Nicrofer® 3033 – alloy 33

Material Data Sheet No. 4042
March 2000 Edition

Corrosion-resistant alloy

A company of
ThyssenKrupp
Stainless

ThyssenKrupp VDM

ThyssenKrupp

Nicrofer® 3033 – alloy 33

Nicrofer 3033 – alloy 33 is a high-chromium austenitic alloy developed by ThyssenKrupp VDM. This alloy combines ease of fabrication with outstanding resistance to highly oxidizing media such as concentrated sulphuric acid. Despite its low molybdenum content, it shows excellent resistance to localized corrosion in halide media.

The nitrogen content ensures high mechanical properties with good ductility.

Nicrofer 3033 is characterized by:
- outstanding resistance to strongly oxidizing media
- excellent resistance to localized corrosion in halide solutions
- excellent resistance to nitric/hydrofluoric acid mixtures
- excellent resistance to caustic soda
- high strength and toughness
- ease of fabrication
- good weldability
- good metallurgical stability
- approved authorization for pressure vessel use in the temperature range -196 to 450 °C (-320 to 840 °F).

Designations and standards

Country National standards	Material designation	Specification							
		Chemical composition	Tube and pipe seamless	 welded	Sheet and plate	Rod and bar	Strip	Wire	Forgings
D VdTÜV-Wbl. SEW	**W.-Nr. 1.4591** X1CrNiMoCuN33-32-1	516 400	400	400	516 400	516 400	400	400	516 400
F AFNOR									
UK BS									
USA ASTM ASME ASME Code Case	UNS R20033		B 622 SB 622 2227	B 619, B 626 SB 619, SB 626 2227	B 625 SB 625 2227	B 649 SB 649 2227	B 625 SB 625 2227	B 649	B 472, B 564 SB 564 2227
ISO									

Table 1 - Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Cu	Mo	N	P	S
min.	30.0	31.0	balance				0.3	0.5	0.35		
max.	33.0	35.0		0.015	2.0	0.5	1.2	2.0	0.6	0.020	0.010

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

Physical properties

Density	7.9 g/cm³	0.285 lb/in.³
Melting range	1330 – 1370 °C	2430 – 2500 °F
Permeability at 20 °C/68 °F (RT)	≤ 1.001	

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	13.4		~ 104	~ 625	195	28.3		
93	**200**								26.8		8.5
100	212			14.6		107	643	185		15.3	
200	392			16.0		109	655	176		15.7	
204	**400**								25.5		8.7
300	572			17.5		112	673	170		16.1	
316	**600**								24.5		9.0
400	752			19.0		114	685	163		16.4	
427	**800**								23.5		9.2
500	932			20.4		116	697	159		16.7	

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

Mechanical properties

The following properties are applicable to Nicrofer 3033 in the indicated forms and size ranges, and in the solution-treated condition. Specified properties of material outside these size ranges are subject to special enquiry. VdTÜV Data Sheet values may be used at present for sheet and plate as well as bars and forgings.

Shett and plate	up to	50	mm	2	in.
Strip	up to	3	mm	1/8	in.
Rod, bar, forgings	up to	150	mm	6	in.
Wire	up to	12.7	mm	1/2	in.

Form	0.2 % yield strength		1.0 % yield strength		Tensile strength		Elongation A_5 [1]	Brinell hardness (informative)
	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%	HB
Strip	500	72	550	80	900	130	35	–
Other product forms	380	55	420	61	720	104	40	max. 240

[1] A80 for sheet and strip of ≤ 3 mm thickness

Table 4 – Minimum mechanical properties at room temperature.

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Form	0.2 % yield strength N/mm² at … °C					1.0 % yield strength N/mm² at … °C				
	100	200	300	400	500	100	200	300	400	500
All	320	270	240	220	210	350	300	270	250	240

Form	ksi at … °F					ksi at … °F				
	200	400	600	800	1000	200	400	600	800	1000
All	46.7	39.0	33.9	31.3	(29.7)	51.0	43.2	38.4	35.7	(34.1)

Table 5 – Minimum mechanical properties at elevated temperatures according to VdTÜV Data Sheet 516.

