Nicrofer® 45 TM – alloy 45 TM

Material Data Sheet No. 4039
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High-temperature alloy

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Nicrofer® 45 TM – alloy 45 TM

Nicrofer 45 TM is a high-chromium, austenitic nickel-chromium-iron alloy with a controlled silicon content and rare earth additions.

The formation of a protective chromium oxide layer, together with a subjacent silicon oxide layer, makes the alloy especially suitable for applications such as waste incineration.

Nicrofer 45 TM is characterized by:

- excellent oxidation behaviour up to 1000 °C (1830 °F)
- good heat resistance and creep properties
- excellent resistance in oxidizing, reducing, nitriding and sulphur containing media, even under alternating conditions
- excellent properties in waste incineration environments at temperatures up to 850 °C (1560 °F)
- approved for pressure vessels with operating temperatures of –196 to 550 °C (–320 to 1020 °F).

Designations 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
D VdTÜV-Wbl.	W.-Nr. 2.4889 NiCr28FeSiCe	519			519				
F AFNOR									
UK BS									
USA ASTM	UNS N06045		B 163 B 167		B 168	B 166	B 168	B 166	B 564
ASME			SB 163 SB 167	SB 516 SB 517	SB 168	SB 166	SB 168	SB 166	SB 564
ASME Code Case			2188	2188	2188	2188	2188	2188	2188
ISO									

Table 1 – Designations and standards

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Al	RE*	P	S
min	45.0	26.0	21.0	0.05		2.5			0.05		
max		29.0	25.0	0.12	1.0	3.0	0.3	0.2	0.15	0.015	0.010
*Ce 0.03 - 0.09											

Table 2 – Chemical composition (wt.-%)

Physical properties

Density	8.0 g/cm³	0.289 lb/in.³
Melting temperature	1390 °C	2530 °F
Permeability at 20 °C/68 °F (RT)	max. 1.003	

Temperature (T)		Specific heat		Thermal conductivity		Electrical resistivity		Modulus of elasticity		Coefficient of thermal expansion between room temperature and T	
°C	°F	J/(kg K)	Btu/(lb °F)	W/(m K)	Btu in./(ft² h °F)	µ Ω cm	Ω circ mil/ft	kN/mm²	10³ ksi	10⁻⁶/K	10⁻⁶/°F
0	32										
20	**68**	500	0.12	13.0	90	118	710	193	28.0		
93	**200**						722		27.1		7.1
100	212					120		187		13.0	
200	392					123		183		14.5	
204	**400**						740		26.5		8.1
300	572					126		171		14.9	
316	**600**						761		24.8		8.3
400	752					128		163		15.4	
427	**800**						773		23.2		8.6
500	932					128		154[1)]		15.7	
538	**1000**						778		22.3[1)]		8.8
600	1112					130		152[1)]		16.2	
649	**1200**						788		21.9[1)]		9.1
700	1292					132		150[1)]		16.6	
760	**1400**						803		20.0[1)]		9.4
800	1472					134		122[1)]		17.0	
871	**1600**						815		16.1[1)]		9.6
900	1652					136		108[1)]		17.3	
982	**1800**						824		14.2[1)]		9.8
1000	1832	540	0.13			137		96[1)]		17.8	

[1)] When making design calculations for process equipment, the creep strength values shown in Tables 6 and 7 should be taken into account.

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

Mechanical properties

The following properties are applicable to Nicrofer 45 TM in the hot or cold formed and solution-treated condition and the indicated size ranges. Specified properties of material outside these size ranges (see Availability) are subject to special enquiry.

Form	Dimensions		0.2 % Yield strength		1.0 % Yield strength		Tensile strength		Elongation A5
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%
Sheet and plate	≤ 50[1)]	≤ 2[1)]	240	35	280	40	620	90	35
Rod and bar	≤ 100	≤ 4							

[1)] according to VdTÜV-Wbl. 519: d max 25 mm/1 in

Table 4 – Minimum mechanical properties at room temperature

	Stress (N/mm²) at elevated temperatures (°C) 100	200	300	400	450	500[1)]	600[1)]	800[1)]	1000 °C[1)]
Rm	≥ 595	≥ 570	≥ 545	≥ 520	≥ 510	500	460	190	170
0.2 % yield strength	≥ 220	≥ 200	≥ 185	≥ 170	≥ 155	150	135	110	50
1.0 % yield strength	≥ 260	≥ 240	≥ 225	≥ 210	≥ 195	190	170	125	65

