Nicrofer® 5020 hMo - alloy 50 PLUS

Material Data Sheet No. 4044
August 2002 Edition

Corrosion-resistant alloy

A company of ThyssenKrupp Stainless

ThyssenKrupp VDM

ThyssenKrupp

Nicrofer® 5020 hMo - alloy 50 PLUS

Nicrofer 5020 hMo is a low-carbon nickel-chromium-iron-molybdenum alloy which has excellent corrosion resistance to a large number of corrosive media.
The alloy can be used for wet-corrosion applications in the solution-annealed or stabilized condition.
Nicrofer S 5020 – FM 50 is an excellent filler metal for joint and overlay welding, especially for duplex, super duplex and 6-Mo stainless steels.

Nicrofer 5020 hMo is characterized by:

- Exceptional resistance to pitting and crevice corrosion and also to erosion and intergranular corrosion
- Resistance to chloride-induced stress corrosion cracking
- Good corrosion resistance to mineral acids such as nitric, phosphoric, sulphuric and hydrochlorid acid
- Good corrosion resistance to alkalis and organic acids
- Very good mechanical properties
- Ease of fabrication and forming

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 DIN EN VdTÜV	**W.-Nr. 2.4850** NiCr20Fe14Mo11WN							**W.-Nr. 2.4849**	
F AFNOR									
UK BS EN									
USA ASTM ASME ASME Code Case	UNS N06650	B 446				B 446			
ISO	NiCr20Fe14Mo11WN								

Table 1 - Designations and standards.

Chemical composition

	Ni	Cr	Fe	C	Mn	Si	Mo	AL	Ti	Nb*	N	W	Mg	Ca	Zr
min.	bal.	18.0	12.0	–	–	–	9.5	0.05	–	0.05	0.05	0.5	0.005	0.001	0.001
max.		21.0	16.0	0.03	0.5	0.5	12.5	0.50	0.1	0.50	0.20	2.5	0.030	0.010	0.030

**In USA Niobium (Nb) is customarily known as Columbium (Cb).*

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

Physical properties

Density Melting range	8.5 g/cm³ 1310–1340 °C	0.307 lb/in.³ 2390–2444 °F
Permeability at 20°C/68°F (RT)		≤1.004

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/(mK)	Btu in./(ft² h °F)	µ Ω cm	Ω circ mil/ft	kN/mm²	10³ ksi	10⁻⁶/K	10⁻⁶/°F
20	**68**	–	–	–	–	108	–	222*	32.2*	–	–
93	**200**	453	0.1083	11.95	82.7	108	648	–	–	11.3	6.3
100	212	454	0.1086	12.05	83.4	110	650	–	–	11.2	6.2
200	392	456	0.1090	13.26	91.8	112	674	–	–	13.1	7.3
204	**400**	456	0.1091	13.30	92.1	112	674	–	–	13.1	7.3
300	572	454	0.1086	14.51	100.4	114	686	–	–	13.9	7.7
316	**600**	453	0.1083	14.68	101.6	115	689	–	–	14.0	7.8
400	752	458	0.1095	15.80	109.4	117	704	–	–	14.3	8.0
427	**800**	460	0.1100	16.18	112.0	119	712	–	–	14.4	8.0
500	932	447	0.1070	16.57	114.7	123	740	–	–	14.4	8.0
538	**1000**	435	0.1040	16.56	114.6	124	745	–	–	14.5	8.1
600	1112	541	0.1293	21.43	148.3	125	752	–	–	14.9	8.3
649	**1200**	559	0.1337	22.85	158.2	125	749	–	–	15.3	8.5
700	1292	559	0.1335	23.55	169	124	746	–	–	15.6	8.7
760	**1400**	554	0.1325	24.19	167.4	124	742	–	–	15.8	8.8
800	1472	556	0.1328	–	–	123	740	–	–	16.0	8.9
871	**1600**	558	0.1335	25.93	179.5	124	744	–	–	16.2	9.0
900	1652	562	0.1342	26.53	183.7	124	746	–	–	16.3	9.1
982	**1800**	567	0.1356	28.03	194.0	124	746	–	–	16.5	9.2
1000	1832	576	0.1376	28.69	198.6	124	746	–	–	16.5	9.2
1093	**2000**	615	0.1471	32.08	222.1	–	–	–	–	16.8	9.4
1100	2012	–	–	–	–	–	–	–	–	–	–