ISO V-notch impact strength
acc. to DIN EN 10045-1 at room temperature.
Mean value of 3 test pieces
longitudinal/transverse

Sheet/plate	≥ 188 J/cm²
Rod, bar, forgings	≥ 150 J/cm²

Temperature		Maximum allowable stress	
°C	°F	N/mm²	ksi
38	**100**		27.3
93	**200**		27.3
100	212	188	
149	**300**		25.7
200	392	170	
204	**400**		24.5
260	**500**		23.5
300	572	157	
316	**600**		22.8
371	**700**		22.1
400	752	150	
427	**800**		21.5

[1] metric values determined by interpolation

Table 6 – Maximum allowable stress values according to ASME Code Case 2227.

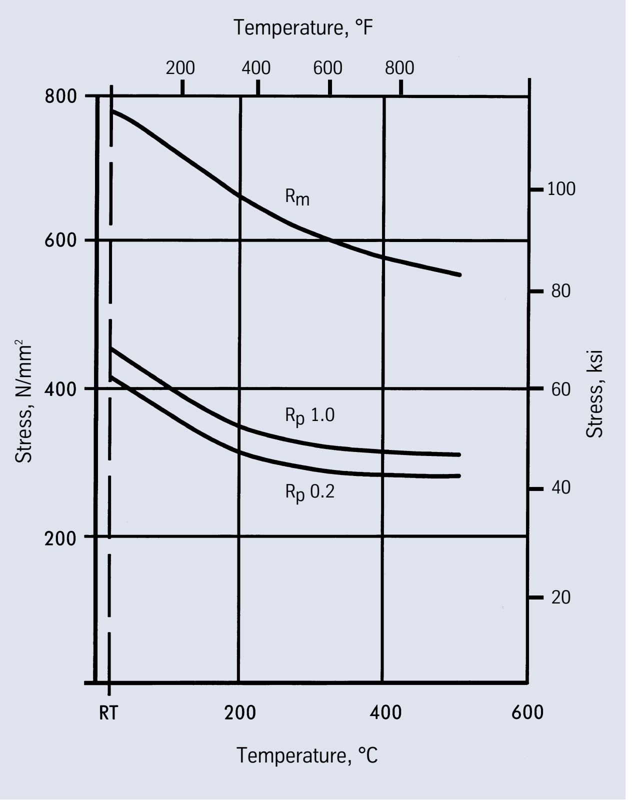
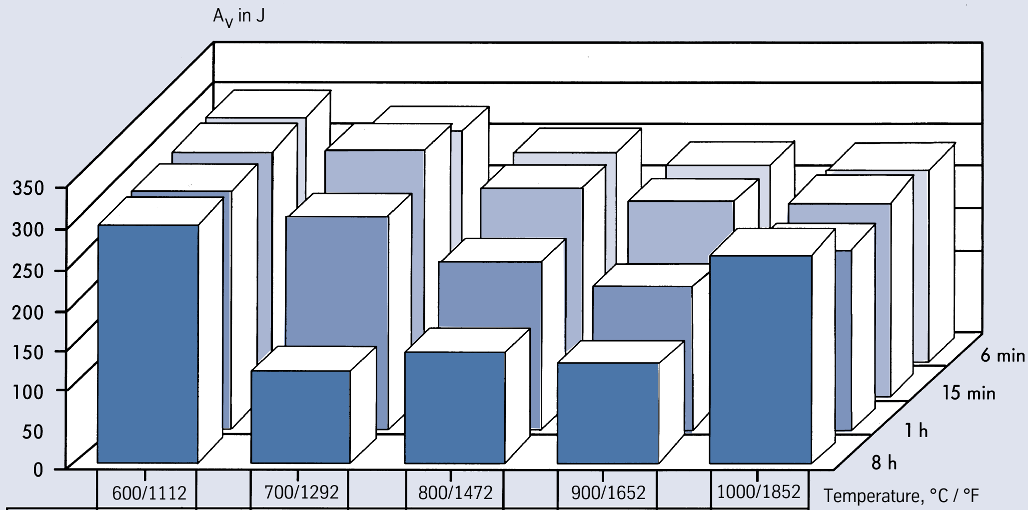


Fig. 1 – Typical mechanical properties of Nicrofer 3033 – alloy 33 sheets in the solution heat-treated condition.