[1)] When making design calculations for process equipment, the creep strength values shown in Tables 6 and 7 should be taken into account

	Stress (ksi) at elevated temperatures (°F) 200	400	600	800	850	1000[1)]	1200[1)]	1400[1)]	1800 °F[1)]
Rm	86	83	78	75	≥ 74	71	57	31	11
0.2 % yield strength	32	29	26	23	≥ 22	20	18	17	7.5
1.0 % yield strength	38	35	32	30	≥ 28	26	23	20	10

[1)] When making design calculations for process equipment, the creep strength values shown in Tables 6 and 7 should be taken into account

Table 5 – Mechanical short-time properties at elevated temperatures, according to VdTÜV-Wbl. 519 (up to 450 °C/850 °F)

ISO V-notch impact strength

Minimum values at RT
(average of 3 specimens) longitudinal ≥ 75 J/cm²
transverse ≥ 63 J/cm²

Temperature		Creep strength Rp 1.0/10⁵ h	
°C	°F	N/mm²	ksi
470	880	106	15.4
480	900	99	14.4
490	915	90	13.1
500	930	84	12.2
510	950	76	11.0
520	970	69	10.0
530	985	63	9.1
540	1000	58	8.4
550	1020	54	7.8

Table 6 – Creep properties according to VdTÜV-Wb. 519 (extension of the survey to 950 °C in preparation)

Base metal; solution heat treated									
Temperature T °C	°F	Creep strength Rp 1.0/10⁴h N/mm²	ksi	Rp 1.0/10⁵h N/mm²	ksi	Creep rupture strength Rm 10⁴h N/mm²	ksi	Rm 10⁵h N/mm²	ksi
500	932	120		84		160		140	
538	**1000**		12.5		8.7		17.8		14.2
600	1112	52		36		80		60	
649	**1200**		4.6		3.3		6.5		4.9
700	1292	22		15		32		23	
760	**1400**		2.1		1.4		2.9		2.2
800	1472	10.5		6.5		15		10.8	
871	**1600**		0.88		0.51		1.33		0.87
900	1652	4.7		2.8		7.5		4.7	
982	**1800**		0.39		0.25		0.73		0.38
1000	1832	2.5		1.5		4.5		2.4	

TIG-welded joint; as welded									
Temperature T °C	°F	Creep strength Rp 1.0/10⁴h N/mm²	ksi	Rp 1.0/10⁵h N/mm²	ksi	Creep rupture strength Rm 10⁴h N/mm²	ksi	Rm 10⁵h N/mm²	ksi
500	932	112		80		155		130	
538	**1000**		11.7		8.3		17.2		13.2
600	1112	48		30		76		55	
649	**1200**		4.25		2.75		6.2		4.5
700	1292	19		11		30		20	
760	**1400**		1.8		1.1		2.75		1.9
800	1472	8.0		4.5		14		7.8	
871	**1600**		0.66		0.36		1.24		0.71
900	1652	3.5		1.8		6.4		3.2	
982	**1800**		0.30		0.16		0.62		0.25
1000	1832	1.3		–		2.8		1.2	

Table 7 – Typical creep properties of Nicrofer 45 TM base metal and TIG-welded material

Metallurgical structure
Nicrofer 45 TM has a face-centred cubic structure.

Corrosion resistance
Nicrofer 45 TM is a high-chromium, nickel-chromium-iron alloy with additions of about 3% silicon and 0.10% rare earth elements.

The increased chromium content ensures the formation of a stable chromium oxide layer as a diffusion barrier, and protects the sub-surface matrix from any loss in chromium to below 18%. At lower oxygen partial pressures, when chromium oxide is unstable, a stable silicon oxide layer provides sufficient protection to the metal.

The following graphs show the result of comparitive testing of Nicrofer 45 TM in various media.

