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STAINLESS STEELS

Stainless steels are distinguished from other steels by a minimum chromium content of 10.5%, which makes them more resistant to corrosive aqueous environments and to oxidation. Although there are exceptions, stainless steel castings are classified as “corrosion-resistant” when used in aqueous environments and vapors below 1200°F (650°C) and "heat-resistant" when used above this temperature.

The usual distinction between the heat and corrosion-resistant casting grades is carbon content. For a stainless steel casting to perform well in a corrosive environment, the carbon content must be low. Heat-resistant grades have higher carbon contents to improve elevated temperature strength.

The chemical composition and microstructure differences between the wrought and cast versions of stainless steels can affect performance. (See Role of Alloying Elements.) Some stainless steel casting grades can be precipitation-hardened by heat treatment, but the mechanical properties of most rely on their chemical composition. The yield and tensile strengths of castings are comparable to their wrought equivalents.

Cast stainless steels generally have equivalent corrosion resistance to their wrought equivalents, but they can become less corrosion-resistant due to localized contamination, microsegregation, or lack of homogeneity. For example, mold quality may cause superficial compositional changes that influence performance, and carbon pick-up from mold release agents can affect corrosion resistance. Heat treatment and weld repair procedures can influence the performance of some cast grades and should be taken into consideration during grade selection.

Additional information about the characteristics, properties and applications of specific cast stainless steel grades can be found in the following corrosion and heat-resistant sections.

NICKEL-BASE ALLOYS

Except for some of the high silicon and proprietary grades, cast nickel-base alloys generally have wrought approximate equivalents. Although the cast and wrought versions of nickel-base alloys are commonly used in combination because they provide similar performance, there are some chemistry differences, primarily to improve castability and soundness.

Like stainless steels, nickel-base castings are categorized as corrosion-resistant if they are used in aqueous environments and vapors below 1200°F (650°C) and heat-resistant if they are capable of continuous or intermittent use for sustained times above this temperature. Carbon content is usually a distinguishing factor between the heat and corrosion-resistant alloys, but this dividing line can be vague, particularly for alloys used in the 900-1200°F (480 to 650°C) range.

Additional information about the characteristics, properties and applications of specific cast nickel-base alloys can be found in the following corrosion and heat-resistant

ROLE OF ALLOYING ELEMENTS

Chromium, nickel, and molybdenum are the primary alloying elements that determine the structure, mechanical properties, and corrosion resistance of stainless steel and nickel-base alloy castings.

Nickel and chromium have the greatest influence on heat-resistant castings. Intentional additions of less than 1% carbon, nitrogen, niobium, tantalum, titanium, sulfur, and slightly larger additions of copper, manganese, silicon, and aluminum are used to modify properties. Some minor elements can have a positive or negative effect on properties depending on the application.

CHROMIUM

A stainless steel contains a minimum of 10.5% chromium because this level of chromium causes the spontaneous formation of a stable, transparent, passive, protective film. Increasing the level of chromium enhances corrosion resistance.

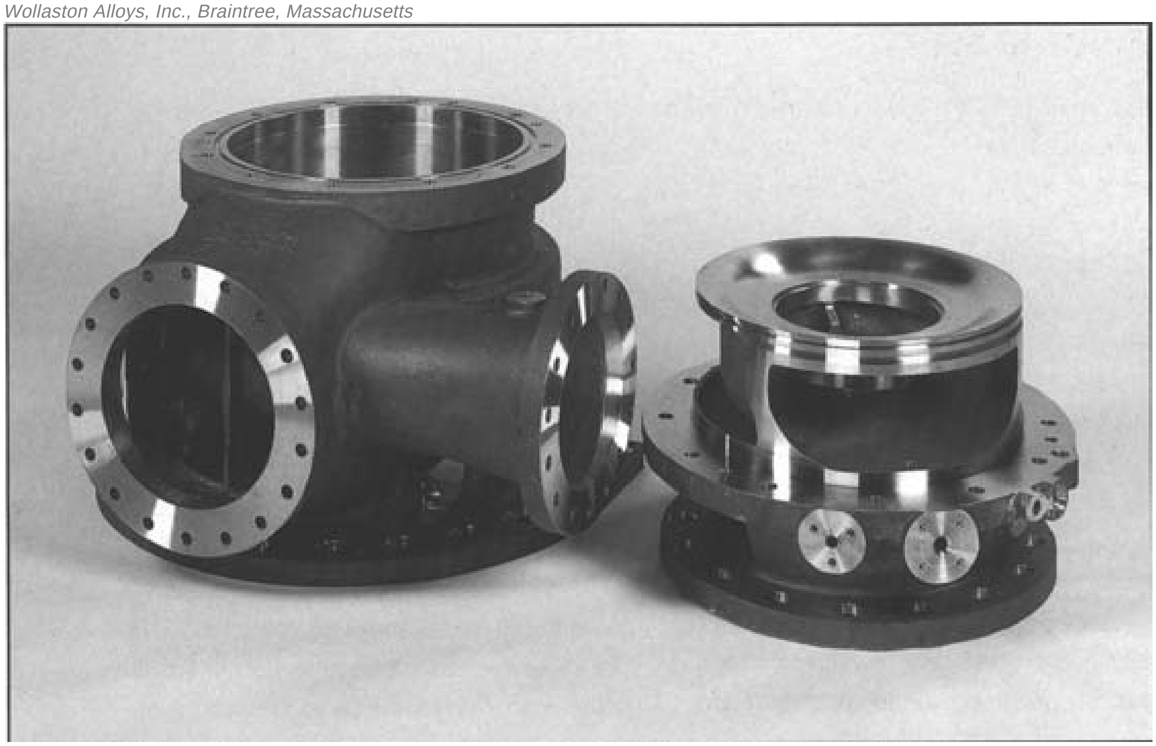
At elevated temperatures, chromium provides resistance to oxidation and sulfur-containing and other corrosive atmospheres; contributes to high temperature creep and rupture strength; and, in some alloys, increases resistance to carburization.

NICKEL

Nickel in stainless steels promotes the stability of austenite. Austenite is stronger and more stable at higher temperatures then ferrite. Less nickel is needed to retain an austenitic structure as the nitrogen or carbon levels increase. When sufficient nickel is added to a chromium stainless steel, the structure changes from ferritic to austenitic. Adding nickel improves toughness, ductility, and weldability.

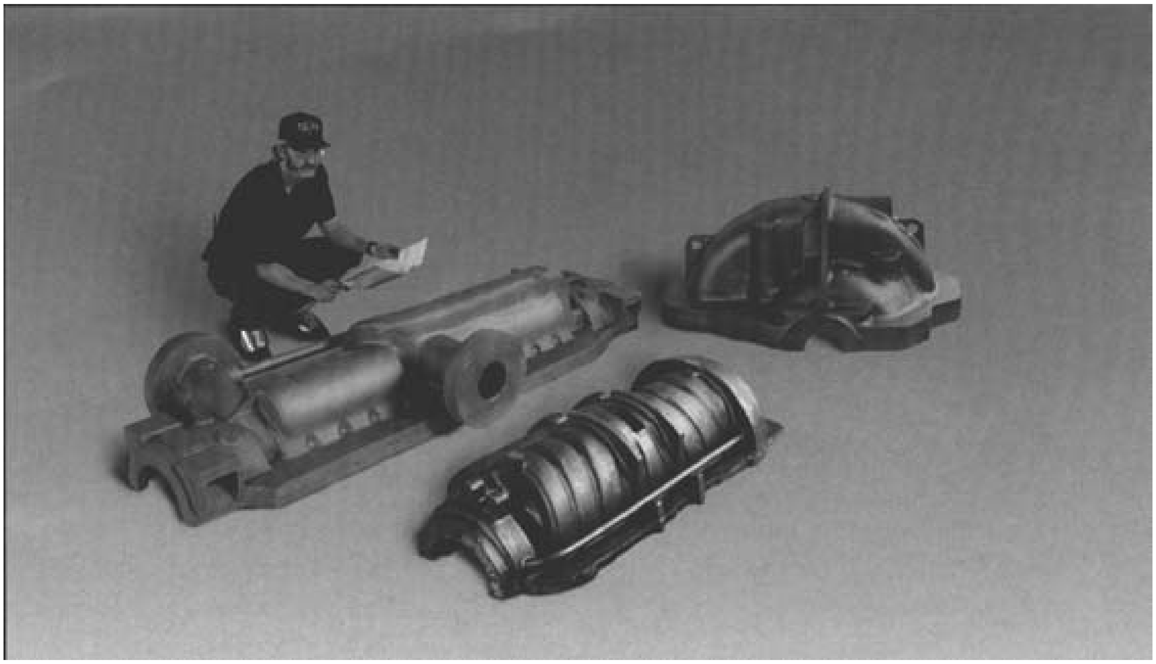
Nickel increases resistance to oxidation, carburization, nitriding, thermal fatigue, and strong acids, particularly reducing acids. It is an important alloying element in stainless steel and nickel-base alloys used for corrosive and high temperature applications.

Wollaston Alloys, Inc., Braintree, Massachusetts



This 1,500 pound (675 kg) main feed booster pump and a 625 pound (281 kg) adaptor are used on aircraft

Atlas Foundry & Machine Company, Tacoma, Washington



Stainless steel pump casings are produced in a variety of sizes and shapes for pipeline, refining, and boiler feed applications.

MOLYBDENUM

Molybdenum additions improve resistance to pitting and crevice corrosion in chloride-containing environments and corrosion by sulfuric, phosphoric, and hydrochloric acids. The elevated temperature mechanical properties of austenitic stainless steels and the strength and tempering resistance of martensitic stainless steels are improved by molybdenum.

MINOR ELEMENTS

The presence of small amounts of carbon and nitrogen cannot be avoided during melting. In some grades, these elements are added deliberately. Increasing the carbon content in high temperature alloys improves high temperature strength and creep resistance, but reduces ductility. Conversely, carbon can be detrimental to corrosion resistance when it combines with chromium to form chromium carbides along grain boundaries. This reduces the chromium adjacent to the grain boundary (sensitization) and can lead to corrosion of chromium-depleted areas (intergranular corrosion). Titanium, columbium, and tantalum additions preferentially combine with carbon and nitrogen to prevent sensitization and eliminate susceptibility to intergranular corrosion.

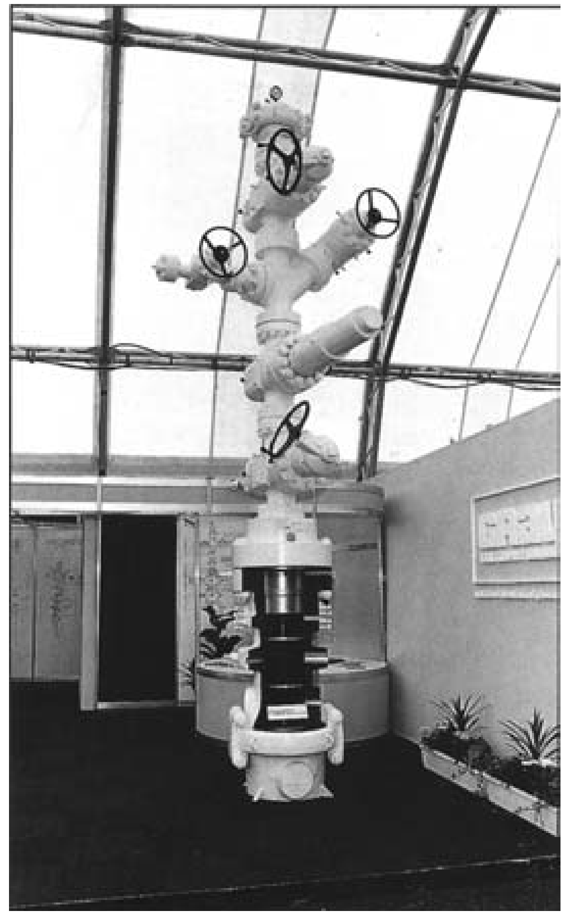
Nitrogen additions to austenitic and duplex stainless steels improve pitting resistance and retard the kinetics of sigma phase formation. Additions of sulfur, selenium, and lead in stainless steel improve machinability. Columbium additions can improve high-temperature creep strength. Copper additions improve resistance to sulfuric acid. A combination of manganese and nitrogen may be used as a partial substitute for nickel in some stainless steels.

Silicon is added to cast stainless steel grades to increase casting fluidity and improve castability. As carbon plus silicon content is increased, partial eutectic solidification improves castability and casting soundness. Silicon is generally limited to 1.5% in castings intended for service above 1500°F (815°C) because it lowers the high temperature creep and rupture properties. Silicon also improves oxidation resistance, particularly where elements with a volatile oxide such as tungsten or niobium (columbium) are used to improve high temperature strength. In carburizing atmospheres such as ethylene furnaces, silicon levels as high as 2% have been found to be beneficial. Aluminum also improves resistance to oxidation.

DESIGNATIONS FOR CAST STAINLESS STEEL AND NICKEL-BASE ALLOYS

In North America, the common designations for cast stainless steel and nickel-base alloys are descriptive of their chemistry and purpose. This designation system was established by the Alloy Casting Institute (ACI) and has been adopted by ASTM.

A designation beginning with the letter "C" indicates that the alloy is used primarily for corrosive service; if the first letter is "H", the alloy is used primarily for high temperature service at or above 1200°F (649°C). The second letter indicates the approximate nickel and chromium contents of the alloy grade on the FeCrNi ternary diagram (ASTM A 781, Appendix X1 and Figure X1.1). For C classifications, the single or double digit number following the first two letters indicates the maximum carbon content of the grade (% x 100). For H classifications, this number is the midpoint of the carbon content range in units of 0.01 % with a ±0.05% limit. Other alloying elements, if present, are represented by one or more letters following the number. For example, the designation CF8M indicates that the grade is corrosion-resistant (C), contains between 17% and 21 % chromium and be tween 8% and 12% nickel (F), a maximum carbon content of 0.08% (8), and molybdenum (M); HD indicates that the grade is heat-resistant (H), and contains between 26% and 30% chromium and between 4% and 7% nickel (D).



This CA6NM, 5-inch (127 mm) multi-bowl wellhead Christmas tree assembly is used in North Sea sour gas production.

Ray Atkinson

This 16-foot (4.9 m) diameter stem turbine blade ring was cast in a CA6NM.

Atlas Foundry & Machine Company, Tacoma, Washington

CORROSION-RESISTANT CASTINGS

STAINLESS STEELS

The corrosion-resistant, cast, stainless steel grades are grouped into families based on their microstructure (martensitic, austenitic, or duplex). General characteristics of each stainless steel family and specific information about each of the widely used grades are provided in the following sections.

Stainless steel castings are classified as "corrosion-resistant" if they are used in aqueous environments and vapors below 1200°F (650°C). For a stainless steel casting to perform well in a corrosive environment, the carbon content and quantity of precipitated carbides in the microstructure must be low. The carbon content in corrosion-resistant grades is usually below 0.20% and sometimes below 0.03%. Increasing the chromium content enhances corrosion resistance and nickel increases resistance to strong acids, particularly reducing acids. The influence of other alloying elements is discussed in the Role of Alloying Elements section.

The chemical compositions, ASTIVI specifications, approximate wrought equivalents, and common end use microstructures of corrosion-resistant stainless steel castings can be found in *Tables 1* and *2*. The ASTIVI strength and elongation requirements are shown in *Table 3* and are compared in *Figures 1* through *3*. Typical short-term high-temperature properties for several grades are shown in *Table 4*. Standard heat treatments are shown in *Table 5*. Typical hardness, impact, and physical properties are shown in *Tables 6* through *8*.

Wisconsin Centrifugal, Waukesha, Wisconsin, USA

These are centrifugally cast CA15 turbine combustor cases.

Table 1 Unified numbering system (UNS) chemical compositions for corrosion resistant stainless steel castings*

UNS	ACI	C	Mn	P	S	Si	Cr	Ni	Other
J91650	CA6N	0.06	0.50	0.02	0.02	1.00	10.5-12.5	6.0-8.0	•••
J91540	CA6NM	0.06	1.00	0.04	0.03	1.00	11.5-14.0	3.5-4.5	0.4-1.0 Mo
J91150	CA15	0.15	1.00	0.040	0.040	1.50	11.5-14.0	1.00	0.50 Mo
J91153	CA40	0.20-0.40	1.00	0.04	0.04	1.50	11.5-14.0	1.0	0.5 Mo
J91804	CB6	0.06	1.00	0.04	0.03	1.00	15.5-17.5	3.5-5.5	0.5Mo
J92180	CB7Cu-1	0.07	0.70	0.035	0.03	1.00	15.50-17.70	3.60-4.60	0.05 N,2.50-3.20 Cu, 0.15-0.35 Nb[1]
J92110	CB7Cu2	0.07	0.70	0.035	0.03	1.00	14.0-15.50	4.50-5.50	0.05 N, 2.50-3.20 Cu, 0.15-0.35 Nb
J92205	CD3MN	0.03	1.50	0.04	0.020	1.00	21.0-23.5	4.5-6.5	0.10-0.30 N, 2.5-3.5 Mo, 1.00 Cu
J93380	CDMWCuN	0.03	1.00	0.030	0.025	1.00	24.0-26.0	6.5-8.5	0.20-0.30 N, 3.0-4.0 Mo, 0.5-1.0 Cu, 0.5-1.0 W[2]
J93370	CD4MCu	0.04	1.00	0.04	0.04	1.00	24.5-26.5	4.75-6.00	1.75-2.25 Mo, 2.75-3.25 Cu
J93372	CD4MCuN	0.04	1.0	0.04	0.04	1.0	24.5-26.5	4.7-6.0	0.10-0.25N, 1.7-2.3 Mo, 2.7-3.3Cu
J93371	CD6MN	0.06	1.00	0.040	0.040	1.00	24.0-27.0	4.00-6.00	0.15-0.25 N, 1.75-2.50 Mo
J93404	CE3MN	0.03	1.50	0.04	0.04	1.00	24.0-26.0	6.0-8.0	0.10-0.30 N, 4.0-5.0 Mo
J93345	CE8MN	0.08	1.00	0.04	0.25	1.50	20.0-27.0	8.0-11.0	0.10-0.30 N, 3.0-4.5 Mo
J92802	CE2ON	0.20	1.50	0.040	0.040	1.50	23.0-26.0	8.0-11.0	0.08-0.20 N
J92500	CF3, CF3A	0.03	1.50	0.040	0.040	2.00	17.0-21.0	8.0-12.0	•••
J92800	CF3M, CF3MA	0.03	1.50	0.04	0.04	1.50	17.0-21.0	9.0-13.0	2.0-3.0 Mo
J92804	CF3MN	0.03	1.50	0.040	0.040	1.50	17.0-21.0	9.0-13.0	0.10-0.20 N, 2.0-3.0 Mo
J92600	CF8, CF8A	0.08	1.50	0.04	0.04	2.00	18.0-21.0	8.0-11.0	•••
J92710	CF8C	0.08	1.50	0.04	0.04	2.00	18.0-21.0	9.0-12.0	Nb[3]
J92900	CF8M	0.08	1.50	0.04	0.04	2.00	18.0-21.0	9.0-12.0	2.0-3.0 Mo
J92590	CF10	0.04-0.10	1.50	0.040	0.030	2.00[5]	18.0-20.0	8.0-11.0	
J92901	CF10M	0.04-0.10	1.50	0.040	0.040	1.50	18.0-21.0	9.0-12.0	2.0-3.0 Mo
J92971	CF10MC	0.10	1.50	0.040	0.040	1.50	15.0-18.0	13.0-16.0	1.75-2.25 Mo,Nb[4]
J92972	CF10SMnN	0.10	7.00-9.00	0.060	0.030	3.50-4.50	16.0-18.0	8.0-9.0	0.08-0.18 N
J92701	CF16F	0.16	1.50	0.04	0.04	2.00	18.0-21.0	9.0-12.0	•••
J92999	CG3M	0.03	1.50	0.04	0.04	1.50	18.0-21.0	9.0-13.0	3.0-4.0 Mo
J93790	CG6MMN	0.06	4.00-6.00	0.04	0.03	1.00	20.50-23.50	11.50-13.50	0.20-0.40 N, 1.50-3.00 Mo, 0.10-0.30 Nb, 0.10-0.30 V
J93000	CG8M	0.08	1.50	0.04	0.04	1.50	18.0-21.0	9.0-13.0	3.0-4.0 Mo
J93001	CG12	0.12	1.50	0.04	0.04	2.00	20.0-23.0	10.0-13.0	•••
J93400	CH8	0.08	1.50	0.040	0.040	1.50	22.0-26.0	12.0-15.0	•••
J93401	CH10	0.10	1.50	0.040	0.040	2.00	22.0-26.0	12.0-15.0	•••
J93402	CH20	0.20	1.50	0.04	0.04	2.00	22.0-26.0	12.0-15.0	•••
J93254	CK3MCuN	0.025	1.20	0.045	0.010	1.00	19.5-20.5	17.5-19.5	0.180-0.240 N, 6.0-7.0 Mo, 0.5-1.0 Cu
J94202	CK20	0.20	2.00	0.04	0.04	2.00	23.0-27.0	19.0-22.0	•••
J94652	CN3M	0.03	2.0	0.03	0.03	1.0	20.0-22.0	23.0-27.0	4.5-5.5 Mo
J94651	CN3MN	0.03	2.00	0.040	0.010	1.00	20.0-22.0	23.5-25.5	0.18-0.26 N, 6.0-7.0 Mo 0.75 Cu
N08007	CN7M	0.07	1.50	•••	•••	1.50	19.0-22.0	27.5-30.5	2.00-3.00 Mo, 3.00-4.00 Cu
J94650	CN7MS	0.07	1.00	0.04	0.03	2.50-3.50	18.0-20.0	22.0-25.0	2.5-3.0 Mo, 1.5-2.0 Cu

