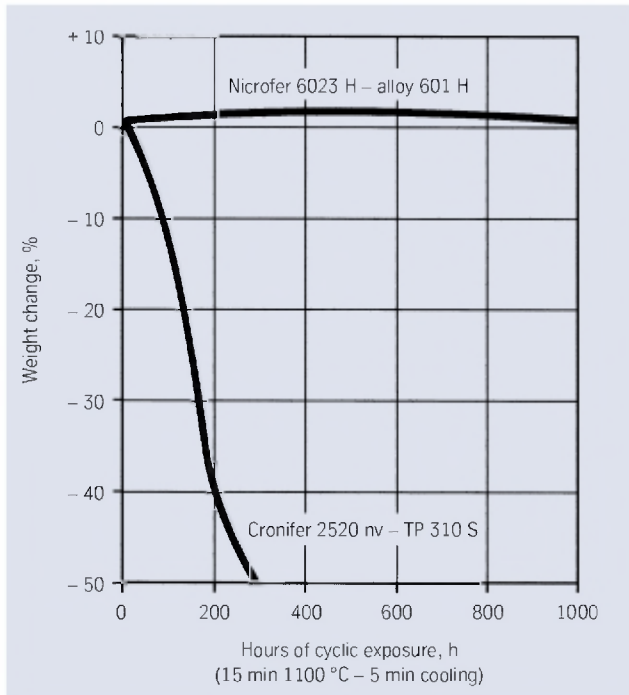


Fig. 2 – Scaling resistance of Nicrofer 6023 H compared to Cronifer 2520 nv.

### Metallurgical structure

Nicrofer 6023 and 6023 H have a face-centred cubic structure.

### Corrosion resistance

An important property of Nicrofer 6023 and 6023 H is resistance to oxidation at temperatures up to 1180 °C (2160 °F). Even under severe conditions, such as under cycling heating and cooling, Nicrofer 6023 and 6023 H retain a tightly adherent oxide layer which is very resistant to spalling.

Resistance to carburisation is good. Nicrofer 6023 and 6023 H have also shown good resistance in carbonitriding conditions.

Due to their high chromium and aluminium contents, Nicrofer 6023 and 6023 H show good resistance to oxidising sulphur-bearing atmospheres at elevated temperatures.

### Applications

Nicrofer 6023 and 6023 H have found a wide variety of applications in industries as diverse as thermal and chemical processing, pollution control and power generation.

Typical applications are:

- trays, baskets and fixtures for heat treatment plant
- refractory anchors, strand-annealing and radiant tubes, high-velocity gas burners, wire mesh belts in industrial furnaces.
- insulating cans in ammonia reformers and catalyst support grids in nitric acid production
- components in exhaust gas systems
- combustion chambers in solid waste incinerators
- tube supports and ash-handling components
- components of waste-gas detoxification systems
- oxygen preheaters

### Fabrication and heat treatment

Nicrofer 6023 and 6023 H are readily fabricated by usual industrial processes. Hot and cold working, however, require high-power machines, due to the high strength of the material.

The weldability of Nicrofer 6023 and 6023 H is good. Joining can be performed by conventional welding processes.

### Heating

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

Nicrofer 6023 and 6023 H 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<sup>3</sup> maximum, of sulphur. Fuel oils containing no more than 0.5% by mass of sulphur are satisfactory.

Electric furnaces are desirable due to their close control of temperature and freedom from contamination. Gas-fired furnaces are acceptable if impurities are at low levels.

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

**Hot working**

Nicrofer 6023 and 6023 H may be hot-worked in the range 1200 to 900 °C (2190 to 1650 °F). Cooling should be by water quenching or as fast as possible.

Heat treatment is recommended after hot working to ensure optimum properties.

For hot working, the material may be charged into the furnace at maximum working temperature of 1200 °C (2190 °F).

When the furnace has reached temperature, the material should be soaked for 60 minutes per 100 mm (4 in) of thickness. After soaking for the required time the metal should be withdrawn immediately and worked within the specified range. If the metal temperature falls below the minimum working temperature, it must be reheated.

**Cold working**

Cold working should be carried out on solution-treated material. Nicrofer 6023 and 6023 H have a much higher work-hardening rate than austenitic stainless steel and the forming equipment must be adapted accordingly.

When cold working is performed, interstage annealing may become necessary.

After cold reduction of more than 10% final solution treatment is required.

**Heat treatment**

Annealing of Nicrofer 6023 should be carried out in the temperature range 920 to 980 °C (1690 to 1800 °F), preferably at about 950 °C (1740 °F).

High temperature solution-treatment of Nicrofer 6023 H, to improve long-time properties at elevated temperatures, is carried out at 1100 to 1180 °C (2010 to 2160 °F). Water quenching is essential for maximum creep resistance and for minimising carbide precipitation in the range 500 to 800 °C (930 to 1470 °F). Below about 3 mm (0.12 in) thickness, rapid air cooling is practicable.

During any heating operation, the precautions outlined earlier regarding cleanliness must be observed.

**Descaling**

High-temperature alloys form a protecting oxide layer in service. Therefore the necessity of descaling should be checked.

Oxides of Nicrofer 6023 and 6023 H and discoloration adjacent to welds, are more adherent than on stainless steels. Grinding with very fine abrasive belts or discs is recommended.

