Nicrofer® 6025 HT – alloy 602 CA

Material Data Sheet No. 4037
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High-temperature alloy

A company of ThyssenKrupp Stainless

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Nicrofer® 6025 HT – alloy 602 CA

Nicrofer 6025 HT is a high-carbon nickel-chromium-iron alloy with additions of the micro-alloying elements titanium and zirconium together with aluminium and yttrium.

It is normally supplied in the solution-annealed condition with an oxidized or descaled surface.

Nicrofer 6025 HT is characterized by:

- excellent high-temperature creep properties.
- excellent fatigue strength in the HCF (high cycle fatigue) and LCF (low cycle fatigue) mode.
- exceptional resistance to oxidation at higher temperatures, even under cyclic conditions. It also possesses very good high temperature corrosion resistance in carburizing and oxidizing/chlorinating media as well as under "metal dusting" conditions.
- approved for pressure vessel use at service temperatures up to 1150 °C (2102 °F) according to VdTÜV Werkstoffblatt (material data sheet) 540 and up to 1650 °F (899 °C) according to ASME code case 2359 for Section I (steam service) and up to 1800 °F (982 °) for Section VIII Div. 1 applications.

Designations and standards

Country / National standards	Alloy designations	Specification								
		Chemical composition	Tube and pipe seamless	Tube and pipe welded	Sheet and plate	Rod and bar	Strip	Wire	Forgings	Fittings
D	**W.-Nr. 2.4633** NiCr25FeAlY									
VdTÜV		540			540	540			540	
DIN EN		10302			10302	10302	10302	10302		
DIN		17742		17751	17750	17752	17750			
F AFNOR										
UK BS										
USA	UNS N06025									
ASTM			B 163 B 167	B 516 B 517 B 546	B 168	B 166	B 168	B 166	B 564	B 366
ASME			SB-163 SB-167	SB-516 SB-517 SB-546	SB-168	SB-166	SB-168	SB-166	SB-564	
ASME Code Case Section I (for steam service only) and Section VIII Div. 1		2359			2359	2359			2359	

Table 1 – Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Al	Ti	Y	Zr	P	S
min.	bal.	24.0	8.0	0.15				1.80	0.10	0.05	0.01		
max.		26.0	11.0	0.25	0.50	0.50	0.10	2.40	0.20	0.12	0.10	0.020	0.010

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

Physical properties

Density Melting range	7.9 g/cm³ 1370–1400 °C	0.285 lb/in.³ 2500–2550 °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	$\frac{J}{kg \cdot K}$	$\frac{Btu}{lb \cdot °F}$	$\frac{W}{m \cdot K}$	$\frac{Btu \cdot in.}{ft^2 \cdot h \cdot °F}$	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**	450	0.107	11.3	78	118	710	215	31.2		
93	**200**		0.112		87		716		30.3		6.6
100	212	470		12.7		119		209		11.9	
200	392	500		14.4		121		201		13.5	
204	**400**		0.119		100		728		29.1		7.5
300	572	525		16.0		123		197		14.0	
316	**600**		0.126		112		742		28.3		7.8
400	752	550		17.6		125		192		14.5	
427	**800**		0.133		126		755		27.7		8.1
500	932	580		19.2		127		189		14.7	
538	**1000**		0.141		139		767		27.3		8.2
600	1112	600		20.6		128		185		14.9	
649	**1200**		0.148		148		773		26.7		8.5
700	1292	630		22.2		129		169[1]		15.7	
760	**1400**		0.155		165		773		23.2[1]		9.0
800	1472	660		24.5		128		154[1]		16.6	
871	**1600**		0.162		178		767		20.4[1]		9.5
900	1652	690		26.1		127		137[1]		17.1	
982	**1800**		0.169		190		768		17.5[1]		9.7
1000	1832	710		27.7		128		118[1]		17.5	
1093	**2000**		0.176		203		782		14.9[1]		9.8
1100	2012	740		29.3		130		102[1]		17.6	

[1] For process vessel design calculations, the creep data shown in Table 8 should be taken into account

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

Mechanical properties

The properties in Table 4 are applicable to Nicrofer 6025 HT in the solution-annealed condition and indicated size ranges. Specified properties of materials outside these size ranges are subject to special enquiry.

Sheet & plate	up to 50 mm	up to 2 in.
Strip	up to 3 mm	up to 0.12 in.
Rod & bar, forgings	up to 100 mm	up to 4 in.
Wire	up to 12 mm	up to 0.47 in.

Temperature		Yield strength $R_{p0.2}$		$R_{p1.0}$		Tensile strength R_m		Elongation A_5
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	270	39.1	310	45.0	675	97.9	30
100	212	240	34.8	280	40.6	650	94.3	30
200	392	220	31.9	260	37.7	625	90.7	30
300	572	200	29.0	240	34.8	600	87.0	30
400	752	190	27.6	225	32.6	580	84.1	30
500	932	180	26.1	210	30.5	560	81.2	30
600	1112	175	25.4	205	29.7	520	75.4	30
700	1292	170	24.7	200	29.0	420	60.9	30

Table 4 – Minimum short-time mechanical properties of Nicrofer 6025 HT in the at 1220 °C (2228 °F) solution-annealed condition (grain size ≥ 70 µm) according to VdTÜV data sheet 540.

Actual short-time mechanical properties of various Nicrofer 6025 HT products in the solution-annealed condition together with the grain size of the test pieces used to obtain these results are listed in Tables 5 - 7.