* maximum unless range is given

1) Columbium (Cb) and Niobium (Nb) are the same element   2) $\%Cr + 3.3 \times \%Mo + 16 \times \%N_2 \geq 40$

3) Nb = 8 x C min., 1.00 max or Nb + Ta = 9 x C min, 1.1 max   4) Nb = 10 x C min, 1.20% max   5) ASTM A 351 maximum silicon level

Table 2 Wrought equivalents*, microstructures, and specifications for corrosion resistant stainless steel castings

UNS	ACI or Other Names	Approximate Wrought Equivalent	Common End-Use Microstructure	ASTM
J91650	CA6N	• • •	martensite	A 743
J91540	CA6NM	F-6NM (S41500)	martensite	A 352, A 356, A 487, A 743
J91150	CA15	410 (S41000)	martensite	A 217, A 743
J91153	CA40	420 (S42000)	martensite	A 743
J91804	CB6	• • •	martensite	A 743
J92180	CB7Cu1	17-4 Type 630 (S17400)	martensite	A 747
J92110	CB7Cu2	15-5, XM-12 (S15500)	martensite	A 747
J92205	CD3MN, 4A	2205 (S31803, S32205)	duplex	A 890
J93380	CD3MWCuN, Zeron 100, 6A	• • •	duplex	A 890, A 351
J93370	CD4MCu, 1A	• • •	duplex	A 744, A 890, A 743, A 351
J93372	CD4MCuN, 1B	• • •	duplex	A 890
J93371	CD6MN, 3A, Zeron 25	• • •	duplex	A 890
J93404	CE3MN, 5A	• • •	duplex	A 890
J93345	CE8MN	• • •	duplex	A 890
J92802	CE20N	• • •	austenite[1]	A 351
J92500	CF3, CF3A	304L (S30403)	austenite[1]	A 351, A 451, A 743, A 744
J92800	CF3M, CF3MA, CPF3M	316L (S31603)	austenite[1]	A 351, A 451, A 744, A 743
J92804	CF3MN	316LN	austenite[1]	A 351, A 743
J92600	CF8, CF8A, CPF8A	304 (S30400)	austenite[1]	A 351, A 451, A 743, A 744
J92710	CF8C, CPF8C	347 (S34700)	austenite[1]	A 351, A 451, A 743, A 744
J92900	CF8M, CPF8M	316 (S31600)	austenite[1]	A 351, A 451, A 743, A 744
J92590	CF10	304H (S30409)	austenite[1]	A 351
J92901	CF10M	316H (S31609)	austenite[1]	A 351
J92971	CF10MC	316Cb (S31640)	austenite[1]	A 351
J92972	CF10SMnN	NITRONIC® 60 (S21800)	austenite[1]	A 743, A 351
J92701	CF16F, CF16Fa	303 Se (S30300)	austenite[1]	A 743
J92999	CG3M	• • •	austenite[1]	A 351, A 743, A 744
J93790	CG6MMN	NITRONIC® 50 (S20910)	austenite[1]	A 351, A, 743
J92701	CF16F, CF16Fa	303 Se (S30300)	austenite[1]	A 351, A 743, A 744
J93001	CG12	• • •	austenite[1]	A 743
J93400	CH8, CPH8	• • •	austenite[1]	A 351, A 451
J93401	CH10	• • •	austenite[1]	A 351, A 743
J93402	CH20, CH2, CPH10, CPH20	309 (S30900)	austenite[1]	A 351, A 451, A 743
J93254	CK3MCuN	254 SMO® (S31254)	austenite[1]	A 351, A 743, A 744
J94202	CK20, CPK20	310 (S31000)	austenite	A 351, A 451, A 743
J94652	CN3M	• • •	austenite	A 743
J94651	CN3MN	AL-6XN® (N08367)	austenite	A 351, A 743, A 744
N08007	CN7M	Alloy 20 (N08020)	austenite	A 351, A 743
J94650	CN7MS	• • •	austenite	A 743, A 744

*Wrought equivalents from ASTM A 781/A 781M, Table X2.1

1) Predominantly austenite but typically contains from 10-20 volume percent ferrite

*Table 3 Strength requirements for corrosion resistant stainless steel castings**

UNS	ACI	Tensile Strength, min		Yield Strength, min		Elongation in 2 inch (50 mm) min[1] %	Reduction Area min %
		ksi	MPa	ksi	MPa		
J91650	CA6N	140	965	135	930	15	50
J91540	CA6NM	110	755	80	550	15	35
J91150	CA15	90	620	65	450	18	30
J91153	CA40	100	690	70	485	15	25
J91804	CB6	115	790	85	580	16	35
J92180[2]	CB7Cu1						
J92110[2]	CB7Cu2						
J92205	CD3MN	90	620	60	415	25	•••
J93380	CD3MWCuN	100	690	65	450	25.0	•••
J93370	CD4MCu	100	690	70	485	16.0	•••
J93372	CD4MCuN	100	690	70	485	16	•••
J93371	CD6MN	95	655	65	450	25	•••
J93404	CE3MN	100	690	75	515	18	•••
J93345	CE8MN	95	655	65	450	25.0	•••
J92802	CE20N	80	550	40	275	30.0	•••
J92500	CF3	70	485	30	205	35	•••
J92500	CF3A	77	530	35	240	35	•••
J92800	CF3M	70	485	30	205	30	•••
J92800	CF3MA	80	550	37	255	30	•••
J92804	CF3MN	75	515	37	255	35	•••
J92600	CF8	70[3]	485[3]	30[3]	205[3]	35	•••
J92600	CF8A	77	530	35	240	35	•••
J92710	CF8C	70	485	30	205	30	•••
J92900	CF8M	70	485	30	205	30	•••
J92590	CF10	70	485	30	205	35	•••
J92901	CF10M	70	485	30	205	30	•••
J92971	CF10MC	70	485	30	205	20	•••
J92972	CF10SMnN	85	585	42	290	30	•••
J92701	CF16F	70	485	30	205	25	•••
J92999	CG3M	75	515	35	240	25	•••
J93790	CG6MMN	85	585	42	290	30	•••
J93000	CG8M	75	515	35	240	25	•••
J93001	CG12	70	485	28	195	35	•••
J93400	CH8	65	450	28	195	30	•••
J93401	CH10	70	485	30	205	30	•••
J93402	CH20	70	485	30	205	30	•••
J93254	CK3MCuN	80	550	38	260	35	•••
J94202	CK20	65	450	28	195	30	•••
J94652	CN3M	63	435	25	170	30	•••
J94651	CN3MN	80	550	38	260	35	•••
N08007[4]	CN7M	62	425	25	170	35	130[3]
J94650	CN7MS	70	485	30	205	35	•••

*ASTM A 743, A 351, A 890

1) When ICI test bars are used in tensile testing as provided for in A 703/A 703M, the gage length to reduced section diameter ratio shall be 4:1.

2) See Table 9 for the mechanical properties for these grades.

3) For low ferrite or nonmagnetic castings of this grade, the following values shall apply: tensile strength, min., 65 ksi (450 MPa) yield point, min., 28 ksi (195 MPa)

4) Water quenched from 2000-2050°F (1093-1121°C)

Table 4 Typical short-time high temperature properties of corrosion resistant stainless steel castings[Ref. 1]

ACI	Temperature		Tensile Strength		Yield Strength 0.2% Offset	
	°F	°C	ksi	MPa	ksi	MPa
CF8	75	24	78	537	34	234
	1000	538	55	379	17	117
	1200	649	44	303	16	110
	1400	760	26	179	15	103
CF8C	75	24	78	537	34	234
	1000	538	58	379	22	151
	1200	649	47	324	20	138
	1400	760	26	179	18	124
CF8M	75	24	79	544	37	255
	1000	538	56	386	21	145
	1200	649	40	275	18	124
	1400	760	26	179	15	103
CH20	75	24	76	524	36	248
	1000	538	41	282	16	110
	1200	649	25	172	16	110
	1400	760	12	82	10	69
CK20	75	24	80	551	33	227
	1000	538	54	372	20	138
	1200	649	32	220	19	131
	1400	760	16	110	13	89

Table 5 Standard heat treatments for corrosion resistant stainless steel castings*

ACI	Heat Treatment, min, °F (°C)**
CA6N	1900 (1040), AC, temper 1500 (815), AC, age at 800(425)
CA6NM	1850 (1010), AC to 200 (95), temper 1050-1150 (565-620)
CA15, CA40	1750 (955), AC temper 1100 (595) or anneal 1450(790)
CB6	1800-1920 (980-1050), FAC to 120 (50) max., temper 1100-1160 (595-625)
CD3MN	2050 (1120), WQ or FC to 1850 (1010) hold for 15 min., WQ
CD3MWCuN	2010 (1100), WQ or RC
CD4MCu	1900 (1040), WQ or RC
CD4MCuN	1900 (1040), WQ or RC
CD6MN	1950 (1070), WQ or RC
CE3MN	2050 (1120), FC to 1910 (1045), WQ or RC
CE8MN	2050 (1120), WQ or RC
CE20N	2225 (1218), Q or FC to 2050 (1121), hold 15 min., WQ or RC
CF3[1]	1900 (1040), WQ or RC
CF3A	1900 (1040), WQ or RC
CF3M[1]	1900 (1040), RC
CF3MA	1900 (1040), RC
CF3MN	1900 (1040), RC
CF8	1900 (1040), WQ or RC
CF8A	1900 (1040), WQ or RC
CF8C	1900 (1040), WQ or RC
CF8M	1900 (1040), WQ or RC
CF10	1900 (1040), WQ or RC
CF10M	1900 (1040), WQ or RC
CF10SMnN	1950 (1065), WQ or RC
CF16F, CF16Fa	1900 (1040), WQ or RC
CG3M	1900 (1040), WQ or RC
CG6MMN	2050 (1120), WQ or RC
CG8M	1900 (1040), WQ or RC
CG12	1900 (1040), WQ or RC
CH8	2000 (1093), WQ or RC
CH10	2000 (1093), WQ or RC
CH20	2000 (1093), WQ or RC
CK3MCuN	2100 (1150), WQ or RC
CK20	2000 (1093), WQ or RC
CN3M	2150 (1175), WQ or RC
CN3MN	2100 (1150), WQ or RC
CN7M	2050 (1120), WQ or RC
CN7MS	2100-2150 (1150-1180) for 2 hrs. min., WQ

AC = air cool
FAC = forced air cool
WQ = water quench
FC = furnace cool
RC = rapid cool by other means

* ASTM A 351, A 352, A 743, A 744, and A 890

** All castings should be held at temperature for a sufficient time to reach uniform heating

1) Can be used in the as-cast condition if corrosion resistance is acceptable

Table 6 Typical room temperature hardness and impact properties of corrosion resistant stainless steel castings [Ref. 2]

ACI	Brinell Hardness	Charpy Impact Energy J	Charpy Impact Energy ft-lbf	Specimen
CA6NM	269	95	70	Charpy V-notch
CA15	225	27	20	Charpy keyhole notch
CA40	310	23	2	Charpy keyhole notch
CB7Cu	400	34	25	Charpy V-notch
CD4MCu	253	75	55	Charpy V-notch
CF3	140	149	110	Charpy V-notch
CF3A	160	136	100	Charpy V-notch
CF3M	150	162	120	Charpy V-notch
CF3MA	170	136	100	Charpy V-notch
CF8	140	100	74	Charpy keyhole notch
CF8A	156	95	70	Charpy keyhole notch
CF8C	149	41	30	Charpy keyhole notch
CF8M	170	95	70	Charpy keyhole notch
CF16F	150	102	75	Charpy keyhole notch
CG8M	176	109	80	Charpy V-notch
CH20	190	41	30	Charpy keyhole notch
CK-20	144	68	50	Izod V-notch

Table 7 Physical properties of corrosion resistant stainless steel castings [Ref. 3,4]

ACI	Melting Point		Specific Heat		Coefficient of Thermal Expansion		Thermal Conductivity 32-212°F (0-100°C)	
	°C	°F	J/Kg-°K	32-212°F Btu/lb/°F	m/m-°K	in 106 in/in/°F°F	Btu/(ft-hr-°F)	W/m-°K
CA6NM	1510	2750	460[1]	.011[1]	3.3[2], 3.9[3]	6.0[2], 7.0[3]	14.5[4], 16.7[5]	25.10[4], 28.90[5]
CA15	1510	2750	460	0.11[1]	3.0[2], 3.6[3]	5.5[2], 6.4[3]	14.5[4], 16.7[5]	25.10[4], 28.89[5]
CA40	1508	2725	460[1]	0.111	3.0[2], 3.6[3]	5.5[2], 6.4[3]	14.5[4], 16.7[5]	25.10[4], 28.89[5]
CB7Cu	1510	2750	460[1]	0.11[1]	3.3[6], 3.7[7]	6.0[6], 6.6[7]	9.9[4]	17.13[4]
CD4MCu	1482	2700	460[1]	0.11[1]	3.5[2], 3.9[3]	6.3[2], 6.9[3]	8.8[4]	15.23[4]
CF3	1454	2650	502[1]	.012[1]	5.0[2], 5.6[3]	9.0[2], 10.0[3]	9.2[4], 12.1[5]	15.92[4], 20.94[5]
CF3M	1427	2600	502[1]	0.12[1]	5.0[2], 5.4[3]	8.9[2], 9.7[3]	9.4[4], 12.3[5]	16.27[4], 21.29[5]
CF8	1427	2600	502	0.12	5.0[2], 5.6[3]	9.0[2], 10.0[3]	9.2[4], 12.1[5]	15.92[4], 20.94[5]
CF8C	1427	2600	502	0.12	5.2[2], 5.8[3]	9.3[2], 10.3[3]	9.3[4], 12.8[5]	16.10[4], 22.15[5]
CF8M	1399	2550	502	0.12	5.0[2], 5.4[3]	8.9[2], 9.7[3]	9.4[4], 12.3[5]	16.27[4], 21.29[5]
CF16F	1399	2550	502	0.12	5.0[2], 5.5[3]	9.0[2], 12.3[3]	9.4[4], 12.3[5]	16.27[4], 21.29[5]
CG8M	1399	2550	502	0.12	5.0[2], 5.4[3]	8.9[2], 9.7[3]	9.4[4], 12.3[5]	16.27[4], 21.29[5]
CH20	1427	2600	502	0.12	4.8[2], 5.3[3]	8.6[2], 9.5[3]	8.2[4], 12.0[5]	14.19[4], 20.77[5]
CK20	1427	2600	502	0.12	4.7[2], 5.3[3]	8.3[2], 9.4[3]	7.9[4], 11.8[5]	13.67[4], 20.42[5]

1) at 70°F (21°C) 2) 68-212°F (20-100°C) 3) 70-1000°F (21-93°C) 4) at 212°F (100°C)
5) at 1000°F (538°C) 6) 70-200°F (21-93°C) aged at 900°F (482°C) 7) 70-200°F (21-93°C) aged at 1100°F (593°C)

Figure 1 Relative tensile strength of corrosion resistant stainless steel castings