	600/1112	700/1292	800/1472	900/1652	1000/1852
6 min	297	280	255	237	229
15 min	> 300	> 300	250	239	233
1 h	> 300	266	211	179	225
8 h	> 300	116	141	123	261

A_V in J

Fig. 2 – Time-temperature-impact strength diagram of Nicrofer 3033 – alloy 33, established on ISO-V-notch samples at ambient temperature; starting condition solution annealed, A_V > 300 J. Typical values.

Metallurgical structure
Nicrofer 3033 has a face-centred cubic structure. Its content of approx. 0.4 % nitrogen together with 31 % nickel stabilizes the austenitic structure and reduces the rate of precipitation of intermetallic phases.

Corrosion resistance
The newly developed austenitic material Nicrofer 3033 has an extremely high chromium content of 33 %, which forms the basis of its resistance to corrosion in oxidizing media. The small amount of added molybdenum improves its resistance in phosphoric acid, and the copper content facilitates passivation in sulphuric acid.

Besides excellent resistance to nitric-hydrofluoric acid mixtures, this alloy also has an outstanding resistance to corrosion by alkaline media.

Its resistance to pitting and crevice corrosion in chloride media and to chloride-induced stress-corrosion cracking is also outstanding.

Optimum corrosion resistance can only be ensured if the material is in clean, bright condition when used.

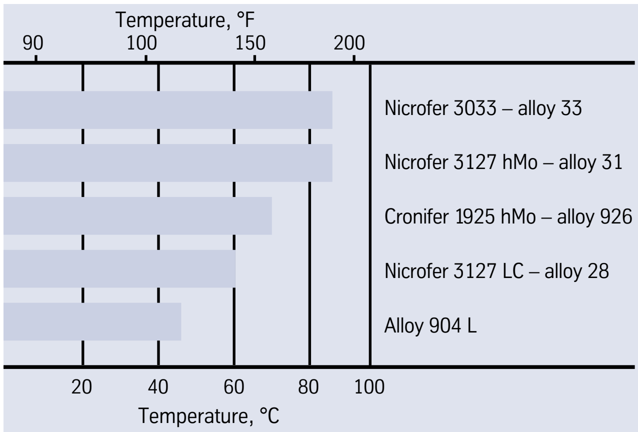


Fig. 3 – Critical pitting temperatures (CPT) of Nicrofer 3033 – alloy 33 and other special stainless steels, tested in 10 % $FeCl_3 \cdot 6\,H_2O$ solution for 24 hrs.

Nicrofer® 3033 – alloy 33

ThyssenKrupp VDM Alloy designation	20 % HNO_3 + 3 % HF	20 % HNO_3 + 5 % HF	20 % HNO_3 + 7 % HF	20 % HNO_3 + 3 % HF	20 % HNO_3 + 5 % HF	20 % HNO_3 + 7 % HF
	Test temperature 25 °C (77 °F)			Test temperature 50 °C (122 °F)		
AISI 316 Ti	3.7	6.8	6.3	19.0[1]	27.0[1]	37.0[1]
Nicrofer 3127 LC – alloy 28	0.03	0.04	0.07	0.20	0.32	0.45
Nicrofer 3033 – alloy 33	0.01	0.01	0.02	0.09	0.12	0.19
Test time 3 x 7 days	[1] Test time 7 days					

Table 7 – Corrosion rates of Nicrofer 3033 – alloy 33 and various other materials in nitric/hydrofluoric acid mixtures at 25 °C (77 °F) and 50 °C (122 °F) in mm/yr (Conversion from mm/yr to mpy: x 40).