16 mm plate, 100% recrystallized; grain size: 106 µm								
Temperature		Yield strength $R_{p0.2}$		$R_{p1.0}$		Tensile strength R_m		Elongation A_5
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	280	40.6	340	49.3	710	103.0	42
100	212	265	38.4	315	45.7	670	97.2	42
200	392	245	29.0	285	41.3	655	95.0	44
300	572	225	32.6	265	38.4	635	92.1	45
400	752	210	30.5	255	37.0	620	89.9	44
500	932	205	29.7	250	36.3	620	89.9	44
600	1112	225	32.6	255	37.0	570	82.7	37
700	1292	270	39.1	305	44.2	555	80.5	34
800	1472	265	38.4	305	44.2	405	58.7	38
900	1652	120	17.4	145	21.0	215	31.2	85
1000	1832	75	10.9	90	13.1	130	18.9	90
1100	2012	50	7.3	60	8.7	80	11.6	96

Table 5 – Actual short-time mechanical properties of 16 mm plate in the solution-annealed condition.

62 mm diameter rod, 80% recrystallized; grain size: 27 µm								
Temperature		Yield strength				Tensile strength		Elongation
		$R_{p0.2}$		$R_{p1.0}$		R_m		A_5
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	430	62.4	500	72.5	875	126.9	37
100	212	425	61.6	560	81.2	875	126.9	32
200	392	405	58.7	500	72.5	840	121.8	31
300	572	390	56.6	445	64.5	780	113.1	34
400	752	315	45.7	365	52.9	715	103.7	33
500	932	400	58.0	450	65.3	730	105.9	32
600	1112	385	55.8	420	60.9	660	95.7	22
700	1292	360	52.2	390	56.6	525	76.1	17
800	1472	240	34.8	275	39.8	290	42.0	63
900	1652	105	15.2	120	17.4	180	26.1	73
1000	1832	70	10.2	85	12.3	105	15.2	74
1100	2012	45	6.5	50	7.3	65	9.4	96

Table 6 – Actual short-time mechanical properties of 62 mm dia. rod in the solution-annealed condition.

1.0 mm strip, 100% recrystallized; grain size: 32 µm								
Temperature		Yield strength				Tensile strength		Elongation
		$R_{p0.2}$		$R_{p1.0}$		R_m		A_{50}
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi	%
20	68	290	42.1	330	47.9	680	98.6	29
100	212	240	34.8	285	41.3	655	95.0	30
200	392	230	33.4	260	37.7	645	93.5	31
300	572	225	32.6	255	37.0	640	92.8	34
400	752	220	31.9	250	36.3	630	91.4	36
500	932	215	31.2	235	34.1	615	89.2	33
600	1112	240	34.8	270	39.1	585	84.8	27
700	1292	245	35.5	280	40.6	540	78.3	22
800	1472	125	18.1	180	26.1	280	40.6	40
900	1652	90	13.1	110	16.0	155	22.5	58
1000	1832	50	7.3	60	8.7	90	13.1	65
1100	2012	25	3.6	35	5.1	55	8.0	66

Table 7 – Actual short-time mechanical properties of 1.0 mm strip in the solution-annealed condition.

As can be seen from the results in Tables 5 - 7 the grain size significantly effects the mechanical properties attained.

Bending test according to DIN 50111 for sheet/plate in the solution-annealed condition without incipient cracking:

Angle of 120° around a mandrel diameter 3x the sheet or plate thickness up to a thickness of 10 mm.

When taking the $R_{p1.0}$ limiting creep stress at the lowest transition temperature T_{tr}, i.e., at the temperature where the $R_{p1.0}$ / 100,000 and the $R_{p1.0}$ / 1.5 curves intersect, as a basis and at the same time applying a safety factor of S = 1.5, long-term high-temperature strength data need only be used for components designed for service at temperatures above the T_{tr} for this alloy of approx. 625 °C (1155 °F) as indicated in Fig. 1.

For lower temperatures, the markedly higher high-temperature strength data (short-time $R_{p1.0}$ minimum values) are used for calculations.

ISO V-notch impact toughness
Average value at room temperature KV: > 55 J and aK: > 69 J/cm² respectively

