Nicrofer® 3228 NbCe – alloy AC 66

Material Data Sheet No. 4033
December 2007 Edition

High-temperature alloy

A company of
ThyssenKrupp
Stainless

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Nicrofer® 3228 NbCe – alloy AC 66

Nicrofer 3228 NbCe is a high-chromium, austenitic nickel-chromium-iron high temperature alloy with additions of about 0.8% niobium and 0.10% cerium. Limiting the silicon and aluminum content significantly reduces occurence of internal oxidation.

The formation of a protective chromium oxide layer, which exhibits significantly improved adhesion due to the cerium addition, makes the alloy especially suitable for applications in waste incineration and petrochemical facilities.

Nicrofer 3228 NbCe is characterized by:

- excellent oxidation resistance up to 1000 °C (1830 °F)
- good heat resistance and creep rupture properties
- excellent resistance in oxidizing and reducing environments containing sulfur, carbon and nitrogen, even under cyclic conditions
- excellent properties in waste incineration and coal gasification environments at temperatures up to 850 °C (1560 °F)
- approved for pressure vessels and boilers with operating temperatures of -10 to 1000 °C (14 to 1832 °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	Flanges and Fittings
D DIN EN DIN VdTÜV	**W.-Nr. 1.4877** X6NiCrNbCe32-27	10095 497	 497		10095 497	10095 497	10095	10095		
F AFNOR										
UK BS										
USA ASTM ASME	UNS S33228		A 213/312 SA-213/312	A 249/312 SA-249/312	A 240/480 SA-240/480	A 314/479 SA-314/479	A 480 SA-480		A 314 SA-314	A 182/403 SA-182/403
ISO										

Table 1 – Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Nb	Al	Ce	P	S
min.	31.0	26.0	Rest	0.04			0.6		0.05		
max.	33.0	28.0		0.08	1.0	0.30	1.0	0.025	0.10	0.020	0.015
Some compositional limits of other specifications may vary slightly.											

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

Physical properties

Density	8.0 g/cm^3	0.289 lb/in.^{3}
Melting temperature	approx. 1360 °C	approx. 2480 °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	$\frac{\Omega \cdot circ\ mil}{ft}$	$\frac{GPa}{mm^2}$	10^3 ksi	$\frac{10^{-6}}{K}$	$\frac{10^{-6}}{°F}$
20	**68**	445	0.11	12	83	96	577	191	28.0		
100	212	500	0.12	14	97	100	602	185	26.8	15.1	8.4
200	392	525	0.13	16	111	104	626	179	26.0	15.5	8.6
300	572	525	0.13	17	118	108	650	172	24.9	15.9	8.8
400	752	550	0.13	19	132	111	668	166	24.1	16.2	9.0
500	932	575	0.14	20	139	114	686	159[1)]	23.1[1)]	16.5	9.2
600	1112	600	0.14	22	153	117	704	151[1)]	21.9[1)]	16.9	9.4
700	1292	610	0.15	23	159	119	716	144[1)]	20.9[1)]	17.3	9.6
800	1472	610	0.15	25	173	120	722	136[1)]	19.7[1)]	17.7	9.8
900	1652	610	0.15	26	180	122	734	128[1)]	18.6[1)]	18.1	10.1
1000	1832	645	0.15	28	194	124	746	119[1)]	17.3[1)]	18.4	10.2

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

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

Magnetic properties
Nicrofer 3228 NbCe cannot be magnetized. However, in the cold formed condition the alloy is slightly magnetic.

Metallurgical structure
The austenitic face-centered cubic structure of Nicrofer 3228 NbCe exhibits high thermal stability. The alloy does not form intermetallic phases, such as σ-phase. It does therefore not become embrittled in service at higher temperatures.

Mechanical properties

The following properties are applicable to Nicrofer 3228 NbCe in the hot or cold formed and solution-annealed condition.