* stabilized

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

Mechanical properties

The following properties are applicable to Nicrofer 5020 hMo in the solution-annealed or stabilized condition and indicated size ranges. Specified properties of materials outside these size ranges are subject to special enquiry.

Condition	Dimensions		Yield strength $R_{p\,0.2}$		Yield strength $R_{p\,1.0}$		Tensile strength R_m		Elongation A_5
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%
solution annealed	≤ 10	≤ 4	360	52.2	420	60.9	720	104.3	40
stabilized	≤ 10	≤ 4	450	65.2	510	73.9	800	115.9	25

Table 4 - Minimum mechanical properties at room temperature.

Condition	Dimensions		Yield strength $R_{p\,0.2}$		Yield strength $R_{p\,1.0}$		Tensile strength R_m		Elongation A_5
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%
solution annealed	≤ 10	≤ 4	230	33.3	270	39.1	580	84.1	35
stabilized	≤ 10	≤ 4	310	44.9	370	53.6	630	91.3	20

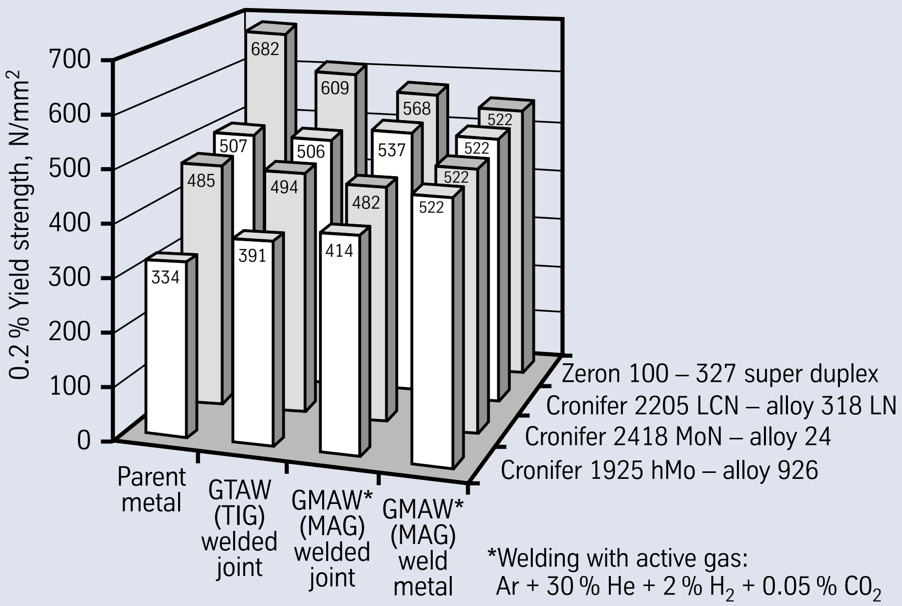
Table 5 - Minimum mechanical properties at 450 °C (842 °F).

Condition	Dimensions		Yield strength $R_{p\,0.2}$		Yield strength $R_{p\,1.0}$		Tensile strength R_m		Elongation A_5
	mm	inches	N/mm²	ksi	N/mm²	ksi	N/mm²	ksi	%
solution annealed	≤ 10	≤ 4	210	30.4	250	36.2	550	79.7	35
stabilized	≤ 10	≤ 4	300	43.5	360	52.2	620	89.9	25

Table 6 - Minimum mechanical properties at 550 °C (1022 °F).