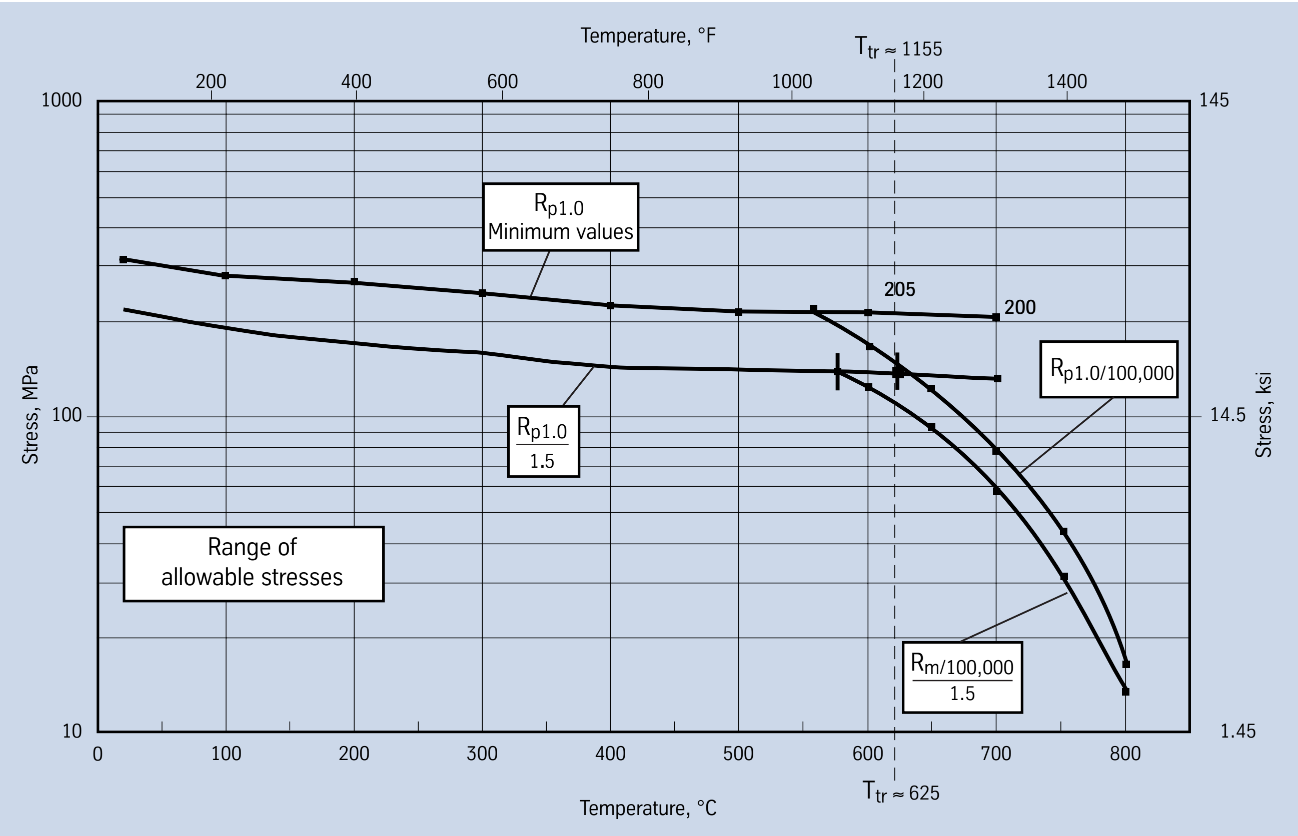

Fig. 1 – Point of intersection of short-time and long-term properties of Nicrofer 6025 HT sheet & plate in the solution-annealed condition.

Base metal solution-annealed at 1220 °C (2228 °F), grain size ≥70 µm						TIG-welded joints (as welded) Filler metal Nicrofer S 6025			
Creep strength		Creep-rupture strength		Temperature		Creep strength		Creep-rupture strength	
$R_{p1.0/10^4h}$ MPa	$R_{p1.0/10^5h}$ MPa	$R_{m/10^4h}$ MPa	$R_{m/10^5h}$ MPa	°C	°F	$R_{p1.0/10^4h}$ MPa	$R_{p1.0/10^5h}$ MPa	$R_{m/10^4h}$ MPa	$R_{m/10^5h}$ MPa
185	120	215	140	**650**	1202	148	96	172	112
132	85	155	100	**700**	1292	108	68	124	80
75	46	90	48	**750**	1382	60	36.8	72	38.4
32	16.5	42	20	**800**	1472	25.6	13.2	33.6	16.0
19	9.7	26	14	**850**	1562	15.2	7.8	20.8	11.2
13	7.5	18	9.7	**900**	1652	10.4	6.0	14.4	7.8
8.8	5.4	12.8	6.7	**950**	1742	7.0	4.3	10.2	5.4
5.8	3.4	9.0	4.5	**1000**	1832	4.6	2.7	7.2	3.6
3.6	1.9	6.2	3.1	**1050**	1922	2.9	1.5	5.0	2.5
2.2	1.0	4.4	2.1	**1100**	2012	1.8	0.8	3.5	1.7
1.0	0.4	3.0	1.4	**1150**	2102	0.8	0.3	2.4	1.1
–	–	2.2	0.8	**1200**[1)]	2192[1)]	–	–	1.7	0.65

[1)]Typical creep-rupture strength not covered by VdTÜV data sheet 540.

Table 8a – Average long-term properties of Nicrofer 6025 HT sheet & plate in the solution-annealed condition according to VdTÜV data sheet 540 and in the TIG-welded condition.

Base metal solution-annealed at 1220 °C (2228 °F), grain size ≥70 µm						TIG-welded joints (as welded) Filler metal Nicrofer S 6025			
Creep strength		Creep-rupture strength		Temperature		Creep strength		Creep-rupture strength	
$R_{p1.0/10^4h}$ ksi	$R_{p1.0/10^5h}$ ksi	$R_{m/10^4h}$ ksi	$R_{m/10^5h}$ ksi	°C	°F	$R_{p1.0/10^4h}$ ksi	$R_{p1.0/10^5h}$ ksi	$R_{m/10^4h}$ ksi	$R_{m/10^5h}$ ksi
26.8	17.4	31.2	20.3	649	**1200**	21.5	13.9	24.9	16.2
18.1	11.6	21.5	13.8	704	**1300**	14.5	9.3	17.1	11.0
9.4	5.4	11.3	5.8	760	**1400**	7.5	4.3	9.0	4.6
3.6	1.9	4.8	2.5	816	**1500**	2.9	1.5	3.8	2.0
2.4	1.3	3.3	1.8	871	**1600**	1.9	1.0	2.6	1.4
1.9	1.1	2.6	1.4	899	**1650**	1.5	0.87	2.1	1.1
1.5	0.91	2.2	1.1	927	**1700**	1.2	0.73	1.8	0.91
0.98	0.59	1.5	0.74	982	**1800**	0.78	0.47	1.2	0.59
0.77	0.44	1.2	0.59	1010	**1850**	0.62	0.35	0.97	0.48
0.58	0.31	0.97	0.48	1038	**1900**	0.46	0.24	0.78	0.38
0.34	0.16	0.67	0.31	1093	**2000**	0.28	0.13	0.54	0.24
0.15	0.06	0.44	0.20	1149	**2100**	0.12	0.04	0.35	0.16
–	–	0.30	0.10	1204	**2200**	–	–	0.25	0.08

Table 8b – Average long-term properties of Nicrofer 6025 HT sheet & plate in the solution-annealed and TIG-welded condition.