Product	0.2 % Yield strength $R_{p\,0.2}$		1.0 % Yield strength $R_{p\,1.0}$		Tensile strength R_m		Elongation A_{50}	Brinell hardness
	MPa	ksi	MPa	ksi	MPa	ksi	%	HB
Sheet & plate Strip Rod & bar	≥ 185	27	≥ 215	31	500 – 750	73 – 109	≥ 30 (across) ≥ 35 (longitu-dinal)	max. 217* (For infor-mation only)
*According to ASTM								

Table 4 – Mechanical properties at room temperature according to VdTÜV data sheet No. 497.

Temperature		0.2% Yield strength $R_{p0.2}$		1.0% Yield strength $R_{p1.0}$		Tensile strength R_m	
°C	°F	MPa	ksi	MPa	ksi	MPa	ksi
100	212	160	23.2	190	27.6	450	65.3
200	392	140	20.3	170	24.7	430	62.4
300	572	120	17.4	145	21.0	410	59.5
350	662	110	16.0	135	19.6	400	58.0
400	752	105	15.2	130	18.9	390	56.6
450	842	100	14.5	125	18.1	380	55.1
500	932	95	13.8	115	16.7	370	53.7
550	1022	90	13.1	110	16.0	360	52.2
600	1112	90	13.1	110	16.0	340	49.3
650	1202	85	12.3	105	15.2	300	43.5
700	1292	80	11.6	100	14.5	250	36.3

Table 5 – Minimum short-time mechanical properties of solution annealed Nicrofer 3228 NbCe at elevated temperatures according to VdTÜV data sheet 497.

The mechanical properties remain unchanged after exposure up to 30,000 hrs at temperatures up to 1000 °C.

Temperature		Creep-rupture strength			
		$R_{m/10^4h}$		$R_{m/10^5h}$	
°C	°F	MPa	ksi	MPa	ksi
580	1076	199	28.9	160	23.2
600	1112	175	25.4	140	20.3
650	1200	120	17.4	92	13.3
700	1292	80	11.6	52	7.5
750	1382	46	6.7	27	3.9
800	1472	25	3.6	9	1.3
850	1562	15.5	2.3	10	1.5
900	1652	10.0	1.5	5.0	0.7
950	1742	6.0	0.9	3.0	0.4
1000	1832	(3.5)	(0.51)	(1.5)	(0.22)
The values in brackets are extrapolated.					

Table 6 – Typical long-term mechanical properties of solution annealed Nicrofer 3228 NbCe at elevated temperatures.

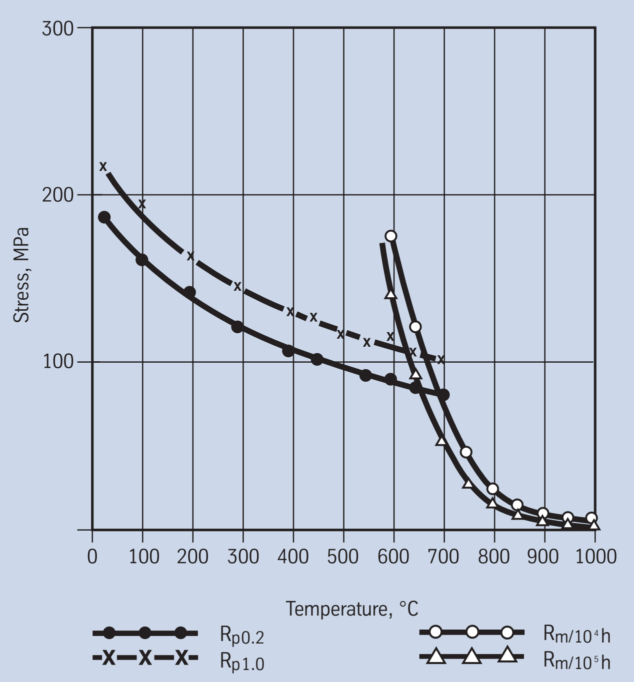

Fig. 1 – Yield strength and creep-rupture strength of Nicrofer 3228 NbCe.