Medium	Temperature °C	Temperature °F	Test time days	Corrosion rate mm/yr
H_2SO_4 – 98 %	100	212	7	0.04
	150	302	7	0.08
	200	392	7	0.04
H_3PO_4 – 85 %	100	212	1	0.20
	100	212	7	0.08
	154	309	1	1.07
NaOH – 25 %	75	167	28	< 0.01
	104*	219*		< 0.01
50 %	75	167		< 0.01
	100	212		< 0.01
	146*	295*		< 0.01

**Boiling temperature. Conversion from mm/yr to mpy: x 40*

Table 8 – Corrosion rate of Nicrofer 3033 – alloy 33 sheet in various media as a function of concentration and temperature.

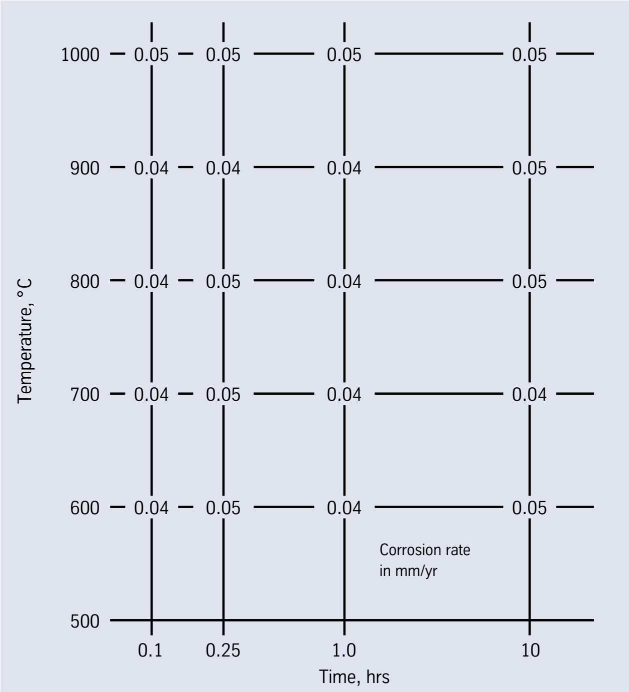


Fig. 4 – Time-temperature-sensitisation diagram (TTS) of Nicrofer 3033 – alloy 33. Huey Test, 15 cycles of 48 hrs.

Applications
Typical applications for Nicrofer 3033 are:

- sulphuric acid production plant
- sulphuric acid heat recovery and distribution systems
- nitric-hydrofluoric acid pickling plant
- seawater systems
- plate or tubular heat exchangers using brackish or seawater as coolant
- bleaching plant for chemical pulp

Fabrication and heat treatment
Nicrofer 3033 is a wrought alloy and can be readily fabricated by the usual industrial techniques.

It is important for the workpieces to be clean and free from any kind of contamination before and during heat treatment.

Nicrofer 3033 may be damaged if heated in the presence of sulphur, phosporus, lead and other low-melting metals. Such contaminants are also present in marking and temperature-indicating paints or crayons, lubricating grease, oils, fuels and the like.

The sulphur content of the fuels should be as low as possible. Natural gas should contain less than 0.1 wt. % sulphur. Fuel oil containing max. 0.5 wt. % sulphur is also suitable.

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 3033 may be hot-worked in the range 1200 to 1000 °C (2190 to 1830 °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 should be charged into the furnace at a maximum working temperature of approx. 1200 °C (2190 °F).

Cold working
Cold working should be carried out on solution heat-treated material. Nicrofer 3033 has a much higher work-hardening rate than other austenitic stainless steels and the forming equipment must be adapted accordingly.

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

After cold reduction of more than 15 %, final solution heat treatment is recommended.

Heat treatment
Solution heat treatment should be carried out in the temperature range 1100 to 1150 °C (2010 to 2100 °F) preferably at 1120 °C (2048 °F). The material should be charged into the furnace at temperature. Water quenching is essential for thicknesses above 3 mm (1/8 in). Below 3 mm, rapid air cooling may be used.