For metal temperature not exceeding		Maximum allowable stress values (Note 1)
°C	°F	ksi
38	100	26.0 (26.0) (Note 2)
93	200	25.5 (26.0) (Note 2)
149	300	24.7 (26.0) (Note 2)
294	400	23.7 (26.0) (Note 2)
260	500	22.7 (26.0) (Note 2)
316	600	21.7 (26.0) (Note 2)
343	650	21.2 (26.0) (Note 2)
371	700	20.8 (26.0) (Note 2)
399	750	20.5 (26.0) (Note 2)
427	800	20.2 (26.0) (Note 2)
454	850	20.0 (26.0) (Note 2)
482	900	19.8 (26.0) (Note 2)
510	950	19.6 (21.3) (Note 2)
538	1000	16.3*
566	1050	12.3*
593	1100	9.2*
621	1150	6.9*
649	1200	4.1*
677	1250	2.8*
704	1300	2.0*
732	1350	1.5*
760	1400	1.2*
788	1450	0.97*
816	1500	0.80*
843	1550	0.68*
871	1600	0.58*
899	1650	0.51*

*Time dependent values

Notes:

(1) This alloy in the solution-annealed condition is subject to severe loss of rupture ductility in the approximate temperature range of 1200 to 1400 °F (649 to 760 °C).

(2) Due to the relatively low yield strength of this material, the higher stress values were established at temperatures where the short-time tensile properties govern to permit the use of this alloy where slightly greater deformation is acceptable. The higher stress values exceed 66 2/3 %, but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. The higher stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

Table 9 – Maximum allowable stress values of Nicrofer 6025 HT in the solution-annealed condition according to ASME Code Case 2359.

Relaxation cracking susceptibility
Nicrofer 6025 HT is susceptible to relaxation cracking if solution-annealed material is exposed to service temperatures within the range of 600 – 725 °C (1112 – 1337 °F). A high degree of cold deformation and welding during fabrication may enhance the susceptibility to relaxation cracking during subsequent service.

A stabilizing heat treatment at 950 °C (1742 °F) for 3 hrs of new material prior to fabrication and welding or prior to repair welding of material which has already been in service alleviates susceptibility to relaxation cracking.

Metallurgical structure
Nicrofer 6025 HT has a face-centered-cubic structure.
It can be age-hardened up to 800 °C (1472 °F) by gamma prime (γ') precipitation.

High temperature corrosion resistance
The most outstanding characteristic of Nicrofer 6025 HT is its oxidation resistance, which is superior to that of Nicrofer 6023 H over the whole temperature range up to 1200 °C (2192 °F). Even under extreme conditions such as cyclic heating and cooling, Nicrofer 6025 HT retains this characteristic, imparted by the tightly adherent layer of aluminium oxide, which is very resistant to spalling. Up to 1100 °C (2012 °F) the change in mass is negligible.

Tests indicate that this alloy has the lowest loss of mass under cyclic stress when compared with other high-temperature alloys.

The superior oxidation resistance of Nicrofer 6025 HT by comparison with Nicrofer 6023 H is illustrated in Table 10 and Fig. 4.

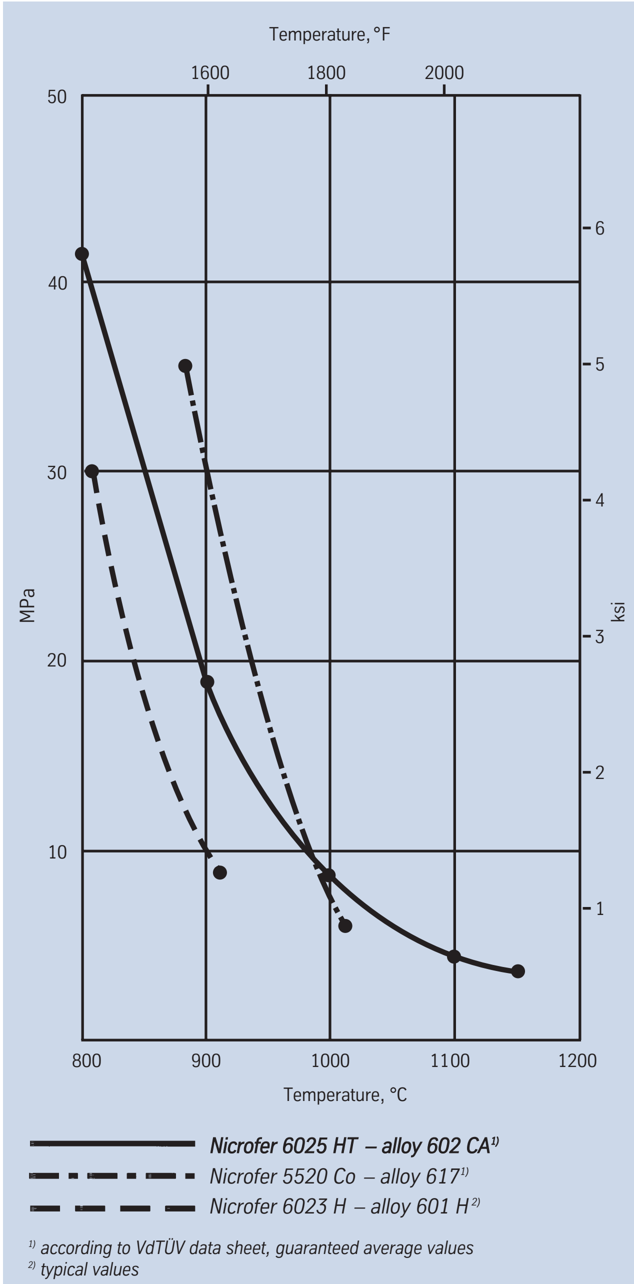

Fig. 2 – Comparison of creep-rupture strength $R_{m}/10^4 h$ of various high-temperature alloys in the solution-annealed condition as a function of temperature.