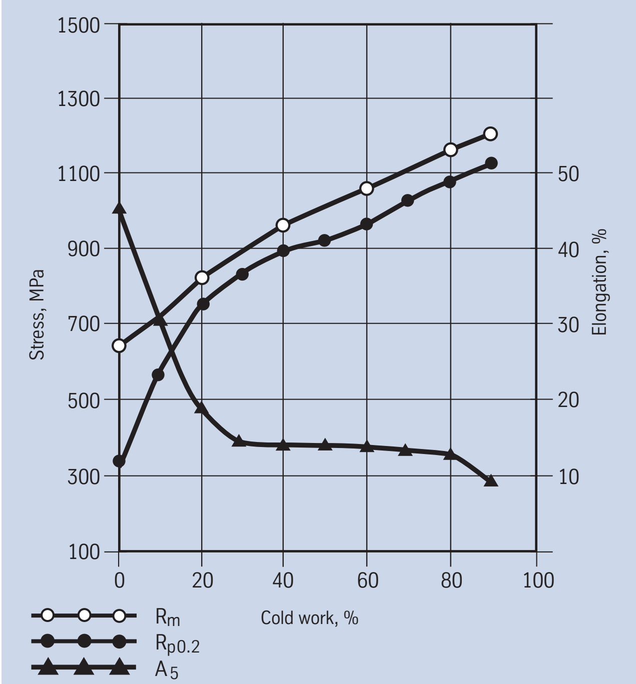

Fig. 2 – Effect of cold work on the mechanical properties of Nicrofer 3228 NbCe.

ISO V-notch impact toughness

Minimum values at room temperature:

Sample direction	a_k J/cm²	KV J
longitudinal	150	120
transverse	100	80

Note: In any 3 Test sequence only one result is permitted to fall at most 30% below the respective average value.

Relaxation cracking susceptibility
Unlike some other high temperature alloys Nicrofer 3228 NbCe in the solution-annealed condition has been found not to be susceptible to relaxation cracking in service at operating temperatures between 500 and 900 °C (932 and 1652 °F).

Corrosion resistance
According to DIN EN 10095 Nicrofer 3228 NbCe is termed a heat-resisting alloy, on account of its excellent resistance above 550 °C (1022 °F) against hot gases and combustion products, as well as against molten salt corrosion, while at the same time exhibiting reasonable mechanical short-time and long-term properties.

In contrast to the nickel and iron content, chromium forms an oxide layer already at very low oxygen partial pressures which impedes diffusion of impairing components of an aggressive medium and thus significantly slows corrosion attack. However, to ensure self-healing of the surface layer which can become damaged for example through creep processes, it is essential that the chromium concentration at the phase boundary between the cover layer and the matrix does not fall below 18%. To assure this the chromium content of Nicrofer 3228 NbCe is adjusted to 26 – 28% which, even at low oxygen partial pressures, leads to formation of a stable chromium oxide layer as a diffusion barrier and prevents chromium depletion below 18% in the matrix near the surface.

The excellent resistance towards high-temperature corrosion is further enhanced through very low concentrations of cerium, which substantially improves the adhesion of the oxide scales even under thermal cyclic conditions.

Fig. 3 shows the effect of the cerium content of Nicrofer 3228 NbCe compared to alloy 800 (UNS N08800), an Fe-Ni-Cr alloy variation with low Si-content, but without cerium under thermal cyclic conditions. For both alloys the weight loss was determined after exposure to 1000 h cycles at 1050 °C (1922 °F) with subsequent cooling to room temperature. The results of 10 cycles with a total time of 1000 hrs show that during oxidation a weight gain is initially observed. During cooling down to room temperature, however, a weight loss is experienced which for the Fe-Ni-Cr alloy without cerium is approximately constant for each cycle. On the other hand for Nicrofer 3228 NbCe the weight loss decreases with each cycle. This indicates that cerium significantly improves the adhesion of the chromium oxide layer.

Furthermore the alloying elements aluminium and silicon are kept as low as melting technology permits. This avoids internal oxidation which is already caused by very low concentrations of these elements, as well as titanium. These elements possessing a very high affinity to oxygen, thus lead to accelerated corrosion during high-temperature service, as illustrated for alloy 800 in Fig. 5.