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

Descaling
Oxides of Nicrofer 3033 and discoloration adjacent to welds are adherent as on other 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 fine-grinding.

Machining
Nicrofer 3033 should be machined in the solution heat-treated condition. The alloy's high work-hardening rate should be considered, i.e. only low surface cutting speeds are possible compared with low-alloyed standard austenitic stainless steels. Tools should be engaged at all times. Heavy feeds are important in getting below the work-hardened 'skin'.

Advice on welding
When welding high-alloyed special stainless steels, the following instructions should be followed:

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 stainless steels. Brushes should be made of rustproof materials. Fabricating and working machinery such as shears, presses or rollers should be equipped with means (felt, cardboard, plastic sheet) of keeping out any ferrous particles which can be pressed into the surface of the material and ultimately lead to corrosion.

Cleaning
Cleaning of the base metal in the weld area (both sides) and the filler metal (e.g. welding rod) should be carried out with Acetone.

No trichloroethylene ("TRI"), no perchloroethylene ("PER"), no carbon tetrachloride ("TETRA") should be used.

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 clearly 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 and a higher rate of thermal expansion. This should be allowed for by means of, among other things, wider root gaps or openings (2mm ± 0.5), while larger included angles (70°) should be used for the individual butt joints owing to the viscous nature of the molten metal, in order to counteract to the pronounced shrinkage tendency.

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 weldment. Striking marks lead to corrosion.

Welding process
Nicrofer 3033 is weldable. For welding, the material should be free from scale, grease and markings.

According to the current qualification status, Nicrofer 3033 is weldable by the GTAW process with matching filler. For GTAW welding of the root, care should be taken to ensure **optimum** root backing (99.99 % argon), i. e. the weld seam should be free from oxides after welding the root. Any tarnishing should be removed.

As shielding gas, **argon with max. 5 % hydrogen** should be used.

Filler metal
The welding filler metal normally used is:
Nicrofer S 3033
W.-Nr. 1.4591

Welding parameters and influences (heat input)
Care should be taken that the work is performed with a deliberately chosen, low heat input. The inter-pass temperature should **not** exceed 120 °C (250 °F) and the stringer bead technique should be used.

In this context, it is important to note that the high nitrogen content makes it necessary to work with very thin beads (little weld metal, multiple-bead technique), so as to give the liquid weld metal the opportunity to outgas and to prevent the formation of voids. Residues on the weld edges should be completely removed by **milling** (grinding is unacceptable) after applying each bead.

For wall thickness upwards of around 20 mm, the intermediate passes should be welded with the filler metal Nicrofer S 3028 (W.-Nr. 1.4563) and capped with at least two passes of the matching filler Nicrofer S 3033. Consultation with our Welding Laboratory is advisable.

Adherence to the above instructions results in appropriate heat inputs, which are shown in Table 9 by way of example. The welding parameters should be monitored as a matter of principle.

For all weldments, the special characteristics of this material should be taken into account at an early stage. Consultation with ThyssenKrupp VDM´s specialists 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