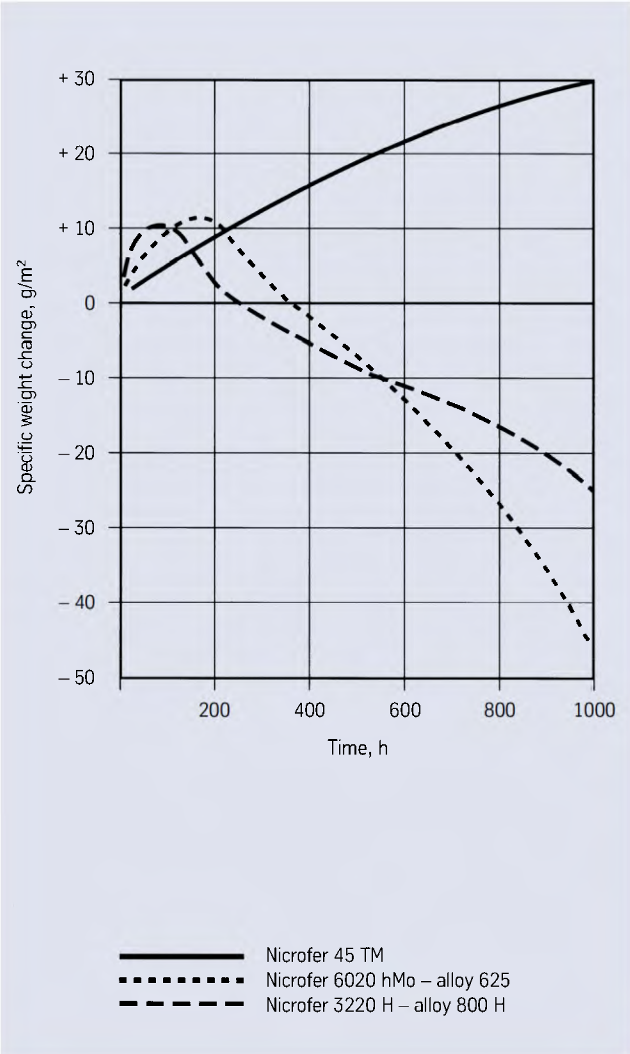

Fig. 1 – Oxidation behaviour in air, simulating firing-side conditions
● *Comparison of specific weight change in air at 1000 °C (1830 °F)/24 hrs cycle*

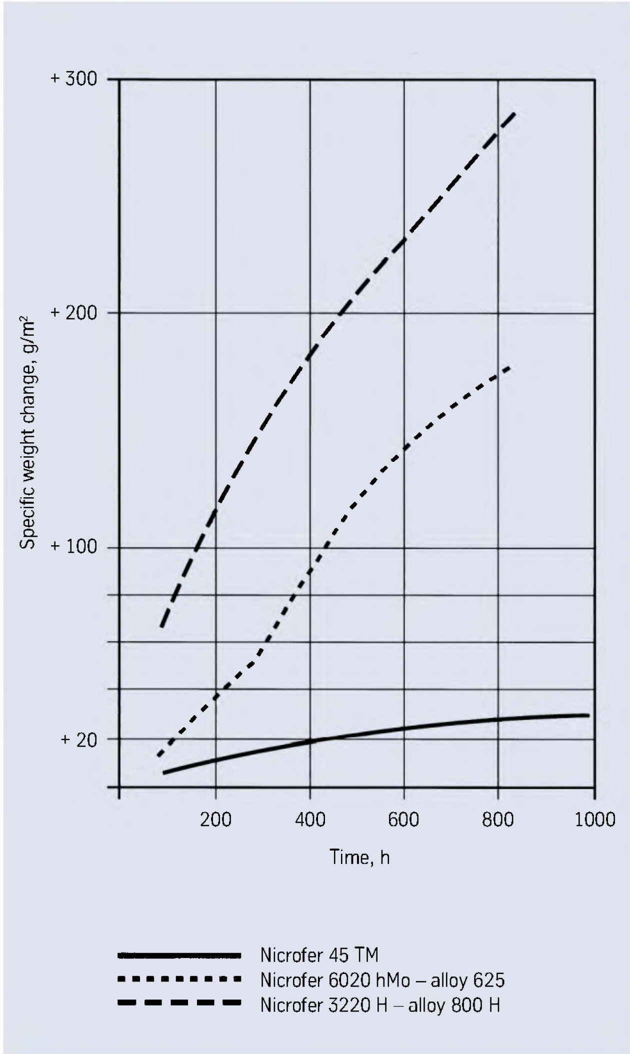

Fig. 2 – Behaviour in a CH_4/H_2 atmosphere, simulating conditions in fluidized bed combustion
● *Comparison of specific weight change under cyclic carburisation CH_4/H_2 with a_c = 0.8 at 1000 °C (1830 °F)*