ISO V-notch impact toughness

Average value at room temperature: ≥ 137 J/cm²



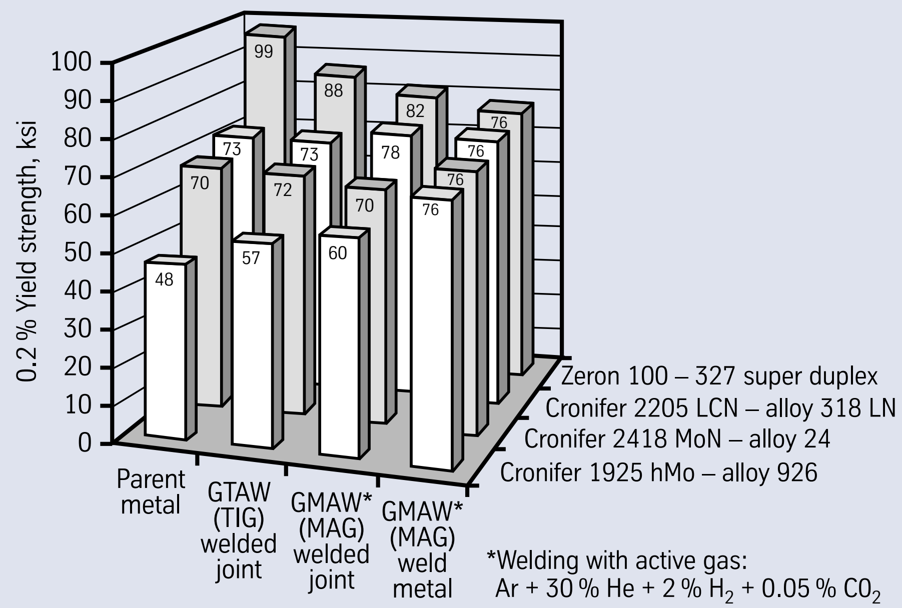


Fig. 1 - 0.2% Yield strengths at room temperature for weld joints of 6-Mo, high nitrogen austenitic, duplex and superduplex stainless steels with Nicrofer S 5020 – FM 50 filler metal.

Metallurgical structure
Nicrofer 5020 hMo has a face-centered-cubic structure. Molybdenum and nitrogen enhance the mechanical properties through solid solution hardening of the nickel-chromium matrix.

Corrosion resistance
Nicrofer 5020 hMo has outstanding corrosion resistance to a large number of media:

- Outstanding resistance to pitting and crevice corrosion in chloride-containing media and also to intergranular corrosion
- Resistance to chloride-induced stress corrosion cracking
- High resistance to corrosive attack by mineral acids such as nitric, phosphoric, sulphuric and hydrochlorid acid, as well as by alkalis and inorganic acids under both oxidizing and reducing conditions
- No corrosive attack in marine and industrial atmospheres; high resistance to seawater and brackish water, even at higher temperatures
- Good resistance to carburization and scaling under static and cyclic conditions
- Optimum corrosion resistance can only be obtained if the alloy is used in a clean and bright condition

The critical pitting temperatures (CPT) of Nicrofer 5020 hMo base material together with those of selected similar nickel-base alloys in “green death” test solution are shown in Fig. 2.

Fig. 3 presents localized corrosion behavior of joint welds of different grades of stainless steels with Nicrofer S 5020 – FM 50 filler metal measured in terms of the critical pitting temperature (CPT) in “green death” test solution.

Applications
The heat treated, low-carbon alloy Nicrofer 5020 hMo is suitable for applications in the chemical process industry, because its good corrosion resistance permits the use of very thin structural elements.

Nicrofer 5020 hMo is also suitable for components in contact with seawater which have very high strength requirements.