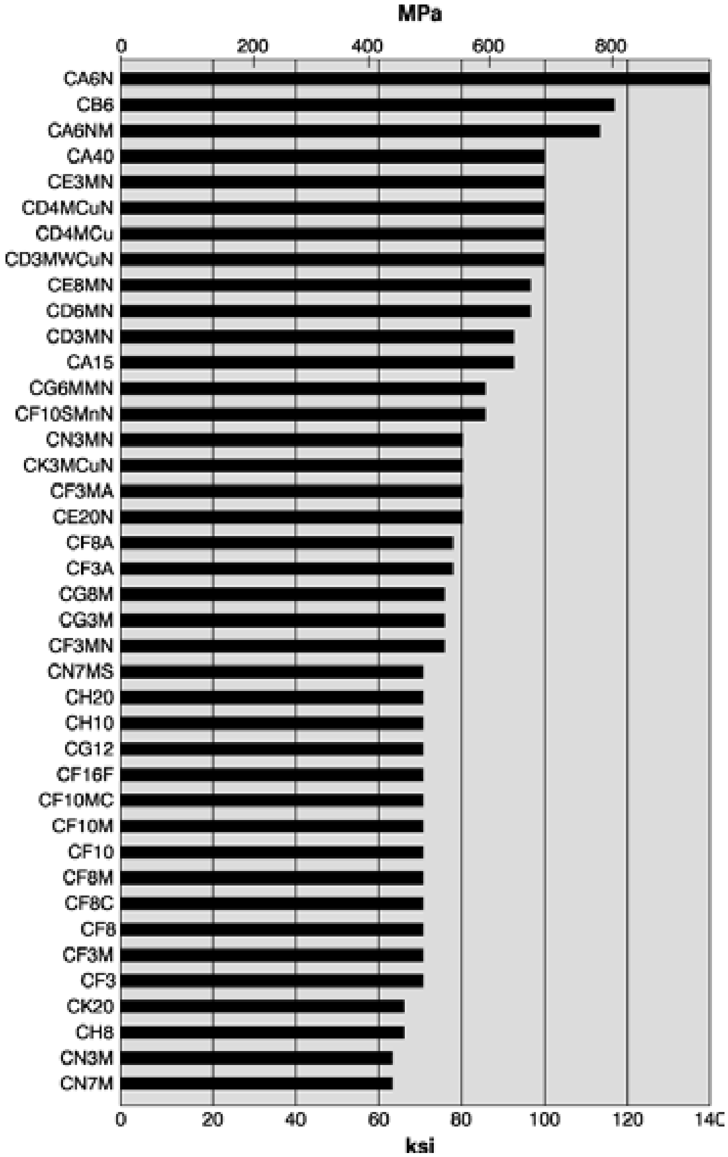
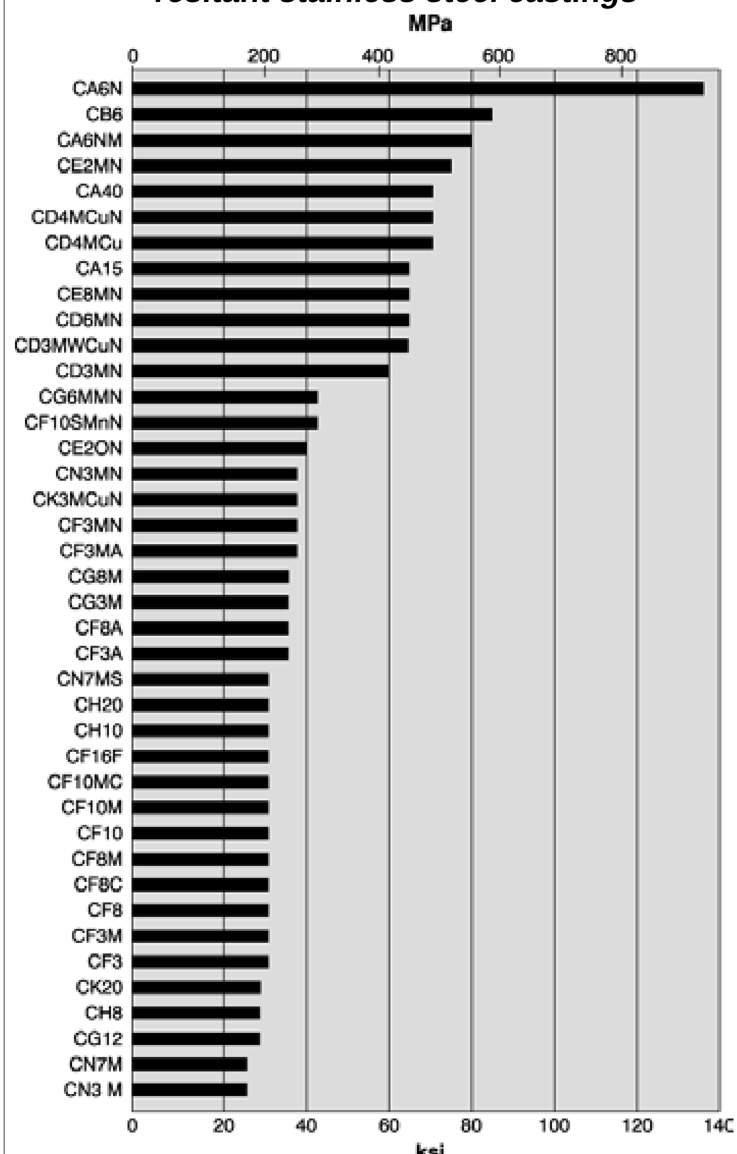


Figure 2 Relative yield strength of corrosion resitant stainless steel castings



MARTENSITIC

The most widely used martensitic grades are CA6NM, CB7Cu1, and CB7Cu2. Martensitics are resistant to moderate atmospheric corrosion and mild organic media corrosion. Their corrosion resistance is lower than that of more highly alloyed grades, limiting their use in process environments. Their strength and tempering resistance are improved by molybdenum.

These grades are ferromagnetic, hardenable by heat treatment, and have poor low-temperature impact strength. They combine hardness with improved corrosion resistance over nonstainless steels and are used for cutlery, turbine blades, and high-temperature parts.

Section thicknesses of about 0.2 inch (5 mm) and above can be cast satisfactorily. Somewhat lighter sections are feasible depending on the casting design and pattern. Complex designs with light and heavy sections are feasible, but drastic changes in section thickness should be avoided.

Figure 3 Relative elongation of corrosion resistant stainless steel castings

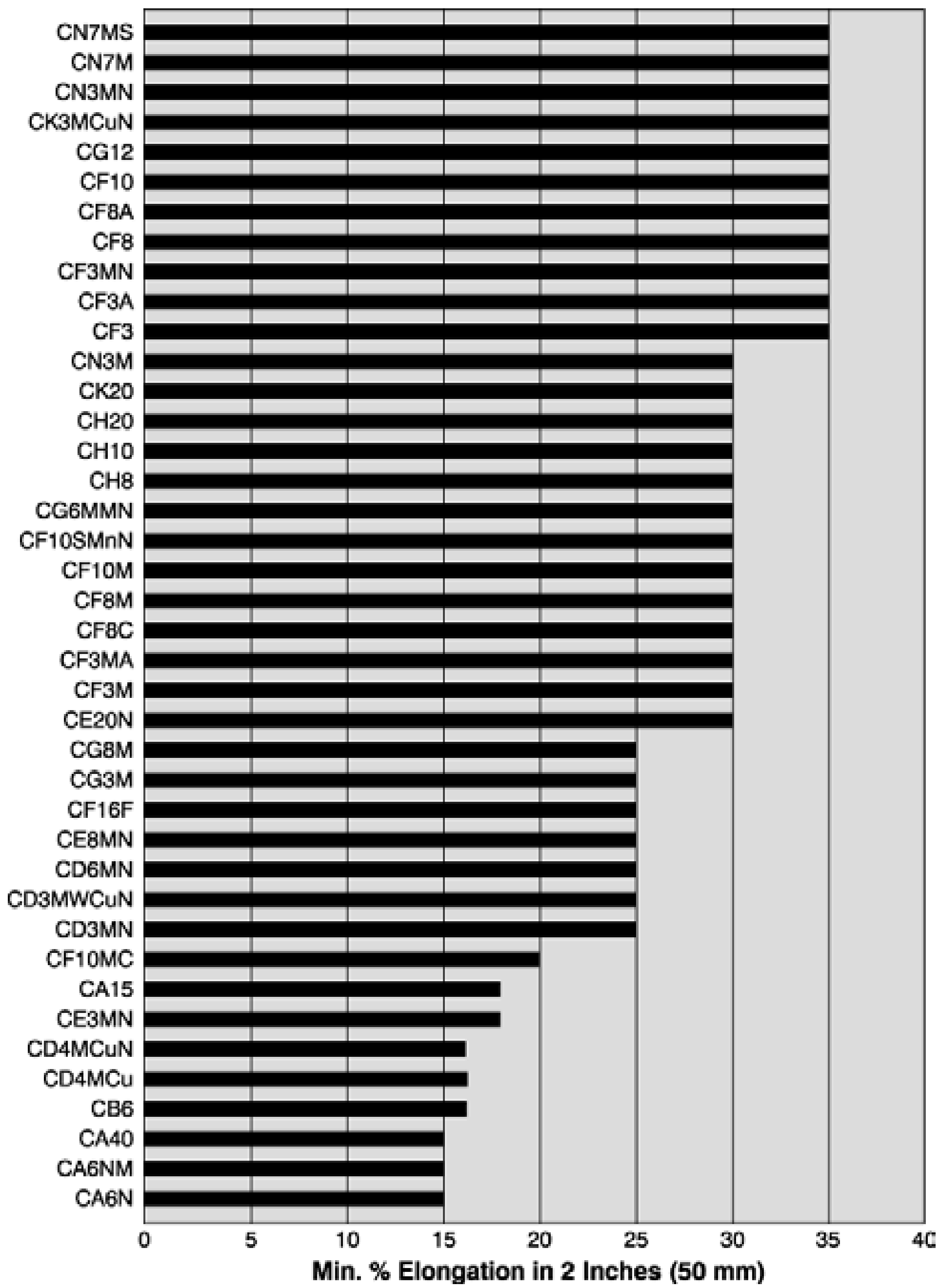


Table 8 Physical properties of corrosion resistant stainless steel castings [Ref. 4]

ACI	Magnetic Permeability	Electrical Resistivity $\mu\Omega$m at 70°F	Modulus of Elasticity		Density	
			ksi x 10^3	MPa x 10^3	lb/in³	kg/m³
CA6NM	ferromagnetic	0.78	29	200	0.278	7695
CACA15	500	0.56	29	200	0.275	7612
CA40	ferromagnetic	0.76	29	200	0.275	7612
CB7Cu	ferromagnetic	0.77	29	200	0.282	7806
CD4MCu	ferromagnetic	0.75	29	200	0.280	7750
CF3	1.2-3.0	0.76	28	193	0.280	7750
CF3M	1.5-3.0	0.82	28	193	0.280	7750
CF8	1.0-1.3	0.76	28	193	0.280	7750
CF8C	1.2-1.8	0.71	28	193	0.280	7750
CF8M	1.5-2.5	0.82	28	193	0.280	7750
CF16F	1.0-2.0	0.72	28	193	0.280	7750
CG8M	1.5-3.0	0.82	28	193	0.280	7750
CH20	1.7	0.84	28	193	0.279	7723
CK20	1.0	0.90	29	200	0.280	7750

CAM (11Cr-7Ni)
UNS J91650

CA6N contains the minimum chromium level needed to form a passive film.
It combines strength and toughness with fairly good machinability and weldability. CA6N is resistant to atmospheric corrosion and staining by many organic media in relatively mild service.

CA6NM (Mr-4Ni)
UNS J91540

CA6NM is CA6N modified with molybdenum to improve corrosion resistance and castability. Its wrought equivalent is F-6NM (S41500). CA6NM provides resistance to mildly corrosive environments under oxidizing conditions and good cavitation resistance. It is used for low-temperature valves, flanges, fittings, and other pressure-containing parts to -100°F (-73°C); boiler feed water to 240°F (115°C); flowing seawater; sulfur; and water to 400°F (205°C). It has been used by the chemical, marine, oil and gas, pollution control and power industries for casings, compressor impellers, diaphragms, diffusers, discharge spacers, hydraulic turbine parts, impulse wheels, packing housings, propellers, pump impellers, suction spacers, and valve bodies and parts.

CA6NM should be heat-treated prior to use and tempered after major weld repairs. Double tempering to achieve hardness values below 22 HRC for wet H_2S environments typically consists of austenitizing at 1925°F (1050°C) followed by tempering at 1250°F (680°C), and then a second temperinq treatment at 1150°F (620°C).

CA15 (13Cr) UNS J91150
CA40 (13Cr) UNS J91153

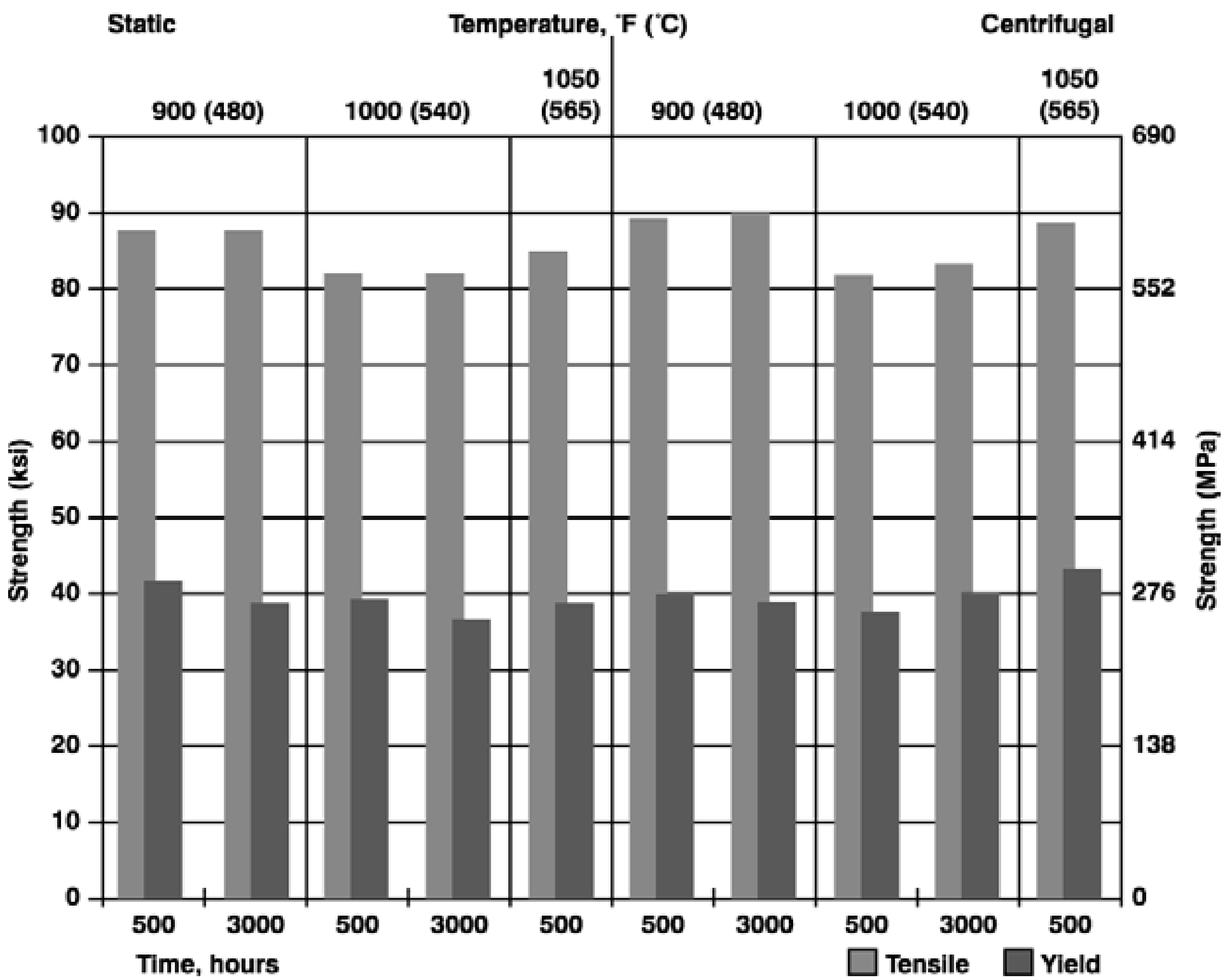
CA15 is an iron-chromium alloy containing the minimum amount of chromium necessary for classification as a stainless steel. It is resistant to atmospheric corrosion and staining by many organic media in relatively mild service and provides fairly good machining and welding properties. CA40 is a higher carbon version of CA15. The higher carbon content permits the grade to be hardened to a maximum of 500 BHN and increases its strength.

CB7Cu1 (16Cr-4Ni-4Cu) UNS J92180
CB7Cu2 (15Cr-5Ni-3Cu) UNS J92110

CB7Cu1 and CB7Cu2 are high strength, low carbon, precipitation-hardenable grades that are not intended for use in the solution annealed condition. The wrought equivalents are 17-4 (S17400) and 15-5 (S15500). These grades are used in applications where both elevated temperature strength (up to 600°F or 315°C) and corrosion resistance are required. Both are similar to Type 304 in performance in many environments.

CB7Cu1 and CB7Cu2 have good resistance to atmospheric corrosion and many corrosive liquids including ethylene glycol-water (-65 to 200°F or -55 to 95°C), food products, pulp liquor, and water up to 400°F (205°C). Common applications include airframe components, centrifuge bowls, compressor impellers, food machinery parts, machine tool parts, propeller shafts, pump impellers, rotors, screw flights, and valve bodies in the aerospace, aircraft, chemical, food processing, gas turbine, marine, petrochemical, and pulp and paper industries. Machining is done in the solution-annealed condition before precipitation-hardening to the desired strength level. If homogenizing is desired prior to solution-annealing, heat the castings to 1900°F (1040°C) minimum, hold for 1.5 hours minimum, and then air-cool to below 90°F (30°C). Because precipitation-hardening is done at a relatively low temperature, there is little danger of cracking, distortion, or oxidation of the machined surfaces. Some shrinkage (0.04 to 0.06%) occurs during precipitation-hardening. The standard precipitation-hardening treatments and the resultant mechanical properties are shown in Table 9.

Figure 4 Effect of elevated temperature on static and centrifugally cast CF8 with a ferrite number of 9 to 11 and 0.081%N [Ref. 5]



AUSTENITIC

While wrought austenitic grades have a single-phase microstructure, their cast equivalents usually have a small amount of ferrite mixed with the austenite. Ferrite is beneficial in reducing the potential for stress corrosion cracking. Therefore, when wrought and cast versions of a grade are subjected to an environment where stress corrosion cracking is possible, the casting may be less likely to crack. Ferrite also improves casting characteristics and mechanical strength. *Figures 4, 5 and 7* show the effect of elevated temperature exposure on mechanical properties and hardness. *Figure 6* shows the beneficial effect of increasing ferrite volume fraction on chloride stress corrosion cracking resistance.

Ferrite is beneficial to weldability and weld repair because it minimizes the hot cracking that may occur in the weld deposits of fully austenitic stainless steels. Because some corrosive solutions are more likely to attack either austenite or ferrite, the presence of ferrite improves corrosion resistance in some environments and is detrimental in others. The effect on corrosion resistance is determined by the specific alloy composition, heat treatment, and service conditions.