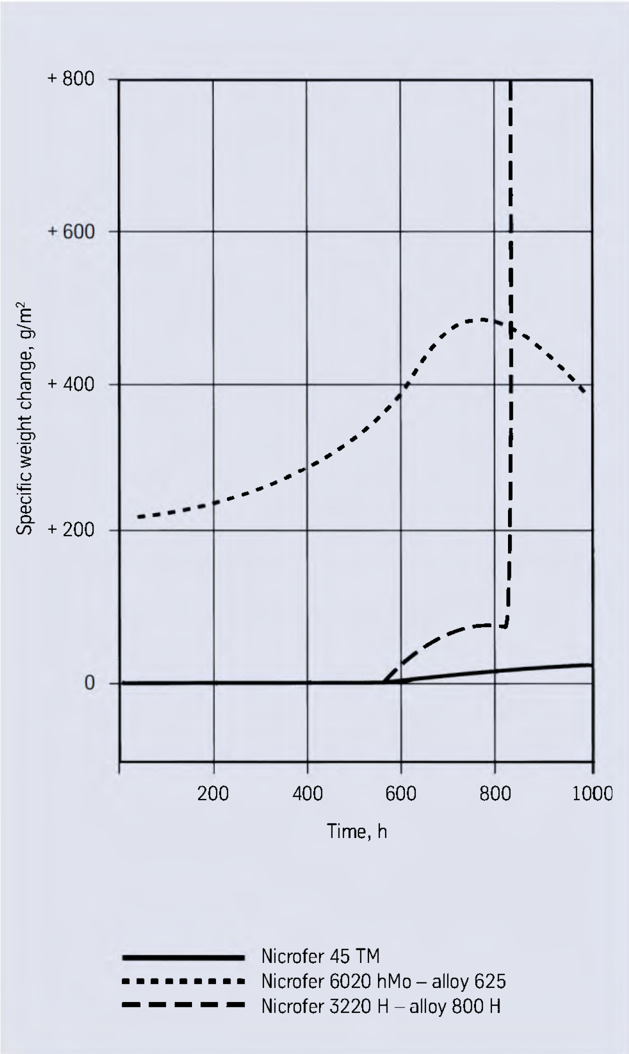

Fig. 3 – Behaviour in N_2 + SO_2, simulating conditions in a strongly sulphidizing flue gas of low oxygen partial pressure

● *Comparison of specific weight change by cyclic sulphidation in N_2 + 10% SO_2 at 750 °C (1380 °F)*

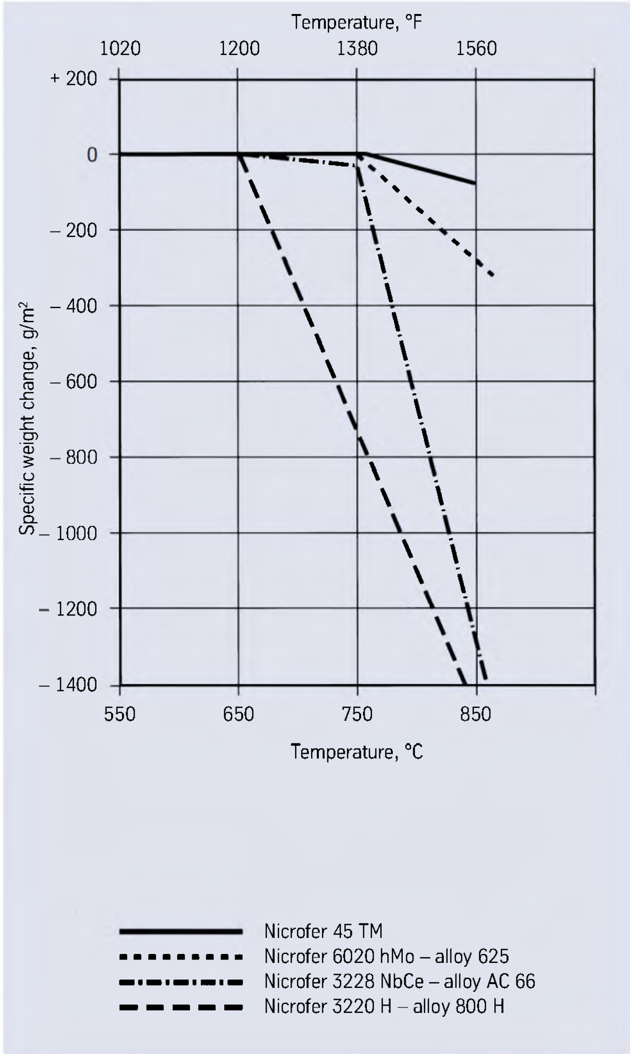

Fig. 4 – Influence of temperature on behaviour in waste incineration gases in the range 550 to 850 °C (1020 to 1560 °F)