Typical applications for filler metal Nicrofer S 5020 – FM 50 (2.4849) are as follows:

- In the offshore industry for joint welding of 6-Mo, duplex and super duplex stainless steels; also for weld-cladding of flanges
- In industrial fabrication for weld-cladding of boiler tubes in waste incineration plants

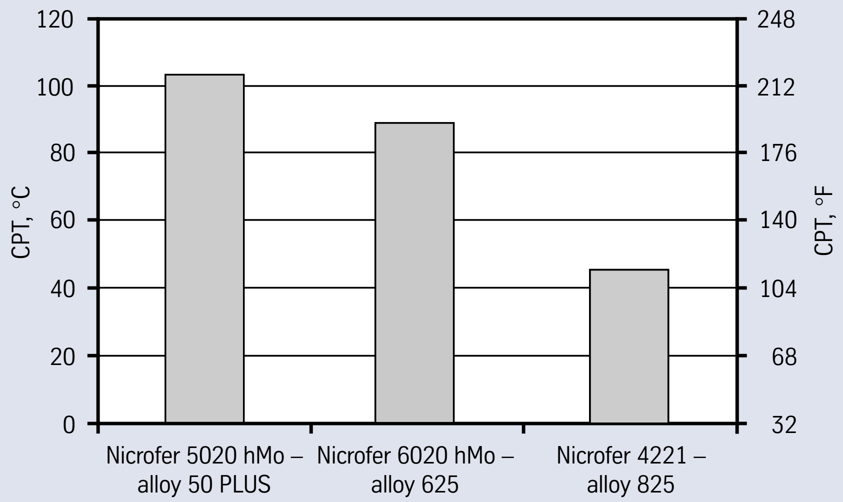


Fig. 2 - Comparison of critical pitting temperatures (CPT) for Nicrofer 5020 hMo and selected similar alloys in "green death” test solution.