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Furthermore, due to their high chromium and aluminium contents, Nicrofer 6025 HT shows good resistance to oxidizing and oxidizing/sulfidizing environments at elevated temperatures.

The resistance to carburization is substantially better in the case of Nicrofer 6025 HT as compared to the already good resistance exhibited by Nicrofer 6023 H (cf. Fig. 5).

It also favourably influences the alloy's resistance to metal dusting, as Fig. 3 confirms by way of example.

The tendency towards nitrogen pick-up is also reduced with Nicrofer 6025 HT compared with Nicrofer 6023 H (cf. Fig. 6).

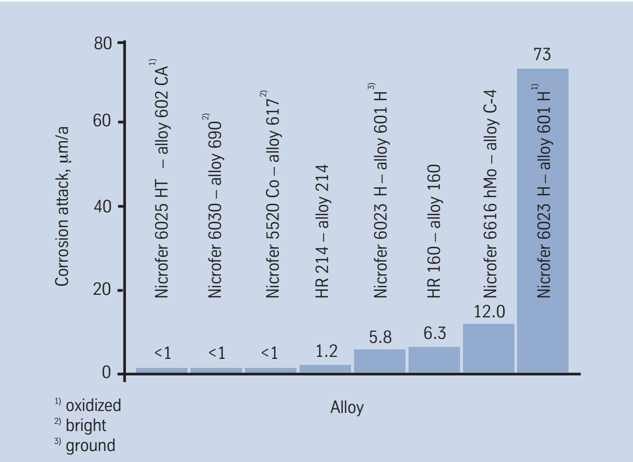

Fig. 3 – Corrosion attack of various high-temperature alloys in a metal dusting environment (T = 650 °C/1202 °F, a_C >> 1, H_2-H_2O-CO-atmosphere, t = 10,000 h) according to Grabke et al., 1996.

Temperature		Specific weigth change in g/m²	
°C	°F	Base metal	TIG-welded joints (as welded) Filler metal Nicrofer S 6025
750	1382	< 1	
760	**1400**	< 1	
850	1562	1	
871	**1600**	1	
982	**1800**	5	10
1000	1832	6	12
1093	**2000**	0	10
1100	2012	– 2	10
1200	2192	– 300	– 125
1204	**2200**	– 360	– 130
Conversion factor: 1 g/m² ≈ 2.048 · 10⁻⁴ lb/ft²			

Table 10 – Specific weight change of Nicrofer 6025 HT in g/m². 1008 h cyclic oxidation test in air.

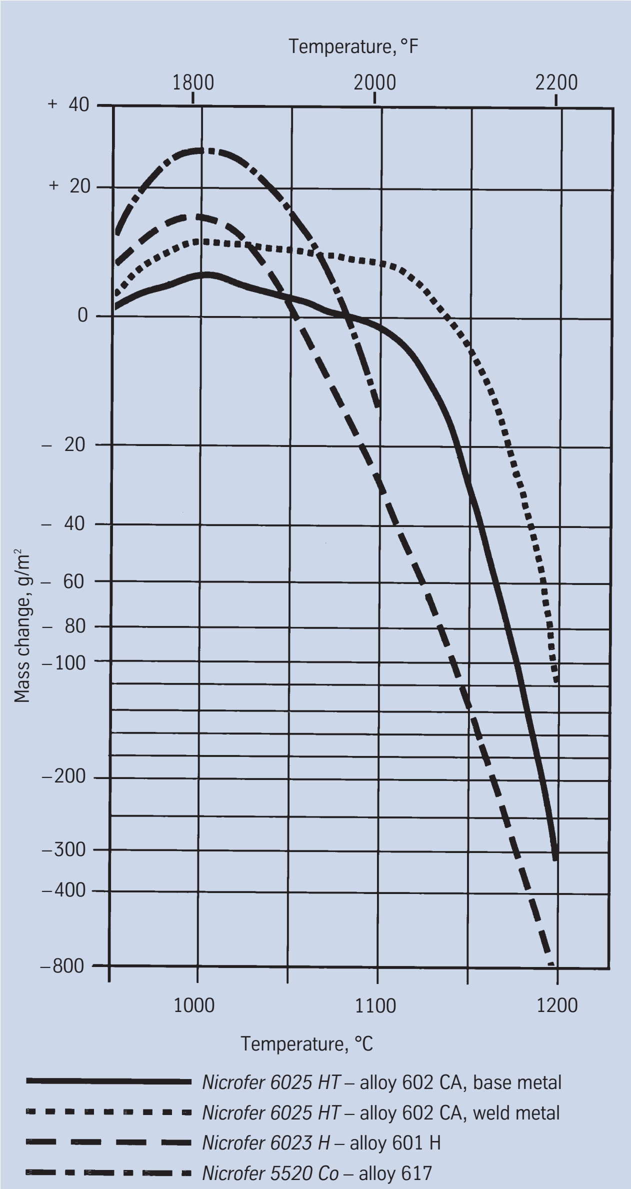

Fig. 4 – Specific weight change of various high-temperature alloys as a function of temperature. 1008 h cyclic oxidation test in air.