Ferrite can be detrimental in some applications because it reduces toughness. Prolonged exposure at temperatures above 600°F (315°C) can reduce toughness because of the 885°F (475°C) embrittlement of the ferrite. The elevated temperature toughness may be adequate, but the ambient temperature toughness is decreased as a result of exposure in this temperature range. The user should not assume that a casting has the wrong composition or heat treatment just because it is magnetic. While wrought austenitic grades are non-magnetic, their cast equivalents often contain from 5 to 40% ferrite and are partially magnetic. For example, wrought Type 316 is not magnetic, but its cast equivalent, CF8M, has ferrite in its microstructure and is partially magnetic. The corrosion-resistant

Figure 5 Effect of elevated temperature on static and centrifugally cast CF8 with a ferrite number of 9 to 11 and 0.081%N [Ref. 5]

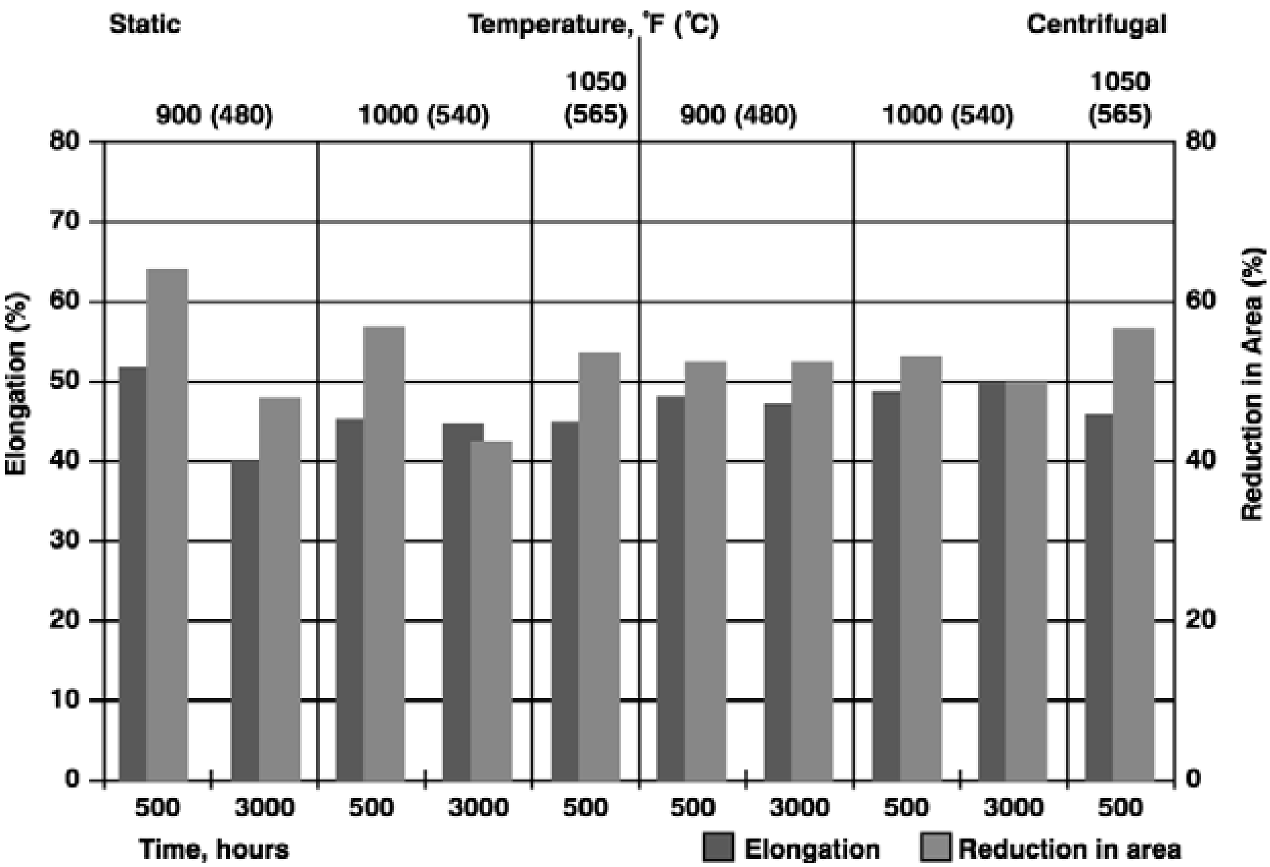


Figure 6 Stress required to produce stress-corrosion cracking with varying amounts of ferrite [Ref. 6]

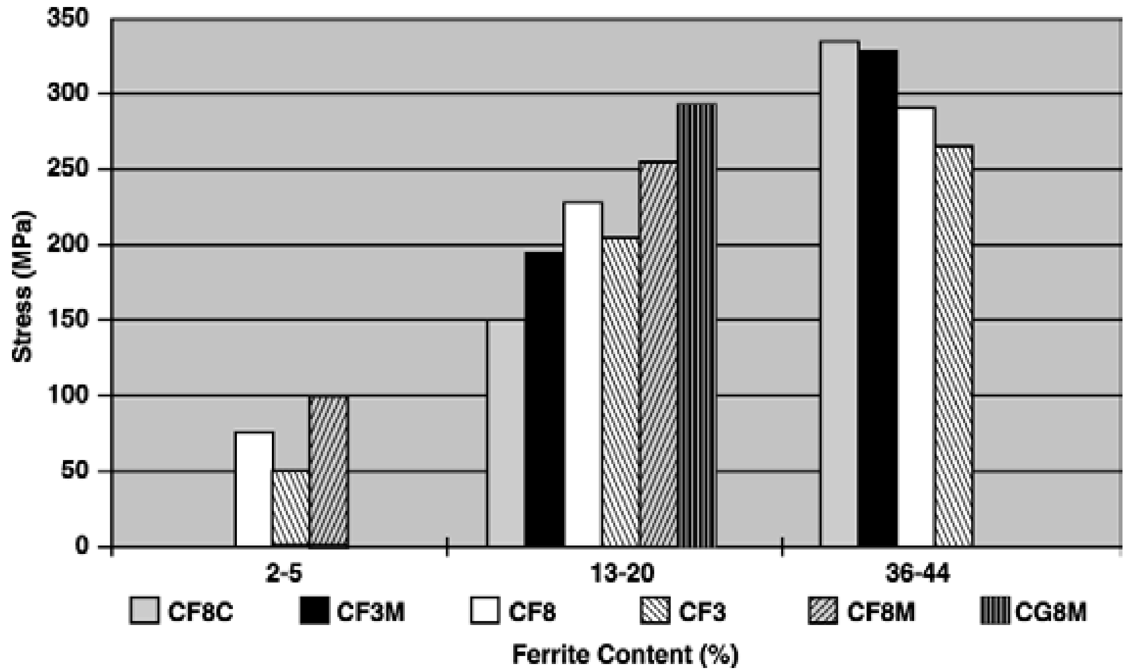
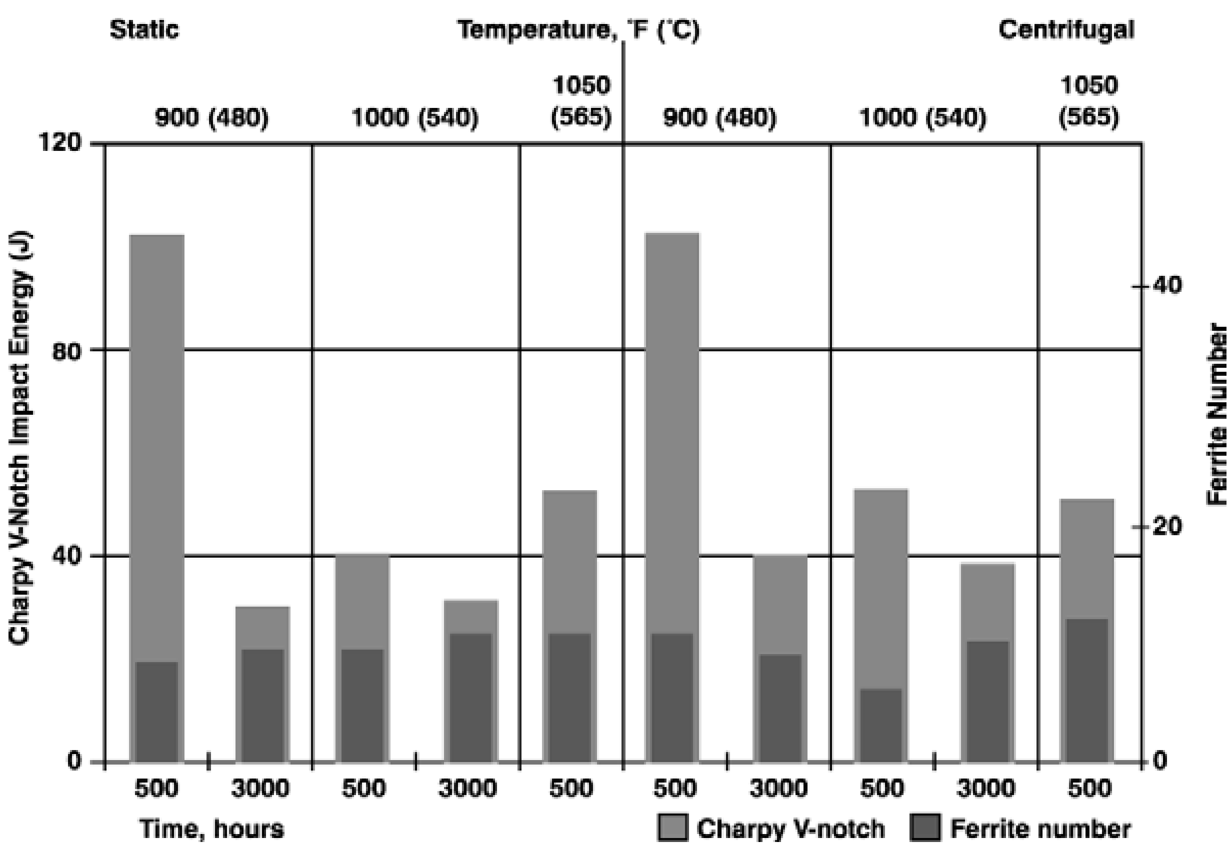


Figure 7 Effect of elevated temperature on static and centrifugally cast CF8 with a ferrite number of 9 to 11 and 0.081%N [Ref. 5]



grades with higher levels of nickel and carbon to stabilize the austenite are predominantly austenitic (i.e., CH20, CK20, CF16F, and CN7MS). The most commonly used austenitic grades are CF3, CF8, CF3M, CF8M, CN7M, and CN7MS. Corrosion data for CF8, CF8M, and CN7M is shown in *Table 10* and *Figures* 8 and *9.*

The CF grades are the most widely used family of corrosion-resistant cast stainless steels. They are used for handling a variety of corrosive fluids in the chemical, textile, petroleum, pharmaceutical, food and other industries. They are resistant to most organic acids and compounds used in the food, dairy and pharmaceutical industries, and to most waters including mine, river, boiler, and potable. The CF grades have been used in some seawater applications under high velocity conditions but should not be used in stagnant or slow-moving seawater because severe pitting is likely. They have also been used by the chemical industry to handle nitric acid, peroxides, and acid mixtures. Halogen acids and acid salts can destroy the surface passivity of the CF grades. This makes them susceptible to attack in media such as hydrochloric acid, acid chloride salts, wet chlorinated hydrocarbons, wet chlorine, and strong hypochlorites. They provide moderate erosion resistance in applications such as pumps, valves, and fittings.

Ferrite content can be estimated and controlled using the Schoefer diagram (derived from the Schaeffler diagram, which is used to determine

Table 9 Precipitation hardening heat treatments and mechanical properties for CB7Cu1 and CB7Cu2*

Heat Treatment	Temperature[2] °F	°C	Time (hours)	Hardness HB	Yield, min ksi	MPa	Tensile ksi	MPa	Elongation in 2 inch (50 mm), min %[3]
CB7Cu1									
H900	900	480	1.5	375 min.	145	1000	170	1170	5
H925	925	495	1.5	375 min.	150	1035	175	1205	5
H1025	1025	550	4.0	311 min.	140	965	150	1035	9
H1075	1075	580	4.0	277 min.	115	795	145	1000	9
H1100	1100	595	4.0	269 min.	110	760	135	930	9
H1150	1150	620	4.0	269 min.	97	670	125	860	10
H1150M[4]	1400	760	2.0						
	1150	620	4.0	310 max.	•••	•••	•••	•••	•••
H1150DBL[4]	1150	620	4.0						
	1150	620	4.0	310 max.	•••	•••	•••	•••	•••
CB7Cu2									
H900	900	480	1.5	375 min.	145	1000	170	1170	5
H925	925	495	1.5	375 min.	150	1035	175	1205	5
H1025	1025	550	4.0	311 min.	140	965	150	1035	9
H1075	1075	580	4.0	277 min.	115	795	145	1000	9
H1100	1100	595	4.0	269 min.	110	760	135	930	9
H1150	1150	620	4.0	269 min.	97	670	125	860	10
H1150M[4]	1400	760	2.0						
	1150	620	4.0	310 max.	•••	•••	•••	•••	•••
H1150DBL[4]	1150	620	4.0						
	1150	620	4.0	310 max.	•••	•••	•••	•••	•••

* ASTM A 747/A 747M

1) All heat treatments are with air cooling.

2) +/-25°F (15°C).

3) If sub-size tension test bars are used, the gage length/gage diameter ratio must be 4 to 1 to assure elongation values comparable to those of the standard test specimen.

4) Double aging heat treatment, hardness data limitations after second aging heat treatment.

Figure 8 Isocorrosion diagrams for solution-annealed and quenched CN-7M in H_2SO_4, HNO_3, NaOH, and H_3PO_4. Tests for (a), (b), (d), and (f) were performed at atmospheric pressure. Tests for (c) and (e) were performed at equilibrium pressures in a closed container. Ref. 2

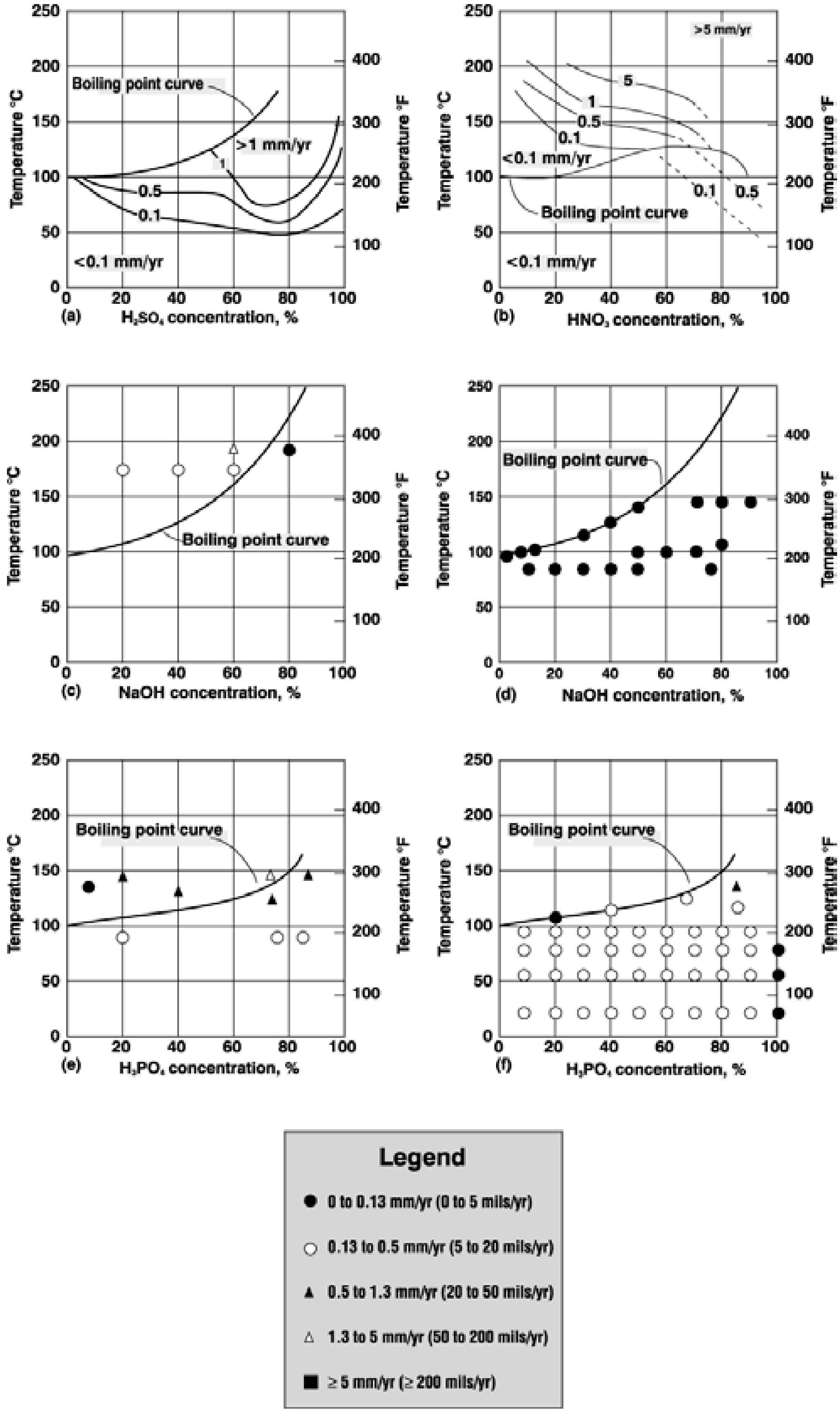


***Figure 9** Isocorrosion diagrams for CF-8 in HNO_3 (a), H_3PO_4 (b and c), and NaOH solutions (d and e). Tests for (b) and (d) were performed in a closed container at equilibrium pressure. Tests for (c) and (e) were performed at atmospheric pressure.* [Ref. 2]

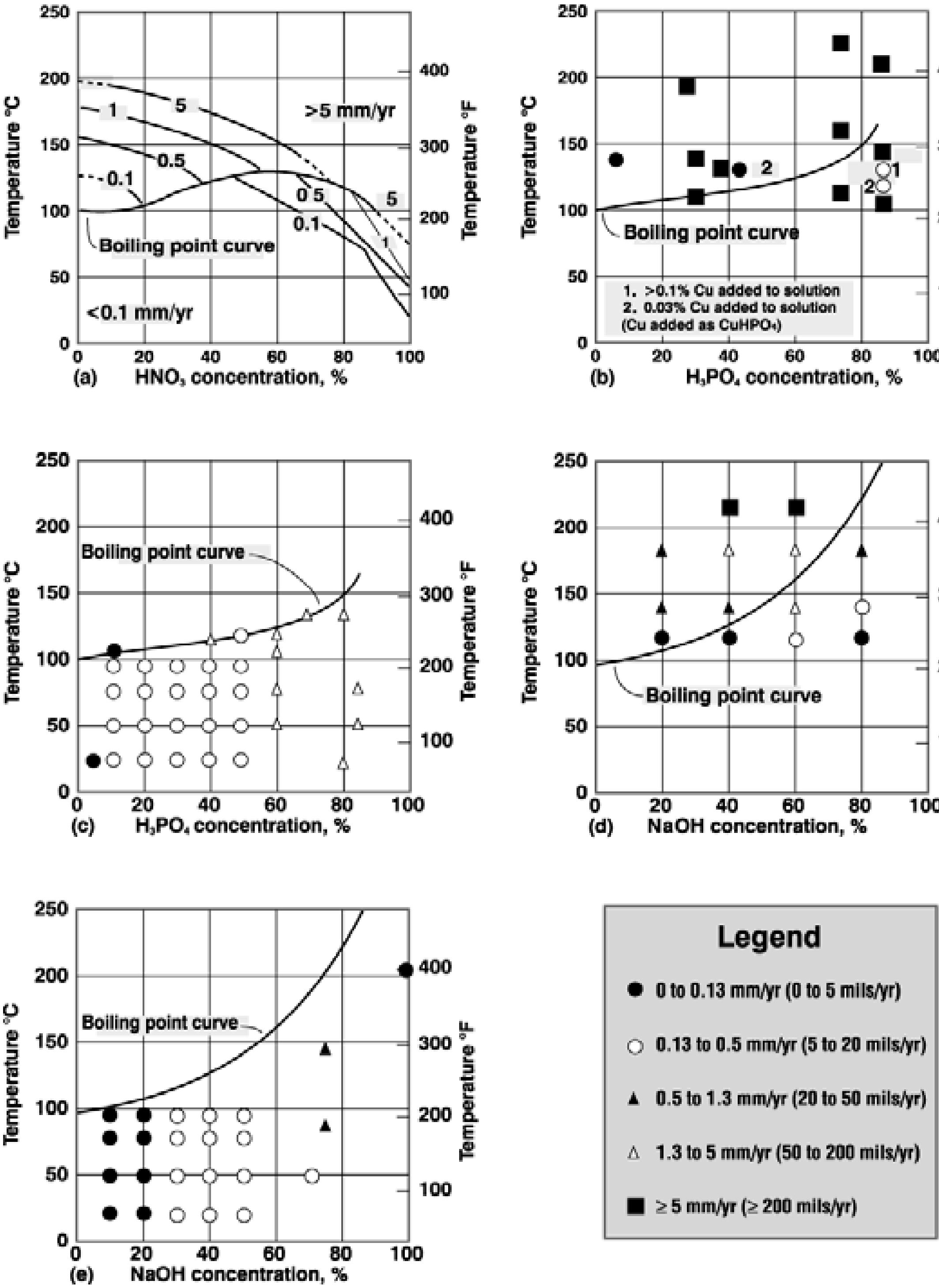


Table 10 Results of in-plant corrosion testing of CF8, CF8M, and CN7M [Ref. 2]