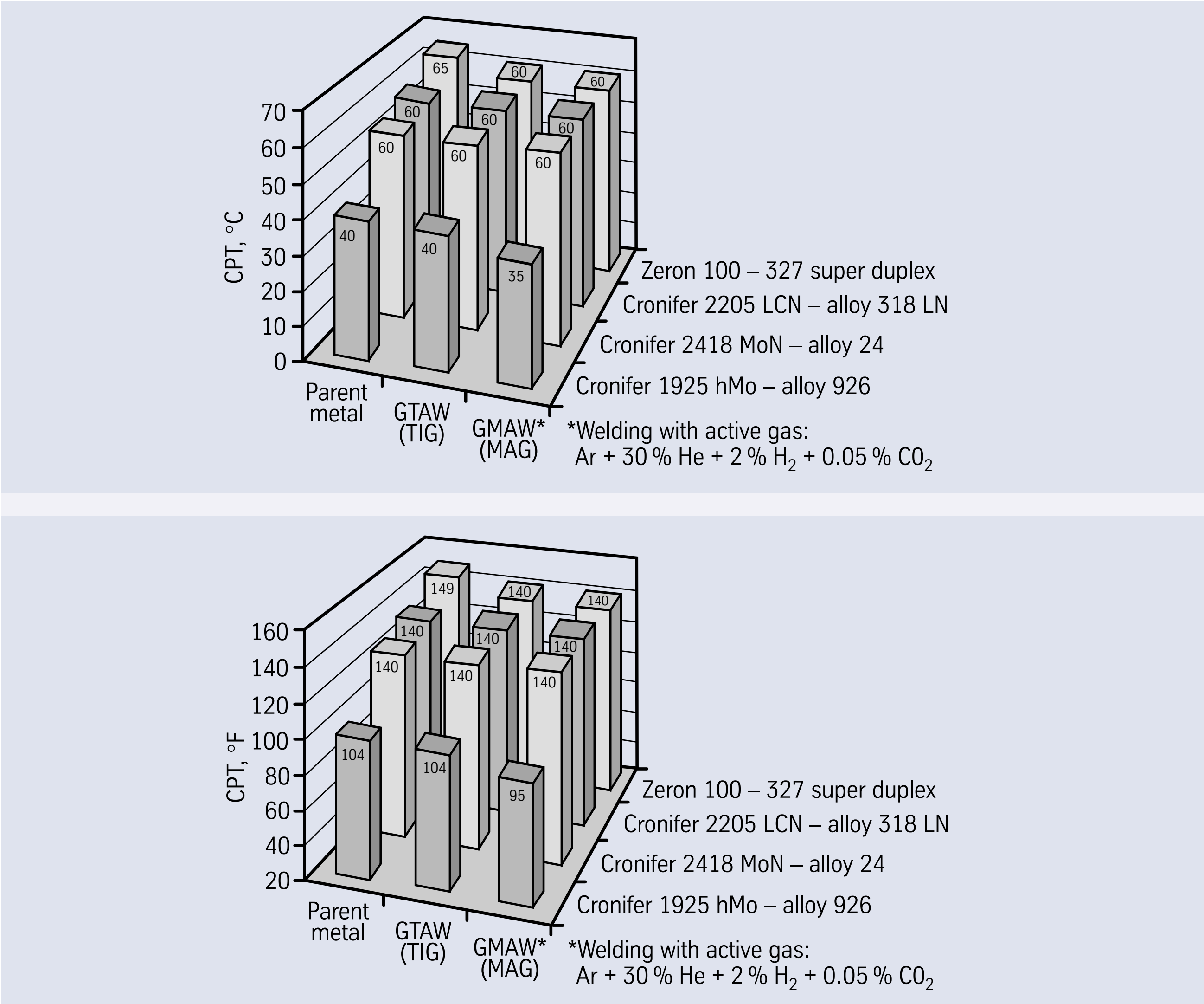


Fig. 3 - Critical pitting temperatures of weld joints of 6-Mo, high nitrogen austenitic, duplex and super duplex stainless steels with Nicrofer S 5020 – FM 50 filler metal in "green death" test solution.

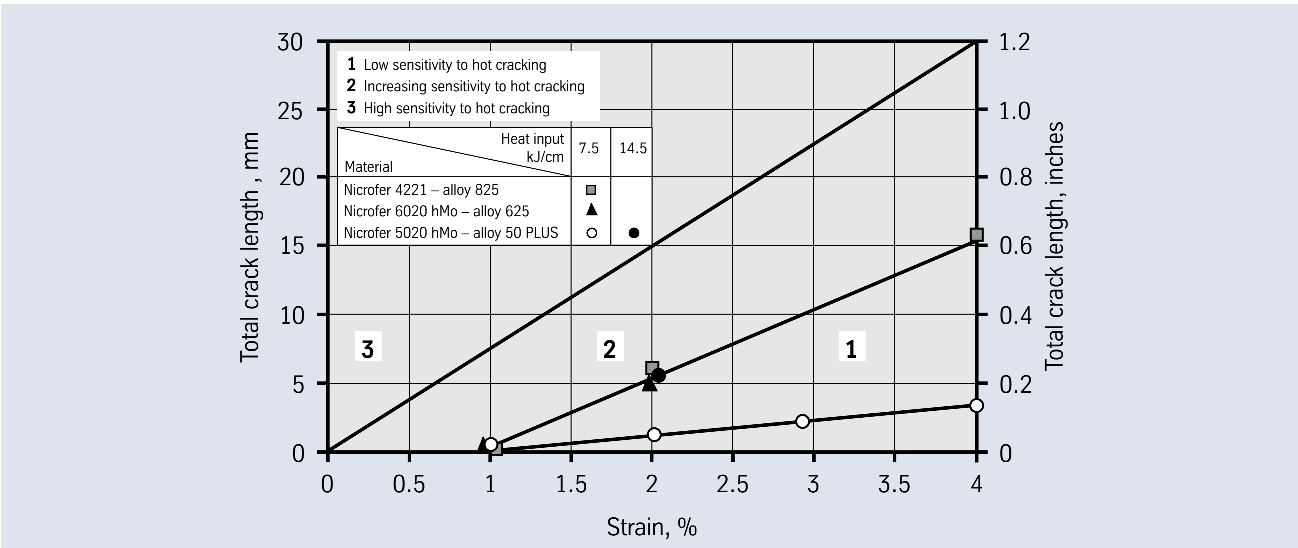


Fig. 4 - Hot cracking behaviour of Nicrofer 5020 hMo in comparison with Nicrofer 6020 hMo and Nicrofer 4221 in the Modified Varestraint Test (MVT).