● *Comparison of specific weight change in a waste incineration environment after 1000 hrs at temperatures of 550 to 850 °C (1020 to 1560 °F)*

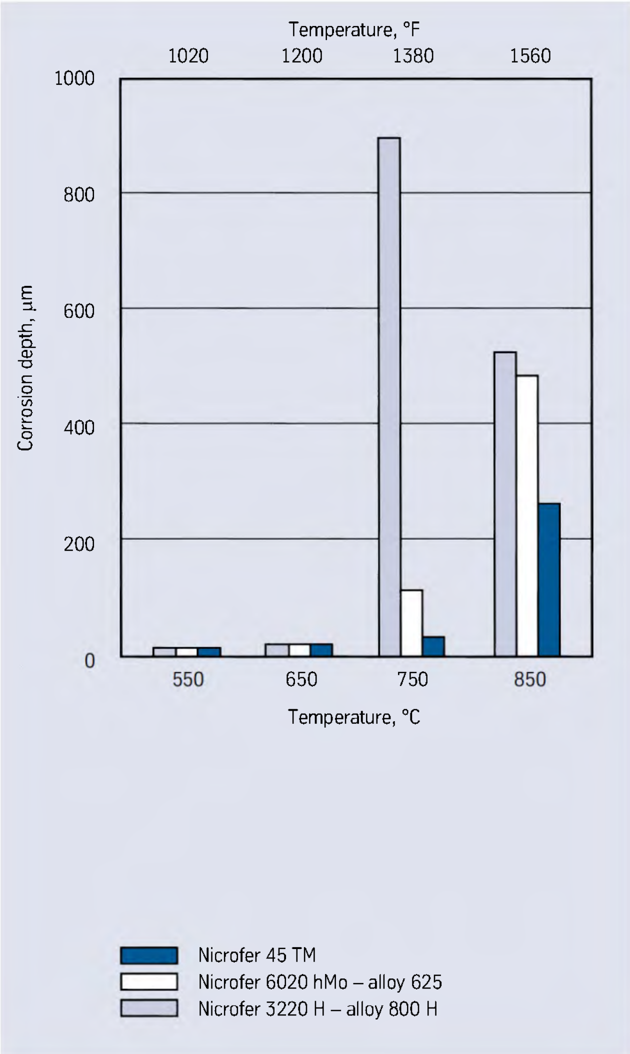

Fig. 5 – Influence of temperature on behaviour in waste incineration gases in the range 550 to 850 °C (1020 to 1560 °F)

● *Comparison of corrosion depth after 1000 hrs exposure in a waste incineration environment*

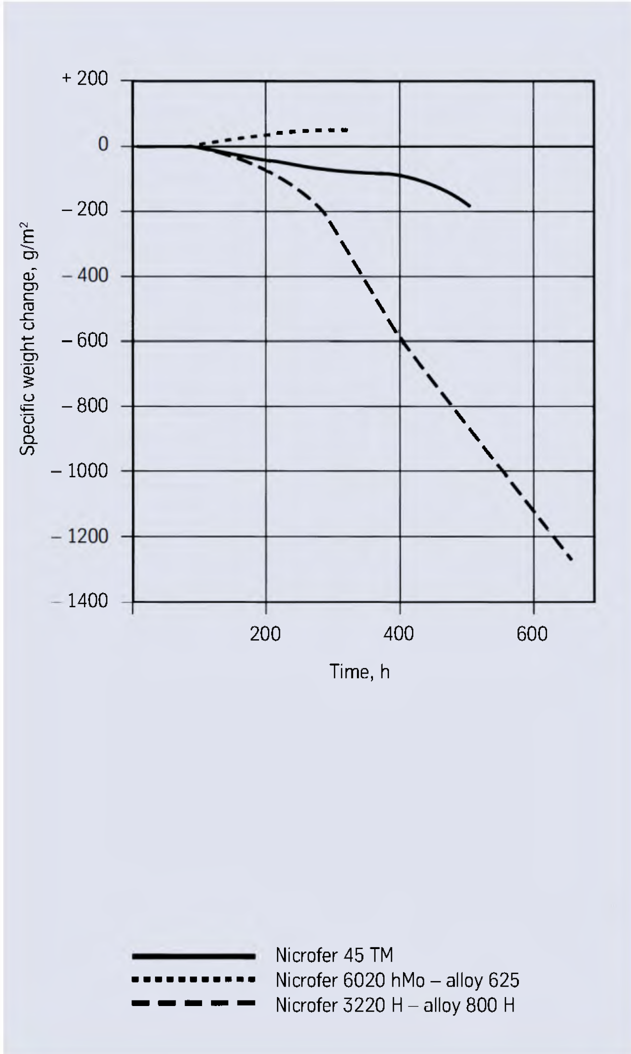

Fig. 6 – Behaviour in a sulphate smelt with
53% Na_2SO_4
40% $CaSO_4$
7% $MgSO_4$
to simulate corrosion under deposits in waste incineration plants