Pre-oxidation in contact with air or the use of material which has been pre-oxidized before being placed in service can result in significantly improved corrosion resistance in service.

The following graphs show the results of comparative testing of Nicrofer 3228 NbCe and other alloys in various media.

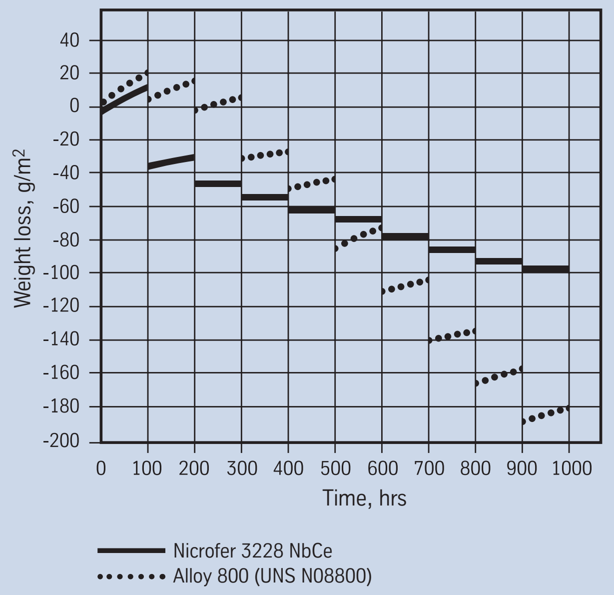

Fig. 3 – Effect of cerium content (< 0.1%) on the weight loss of austenitic Fe-Ni-Cr alloys under thermal cyclic conditions involving 10 cycles of 100 hrs each at 1050 °C (1922 °F) followed by cooling to room temperature.

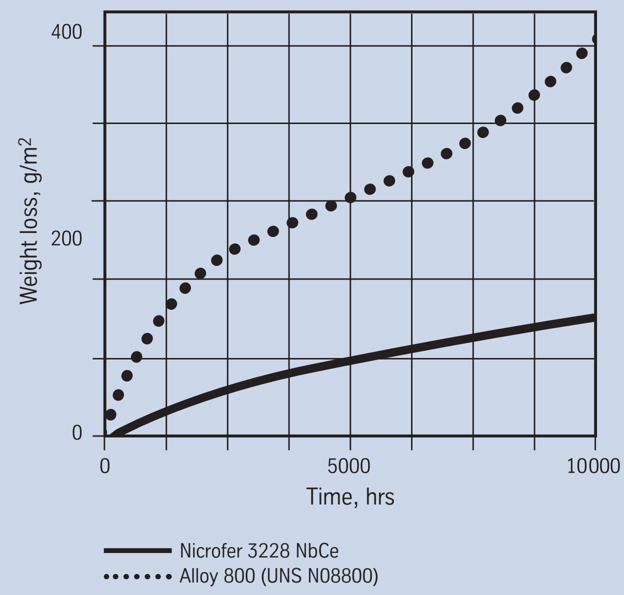

Fig. 4 – Weight loss comparison in air at 980 °C (1796 °F) during 10,000 hrs simulating oxidation behaviour under oxidizing conditions at high temperature of Nicrofer 3228 NbCe with alloy 800.

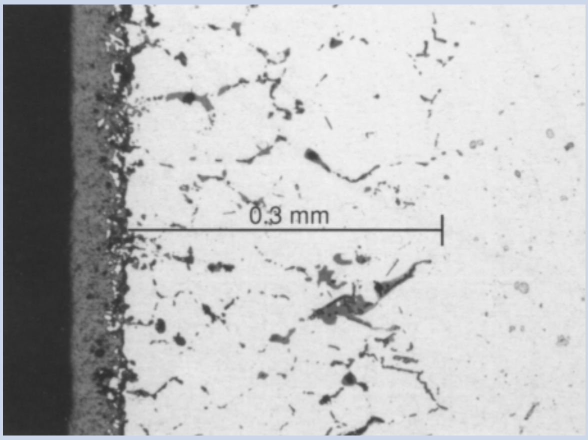

Fig. 5 – Internal oxidation of alloy 800 (N08800) in an oxidizing atmosphere at 980 °C (1796 °F) after 10,000 hrs.