Before pickling in a nitric/hydrofluoric acid mixture, oxides must be broken up by grit-blasting or by pretreatment in a fused salt bath.

**Machining**

Nicrofer 6023 and 6023 H should be machined in the annealed or solution-treated condition. The alloys high work-hardening rate should be considered, i.e. only low surface cutting speeds are possible compared with low-alloy standard austenitic stainless steels. Tools should be engaged at all times. Heavy feeds are important in getting below the work-hardened 'skin'.

**Joining**

Nicrofer 6023 and 6023 H can be welded by most conventional methods.

**Tested welding processes:**

	(1 = very good	2 = good	3 = possible)
GTAW		2	
GMAW (6023 only)		3	
MMA		3 (> 5/16 in thickness)	
Plasma Arc		2	

Pulsed-arc welding is preferred with GMAW.

Prior to welding, material should be in the annealed or solution-treated condition, clean and free from scale, grease, marking paints etc. A zone approximately 25 mm (1 in) wide on each side of the joint should be ground to bright metal. Sometimes tarnishing can be removed by brushing the joint in the warm condition.

Low heat input is necessary. Interpass temperature should not exceed 120 °C (250 °F).

Neither pre- nor post-weld heat treatment is required.





## Discs and rings

Conditions:  
hot rolled or forged,  
annealed or solution treated,  
oxidised or descaled or machined

Product	Weight kg	Thickness mm	O D* mm	I D* mm
Disc	≤ 4000	≤ 200	≤ 2000	–
Ring	≤ 3000	≤ 200	≤ 2500	on request

	lb	inches	inches	inches
Disc	≤ 8800	≤ 8	≤ 80	–
Ring	≤ 6600	≤ 8	≤ 100	on request

\* other sizes subject to special enquiry

## Rod and bar

Conditions:  
forged, rolled, drawn,  
annealed or solution treated, oxidised or descaled,  
machined, peeled or ground

Product		forged* mm	rolled* mm	drawn* mm
round	d	≤ 300	15 – 75	12 – 65
square	a	40 – 300	15 – 100	12 – 65
flat		40 – 80	5 – 20	10 – 20
a x b		x 200 – 600	x 120 – 600	x 30 – 80
hexagon	s	40 – 80	13 – 50	12 – 60

		inches	inches	inches
round	d	≤ 12	$\frac{5}{8}$ – 3	$\frac{1}{2}$ – 2 $\frac{1}{2}$
square	a	$1\frac{5}{8}$ – 8	$\frac{5}{8}$ – 4	$\frac{1}{2}$ – 2 $\frac{1}{2}$
flat		$1\frac{5}{8}$ – 3 $\frac{1}{8}$	$\frac{3}{16}$ – $\frac{3}{4}$	$\frac{3}{8}$ – $\frac{3}{4}$
a x b		x 8 – 24	x 5 – 24	x 1 $\frac{1}{4}$ – 3 $\frac{1}{8}$
hexagon	s	$1\frac{5}{8}$ – 3 $\frac{1}{8}$	$\frac{1}{2}$ – 2	$\frac{1}{2}$ – 2 $\frac{3}{8}$

\* other sizes subject to special enquiry

## Strip\*

Conditions:  
cold rolled,  
annealed or solution treated,  
oxidised or descaled or bright annealed\*\*

Thickness mm	Width mm	Coil I D mm		
0.04 ≤ 0.10	30–120	100	300	
> 0.10 ≤ 0.20	4–200		300	400
> 0.20 ≤ 0.25	4–400		300	400
> 0.25 ≤ 0.60	5–635		300	400
> 0.60 ≤ 1.0	8–635			400 500
> 1.0 ≤ 2.0	15–635			400 500 600
> 2.0 – 3.0	25–635			400 500 600

inches	inches	inches		
0.0016 ≤ 0.004	1.20– 5	4	12	
> 0.004 ≤ 0.008	0.16– 8		12	16
> 0.008 ≤ 0.010	0.16–16		12	16
> 0.010 ≤ 0.024	0.20–25		12	16
> 0.024 ≤ 0.04	0.32–25			16 20
> 0.04 ≤ 0.08	0.60–25			16 20 24
> 0.08 – 0.12	1.0 –25			16 20 24

\* cut-to-length available in lengths from 500 to 3000 mm (20 to 120 in)

\*\* maximum thickness 3.0 mm ( $\frac{1}{8}$  in)

## Wire

Conditions:  
bright drawn,  $\frac{1}{4}$  hard to hard  
bright annealed or oxidised

## Dimensions:

0.01 – 12.7 mm (0.0004 –  $\frac{1}{2}$  in) diameter  
in coils, pay-off packs, on spools and spiders

## Welding filler metals

Suitable welding rods and wire are available in 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](mailto: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 concerning Nicrofer 6023/6023 H may be obtained from ThyssenKrupp VDM GmbH:

Ulrich Brill

„Korrosion von Nickel, Cobalt und Nickel- und Cobalt-Basislegierungen“

Reprint of „Korrosion und Korrosionsschutz“, 1992.

VDM-Report No. 15

“Krupp VDM’s high-temperature alloys and their use in furnace construction.”

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