Type and Composition of Corroding Solution	Solution Temperature		Grade	Metal Surface Loss		Visible Surface Condition	Remarks
	°F	°C		µm/yr.	mils/yr.		
Neutralizer after formation of ammonium sulfate; ammonium sulfate plus excess of sulfuric acid, ammonia vapor, and steam	212	100	CF8 CF8M CN7M	665 28 18	26.2 1.1 0.7	Very heavy etch Light tarnish Bright	CF8M was installed for low corrosion tolerance equipment in this service and performed satisfactorily
Setting tank after neutralizer; ammonium sulfate plus excess of sulfuric acid	122	50	CF8 CF8M CN7M	385 10 2.5	15.2 0.4 0.1	Very heavy etch Slight tarnish Bright	CF8 in service showed excessive corrosion rate plus heavy concentration cell attack
Ammonium sulfate processing solution; ammonium sulfate at pH 8.0	122	50	CF8 CF8M CN7M	685 175 50	27.0 6.8 2.0	Heavy etch Moderate etch Light etch	CF8M had too high a corrosion rate in service for good valve life, although suitable for equipment of greater corrosion tolerance. CN7M was installed in this service.
99 to 100% fuming **nitric** acid	68	20	CF8 CF8M CN7M	245 345 79	9.6 13.5 3.1	Moderate etch Moderate etch Light etch	CF8 was satisfactory except for low-tolerance equipment such as valves. CN7M valves performed satisfactory in service.
Saturated solution of sodium chloride plus 15% sodium sulfate; pH 4.5	140	60	CF8M CF8	2.5 240	9.5 0.1	Bright Concentration cell corrosion in various small areas	CF8M was installed for valves in service

the structure of weld deposits), which is shown in *Figure 10*. It is used to estimate the ferrite content of stainless steel castings with a composition range of 16-26% Cr, 6-14% Ni; 4% Mo max., 1% Nb max., 0.2% C max., 0.19% N max., 2% Mn max., and 2% Si max. The ferrite content is obtained using the ratio of the chromium and nickel equivalents, which can be computed as follows:

$$Cr_e = \%Cr + 1.5(\%Si) + 1.4(\%Mo) + \%Nb - 4.99$$
$$Ni_e = \%Ni + 30(\%C) + 0.5(\%Mn) + 26(\%N - 0.02) + 2.77$$

Foundries compare a preliminary chemical analysis of the furnace charge to the Schoefer diagram to determine whether the casting will have the desired ferrite content range. This permits adjustment of the composition before casting. The effect of ferrite content on mechanical properties is shown in *Tables 11 and 12* and *Figure 11.*

The Ferrite Number (FN) can be measured by magnetic methods. The Magne-Gage and the Severn Gage procedures for calibrating magnetic instruments are contained in ANSI/AWS A4.2-91. With proper metallographic preparation, volume percent ferrite can be measured manually by point counting(ASTM E 562) or by automated image analysis (ASTM E 1245). The ferrite content can also be measured by x-ray defraction methods.

CF3 (Mr-8Ni) UNS J92500

CF3 is the cast equivalent of Type 304L (S30403) and is weakly magnetic. It is a lower carbon content version of CF8. Their applications are similar, but CF3 is preferred when there will be no post-weld heat treatment. Solution annealing is necessary for maximum corrosion resistance and to prevent intergranular attack. CF3 is used for applications below 650°F (345°C).

CF3 has been used in the food and beverage, heavy water, nuclear power, petroleum, and soap and detergent manufacturing industries. Components include autoclaves, blast furnaces, bushings, filter press plates, headers and heating coils, spray nozzles, bowls, discharge cases, impellers, propellers, pump casings, retaining rings, suction manifolds, tubes, and valve bodies and parts. It has been used in corrosive solutions including brackish water, phosphate solutions, and steam. Data for CF3 in various concentrations of HNO_3 at various temperatures is shown in *Figure 12*.

CF8 (Mr-8Ni) UNS J92600

CF8 is the cast equivalent of Type 304 (S30400). It has good strength and ductility. It also has good cavitation resistance, which is important for hydroturbines, pump impellers, and related equipment. It is primarily used for water handling but also provides resistance to strongly oxidizing environments such as boiling nitric acid. Other corrosive media applications have included adipic acid, antibiotics and drugs, bleaching compounds, dye, fatty acids, fruit juices, gasoline, hot air, hot water, hydrocarbons, liquid oxygen, mixed H_2S0_4 HNO3, nicotinic acid, nitric acid (hot and concentrated), organic liquids and acids, organic salts, sewage, sodium carbonate, sodium sulfate, steam, sub-zero gases, 50% sulfuric acid, vinegar, and white liquor. See the results of in-plant corrosion testing in Table 10, and data on the performance of CF8 in various solutions in Figure 9.

Products made from CF8 include architectural trim, autoclaves, blast furnace bushings, computer parts, valves and fittings, engine mountings, fan parts, filter press plates and frames, flanges, hardware, heating coils, mixing agitators and propellers, mixing kettles, oil burner throat rings, pumps, retaining rings, rotary strainers, sanitary fittings (dairy), shaft sleeves, and spray nozzles.

Figure 10 Schoefer diagram

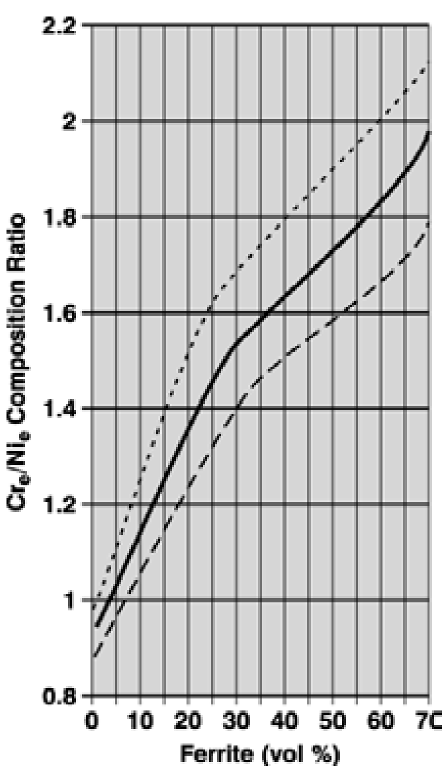


Figure 11 Yield and tensile strength versus ferrite percentage for CF8 and

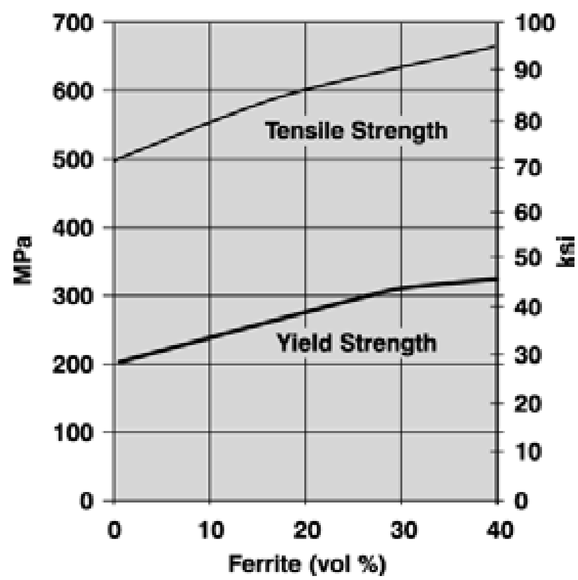
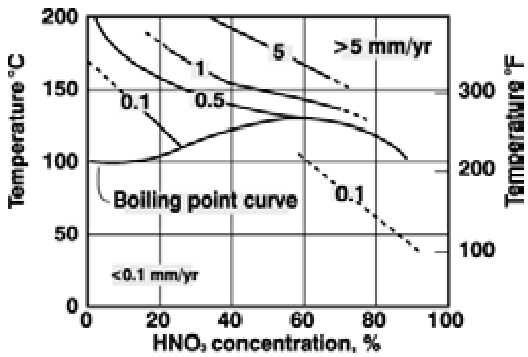


Figure 12 Isocorrosion diagram for solution-treated, queched and sensititzed CF3 in HNO_3 [Ref.2]



CF8 has good machining and welding characteristics. The as-cast structure is normally about 10% ferrite, which helps to reduce the potential for intergranular corrosion in castings exposed to temperatures in the sensitizing range. The ferrite promotes carbide precipitation in discontinuous pools rather than at the grain boundaries. At higher ferrite levels, strength and resistance to stress corrosion cracking are substantially improved. This grade has excellent low temperature properties and retains high impact strength levels at temperatures as low as -400°F (-240°C). When exposed to temperatures between 900 and 1200°F (480 to 650°C), it will become sensitized and suffer diminished corrosion resistance. CF8 cannot be hardened by heat treatment.

Table 11 Charpy V-notch impact energy, ferrite content, and Cr_e /Ni_e ratio of ferrite-containing cast austenitic grades [Ref. 6]

Grade	Charpy V-Notch Energy		Ferrite Content (%)			Cr_e/Ni_e
	J	ft-lbf	Calculated	MG[1]	FS[2]	Ratio[3]
CF3M	197	145	28.5	20	20	1.5
CF3C	183	135	20.7	12.5	14	1.4
CG8M	216	159	18	9	10	1.34
CF3C	>358	>264	15	13	15	1.29
CF3M	>358	>264	7.7	6	7	1.12

1) MG = Magne-Gage 2) FS = Feritscope
3) Calculated composition ratio used with the Schoefer diagram to determine ferrite content

Table 12 Effect of ferrite content on tensile properties of 19Cr-9Ni grades [Ref. 6]

Ferrite %	Tensile Strength		Yield Strength 0.2% Offset		Elogation in 2 inch (50 mm) %	Reduction in Area %
	MPa	ksi	MPa	ksi		
Tested at Room Temperature						
3	465	67.4	216	31.3	60.5	64.2
10	498	72.2	234	34.0	61.0	73.0
20	584	84.7	296	43.0	53.5	58.5
41	634	91.9	331	48.0	45.5	47.9
Tested at 670°F (355°C)						
3	339	49.1	104	15.1	45.5	63.2
10	350	50.8	109	15.8	43.0	69.7
20	457	66.3	183	26.5	36.5	47.5
41	488	70.8	188	27.3	33.8	49.4

CF8C (18Cr-10Ni-Cb) UNS J92710

CF8C is the cast equivalent of Type 347 (S34700) and it is CF8 modified with an addition of niobium. The niobium prevents grain boundary precipitation of chromium carbides and subsequent intergranular corrosion if the material is exposed to a corrosive environment. It provides corrosion resistance equivalent to CF8 and is used as a substitute for it when field welding is required or in applications requiring long exposures to elevated temperatures. Although it can be used in the as-cast condition, it is normally heat treated. After heat treatment, the microstructure contains 5-20% ferrite uniformly distributed throughout the matrix in discontinuous pools.

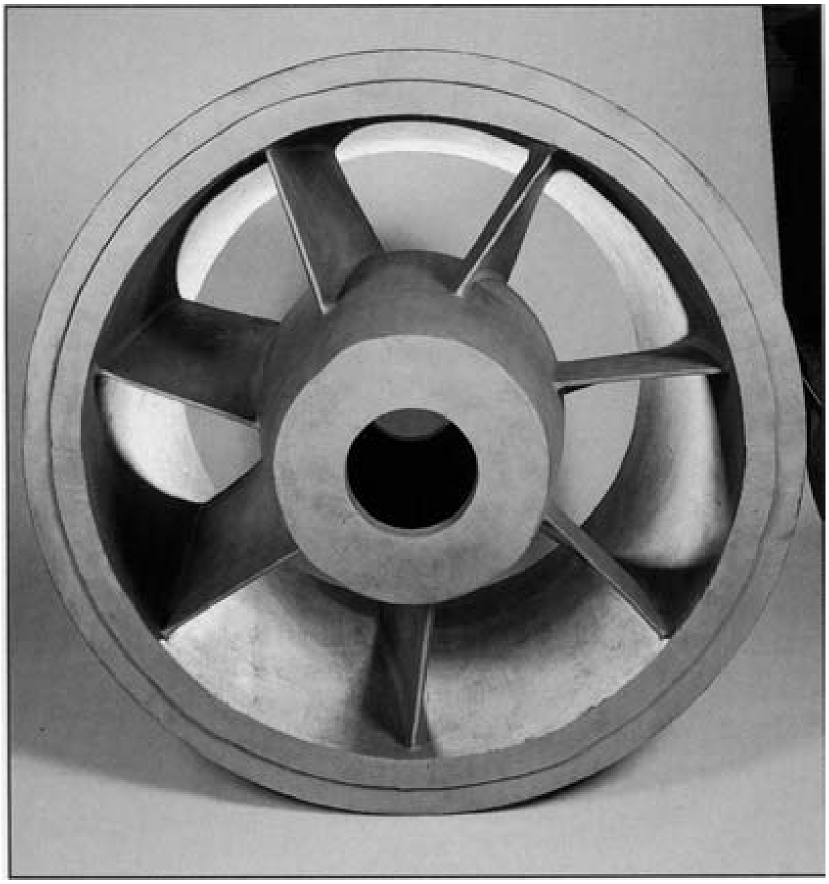
CF8C is used in the aircraft, nuclear, chemical processing, marine, oil refining, and plastics industries for handling hydrogen sulfide gas, petroleum products at high temperatures and pressures, plastics, and high-octane gasoline combustion products. Applications include aircraft shroud assemblies, autoclaves, engine exhaust fittings, filter press plates, jet engine parts, marine fittings, pump parts, return bends, rotors, tank parts, and valve bodies.

CF10 (Mr-W) UNS J92590

CF10 is the cast equivalent of 304H (S30409). It is not hardenable by heat treatment but should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures.

CK3MCuN was used for these 2-inch (51 mm) and 42-inch (1067 mm) diameter water check valves.

Ray Atkinson



Wollaston Alloys, Inc., Braintree, Massachusetts

This is a 4,500 pound (2,025 kg), austenitic CF3M diffuser.

CF3M (16Cr-12Ni-2Mo) UNS J92800

CF3M is the cast equivalent of Type 316L (S31603). Ferrite accounts for about 20% of the microstructure. It is a modification of CF3 with 2.0-3.0% molybdenum added to improve pitting and crevice corrosion resistance in chloride-containing environments. It is in the same family as CF8M but with a lower carbon content. CF3M has good resistance to corrosive sulfurous media and acetic acids.

For maximum corrosion resistance, CF3M should be heat treated. Post-weld heat treatment is not required because the alloy's low carbon content limits formation of significant amounts of chromium carbide.

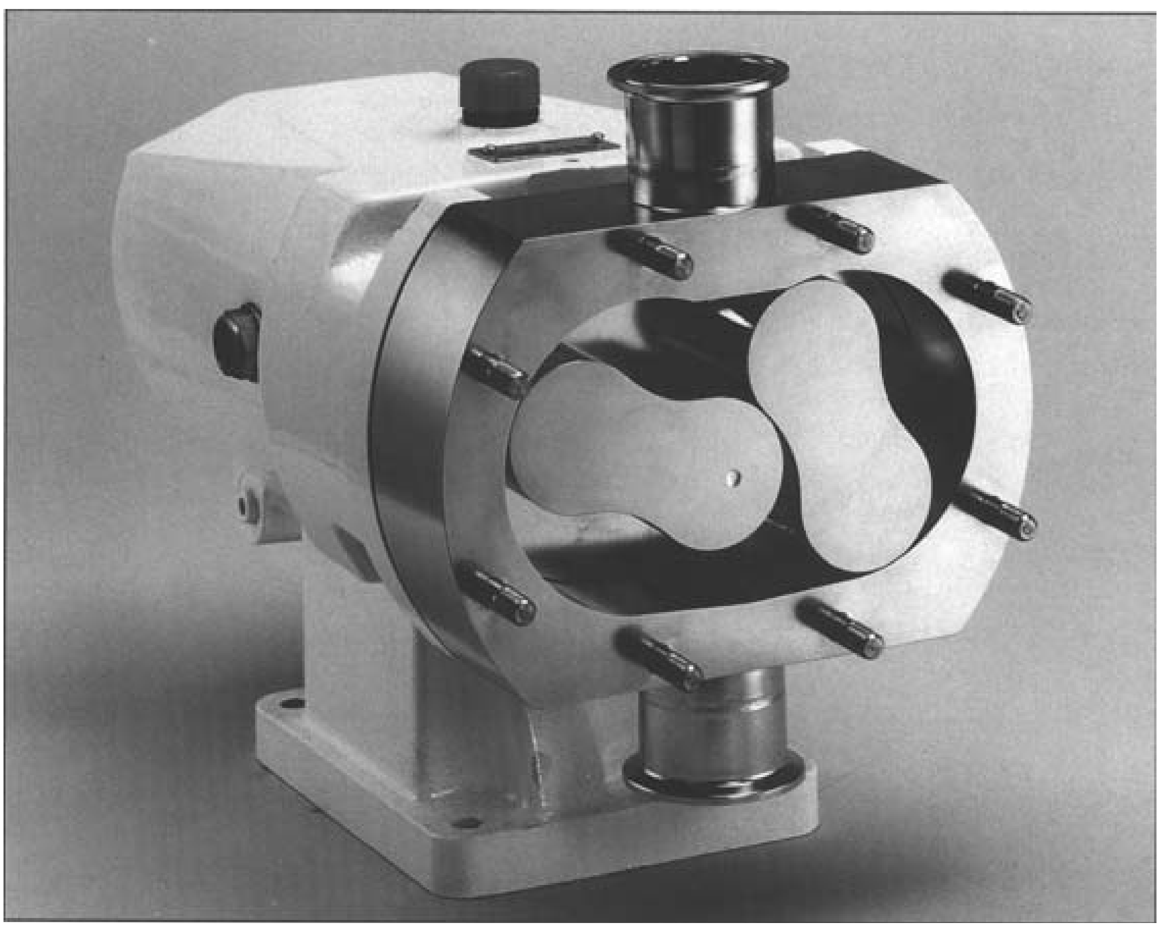
CF3M castings have good machining and welding characteristics. Magnetic permeability may change after heat treatment depending on the section thickness and casting configuration. CF3M is used for mixer parts, pump casings and impellers, tubes, and valve bodies and parts by the chemical, copper mining, food processing, paper mill, petroleum, pipeline, power plants, and water supply industries. It has been used in corrosive environments such as acetic acid; calcium carbonate; calcium lactate; potable and seawater; steam; sulfites; ammonium nitrate; ammonium sulfate; fatty acids and tall oil; phenol heated over 106°F (41°C); cold concentrated sulfuric acid; refined ethyl, isopropyl, butyl, amyl, or vinyl acetate; phosphoric acid; and sulfuric acid concentrations of 70% or more in higher velocity applications.