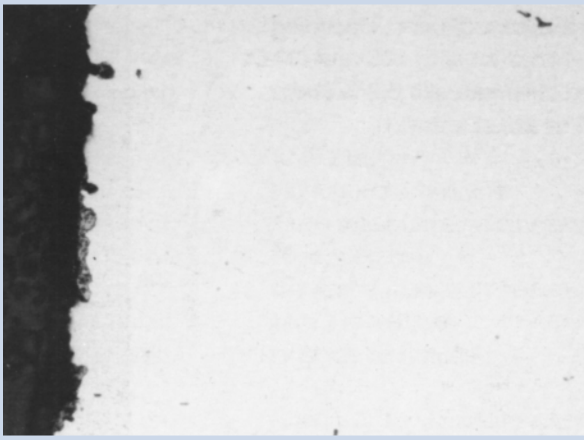

Fig. 6 – Nicrofer 3228 NbCe without evidence of internal oxidation in an oxidizing atmosphere at 980 °C (1796 °F) after 10,000 hrs.

After approx. 5000 hrs the corrosion attack is distinctly intensified which, even in the creep range, leads to a reduction in the load-bearing cross section. The illustration in Fig. 4 clearly indicates, however, the superior behaviour of Nicrofer 3228 NbCe compared to alloy 800.

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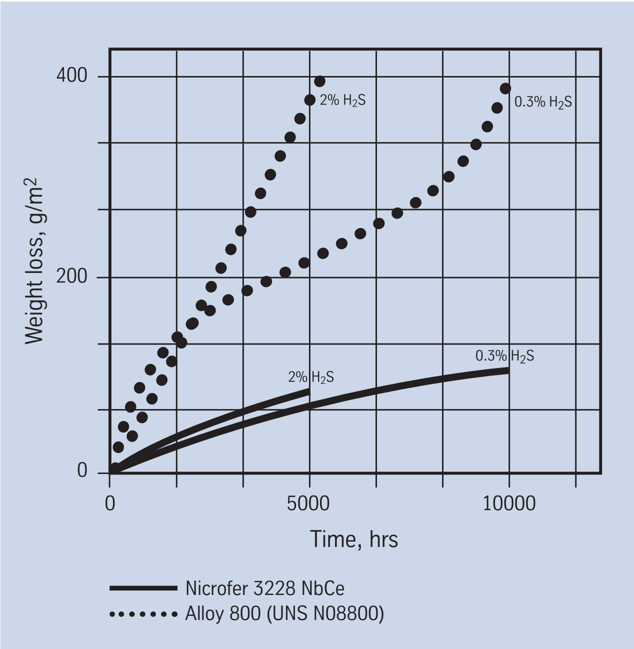

Fig. 7 – Comparison of weight loss of Nicrofer 3228 NbCe and alloy 800 respectively in high- and low-sulfur containing process gases at 940 °C (1724 °F) after 10,000 hrs.

Also in sulfidizing atmospheres Nicrofer 3228 NbCe shows a significantly lower weight loss than 800 as indicated in Fig. 7.