Fabrication and heat treatment
Nicrofer 5020 hMo can readily be hot- and cold-worked and machined.

Heating
Work pieces must be clean and free from all kinds of contaminants before and during heat treatment.

Nicrofer 5020 hMo may be impaired if heated in the presence of contaminants such as sulphur, 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 sulphur as possible. Natural gas should contain less than 0.1 wt.-% sulphur. Fuel oils with a sulphur content not exceeding 0.5 wt.-% is 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 5020 hMo may be hot-worked in the temperature range 1170 to 900 °C (2138 to 1650 °F), followed by water quenching or rapid air cooling.

For heating up, workpieces should be charged into the furnace at maximum hot forming temperature. When the furnace has returned to temperature, the workpiece should be soaked for 60 minutes per 100 mm (4 in.) of thickness. At the end of this period it should be withdrawn immediately and worked within the above temperature range. If the metal temperature falls below 950 °C (1740 °F), it must be reheated.

Heat treatment after hot working is recommended in order to achieve optimum properties and to ensure maximum corrosion resistance.

Cold working
Nicrofer 5020 hMo has a higher work-hardening rate than austenitic stainless steels. This should be taken into account when selecting forming equipment. The material should be in the solution-annealed condition. Interstage annealing may be necessary with high degrees of cold forming.

The inside bending diameter should be at least three times the sheet/plate thickness.

After final cold working with more than 15 % deformation it is recommended to repeat solution annealing or to carry out a stabilizing heat treatment.

Heat treatment
Nicrofer 5020 hMo is used in the solution-annealed or stabilize-annealed condition.

Solution annealing is carried out at 1160 – 1200 °C (2120 – 2192 °F).

Stabilize annealing should be carried out at 950 – 1050 °C (1740 – 1922 °F) preferably at 980 °C (1795 °F).

A **stabilizing anneal** within a temperature range of > 900 °C (1650 °F) and up to 1100 °C (2010 °F) is generally carried out to improve resistance against intergranular corrosion particularly at welds during subsequent service under wet corrosive conditions. Its purpose is to modify finely distributed chromium carbides along grain boundaries formed during prior processing due to unfavourable thermal treatment conditions. This results in chromium depletion adjacent to the grain boundaries lowering in turn the alloy’s corrosion resistance.

The stabilizing anneal causes the fine carbide precipitates to agglomerate to fewer, coarser, and rather more globular nodes which have a less adverse effect on wet corrosion resistance than finely divided carbides located almost completely on the grain boundaries. It also serves to remove any prior cold work which tends to accelerate carbide precipitation under unfavourable thermal treatment or service conditions. Higher carbon contents in stainless steels and Ni-Cr-(Mo)-alloys enhance carbide precipitation.

Furthermore, to reduce the incidence of chromium depletion, titanium or niobium is generally added to these alloys. These elements preferentially precipitate carbon as titanium or niobium carbides within the matrix rather than along the grain boundaries, thus further alleviating any danger of corrosion attack occurring.

A stabilizing anneal in contrast to a solution anneal does not generally involve recrystallization of the grain structure.

Water quenching or rapid air cooling is recommended and is essential for maximum corrosion resistance.

For any thermal treatment the material should be charged into the furnace at temperature, observing the precautions concerning cleanliness mentioned earlier under **‘Heating’**.

Descaling and Pickling
Oxides of Nicrofer 5020 hMo and discoloration adjacent to welds are more adherent than on stainless steels. Grinding with very fine abrasive belts or wheels 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.