● *Comparison of specific weight change in molten sulphate at 700 °C (1290 °F)*

Applications

On account of its high strength values – also at elevated temperatures and over prolonged periods – and its excellent resistance to sulphurous atmospheres, Nicrofer 45 TM finds application in a wide range of fields:

- Environmental technology: thermal disposal of household and specialized wastes, incineration (superheater and evaporator tubes), pyrolysis (rotary kilns), hydrogenating treatment of plastic wastes.
- Energy technology: coal gasification (heat exchanger tubes and pipework, burner components).
- Chemical process technology: process furnaces for strongly sulphidizing and/or carburizing operating conditions, burner components for fuels which still contain sulphur, heat exchangers in sulphidizing and/or carburizing media.
- Manufacture of heat treatment and industrial furnaces: salt bath furnaces (tank, internal equipment, baskets, supports), gas carburizing furnaces (furnace shell and lining), heat treatment furnaces with gaseous reaction products (conveyor belts, burner components, furnace shell and lining, internal furnace equipment).

Fabrication and heat treatment

Fabricating with Nicrofer 45 TM is readily accomplished by conventional industrial processes.

Heating

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

Nicrofer 45 TM 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.

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

Hot working

Nicrofer 45 TM may be hot-worked in the range 1180 to 900 °C (1980 to 1650 °F). Cooling after hot working should be by water quenching or as fast as possible.

Solution treatment is recommended after hot working to ensure optimum properties, particularly high creep strength.

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

Cold working

Cold working should be carried out on solution-treated material. Nicrofer 45 TM has a 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 reductions of more than 8%, final solution annealing is required before use.

Heat treatment

Solution treatment should be carried out in the temperature range 1160 to 1200 °C (2120 to 2190 °F). Water quenching is essential for optimum creep properties. For thicknesses below about 3 mm (0.12 inch) rapid air cooling is possible.

Pre-oxidation in contact with air or the use of material which is already pre-oxidized on delivery can lead to markedly increased corrosion resistance.

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

Descaling

High-temperature alloys form a protective oxide layer during application. The necessity of descaling should be checked before ordering the material.

Oxides of Nicrofer 45 TM and discoloration adjacent to welds are more adherent than on stainless steels.
Grinding with very fine abrasive belts or wheels is recommended.

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

Machining

Nicrofer 45 TM should be machined in solution-treated condition. The alloy's high work-hardening rate should be borne in mind; i. e. only low surface cutting speeds are possible compared with low-alloy standard austenitic stainless steel. Tools should be engaged at all times. Heavy feeds are important in getting below the work-hardened 'skin'.

Advice on welding
When welding nickel alloys and high-alloyed special stainless steels, the following instructions should be adhered to:

Workplace
The workplace should be in a separate location, well away from the areas where carbon steel is worked. Maximum cleanliness, partitions, and avoidance of draughts are required.

Auxiliaries, clothing
Clean fine leather gloves and clean working clothes should be used.

Tools and machinery
The tools should be used only for nickel alloys and high-alloyed special stainless steels. 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 surface of the metal with ferrous material.

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.

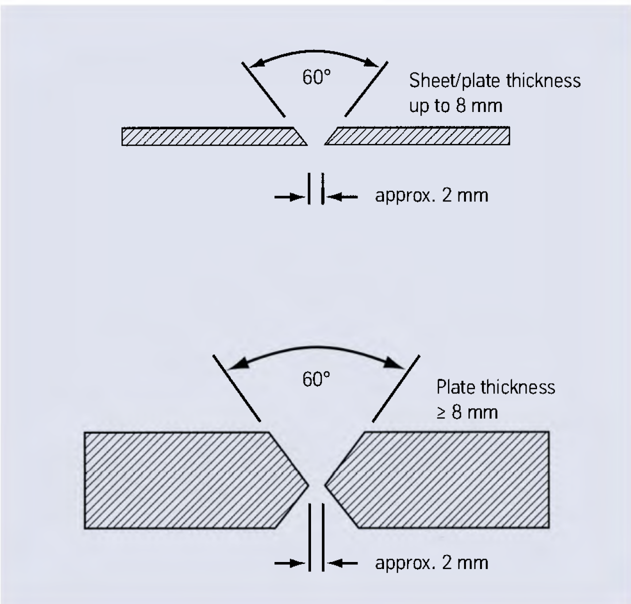

Fig. 7 – Edge preparation for welding Nicrofer 45 TM

Edge preparation
Preferably 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 cleanly finished. Careful grinding without overheating is permissible.