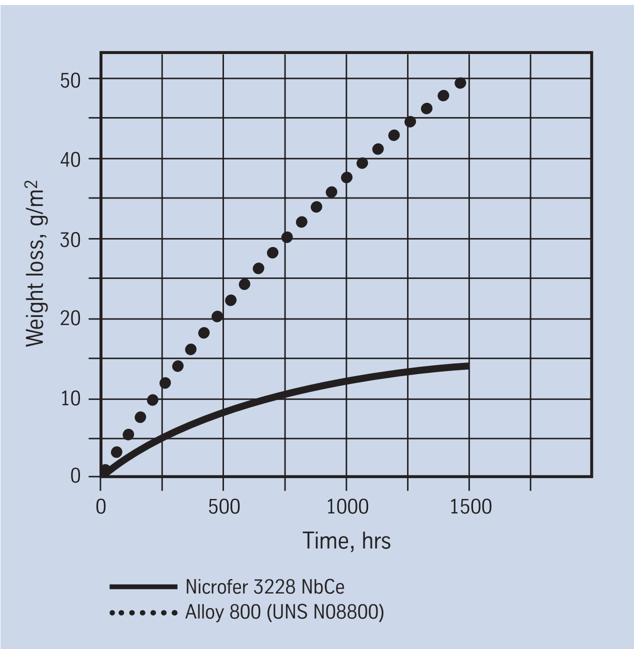

Fig. 8 – Comparison of weight loss of Nicrofer 3228 NbCe and alloy 800 in an $H_2/H_2O/HCl$ atmosphere at 900 °C (1652 °F) after 1500 hrs.

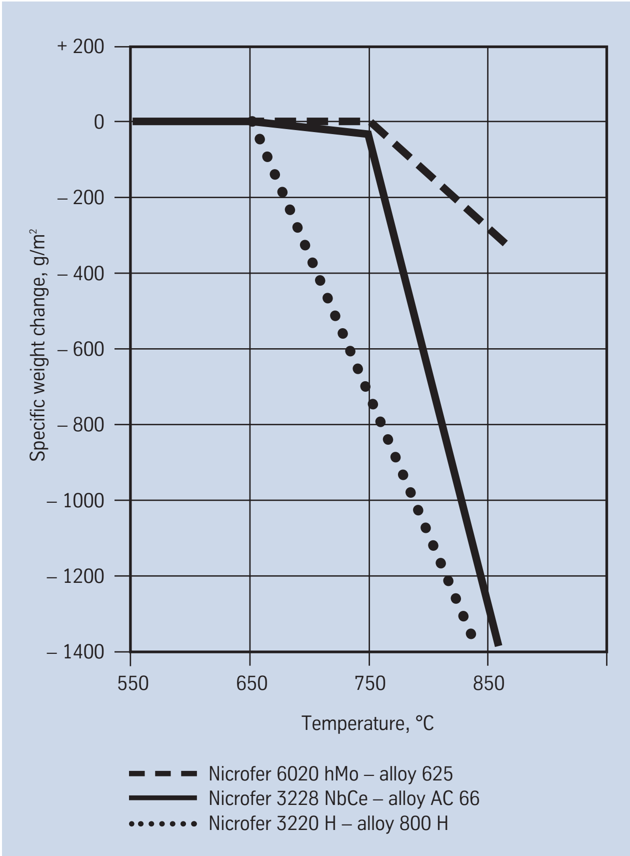

Fig. 9 – Influence of temperature on behaviour in a typical waste incineration atmosphere under cyclic conditions: Comparison of specific weight change in a simulated waste incineration environment consisting of nitrogen with 9% O_2, 2.5 g/m³ HCl and 1.3 g/m³ SO_2 after 1000 hrs cyclic exposure at temperatures of 550 to 850 °C (1022 to 1562 °F).

Coal often contains significant amounts of chlorides. During gasification, these may lead, for example, to high HCl contents in the gas atmosphere. Fig. 8 shows the weight loss of Nicrofer 3228 NbCe and alloy 800 after exposure in an atmosphere with 4.5% HCl at 900 °C (1652 °F) for 1500 hrs. As indicated in other media Nicrofer 3228 NbCe shows also in this case a significantly lower weight loss than experienced with alloy 800.

Applications

On account of its high strength values and its excellent resistance to sulfurous atmospheres, Nicrofer 3228 NbCe is being used in a wide range of applications:

- Environmental technology: thermal disposal of household and specialized wastes, incineration and fluidized bed combustion (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: furnaces operating especially under sulfidizing and/or carburizing process conditions, burner components for fuels which contain sulfur, heat exchangers in sulfidizing and/or carburizing media.
- Manufacture of heat treatment and industrial furnaces: gas carburizing furnaces (furnace shell and lining), heat treatment furnaces with gaseous reaction products (conveyor belts, burner components, furnace shell and linings, internal furnace components).

Fabrication and heat treatment

Nicrofer 3228 NbCe can readily be hot- and cold worked and machined.