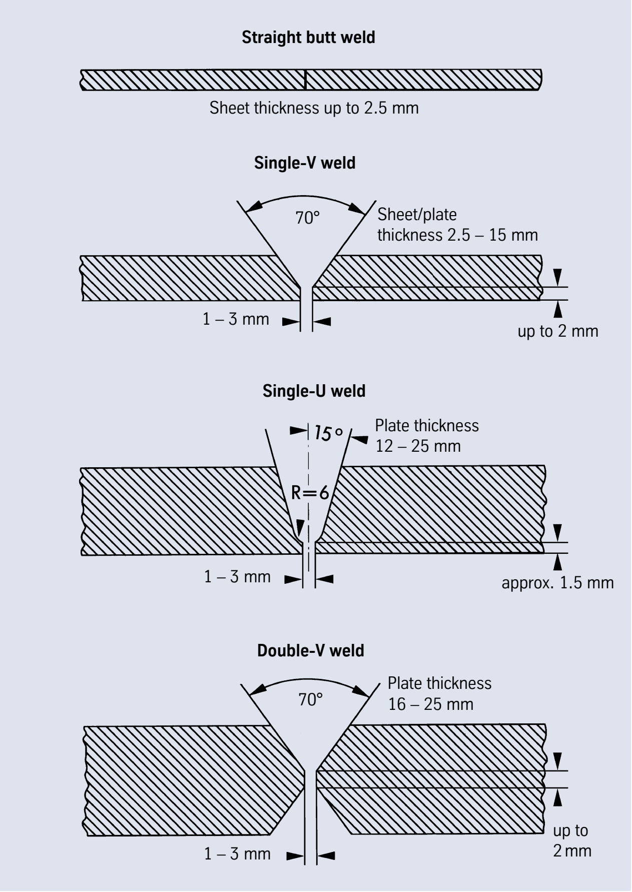


Fig. 5 – Edge preparation for welding of special stainless steels.

Sheet/ plate thickness mm	Welding process	Filler metal Diameter mm	Speed m/min	Welding parameters Root pass A	V	Intermediate and final pass A	V	Welding speed cm/min	Flux/ shielding gas rate l/min	Heat input kJ/cm
2.0	manual GTAW	2.0		70	9			15	Argon W 5 8	max. 3.5
6.0	manual GTAW	2.0–2.4		90	10	120	11	15	Argon W 5 8	max. 6.5
12.0	manual GTAW	2.4		100	10	140	14	15	Argon W 5 8	max. 6.5

Heat dissipation is not taken into account in the above figures.
In GTA welding operations, it is imperative to ensure adequate back shielding with argon 99.99, in order to avoid impurities due to atmospheric oxygen.
These figures are only a guide and are intended to facilitate setting of the welding machines.

Table 9 – Welding parameters (guide values).

Postweld treatment (pickling and brushing)
Pickling, if required or prescribed, is generally the last operation performed on the weldment. 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.

Availability

Nicrofer 3033 is available in the following mill product forms:

Sheet and plate
(for cut-to-length availability, refer to strip)

Conditions:
hot or cold rolled (hr, cr),
solution heat-treated and descaled

Thickness mm	hr / cr	Width* mm	Length* mm
1.30 – < 1.30	cr	2000	6000
≥ 1.50 – < 6.0	cr	2500	8000
≥ 6.0 – < 10.0	cr	2500	8000
≥ 6.0 – < 10.0	hr	2500	8000
≥ 10.0 – < 25.0	hr	2500	8000
> 25.0*	hr		

inches	hr / cr	inches	inches
0.050 – < 0.060	cr	80	240
≥ 0.060 – < $^1/_4$	cr	100	320
≥ $^1/_4$ – < $^3/_8$	cr	100	320
≥ $^1/_4$ – < $^3/_8$	hr	100	320
≥ $^3/_8$ – < 1	hr	100	320
> 1	hr		

*other sizes subject to special enquiry

Forgings
Shapes other than discs, rings, rod and bar are subject to special enquiry.

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Discs and rings
Conditions:
hot rolled or forged,
solution heat-treated,
descaled or machined

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

	lb	inches	inches	inches
Disc	≤ 6600	≤ 8	≤ 80	–
Ring	≤ 4400	≤ 8	≤ 100	on request

*other sizes subject to special enquiry

Rod & bar
Conditions:
forged, rolled, drawn,
solution heat-treated,
descaled, machined, peeled or ground

Product	forged* mm	rolled* mm	drawn* mm
round d	≤ 300	8 – 75	12 – 65
square a	40 – 200	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	≤ 12	$^5/_{16}$ – 3	$^1/_2$ – $2^1/_2$
square a	$1^5/_8$ – 8	$^5/_8$ – 4	$^1/_2$ – $2^1/_2$
flat a x b	$1^5/_8$ – $3^1/_8$ x 8 – 24	$^3/_{16}$ – $^3/_4$ x 5 – 24	$^3/_8$ – $^3/_4$ x $1^1/_4$ – $3^1/_8$
hexagon s	$1^5/_8$ – $3^1/_8$	$^1/_2$ – 2	$^1/_2$ – $2^3/_8$

*other sizes subject to special enquiry

Strip*
Conditions:
cold rolled, solution heat-treated,
descaled or bright annealed

Thickness mm	Width mm	Coil I. D. mm			
0.04 – ≤ 0.10	4 – 200	300	400		
> 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	16		
> 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.)