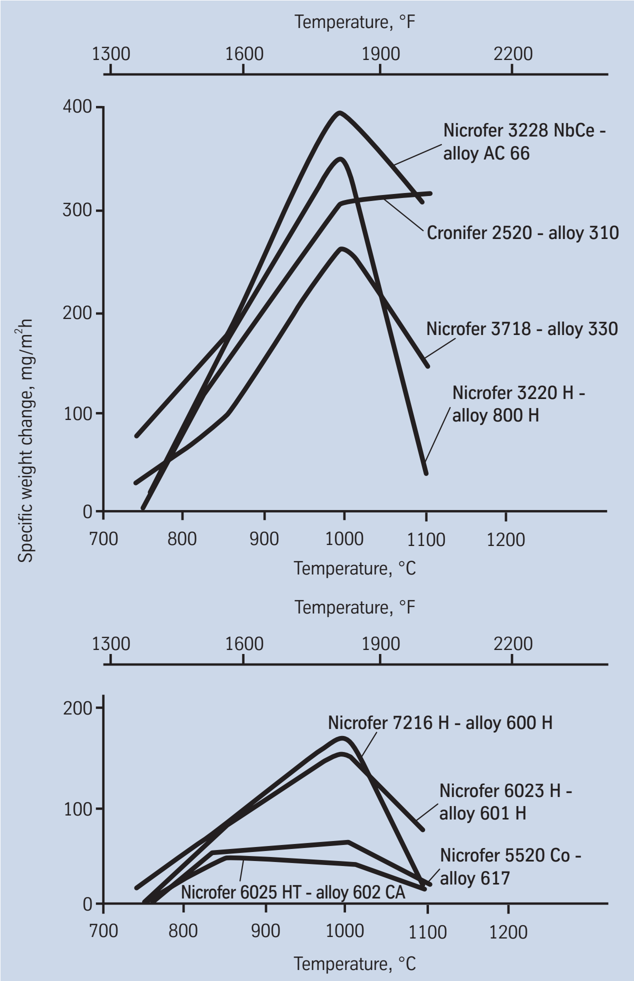

Fig. 5 – Cyclic carburization behaviour (42 x 24 h) of some high-temperature stainless steels and nickel alloys in CH_4/H_2 with a_c = 0.8.

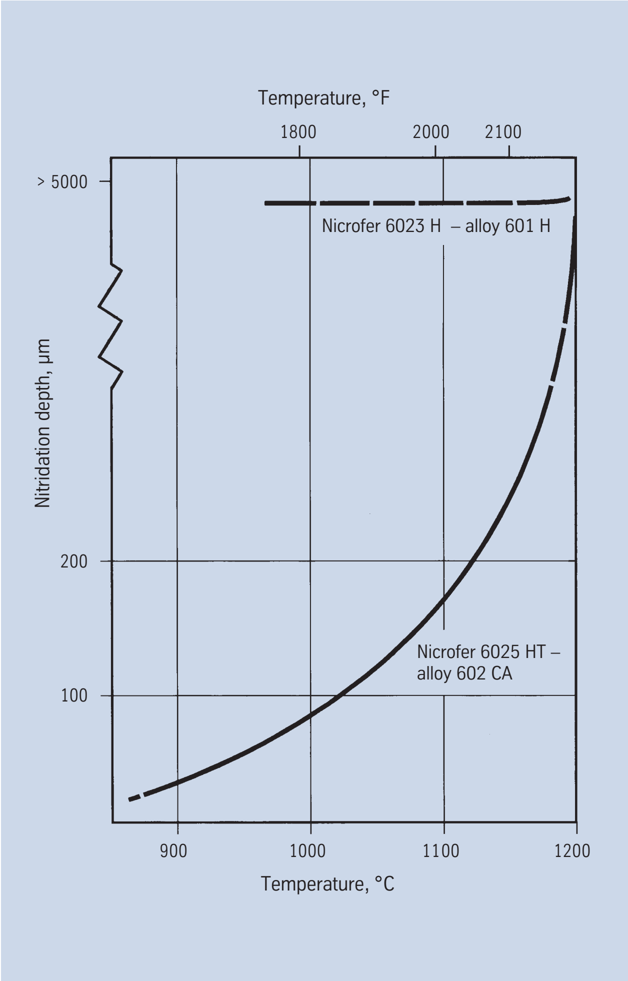

Fig. 6 – Nitridation depth after 1000 h exposure in air. Comparison of Nicrofer 6025 HT with Nicrofer 6023 H.

Applications

Nicrofer 6025 HT has been utilized in a wide range of applications in thermal and chemical/petrochemical processes as well as in power plant equipment.

Typical applications are:

- Radiant heater tubes
- Furnace rolls
- Muffles in bright annealing furnaces (H_2 atmosphere)
- Rotary kilns and shaft furnaces
- Furnace components
- Pipe hangers/restraints
- Components in waste gas systems and waste gas cleaning plants
- Moulds used in vitrification of radioactive waste
- Methanol and ammonia synthesis
- Hydrogen production
- Reformers in chemical and petrochemical industries
- Glow plugs
- Automotive catalytic support systems

Fabrication and heat treatment

Nicrofer 6025 HT can readily be hot- and cold worked and machined.

Heating

Workpieces must be clean and free from all kinds of contaminants before and during heat treatment.

The quality of Nicrofer 6025 HT may be impaired 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, fluids and fuels.

Fuels must be as low in sulfur as possible. Natural gas should contain less than 0.1 wt.-% 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 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 6025 HT may be hot worked in the temperature range 1200 to 900 °C (2190 to 1650 °F), followed by water quenching or rapid air cooling.

Nicrofer 6025 HT has reduced ductility between 800 and 600 °C (1472 and 1112 °F).

Heat treatment after hot working is recommended in order to achieve optimum properties. For heating up, workpieces should be charged into the furnace at maximum working temperature.

Cold working

For cold working the material should be in the solution-annealed condition. Nicrofer 6025 HT 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 final cold working with more than 7% deformation (> 5% in the case of weldments) solution annealing must be repeated to achieve optimum creep properties. Also note the information on **'Relaxation cracking susceptibility'**.