Heating

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

Nicrofer 3228 NbCe may become 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 3228 NbCe may be hot worked in the temperature range 1200 to 850 °C (2190 to 1560 °F), followed by water quenching or rapid air cooling

Heat treatment after hot working is recommended to achieve optimum properties particularly high creep strength. For heating up, workpiecec should be charged into the furnace at maximum working temperature (solution annealing temperature).

Cold working

For cold working the material should be in the annealed condition. Nicrofer 3228 NbCe has a work-hardening rate simular to austenitic stainless steels. This should be taken into account when selecting forming equipment.

Interstage annealing may be necessary with high degress of cold forming. After cold working with more than 15% deformation or more than 10% deformation, if full use of the design values are contemplated, solution annealing is required before use.

Heat treatment

Solution heat treatment should be carried out in the temperature range 1120 to 1180 °C (2050 to 2160 °F).

Water quenching is essential for optimum creep properties. For thicknesses below about 3 mm (0.12 in.) rapid air cooling is possible.

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 form a protective oxide layer during service. The necessity of descaling should therefore be checked before ordering Nicrofer 3228 NbCe.

Oxides of Nicrofer 3228 NbCe 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, the surface oxide layer must be broken up by abrasive blasting, by carefully performed grinding or by pretreatment in a fused salt bath. Particular attention must be paid to the pickling time and temperature.

Machining

Nicrofer 3228 NbCe should be machined in solution-treated condition. As the alloy readily work-hardens suitably finished tools must be used to prevent heavy surface hardening which would render further maching problematic. Therefore only low cutting speeds should be used, with the tool being engaged at all times. An adequate depth of cut is important in order to cut below the previously formed work-hardened zone.
Owing to the low thermal conductivity of Nicrofer 3228 NbCe sufficient cooling must be provided for during machining.

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 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 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 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 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 (2 mm ± 0.5 mm), while larger included angles (60 – 70°), as shown in Fig. 10, 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 3228 NbCe can be joined to itself and to many other metals by conventional welding processes. These include GTAW (TIG), plasma arc and SMAW (MMA). Pulsed arc welding is the preferred technique.

For welding, Nicrofer 3228 NbCe 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 6020 – FM 625 UNS N06625 AWS A5.14: ERNiCrMo-3 DIN EN ISO 18274: S Ni 6625 (NiCr22Mo9Nb) (W.-Nr. 2.4831)
Covered electrodes:	UNS W86112 AWS A5.11: ENiCrMo -3 DIN EN ISO 14172: E Ni 6625 (NiCr22Mo9Nb) (W.-Nr. 2.4621)