Machining
Nicrofer 5020 hMo should 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 any previously formed work-hardened zone.

Welding
When welding nickel-base 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-base 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.

Edge preparation
This should preferably be done by mechanical means by turning, milling or planing; 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-base alloys 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). For welding Nicrofer 5020 hMo, an included angle of 60° is recommended on account of the low viscosity of the weld metal and the low shrinkage.

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
Nicrofer 5020 hMo can be welded by the following welding processes: GTAW (TIG), plasma arc, GMAW (MAG) and SMAW (MMA). For the MAG process the use of the shielding gas Cronigon He 30S or Argomag-Ni, for example, is recommended.

For welding, Nicrofer 5020 hMo 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. The shielding gas used for the GTAW and plasma-arc processes should be an argon/hydrogen mixture (argon + max. 3 % H_2).

Filler metal
For the gas-shielded welding processes, filler metal with the same composition as the base metal is recommended:

Bare electrodes:	Nicrofer S 5020 – FM 50 W.-Nr. 2.4849 SG-NiCr20Fe14Mo11WN
Covered electrodes:	W.-Nr. 2.4848 El-NiCr20Fe14Mo11WN

Welding parameters and influences
(heat input/linear energy input per unit length of weld)

Weldability of Nicrofer 5020hMo metal is characterized by its hot cracking behavior. This was tested by means of the Modified Varestraint Test (MVT). In this test the surface of a sheet specimen is melted with a GTAW torch under defined conditions over a specific distance while being mechanically bent at the same time. The total length of all cracks visible on the surface of the metal at 25x magnification is then ascertained and serves as a measure of the material's susceptibility to hot cracking in relation to the bending strain applied, i.e. a small total crack length corresponds to a low susceptibility to hot cracking. Fig. 4 shows MVT results for different heat inputs. It can be seen that in this test Nicrofer 5020 hMo exhibits the lowest sensitivity to hot cracking compared to other nickel-base alloys such as alloys 625 and 825 when using a heat input of 7.5 kJ/cm. Even with a heat input of 14.5 kJ/cm which is almost twice as much, Nicrofer 5020 hMo is still on the transient line which limits the "low sensitivity to hot cracking" region.

Care should thus be taken that the work is performed with a deliberately chosen, low heat input and rapid heat dissipation. Use of the stringer bead technique should be aimed at. Interpass temperature should be kept below 150 °C (300 °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.

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 required.

Availability
Nicrofer 5020 hMo is available in the following standard product forms:

Wire
Conditions:
bright drawn, 1/4 hard to hard,
bright annealed

Dimensions:
0.01 – 12.0 mm (0.0004 – 0.47 in.) diameter,
in coils, pay-off packs, on spools and spiders

Welding filler metals
Suitable welding rods, wire and electrode core wire are available in all standard sizes.

Technical publications
The following publications concerning Nicrofer 5020 hMo – alloy 50 PLUS may be obtained from ThyssenKrupp VDM GmbH:

U. Brill, R. Mast, M. Gutsch
Nicrofer 5020 hMo - ein neuer Multipurpose Werkstoff für die Chemietechnik,
Corrosion Protection Seminar "Korrosionsbeständige Werkstoffe für die Chemie-, Energie- und Umwelttechnik", 22 September 1999 in Dresden, Germany.

U. Brill, R. Mast
Alloy 50 - A New Cb-free NiCrMo Filler Metal
- A Better Alternative to Alloy 625
CORROSION 2000, Paper No. 249, Nace International, Houston, Texas, 2000.

U. Brill, G. K. Grossmann
Corrosion behavior of weld overlays of the new alloy 50
CORROSION 2001, Paper No. 1170, Nace International, Houston, Texas, 2001

U. Brill, J. Heinemann
Corrosion behavior of alloy 50 weldments
CORROSION 2001, Paper No. 1483, Nace International, Houston, Texas, 2001

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Nicrofer

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