Oxidized sheet and plate can also be bent and cold worked. The inside bending diameter should be at least three times the sheet/plate thickness.

Heat treatment

Nicrofer 6025 HT should generally be used in the solution-annealed condition, so that optimum creep strength is achieved. For maximum creep strength Nicrofer 6025 HT is solution annealed at 1220 °C (2232 °F) to specifically establish a grain size ≥ 70 µm.

As with some other high-temperature, high-strength nickel alloys, Nicrofer 6025 HT too may suffer stress relaxation cracking if the material is exposed to service temperatures within the range 600 – 725 °C (1112 – 1337 °F), especially after repair in welded or cold formed areas. In such cases, stabilization annealing at 950 °C (1742 °F) is recommended in order to relieve stresses and deliberately influence precipitation processes.

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

Descaling and pickling

High-temperature alloys develop a protective oxide layer in service. Pre-oxidation in air can produce increased corrosion resistance. Therefore on the basis of the end use the necessity of descaling should be checked.

Oxides of Nicrofer 6025 HT 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 in a nitric/hydrofluoric acid mixture, the surface oxide layer must be broken up by abrasive blasting or grinding or by pretreatment in a fused salt bath. Particular attention should be paid to the pickling time and temperature.

Machining

Nicrofer 6025 HT should preferably be machined in the heat-treated condition. As the alloy is prone to work-hardening, a low cutting speed should be used and the tool 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 machines

Tools used for nickel alloys and stainless steels must not be used for other materials. Brushes should be made of stainless materials.

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 as they are detrimental to health.

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 possible. However, in the latter case the cut edge (the face to be welded) must be finished off cleanly. Careful grinding without overheating is permitted.

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. 7, 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 of 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 processes

For welding, Nicrofer 6025 HT must be in the solution-annealed condition and be free from scale, grease and markings. Nicrofer 6025 HT can be welded by the following welding processes: GTAW (TIG), plasma arc, GMAW (MAG = metal active gas) and SMAW (MMA = manual metal arc). For the MAG process the use of the shielding gas Cronigon Ni30 is recommended. If the submerged-arc process is used, the high aluminium burn-off makes it necessary to cover the weld metal with two weld layers using the GTAW process.

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. The shielding gas used for the GTAW and plasma-arc processes should be an argon/nitrogen mixture (argon + 2% N_2). This gas should be used for all welding passes, i.e., for depositing root, intermediate and cover layers. 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, filler metal with the same composition as the base metal is recommended:

Bare electrodes: Nicrofer S 6025 - FM 602
(W.-Nr. 2.4649)
UNS N06025
AWS A5.14: ERNiCrFe-12
DIN EN ISO 18274: S Ni 6025
(NiCr25Fe10AlY)

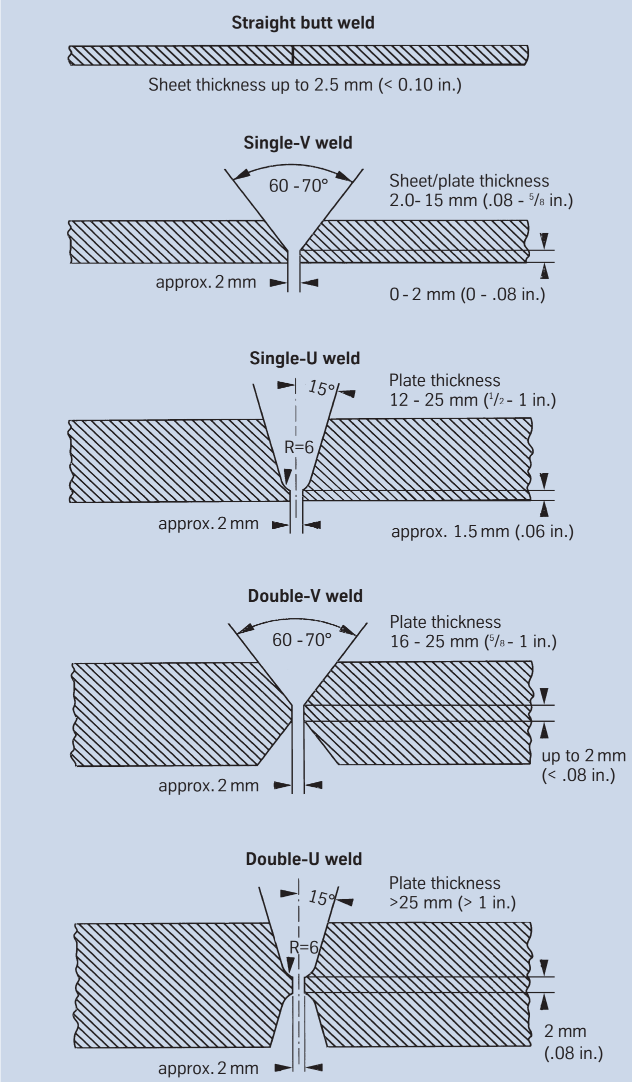

Fig. 7 – Edge preparation for welding of nickel alloys and special stainless steels.

Covered electrodes: UNS W86025
AWS A5.11: ENiCrFe-12
DIN EN ISO 14172: E Ni 6025
(NiCr25Fe10AlY)

According to VdTÜV approval, Nicrofer S 6025 filler wire is also suitable for GTAW, GTAW-plasma and MAG welding of alloy 601 H.

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 11 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.