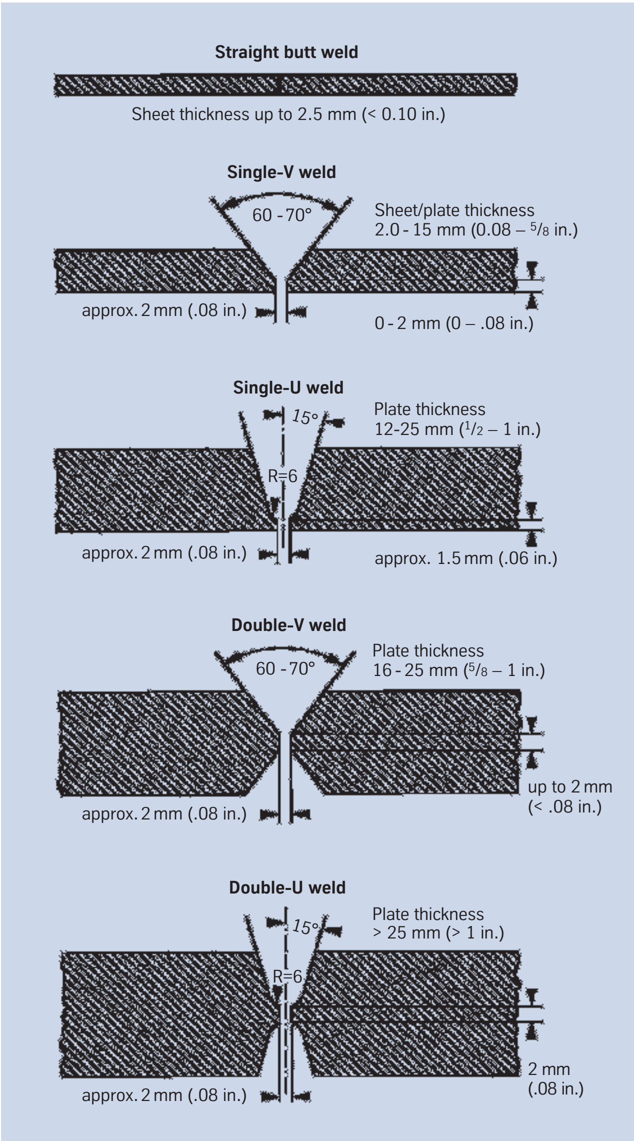

Fig. 10 – Edge preparation for welding of nickel alloys and special stainless steels.

Welding parameters and influences (heat input)

Care should be taken that the work is performed with a deliberately chosen, low heat input as indicated in Table 8 by way of example. Use of the stringer bead technique should be aimed at. Interpass temperature should be kept below 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.

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 normaly required.

Sheet/plate thickness mm	Welding process	Filler metal Diameter mm	Filler metal Speed m/min.	Welding parameters Root pass[1)] I A	Root pass U V	Intermediate and final passes I A	Intermediate and final passes U V	Welding speed cm/min.	Shielding gas Type & rate l/min.	Plasma gas Type & rate l/min.
3.0	Manual GTAW	2.0		90	10	110 – 120	11	approx. 15	Ar 4.6 8 – 10	
6.0	Manual GTAW	2.0 – 2.4		100 – 110	10	120 – 140	12	14 – 16	Ar 4.6 8 – 10	
8.0	Manual GTAW	2.4		100 – 110	11	130 – 140	12	14 – 16	Ar 4.6 8 – 10	
10.0	Manual GTAW	2.4		100 – 110	11	130 – 140	12	14 – 16	Ar 4.6 8 – 10	
3.0	Autom. GTAW	1.2	approx. 1.2	Manual GTAW		150	11	25	Ar 4.6 12 – 14	
5.0	Autom. GTAW	1.2	approx. 1.4	Manual GTAW		180	12	25	Ar 4.6 12 – 14	
4.0	Plasma arc	1.2	approx. 1.0	approx. 180	25			30	Ar 4.6 30	Ar 4.6 3.0
6.0	Plasma arc	1.2	approx. 1.0	200 – 220	26			26	Ar 4.6 30	Ar 4.6 3.5
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	approx. 22			
16.0	SMAW	4.0		70 – 100	approx. 22	90 – 130	approx. 22			

[1)] In all gas-shielded welding operations, ensure adequate back shielding with Ar 4.6 (pure argon).
These figures are only a guide and are intended to facilitate setting of the welding machines.

Table 7 – Welding parameters (guide values).

Welding process	Heat input per unit length kJ/cm
GTAW, manual, fully mechanized	max. 8
SMAW, manual metal arc (MMA)	max. 7
Plasma arc	max. 10

Table 8 – Heat input per unit length (guide values).

Availability

Nicrofer 3228 NbCe is available in the following standard product forms:

Sheet & plate

Conditions:
hot or cold rolled (hr, cr),
thermally treated and descaled

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
> 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 and conditions subject to special enquiry
[2] maximum piece weight: 2700 kg (6000 lbs); up to 4500 kg (9900 lbs) subject to special enquiry

Blanks

Conditions as for sheet & plate

Customized, laser-cut blanks according to drawing may be available in the thickness range 1.0 – 20 mm (0.040 – 0.800 in.) 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

Seamless tube and pipe

Using ThyssenKrupp VDM cast materials seamless tubes and pipes are produced and may be available from Mannesmann DMV STAINLESS Deutschland GmbH, Wiesenstr. 36, D-45473 Mühlheim/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.

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