CF3MN (16Cr-12M-2Mo-N) UNS

CF3MN is the cast equivalent of Type 316LN (S31653). It is CF3M (J92800) modified with nitrogen, which increases strength and pitting resistance and reduces the tendency to form sigma phase.

CF8M (16Cr-12NII-2Mo) UNS J92900

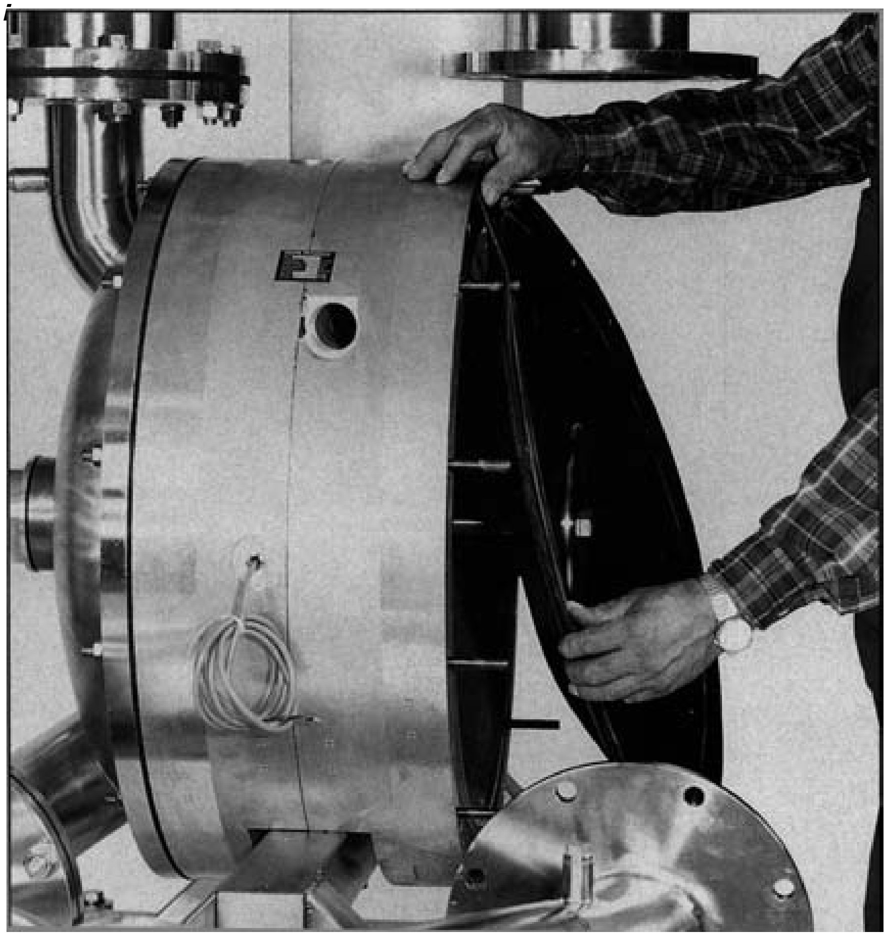
CF8M is the cast equivalent of Type 316 (S31600). It is readily weldable and is not hardenable by heat treatment. Its microstructure is usually 5-20% delta temperatures of 800-1600°F (430-870°C) causes formation of chromium carbides (sensitization) and a loss of corrosion resistance. The molybdenum improves resistance to corrosion in moderately or rapidly flowing seawater, however, CF8M should not be used for slow moving or stagnant seawater.



This CF3M aseptic rotary lobe pump was highly polished to meet cleaning requirements.

Alfa Laval Flow GmbH, Pump Division, Düsseldorf, Germany

This large air-operated CF3M diaphram pump is used for powder transfer in the chemical industry.



Alfa Laval Flow GmbH, Pump Division, Düsseldorf, Germany,

CF8M has been used to handle acetone, acetic acid, alkaline carbonate, amyl-acetate, ashladen water, benzene, hexachloride, black liquor, bleaching compounds, blood plasma, chloride solutions, copper refining electrolyte, crude methacrylic acid, hot dyes, fatty acids, high sulfur mine waters, hydrocarbon vapors, hydrogen peroxide, riboflavin syrup, slurries (phosphoric plus sulfuric and hydrofluoric acids), steam at high pressures and temperatures, sulfate and sulfite liquors, sulfuric acid (dilute or concentrated oleum), sulfurous acid, and vinyl alcohol. It has been used by the aircraft, chemical, electronics, food processing, marine, mining, oil refining, pharmaceutical, power, and textile industries for applications like agitators, centrifuges, evaporator parts, filter press plates and frames, fittings, mixing propellers, pump parts, radar masts, rolls, spool heads, spray nozzles, high pressure steam valves, and valve bodies and parts. See the results of in-plant corrosion testing in *Table 10*.

CF10M (Mr-10Ni-2Mo) UNS J92901

CF10M is the cast equivalent of Type 316H (S31609) and is CF10 modified with molybdenum to improve pitting and corrosion resistance, particularly with respect to chlorides. It is not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures.

CF10MC (16Cr-14Ni-2Mo-Nb) UNS J92590

CF10MC is the cast equivalent of Type 316Cb (S31640). It is not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures.

CF10SMnN (Mr-8Ni-4&-N) UNS J92972

CF10SMnN is the cast equivalent of NITRONIC° 60 (S21800). In most media, it provides better corrosion resistance than CF3 or CF8. It is not hardenable by heat treatment, should be solution-annealed for maximum corrosion resistance, and it provides good impact resistance at low temperatures. CF10SMnN provides significantly better galling resistance than CF3/CF8 and CF3M/CF8M and excellent cavitation erosion and fretting wear resistance.

CF16F (Mr-8Ni-S) UNS J92701

The wrought equivalent for CF16F is Type 303 Se (S30323). It is similar to CF8 but with small additions of selenium, phosphorus, and, in some cases, molybdenum. The phosphorus addition improves machinability, as do the complex selenides that serve as chip breakers. It contains 0-15% ferrite distributed evenly throughout the matrix. For maximum corrosion resistance, CF16F must be heat-treated to put the carbides into solution.

If the heat-treated casting is exposed to temperatures between 800 and 1600°F (425-870°C), the carbides will precipitate. This begins to occur rapidly at about 1200°F (650°C). Full corrosion resistance can be restored after welding or exposure to elevated temperatures by solution annealing. This grade is not widely used because CF8 is machinable using modern techniques.

The chemical processing, explosives, food and dairy, marine, oil refinery, pharmaceutical, power plants, pulp and paper, and textiles industries have used CF16F for applications such as bearings; bushings; fittings; flanges; machinery parts; pump casings; and valves for corrosive environments such as bleaching compounds, caustic salts, food products, hydrocarbon vapors, sulfite liquor, and sulfurous acid.

Bird Machine Co., Milwaukee, Wisconsin

CF3M was centrifugally cast into this bowl shell and extension for Decantur Centrifuge.

CG3M (19Cr-11 Ni-Mo) UNS J92999

CG3M is not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures. It is similar in composition to CF3M (J92800) but with slightly higher chromium and molybdenum levels for improved corrosion resistance.

CG6MMN (22Cr-13Ni-5Mn-2Mo) UNS J93790

The wrought equivalent of CG6MMN is NITRONIC® 50 (S20910). It is not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures and, in most media, better corrosion resistance and higher strength than CG8M or CF8M. It has been in used in chloride-containing environments and oil field applications where sulfide stress corrosion-cracking can be a problem.

CG8M (18Cr-13Ni-3Mo) UNS J93000

CG8M is the cast equivalent of Type 317 (S31700) and has excellent resistance to corrosion in reducing

These centrifugally cast precision tube forming rings were made from CK20 modified to customer requirements.

Wisconsin Centrifugal, Waukesha, Wisconsin, USA

environments. Its composition is similar to that of CF8M, but the molybdenum content (34%) is higher. The additional molybdenum increases resistance to hot sulfurous and other organic acids and dilute sulfuric acid solutions, halide-bearing media, and reducing acids. Solution annealing provides maximum corrosion resistance. After heat treatment, the microstructure contains 15-35% ferrite. Extended exposure at temperatures between 1200-1700°F (650925°C) may cause embrittlement and reduce corrosion resistance as ferrite is transformed into sigma phase.

CG8M is not used for nitric acid service or other strongly oxidizing environments. It is especially useful for dyeing equipment, flow meter components, propellers, pump parts, valve bodies and parts, ink, river water, and sulfite liquor in the nuclear, petroleum, power, paper, printing, and textile industries.

CG12 (21Cr-1111l UNS J93001

CG12 is not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. It provides good impact resistance at low temperatures.

CH8 UNS J93400
CH10 UNS J93401
CH20 UNS J93402
(Mr-12NII grades)

The only chemical composition difference between these grades is the maximum carbon and silicon levels. CH8 has a maximum carbon level of 0.08%; CH10 a maximum of 0.10%; and CH20 a maximum of 0.20%. They are not hardenable by heat treatment and should be solution-annealed for maximum corrosion resistance. Ductility and strength are improved with heat treatment.

The wrought equivalent of CH20 is Type 309 (S30900). If heat treated castings are exposed to temperatures between 800 and 1600°F (425 and 870°C), the carbides will precipitate. CH20 has better corrosion resistance than CF8 and is less susceptible to intergranular corrosion after short-term, elevated temperature exposure. It is most frequently used in applications requiring contact with hot, dilute sulfuric acid. Applications include digester fittings, pumps and parts, roasting equipment, and valves. CH8 provides good impact resistance at low temperatures.

CK20 (25Cr-20Ni) UNS J94202

CK20, the cast equivalent of Type 310, provides resistance to many highly oxidizing solutions. It is primarily used in the as-cast condition for high temperature corrosive service in conjunction with Type 310 components. CK20 is less likely than CF8 to suffer from intergranular corrosion after elevated temperature exposure, particularly if the exposure time is short. It is used in the pulp and paper industry to handle sulfite solutions. Other applications include digesters, filter press plates and frames, fittings, jet engine parts, mixing kettles, pumps, return bends, tar still fittings, and valves. Heat treatment does not harden CK20, but it does provide an improvement in strength and ductility. CK20 is almost non-magnetic.

CK3MCuN (Mr-18M-6Mo-Cu-N) UNS 93254

CK3MCuN is the cast equivalent of 254 SMO° (S31254) and is used for equipment handling pulp mill bleach systems; desalination and other equipment used in brackish, sea, and other high-chloride waters; tall oil distillation; chemical processing; food processing; and oil and gas production equipment. It provides better resistance to pitting and crevice corrosion and is stronger than lower alloyed austenitics. It is used when CF3M does not provide sufficient corrosion resistance. It combines high strength and excellent ductility.

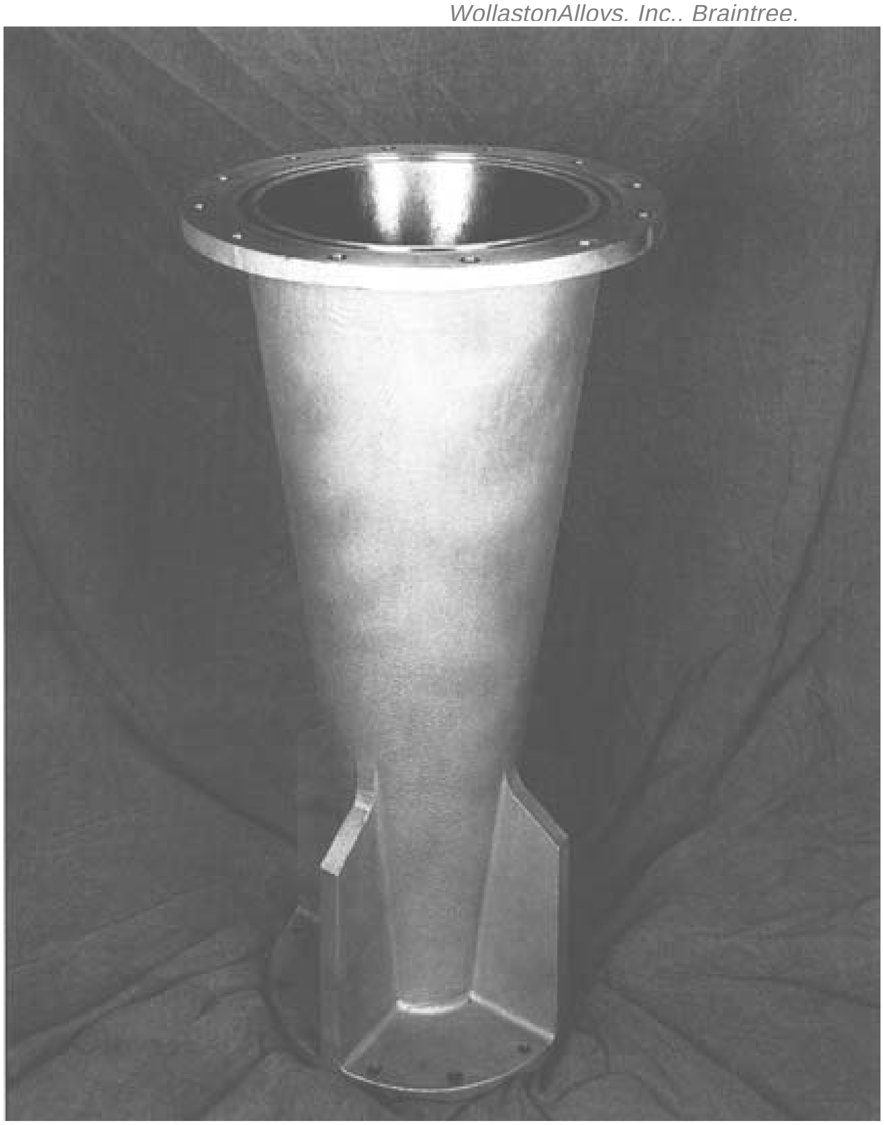
CN3MN (21Cr-24Ni-Mo-N) UNS J94651

CN3MN is the cast equivalent of AL 6XN® (N08367) and is used in equipment for pulp mill bleach systems; desalination and other equipment used in handling brackish, sea, and other high chloride waters; tall oil distillation; chemical processing; food processing; and oil and gas production. It provides better resistance to pitting and crevice corrosion than lower alloyed austenitics and is stronger. It is used when CF3M does not provide sufficient corrosion resistance. It combines high strength and excellent ductility.

CN7M (29Ni-20Cr-3Cu-2Mo) UNS N08007
CN7MS (24Ni-19Cr-2Cu-3Mo) UNS J94650

In the heat treated condition, CN7M has an austenitic structure and provides good resistance to sulfuric acid, dilute hydrochloric acid, hot chloride salt solutions, and nitric and phosphoric acids. It is used in oil well equipment to separate the brine from the oil and for pumping the brine back into the well; sulfuric acid processing (0-25%) when velocity and turbulence are high; oleum manufacturing; more aggressive ammonium sulfate conditions or where erosion is a problem; phenol heated to >105°F (40°C); and for hot acetic acid.

WollastonAlloys, Inc., Braintree.



This 600 pound (270 kg), duplex CD4MCu fiber cone is used in the pulp and paper industry.

The primary components cast from CN7M are pumps, valves, and fittings. Other applications include filter and heat exchanger parts; mixer components; steam jets; ventilating fans; pickling rolls, hooks, and racks; urea valves and pumps; and tanks.

For maximum corrosion resistance and to eliminate susceptibility to intergranular attack, the carbides must be put into solution by heat treatment. If heat treated castings are exposed to temperatures in the range of 800-1600°F (425-870°C), carbide precipitation will occur and the castings must be heat treated again to restore full corrosion resistance. CN7M cannot be age hardened. Figure 8 shows the performance of CN7M in various solutions at different temperatures (see Table 10 for inplant corrosion data).

CN7MS is a modification of CN7M. It was developed for improved castability and weldability. The corrosion resistance of CN7MS is similar to that of CN7M.

DUPLEX

First generation duplex stainless steels such as CD4MCu have been in use for more than fifty years. Their structure is usually 40 to 50% ferrite with the balance of the microstructure austenite. Their higher ferrite levels provide significantly better chloride stress corrosion cracking resistance than austenitics and higher chromium and molybdenum contents provide good localized corrosion resistance. Welding may reduce corrosion resistance and ductility unless it is followed by a post-weld solution heat treatment. None of the duplex stainless steels should be used in continuous service above 600°F (315°C) because of the potential for 885°F (475°C) embrittlement of the ferrite phase.

Schmidt + Clemens, Lindlar, Germany

***These FGD pump housings are made from duplex stainless steel 1.4517 (G-X 2 CrNiMoCuN 26 6 3 3) which is* similar to CE3MN (J93404) but with a 3% Cu addition.**

Second generation duplex stainless steels such as CD3MN, CD3MWCuN, CD4MCuN, CD6MN, CE3MN, and CE8MN provide improved weldability and corrosion resistance over first generation duplexes. The most commonly used duplex casting grade is CD4MCuN. The duplex casting grades are characterized by the addition of nitrogen as an alloying element and an approximate 50-50 mixture of ferrite and austenite. When proper weld procedures are followed, there is minimal reduction of corrosion resistance or ductility. They provide excellent resistance to pitting, crevice corrosion, and chloride stress corrosion cracking; good toughness; and improved strength over the 300-series austenitic stainless steels.

CD3MN (Mr-5Ni-Mo-N) UNS J92205

The wrought equivalent of CD3MN is 2205 (S31803 and S32205). It provides better corrosion resistance and about twice the yield strength of CF3M or CF8M. As with all duplex stainless steels, CD3MN has excellent chloride stress corrosion cracking (SCC) resistance. For those reasons, it is often the upgrade for CF3M or CF8M in valve applications where higher strength or improved pitting, crevice corrosion, or SCC resistance is needed.