Wire
Conditions:
bright drawn, $^1/_4$ hard to hard
bright annealed

Dimensions:
0.01 – 12.7 mm (0.0004 – $^1/_2$ 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 Int. Sales, Tour Neptune, F-92086 Paris, La Défense Cedex (Fax: +33-1-4796 8126; Tel.: +33-1-4796 8128).

Welded tube and pipe
Welded tubes and pipes are obtainable from qualified manufactures using ThyssenKrupp VDM semi-fabricated products.

Technical publications

The following publications concerning Nicrofer 3033 may be obtained from ThyssenKrupp VDM GmbH:

M. Köhler, U. Heubner, K.-W. Eichenhofer, M. Renner:
Alloy 33, A New Corrosion-Resistant Austenitic Material for the Refinery Industry and Related Applications,
Corrosion 95, Paper No. 338
NACE International, Houston, Texas, 1995

M. Köhler, U. Heubner, K.-W. Eichenhofer:
Progress with Alloy 33, A New Corrosion-Resistant Chromium-Based Austenitic Material,
Corrosion 96, Paper No. 428
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M. Köhler, U. Heubner, K.-W. Eichenhofer, M. Renner:
Alloy 33. A New Nitrogen-Alloyed Chromium-Based Material for Many Corrosive Environments,
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M. Köhler, U. Heubner, K.-W. Eichenhofer, M. Renner:
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Nichtrostende Stähle ´96,
2. Europäischer Kongreß, Düsseldorf/Neuss, 1996

D. C. Agarwal, M. Köhler:
Alloy 33. A New Material Resisting Marine Corrosion,
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Corrosion 97, Paper No. 115,
NACE International, Houston, Texas, 1997

C. Voigt, G. Riedel, H. Werner, M. Köhler:
Kühlwasserseitige Korrosionsbeständigkeit von metallischen Werkstoffen zur Handhabung von Schwefelsäure,
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Corrosion resistance of various high chromium alloys in simulated chemical processing nuclear plant waste solutions,
Corrosion 98, Paper No. 164,
Nace International, Houston, Texas, 1998

Pedro D. Portella, M. Köhler, M. Renner:
Investigation of microstructure and properties of a chromium-rich austenitic material with high nitrogen content,
5th International Conference on High Nitrogen Steels,
Espoo/Stockholm, May 24-28, 1998

VDM Report No. 24: Nicrofer 3033 - alloy 33:
A new corrosion-resistant austenitic material for many applications, June 1998

M. Köhler:
Pitting corrosion and crevice corrosion of an advanced chromium-based stainless steel,
Corrosion 99, Paper No. 444,
Nace International, Houston, Texas, 1999

M. Köhler, A. Houghton:
Nicrofer 3033 – alloy 33: A new high strength austenitic material for marine applications,
Stainless Steel ’99 Science and Market,
Chia Laguna, Sardinia, Italy, June 7-9, 1999

M. H. Renner, D. Michalski-Vollmer:
Corrosion behaviour of alloy 33 in concentrated sulphuric acid,
Stainless Steel World 99 Conference,
The Hague, Netherlands, November 16-18, 1999

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Nicrofer

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ThyssenKrupp VDM GmbH
Plettenberger Strasse 2
58791 Werdohl
P.O. Box 18 20
58778 Werdohl
Germany
Phone: +49 (23 92) 55 - 0
Fax: +49 (23 92) 55 - 22 17
E-Mail: info@tks-vdm.thyssenkrupp.com
www.thyssenkruppvdm.com