Sheet/ plate thick-ness mm	Welding process	Filler metal dia-meter mm	Welding parameters Root I A	U V	Intermediate and final passes I A	U V	Welding speed cm/min.	Heat input kJ/cm	Shielding gas Type and rate l/min.
2.0	manual GTAW	2.0	90–100	10			10–15	max. 8	Argon + 2% N_2 8–10
6.0	manual GTAW	2.0–2.4	110	11	130–150	15	10–15	max. 8	Argon + 2% N_2 8–10
12.0	manual GTAW	2.4	110	11	130–150	15	10–15	max. 8	Argon + 2% N_2 8–10
3.0	autom. GTAW	0.8–1.2	manual GTAW		150–250	10–15	20–30	max. 8	Argon + 2% N_2 15–20
8.0	autom. GTAW	0.8–1.2	manual GTAW		150–250	10–15	20–30	max. 8	Argon + 2% N_2 15–20
5.0	Plasma arc	1.0–1.2	200–220	≈ 26			25–30	≈ 11	Argon + 2% N_2 30
12.0	Plasma arc	1.0–1.2	220–240	≈ 26			25–30	≈ 12	Argon + 2% N_2 30
8.0	GMAW (MAG)	1.0–1.2	GTAW		130–140	23–27	24–30	max. 8	Cronigon Ni30: Argon + 5% N_2 + 5% He + 0.05% CO_2 16 – 20
8.0	SMAW (MMA)	2.5–3.2	40–70	approx. 21	70–100	approx. 22		max. 7	–
16.0	SMAW (MMA)	3.2–4.0	70–100	approx. 21	90–130	approx. 22		max. 7	–

In all gas-shielded welding operations, adequate back shielding must be ensured.
Figures are for guidance only and are intended to facilitate setting of the welding machines.

Table 11 – Welding parameters (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'**.

Neither pre- nor postweld thermal treatments are normally required.

However, to eliminate the risk of relaxation cracking of material exposed to service temperatures within the range of 600 – 725 °C (1112 – 1337 °F) following cold working and/or (repair) welding, the stabilization annealing recommendations given under **'Relaxation cracking susceptibility'** should be adhered to.

Availability

Nicrofer 6025 HT 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
1.00 – < 2.00	cr	1000 – 2400	10,000
2.00 – < 8.00	cr / hr	2500	10,000
8.00 – < 25.00	hr	2500	10,000[2]
> 25.00[1]	hr	2500[2]	10,000[2]

inches		inches	inches
0.040 – < 0.080	cr	40 – 95	395
0.080 – < 0.310	cr / hr	100	395
0.310 – < 1.000	hr	100	395[2]
> 1.000[1]	hr	100[2]	395[2]

[1] other sizes subject to special enquiry
[2] maximum piece weight: 2700 kg (6000 lbs);
up to 4500 kg (9900 lbs) subject to special enquiry

Discs and rings

Conditions:
hot rolled or forged,
thermally treated,
oxidized, 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,
oxidized, descaled or pickled, machined, peeled or ground

Product	Forged[1] mm	Rolled[1] mm	Drawn[1] mm
Rod (O. D.)	≤ 600	7 – 120	8 – 75
Bar, square (a)	40 – 500	15 – 280	not standard
Bar, flat (a x b)[2]	(40 – 80) x (200 – 600)	(5 – 20) x (120 – 600)	not standard
Bar, hexagonal (s)[2]	40 – 80	13 – 41	≤ 50

	inches	inches	inches
Rod (O. D.)	≤ 24	5/16 – 4 3/4	5/16 – 3
Bar, square (a)	1 5/8 – 20	10/16 – 11	not standard
Bar, flat (a x b)[2]	(1 5/8 – 3 1/8) x (8 – 24)	(3/16 – 3/4) x (4 3/4 – 24)	not standard
Bar, hexagonal (s)[2]	1 5/8 – 3 1/8	1/2 – 1 5/8	≤ 2

[1] other sizes subject to special enquiry
[2] 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.

Nicrofer® 6025 HT – alloy 602 CA

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 – ≤ 0.25	4 – 720[4]	300	400	500	
> 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			
0.0008 – ≤ 0.004	0.16 – 8[4]	12	16		
> 0.004 – ≤ 0.010	0.16 – 28.5	12	16	20	
> 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 (0.120 in.),
cold rolled only - 3.5 mm (0.140 in.)
[3] Wider widths are subject to special enquiry
[4] Wider widths up to 730 mm (29 in.) are subject to special enquiry

Wire
Conditions:
shaved; bright drawn, 1/4 hard to hard;
bright annealed or oxidized

Dimensions:
0.1 – 19.0 mm (0.004 – 0.75 in.) diameter,
in coils, pay-off packs, on spools and spiders.
Other dimensions as well as flat and contoured wire are subject to special enquiry.

Welding filler metals
Suitable welding rods, wire 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 Mannesmann DMV STAINLESS Deutschland GmbH, Wiesenstr. 36, D-45473 Mülheim/Ruhr; Tel.: +49 208 458-2611; Fax: +49 208 458-2641; Email: salesgermany@dmv-stainless.com; Internet: www.mannesmann-dmv.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 6025 HT may be obtained from ThyssenKrupp VDM GmbH:

U. Brill, D. C. Agarwal:
Alloy 602 CA, a new high-strength, high-temperature alloy for service temperatures up to 1200 °C,
CORROSION '93, Paper No. 226, NACE International, Houston, Texas, 1993

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Zeitschrift Stahl, Heft 6/1995

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Mitteilung des Deutschen Email Verbandes, 1996, pp. 7 – 10

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U. Brill, J. Klöwer:
Vergleichende Untersuchung des Oxidationsverhaltens der Werkstoffe Nicrofer 7216 H, 6023 H und 6025 HT,
Zeitschrift Metall, 51. Jahrgang, Nr. 5/97, pp. 263 – 266

O. Ibas, U. Brill:
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Werkstoffprüfung 98, pp. 137 – 144

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