CD3MWCuN (Mr-7Ni-Mo-N) UNSJ93380

CD3MWCuN is the cast equivalent of ZERON® 100 (S32760). It provides resistance to pitting, crevice corrosion, stress corrosion cracking in chloride and sour environments, erosion corrosion and corrosion fatigue, and good weldability. The oil and gas industry has used this grade for valves and other components in process, seawater, firewater, and sub-sea piping systems, particularly under sour or higher temperature conditions. The chemical process, pulp and paper, power generation, and pharmaceutical industries have used it to handle a wide range of corrosive media. It has also been used in pollution control equipment, flue gas desulfurization, desalination, and marine components.

ODMW(Z5Cr-5Ni-Mo-Cu) UNSJ93370

CD4MCuN has generally replaced CD4MCu. The addition of nitrogen in the newer grade improves corrosion resistance, increases strength, and improves castability. Data showing the performance of CD4MCu in various concentrations of HNO, and H_2SO_4 at different , temperatures is shown in *Figures 13 and 14.*

This submersible motor is used to mix slurries in waste water treatment or chemical processing plants. The motor housing and blades are cast duplex stainless steel. (Proacid 60, 25 Cr, 5.5 Ni, 3Mo, 2Cuand0.15N)

ITT FlyggtPumps

CD4MCuN (Mr-5Ni-Mo-Cu-N) UNS J93372

CD4MCuN is CD4MCu modified with nitrogen to improve corrosion resistance, strength, weldability, and castability. It is resistant to some concentrations of sulfuric and dilute hydrochloric acids; acid and wet process phosphoric acid slurries; stress corrosion cracking in chloride-containing solutions and fumes; concentrated brine and seawater; fatty acids; pulp liquors at 220°F (104°C); and steam. CD4MCuN is able to handle soft abrasives and is used in some corrosion-erosion service applications. It is used in a variety of industries including chemical processing, marine, municipal water supply, naval, paint, petroleum refining, power plant, pulp and paper, soap manufacturing, textile, and transportation. Applications include processing equipment requiring higher strength than CF8, compressor cylinders, digester valves, feed screws, pump impellers, liners, pump casings, runway light fixtures, and centrifugal pumps seal rings.

CE3MN (Mr-7Ni-Mo-N) UNS J93404

CE3MN is the cast equivalent of 2507 (S32750) superduplex stainless steel. The combination of high chromium, molybdenum, and nitrogen provides excellent localized corrosion resistance in chloride-containing environments. CE3MN has been used in oxidizing chloride environments in the pulp and paper industry, and for handling seawater and process streams on offshore oil and gas platforms. As with all duplex stainless steels, CE3MN has excellent chloride stress corrosion cracking resistance.

CE8MN (Mr-10NII-Mo-N) UNS J93345

CE8MN provides excellent impact toughness, even at temperatures as low as -100°F (-73°C). Good resistance in sulfide stress corrosion cracking tests (MACE TM-01-77) has been reported. In comparison with other cast duplex stainless steels in the same strength range, CE8MN provided better corrosion resistance to H_2S-containing environments. Otherwise, it has corrosion resistance similar to other duplex stainless steels.

These investment cast duplex stainless steel 1.4517 (G -X 2 CrNiMoCuN 26 6 3 39) pressure and suction chambers for moveable pumps are used in offshore installations.

Schmidt + Clemens, Lindlar, Germany

NICKEL-BASE ALLOY CASTINGS

Nickel-base alloys are classified as corrosion-resistant if they are used below 1200°F (650°C). Carbon content is usually a distinguishing factor between the heat and corrosion-resistant alloys, but this dividing line can be vague, particularly for alloys used in the 900-1200°F (480 to 650°C) range. Nickel and nickel-copper, nickelchromium-iron, nickel-chromium-molybdenum, nickel-molybdenum, and special proprietary nickel-base alloys are used for corrosive applications. These alloys are also important because of their strength, and resistance to wear and galling. Some nickel-chromium-iron alloys are also used in high temperature applications. Nickel increases resistance to strong acids, particularly reducing acids.

The chemical compositions, ASTM specifications, and approximate wrought equivalents for the nickel-base alloy castings are in *Tables 13* and *14.* ASTM tensile and elongation requirements are shown in *Table 15* and illustrated in *Figures 15 through 17.* The heat treatments and physical properties are shown in *Tables 16 and 17.*

Table 13 UNS designations and chemical compositions* for nickel-base alloy castings

UNS	ACI and Other Names	C	Mn	Si	Mo	P	S	Cu	Fe	Cr	Ni	Other
N08826	Cu5MCuC	0.050	1.0	1.0	2.5-3.5	0.030	0.030	1.50-3.50	rem	19.5-23.5	38.0-44.0	0.60-1.20 Nb
N06040	CY40[2]	0.40	1.50	3.00	***	***	***	***	11.0	14.0-17.0	rem	***
N26455	CW2M	0.02	1.00	0.80	15.0-17.5	0.03	0.03	***	2.0	15.0-17.5	rem	1.0 W
N26625	CW6MC	0.06	1.00	1.00	8.0-10.0	0.015	0.015	***	5.0	20.0-23.0	rem	3.15-4.50 Nb
N30107	CW6M[2]	0.07	1.00	1.00	17.0-20.0	0.040	0.030	***	3.0	17.0-20.0	rem	***
N30002	CW12MW[2]	0.12	1.00	1.00	16.0-18.0	0.040	0.030	***	4.5-7.5	15.5-17.5	rem	0.20-0.40V, 3.75-5.25W
N26022	CX2MW	0.02	1.0	0.80	12.5-14.5	0.025	0.025	***	2.0-6.0	20.0-22.5	rem	0.35 V, 2.5-3.5 W
N26055	CY5SnBiM	0.05	1.5	0.5	2.0-3.5	0.03	0.03	***	2.0	11.0-14.0	rem	3.0-5.0 Bi, 3.0-5.0 Sn
N02100	CZ100	1.00	1.50	2.00	***	***	***	1.25	3.00	***	rem	***
N24025	M25S[2]	0.25	1.50	3.5-4.5	***	0.03	0.03	27.0-33.0	3.50	***	rem	***
N24030	M30H	0.30	1.50	2.7-3.7	***	0.03	0.03	27.0-33.0	3.50	***	rem	***
N24130	M30C[1]	0.30	1.50	1.0-2.0	***	0.03	0.03	26.0-33.0	3.50	***	rem	1.0-3.0 Nb
N24135	M35-1	0.35	1.50	1.25	***	0.03	0.03	26.0-33.0	3.50	***	rem	0.5 Nb
N04020	M35-2	0.35	1.50	2.00	***	***	***	26.0-33.0	2.50	***	rem	0.5 Nb, 0.50 Al
N03220	M220C	0.30-0.50	***	***	***	***	***	***	***	***	rem	1.80-2.30 Be
N30007	N7M[2]	0.07	1.00	1.00	30.0-33.0	0.040	0.030	***	3.00	1.0	rem	***

* Maximum unless range is given

1) Order M35-1 or M30C when weldability is required

2) Specify Class 1, 2, or 3 in addition to grade

Table 14 Approximate wrought equivalents and specifications for nickel-base alloy castings

UNS Number	ACI and Other Names	Approximate Wrought	ASTM Specifications
N08826	Cu5MCuC	Alloy 825	A 494
N26455	CW2M	C4 (N06455)	A 494
N30107	CW6M	•••	A 494
N30002	CW12MW	C(N10002)	A 494
N26022	CX2MW	C 22 (NO6022)	A 494
N26055	CY5SnBiM	•••	A 494
N06040	CY40	600 (N06600)	A 494
N02100	CZ100	200 (N02200)	A 494
N03220	M220C	•••	A 494
N04020	M35-2	400 (N04400)	A 494
N24025	M25S	•••	A 494
N24030	M30H	•••	A 494
N24130	M30C	•••	A 494
N24135	M35-1	400 (N04400)	A 494
N30007	N7M[2]	B2 (N10665)	A 494

*Wrought equivalents are from ASTM A 781 Table X2.1 and other sources

Table 15 Tensile requirements for nickel-base alloy castings*

Grade	Tensile Strength, min		Yield Strength, min		Elongation in 2 inch (50 mm) min %	Brinell Hardness
	ksi	MPa	ksi	MPa		
Cu5MCuC	75	520	35	240	20	•••
CW12MW[1]	72	495	40	275	4.0	•••
CW2M	72	495	40	275	20.0	•••
CW6M[1]	72	495	40	275	25.0	•••
CW6MC	70	485	40	275	25.0	•••
CX2MW	80	550	45	280	30	•••
CY40[1]	70	485	28	195	30.0	150-200[4,5]
CZ100	50	345	18	125	10.0	90-130[4,5]
M30C	65	450	32.5	225	25.0	125-150
M30H	100	690	60	415	10.0	243-294
M35-1	65	450	25	170	25.0	110-140[3]
M35-2	65	450	30	205	25.0	125-150[3]
M220C[2]	170	•••	160	•••	1.0	Rc 48-52
N7M[1]	76	525	40	275	20.0	•••

* ASTM A 494 and A 351 except where noted
1) Specify Class 1 or Class 2 in addition to grade designation 2) Source: Brush Wellman Inc. M220C data sheet
3) Source: *Metals Handbook Desk Edition* 4) Source: *Heat and Corrosion Resistant Castings*, INCO 5) As-cast

Table 16 Heat treatment requirements for nickel-base alloy castings

Grade	Heat Treatment, minimum, °F(°C)
CZ100, M35-1, M35-2, CY40, Class 1, M30H M30C, M25S, Class 1, CY5SnBiM	As-Cast
M220C⁴	1900-2000 (1038-1093), OQ, age harden 950 (510) for 3 hours, AC
Cu5MCuC	2100F (1150), WQ, 1725-1815 (940-990), WQ or RC
CW12MW, CW6M, CW6MC, CW2M	2150 (1175), WQ or RC
CY40 Class 2	1900 (1040), WQ or RC
CX2MW	2200 (1205), WQ or RC
M25S Class 2¹	Load at 600 (315) max., 1600 (870) for 1 hour plus 30 min. for each 0.5 inch (13mm) of cross section over 1 inch (25.4mm), FC to 1300 (705) hold 30 minutes. OQ
M25S Class 3	Load at 600 (315) max. Heat slowly to 1100 (605), hold to attain amx. hardness, FC or AC
N7M	2000 (1095), WQ or RC

*ASTM A 494 and A 743 except where noted

1) While M25S can be machined in the as-cast condition, it can be solution annealed for improved machinability. It may be subsequently age hardened and finish machined and ground.

2) For cross sections over 6 inches (125 mm), it may be necessary to increase the hold time if maximum softness is desired.

3) For maximum softness and the least variation in hardness levels, castings should be transferred from a furnace at 1600°F (870°C) to a second furnace at 1300°F (705°C).

4) Source: Brush Wellman Inc. M220C data sheet

Figure 13 Isocorrosion diagram for CD4MCu in HNO_3. The material was solution treated at 1120C (2050F) and water quenched. [Ref.2]

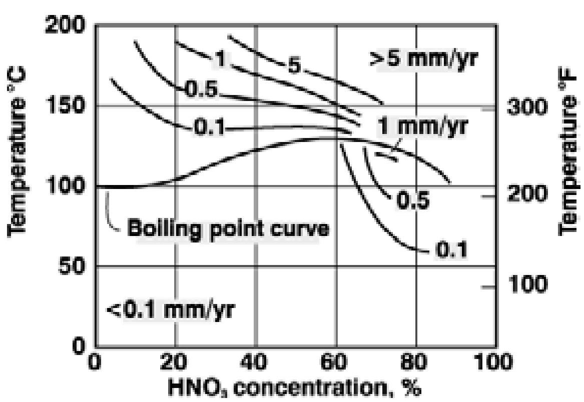


Figure 14 Isocorrosion diagram for CD4MCu in H_2SO_4. The material was solution annwealed at 1120C(2050F) and water quenched [Ref.@]

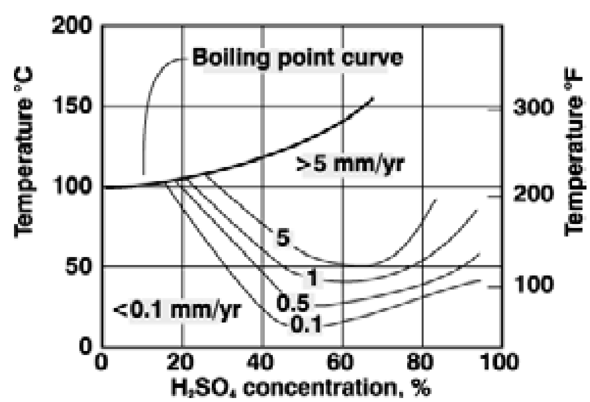


Figure 15 Relative tensile strength of corrosion resistant nickel-base castings

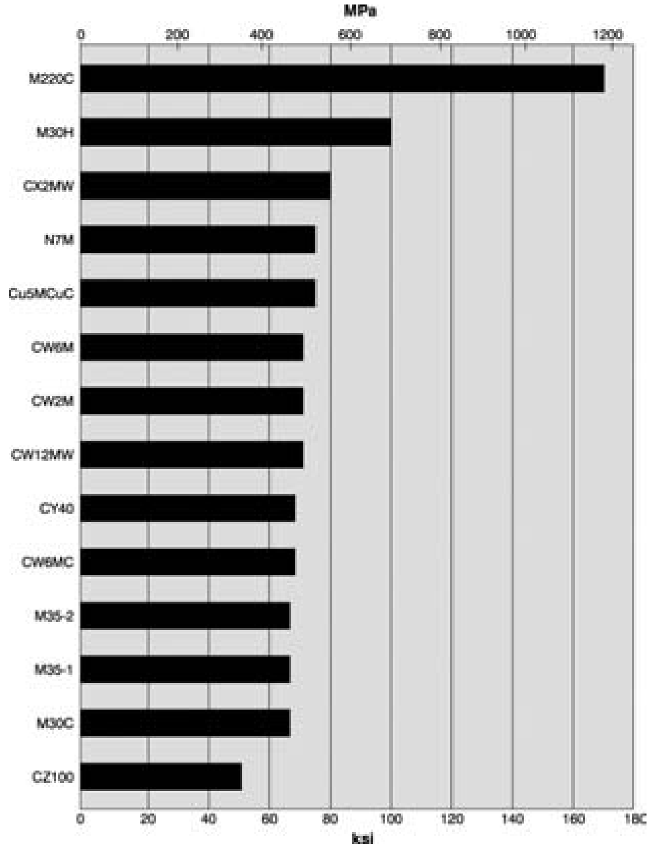
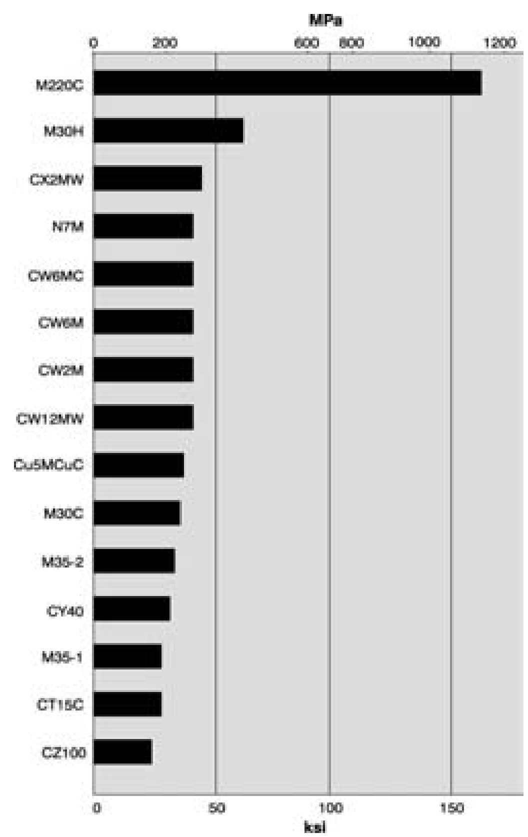


Figure 16 Relative yield strength of corrosion resistant nickel-base castings



Cu5MCuC (41N1-21Cr-2Mo-1Cb) UNS N08826

Cu5MCuC is also known as 825 CP and has found considerable use in valves and manifolds that handle sour gas in the North Sea. It provides excellent resistance to both reducing and oxidizing acids, stress-corrosion cracking, localized attack such as pitting and crevice corrosion, and sulfuric and phosphoric acids.
It has been used in chemical processing, pollution-control equipment, acid production, and pickling equipment applications.

CW2M (61 NII-16Mo-16Cr) UNS N26455 CW6M (59NII-18W-Mr) UNS N30107 CW2M and CW6M are used in severe service conditions that usually involve combinations of acids at elevated temperatures. They are being used as replacements for CW12MW in many applications (see CW12MW). CW6M has higher chromium and molybdenum levels and is the more corrosion-resistant of the two alloys. These alloys have high molybdenum levels for improved resistance to non-oxidizing acids and increased high-temperature strength.