Included angle
The different physical behaviour of nickel alloys and special stainless steels compared with carbon steel generally manifests itself in a lower thermal conductivity. This should be allowed for by means of, among other things, wider root gaps (2mm ± 0.5 mm). An included angle of 60° is recommended for welding Nicrofer 45 TM, owing to the low viscosity of the weld metal and the small amount of shrinkage.

Striking the arc
The arc should only be struck in the weld area, e.g. on the faces to be welded, not on the surface of the metal. Strike marks lead to corrosion.

Welding processes
Nicrofer 45 TM has reduced weldability. For welding, the material should be in the solution heat treated condition and be free from scale, grease and markings. A zone approximately 25 mm wide on both sides of the joint should be ground to bright metal. Proven welding processes are TIG (GTAW) and MMA. The use of other welding processes should be agreed with our Welding Laboratory. When welding the root passes by the TIG (GTAW) process, care should be taken to ensure **optimum** root shielding, i.e. after welding the root, the weld must be free from oxides. Any tarnishing is to be removed. Argon 99.99 should always be used as the shielding gas for the root and the torch.

Filler metal
Only the material Nicrofer S 3028 (W.-Nr. ~ 1.4563) should be used as filler metal for TIG welding, while for manual arc welding, the electrode which corresponds to W.-Nr. 1.4563 should be used.

Welding parameters and influences (heat input)
Care should be taken to ensure that the work is performed with a deliberately chosen, low heat input. The inter-pass temperature should not exceed 120 °C and the stringer bead technique should be used. In this connection, it should also be ensured that the filler metal source is of the correct dimension and that dilution by the base metal is minimized.

Using these principles, the energy inputs per unit length shown by way of example in Table 10 can be achieved. The welding parameters should be monitored as a matter of principle.

	Ni	Cr	Fe	C	Mo	Cu	N
min	30.0	26.0	balance		3.0	1.0	0.04
max	32.0	28.0		0.015	4.0	1.4	0.07

Table 8 – Chemical composition (%) for Nicrofer S 3028 welding wire and welding rod

Ni	Cr	Fe	C	Mo	Cu
31.0	27.0	balance	< 0.03	3.8	1.2

Table 9 – Chemical composition (%) for deposited weld metal from the sheathed stick electrode

For all weldments, the special characteristics of this material should be taken into account at an early stage. Consultation with ThyssenKrupp VDM's experts is therefore recommended.

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 strength, amps
v = welding speed, cm/minute

Postweld treatment (pickling and brushing)
Pickling, if required or prescribed, is generally the last operation performed on the weldment. The information given under "Descaling" should also be noted. In such a case, the work should be carried out by specialized firms. Consultation with our specialists is strongly recommended. If the workmanship is of the highest quality, brushing immediately after welding, i.e. while the metal is still hot, can often produce the desired surface condition, i.e. heat tints can be completely removed.

Sheet/ plate thick- ness mm	Welding process	Filler metal dia- meter mm	Welding parameters Root A	V	Intermediate and final passes A	V	Welding speed cm/min	Heat input kJ/cm	Plasma gas Type and rate l/min
2.0	manual TIG	2.0	70	9			approx. 12	max. 3.5	Ar 99.99 8
6.0	manual TIG	2.0–2.4	90	10	110	11	approx. 12	max. 6.5	Ar 99.99 8
12.0	manual TIG	2.4	100	10	110	11	approx. 12	max. 6.5	Ar 99.99 8
8.0	MMA	2.5–3.25	90	10	60–80	approx. 24	approx. 25	max. 6.5	
12.0	MMA	2.5–3.25	90	10	60–80	approx. 24	approx. 25	max. 6.5	
In TIG welding work, care should be taken to ensure adequate root shielding with argon 99.99 so as to prevent contamination by atmospheric oxygen. All these figures are only a guide and are intended to facilitate setting of the welding machines.									

Table 10 – Welding parameters (guide values)

Nicrofer® 45 TM – alloy 45 TM

Availability
Nicrofer 45 TM is available in the following standard mill product forms.

Sheet and plate
Conditions:
Hot or cold rolled (hr, cr),
solution annealed,
with oxidized or descaled surface

Thickness mm			Width* mm	Length* mm
1.10	< 1.50	cr	2000	6000
≥ 1.50	< 6.0	cr	2400	8000
≥ 6.0	< 10.0	cr	2400	8000
≥ 6.0	< 10.0	hr	2400	8000
≥ 10.0	< 20.0	hr	2400	5000**
≥ 20.0*		hr		
inches			inches	inches
0.043	< 0.060	cr	80	240
≥ 0.060	< 1/4	cr	96	320
≥ 1/4	< 3/8	cr	96	320
≥ 1/4	< 3/8	hr	96	320
≥ 3/8	< 3/4	hr	96	200**
≥ 3/4*		hr		

* other sizes subject to special enquiry
** depending on piece weight

Discs and rings
Conditions:
Hot rolled or forged,
solution annealed,
with oxidized or descaled surface,
flame-cut or turned

Product	Weight kg	Thickness mm	O D* mm	I D mm
Disc	≤ 10000	≤ 300	≤ 3000	–
Ring	≤ 3000	≤ 200	≤ 2500	on request
	lb	inches	inches	inches
Disc	≤ 22000	≤ 12	≤ 120	–
Ring	≤ 6600	≤ 8	≤ 100	on request

* other sizes subject to special enquiry

Wire
Conditions:
Bright drawn, 1/4 hard to hard, bright annealed or with oxidized surface
Dimensions:
0.01 – 12.7 mm (0.0004 – 1/2 in) diameter
in coils and pay-off packs, on spools and spiders

Seamless tube and pipe
Production of seamless tubes and pipes is carried out at DMV Stainless BV using starting stock supplied by ThyssenKrupp VDM.

Rod and bar
Conditions:
Forged, rolled, drawn,
solution heat treated, pickled, machined,
peeled or ground

Product		forged* mm	rolled* mm	drawn* mm
round	d	≤ 100	15 – 75	12 – 65
square	a	40 – 100	15 – 100	12 – 65
flat a x b		40 – 80 x 200 – 600	5 – 20 x 120 – 600	10 – 20 x 30 – 80
hexagon	s	40 – 80	13 – 50	12 – 60
		inches	inches	inches
round	d	≤ 4	0.32 – 3	$\frac{1}{2}$ – $2\frac{1}{2}$
square	a	$1\frac{5}{8}$ – 4	$\frac{5}{8}$ – 4	$\frac{1}{2}$ – $2\frac{1}{2}$
flat a x b		$1\frac{5}{8}$ – $3\frac{1}{8}$ x 8 – 24	$\frac{3}{16}$ – $\frac{3}{4}$ x $5\frac{1}{2}$ – 24	$\frac{3}{8}$ – $\frac{3}{4}$ 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,
soft-annealed or stress relieved and hard,
pickled or bright annealed**

Thickness mm		Width mm	Coil I D mm			
0.04	≤ 0.10	4–200	300			
> 0.10	≤ 0.20	4–350	300	400	500	
> 0.20	≤ 0.25	4–750		400	500	600
> 0.25	≤ 0.60	5–750		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			
> 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	≤ 0.04	0.32–30		16	20	24
> 0.04	≤ 0.08	0.60–30		16	20	24
> 0.08	– 0.12	1.0 –30		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)

Technical publications

The following puplications concerning Nicrofer 45 TM may be obtained from ThyssenKrupp VDM GmbH:

M.B. Rockel, W.R. Herda, U. Brill, G.K. Grossmann
„Der Einsatz hochlegierter Nickelwerkstoffe in Hochtemperatur- und Nasskorrosionsbereichen von Abfallverbrennungsanlagen."
VDI-Berichte Nr. 917, 1992, 373 - 378

U. Brill, J. Klöwer
„Cronifer III TM und Nicrofer 45 TM: Zwei neue Werkstoffe für den Einsatz in Müllverbrennungsanlagen."
Z. Metall, September 1992, 921 - 926

U. Brill, J. Klöwer
"Corrosion Behaviour of High Silicon Alloys in Carbon-Bearing and High Sulphur Atmospheres."
Materials of High Temperatures, Vol. 11, Nos. 1 - 4, 1993, 151 - 158

U. Brill, M.B. Rockel
„Nickellegierungen in Müllverbrennungsanlagen."
Ingenieur-Werkstoffe 4 (1992), 2 - 4

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