CW6MC (60N1-22Cr-9Mo-3.5Cb) - UNS N26625

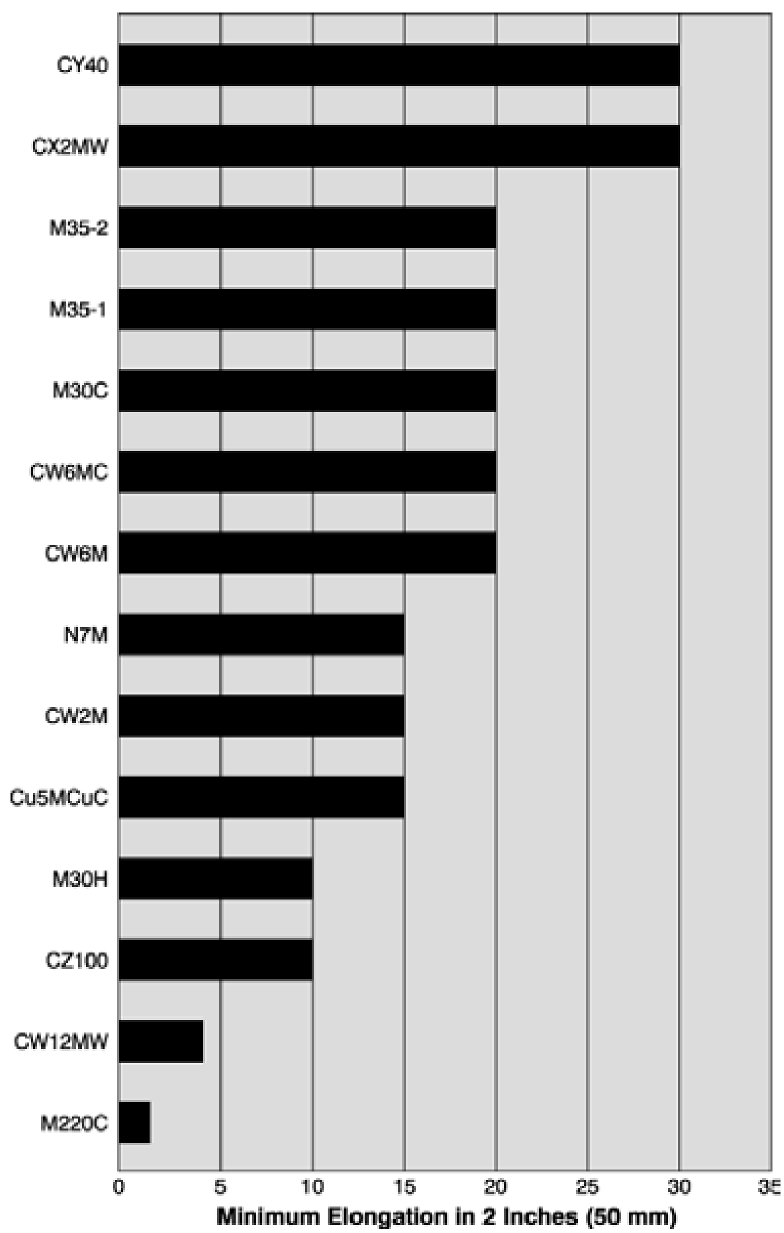
CW6MC is the cast equivalent of Alloy 625 (N06625) and provides excellent resistance to seawater and chloride stress corrosion cracking. It also has high fatigue and creep strength. Service environment examples include oxidizing atmospheres, sulfur, and handling organic and inorganic compounds over a wide temperature range. It is frequently used in severe service conditions that involve combinations of acids at

Table 17 Physical properties of some nickel-base alloy castings [7,8]

Designation or Grade	Melting Point °F (°C)	Density Lb/in^3 (kg/m^3)	Coefficient of Thermal μin./in•°F (μm./m•°K)	Mean Specific Btu/lb•°F (J/kg•°K)	Modulus of Elasticity psi x 10^6 (MPa x 10^4)	Thermal Conductivity Btu/ft•hr•°F (W/m•°K)	Electrical Resistivity μΩ•m
CW12MW	2310-2450 (1266-1343)	0.323 (8940)	8.07 (14.26)[10]		29.8 (20.8)	6.50 (11.23)	•••
CY40	2540 (1393)	0.300 (8300)	8.9 (15.72)[5]	0.11 (460)[8]	23 (16.1)	8.67 (14.97)	1.164
CZ100	2510 (1377)	0.301 (8340)	8.85 (15.64)[5]	•••	21.5 (15.1)	34.16 (59.57)	0.208
M35-1, M35-2	2400 (1316)	0.312 (8630)	9.1 (16.08)[6]	0.13 (544)[8]	23 (16.1)	15.50 (26.78)	0.532
M220C	2400 (1316)	0.29 (8000)	8.7 (15.40)[7]	0.11 (460)[9]	26-28 (17.9-19.3)	21 (36.35)[1] 25 (43.25)[2] 29 (50.19)[3] 33 (57.11)[4]	•••

1) 100°F (40°C) 2) 600°F (315°C) 3) 1000°F (540°C) 4) 1200°F (650°C) 5) 70-1400°F (21-760°C)
6) 70-1100°F (21-593°C) 7) 68-1000°F (20-540°C) 8) 80-750°F (27-399 °C) 9) 70°F (21°C) 10) 70-1500°F (21-816°C)

Figure 17 Relative elongation of corrosion resistant nickel-base castings



elevated temperatures. The relatively high molybdenum level improves resistance to non-oxidizing acids and increases high-temperature strength. It can be air-melted and poured. It can be welded using Shielded Metal Arc Welding (SMAW) or Gas Metal Arc Welding (GMAW) without pre- or post-heat treatments.

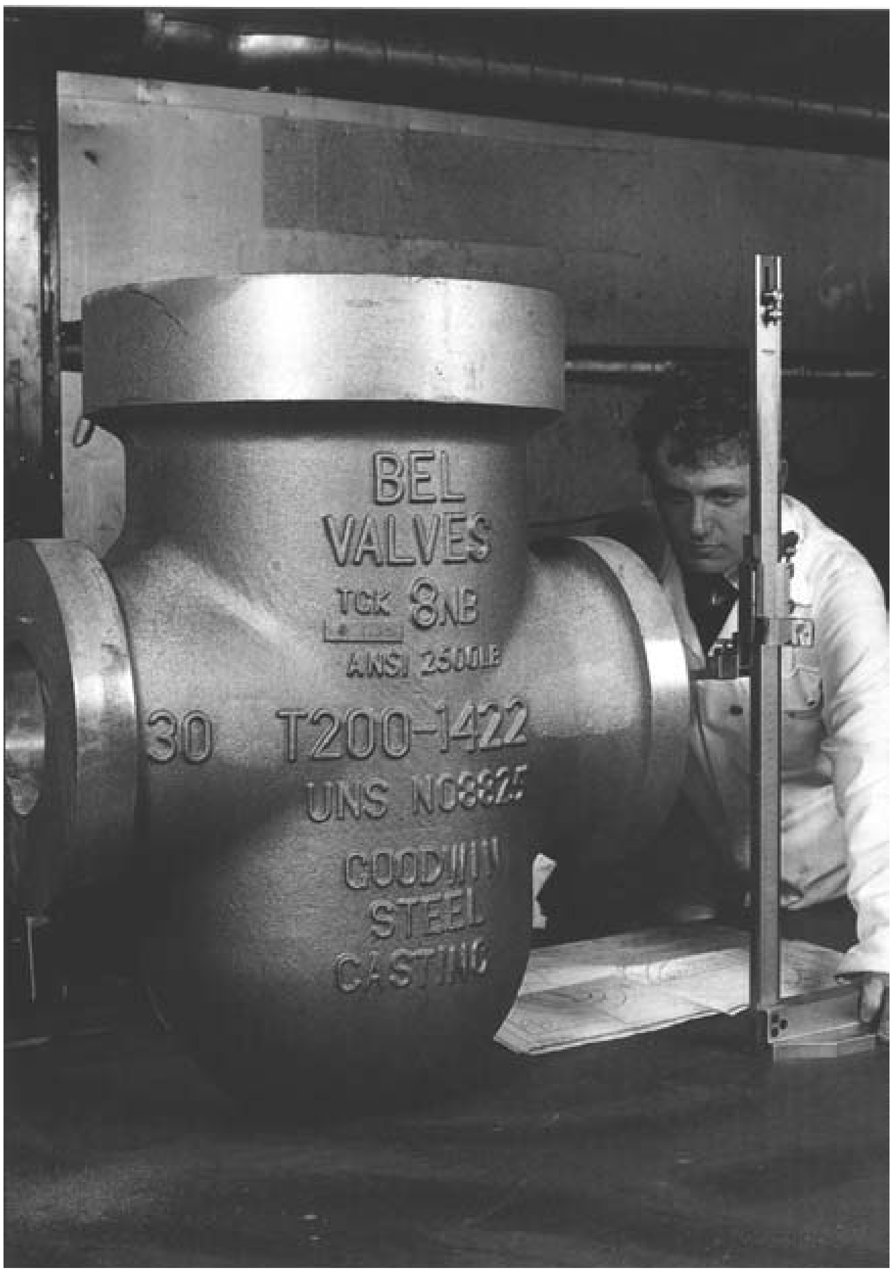
CW12MW (55Ni-17Mo-16Cr-4W) – UNS N30002

The nearest wrought equivalent to CW12MW is Alloy C (N10002). Lower carbon alloys, CW2M, CW6M, and CX2MW have replaced CW12MW in most applications. Although the compositions of these alloys are different, they are generally interchangeable in traditional CW12MW applications. CW12MW is resistant to highly corrosive media such as wet chlorine, strong hypochlorite solutions, ferric chloride, and cupric chloride. It is usually used in severe service conditions with combinations of acids at elevated temperatures, but it has also been used for handling boiling, concentrated organic acids such as acetic, formic, lactic, and fatty.

Its relatively high molybdenum level improves resistance to non-oxidizing acids and increases high-temperature strength. The solution-hardening effects of chromium, molybdenum, silicon, tungsten, and vanadium give CW12MW relatively high yield strength. Ductility is excellent, but inadequate heat treatment or improper composition balance may result in formation of a brittle intermetallic phase and significant loss of ductility. Heat treatment is necessary for maximum corrosion resistance. Carbon and sulfur levels should be kept as low as possible.

This 1,936 lb. (800 kg) Cu5MCuC, 8-inch (203 mm) valve is used for North Sea sour gas production.

Ray Atkinson



CX2MW (57N1-13Mo-21Cr) UNS N26022

CX2MW is the cast equivalent of wrought Alloy C 22 (N26022). It is usually used in severe service conditions with combinations of acids at elevated temperatures, and is one of several alloys being used as a replacement for CW12MW in many applications (see CW12MW).

CY5SnBiM (74Ni-12Cr-4Bi-4Sn) UNS N26055

CY5SnBiM is a galling-resistant alloy used primarily for pump rings and seals where the pump may briefly run dry after fluid transfer.

CZ100 was centrifugally cast for these front and rear drive hubs for a horizontal centrifuge.

Bird Machine Co. Milwaukee, Wisconsin

CY40 (72Ni-15Cr-8Fe) UNS N06040

CY40 is strong and ductile, even at elevated temperatures (Tables 18 *and* 19), and is readily welded. The nearest wrought equivalent is Alloy 600 (N06600), but they differ in carbon, manganese, and silicon content. These modifications improve castability and soundness, but CY40 is difficult to cast in heavy sections. If heavy section, nickel-base alloy castings are needed, the CW grades are suggested. Like CZ100, CY40 is used to protect product purity in the drug, chemical, and food industries, but it is more resistant to oxidizing conditions and is stronger and harder. It is especially useful for handling corrosive vapors at temperatures above 1470°F (800°C) and for handling nitric acid, fatty acids, and ammonium hydroxide solutions. It is also used for heat treating equipment and for petroleum, power, and pulp and paper industry applications such as cylinder liners, fittings, mixers, pickling equipment, valves, and vanes. CY40 is structurally stable to cryogenic temperatures.

Table 18 Typical CY40 elevated-temperature tensile properties* Ref. 9

Temperature °F(°C)	Tensile Strength		Yield Strength		Elongation 1 inch (25 mm) %
	MPa	ksi	MPa	ksi	
Room	486	70.5	293	42	16
900 (480)	427	62	•••	•••	20
1200 (650)	372	54.5	•••	•••	21
1350 (730)	314	45.5	•••	•••	25
1500 (815)	186	27	•••	•••	34

*Data are typical for investment cast test bars with a nominal composition of 0.20% C and 1.50% Si.

CZ100 (95Ni) UNS N02100

This cast nickel alloy is similar to the wrought Alloy 200 (N02200). CZ100 is widely used to maintain the purity of drugs, foods, and chemicals including the manufacturing, handling, and processing of hot, concentrated and anhydrous caustics at elevated temperatures where it is important that the equipment have a low iron and copper content. It is used in marine environments and in the petroleum and pulp and paper industries for caustic soda production equipment, cylinder liners, fittings, flow meters, pumps, and valves.

CZ100 has mechanical properties similar to those of mild steel. Castability is greatly enhanced by alloying with carbon plus silicon and treating with magnesium to produce spherical graphite in the microstructure. The spherical graphite does not affect corrosion resistance. Where cast to wrought nickel fabrication is required, low carbon CZ100 is suggested to avoid grain boundary precipitation of graphite in the heat-affected zone, however, low carbon CZ100 is difficult to cast. Higher carbon or silicon levels are occasionally specified for greater resistance to wear and galling.

M25S (63Ni-29Cu-4SII) UNS N24025

M25S provides exceptional resistance to galling due to the solution hardening effect of the high silicon content and small amount of silicide in the microstructure. This grade is not weldable.

M30C (63Ni-29Cu-Mb) UNS N24130

M30C is used for corrosion-resistant valves, pumps, and fittings, often in conjunction with nickel-copper and copper-nickel alloys. The tensile strength is controlled by the relationship between the silicon and niobium compositions.

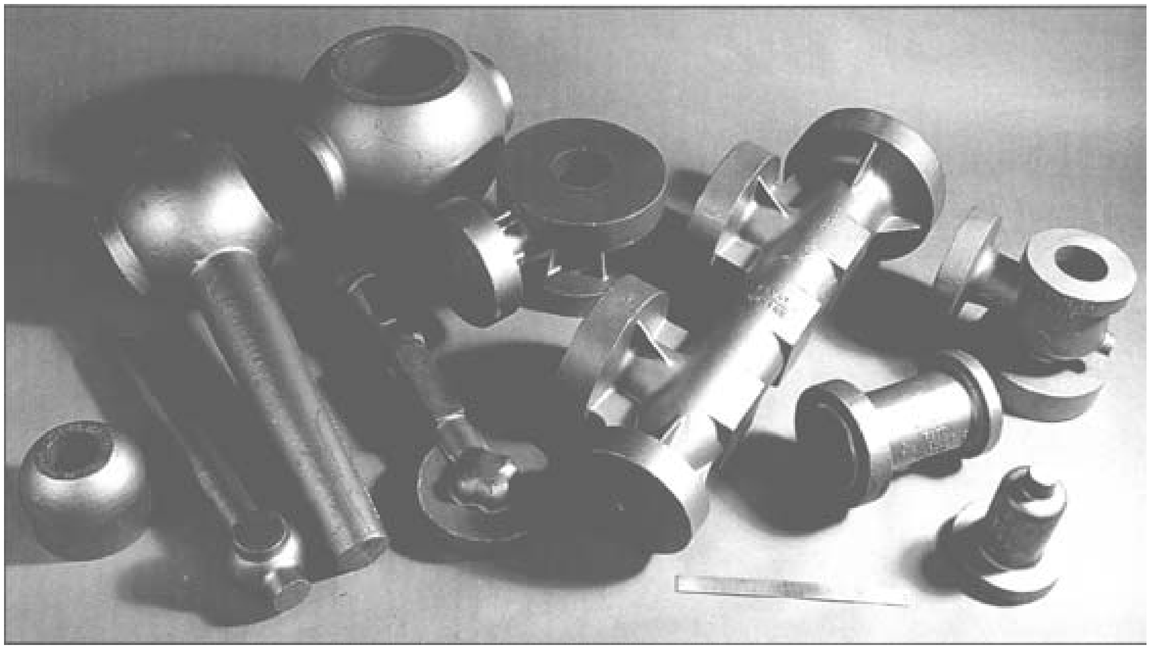
Table 19 Typical elevated-temperature stress-rupture properties* of CY40[Ref. 9]

Temperature °F (°C)	Stress to rupture in 100 hours	
	MPa	ksi
1200 (650)	165	24
1350 (730)	103	15
1500 (815)	62	9
1700 (925)	38	5.5

*Data are typical for investment cast test bars with nominal analysis of 0.20% C and 1.50% Si

Wisconsin Centrifugal, Waukesha, Wisconsin, USA

These CW6MC marine propulsion shaft sleeves and Ferralium® 255 Qecantur centrifugal bowl shells were centrifugally cast.



These CW6MC valve castings are used in the Shell Fulmar gas field.

Ray Atkinson

M30H (63Ni-29CuSi) UNS N24030

M30H combines corrosion resistance with high strength and wear resistance and is often used for wear rings. Although it is weldable, welding should not be permitted on wear surfaces. Because of the large difference in hardness and strength between the base metal and a weld deposit, the alloy will not meet the 180-degree bend test. Dye penetrant inspection of the heataffected zone should be specified.

M35-1 (67Ni-30Cu) UNS N24135

M35-2 (67Ni-30Cu) UNS-N04020

These grades are similar to the wrought Alloy 400 (N04400). They combine high strength and toughness with resistance to mineral acids, hydrochloric acid, organic acids, food acids, salt solutions, and strong alkalis. M35-1 and M35-2 are used in the chemical, food processing, marine, pickling, power, sanitation, plastics, petroleum, steel, and pulp and paper industries for centrifuges, cylinder liners, filter parts, flow meters, pickling equipment, pump parts, ship propeller sleeves, soot blowers, and valves. These grades are readily weldable to 180-degree side bend requirements.

M220C (98Ni-2113e) UNS N03220

M220C is an age-hardenable casting alloy which has been used as a mold material for high precision glass lenses molds, plungers for forming the necks of glass containers, rubber steering wheel molds, and other applications where a high degree of detail, corrosion, and wear resistance is required. It provides very high strength and hardness combined with wear, corrosion, thermal shock and oxidation resistance to operating temperatures of 1000°F (540°C). With its high fluidity, a high level of detail can be cast.

Electric melting in air, preferably in an induction furnace with magnesia or high alumina crucibles, is most common. Melting in gas or oil-fired furnaces is not recommended. The 0.002 inch/ inch (0.05 mm/mm) expansion during annealing is offset by an equal contraction during age-hardening. It should be machined while in the annealed condition. Its machinability is similar to annealed H-13 tool steel.

N7M (65Ni-28Mo-2Fe) UNS N30007

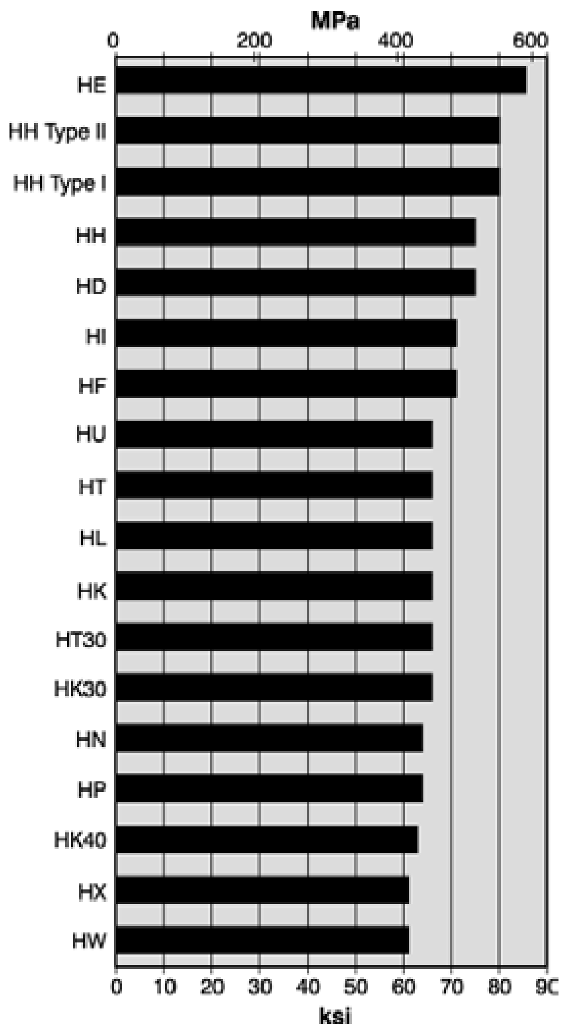
N7M is used in large quantities, primarily for handling hydrochloric acid at all concentrations and temperatures. It is similar to the wrought Alloy B2 (N10665). N7M provides good yield strength because of the solution hardening effect of molybdenum. Carbon and molybdenum content control ductility. For optimum ductility, carbon content should be as low as possible and molybdenum content adjusted to avoid formation of intermetallic phases.

HEAT RESISTANT CASTINGS

STAINLESS STEELS

Stainless steels are generally classified as "heat-resistant" when used in environments above 1200°F (650°C). They have higher carbon contents (some as high as 0.75%) than the corrosion-resistant grades to improve elevated-temperature strength and creep resistance. The higher carbon levels also reduce ductility.

Figure 18 Relative tensile strength of heat-resistant stainless steel nickel-base alloy castings

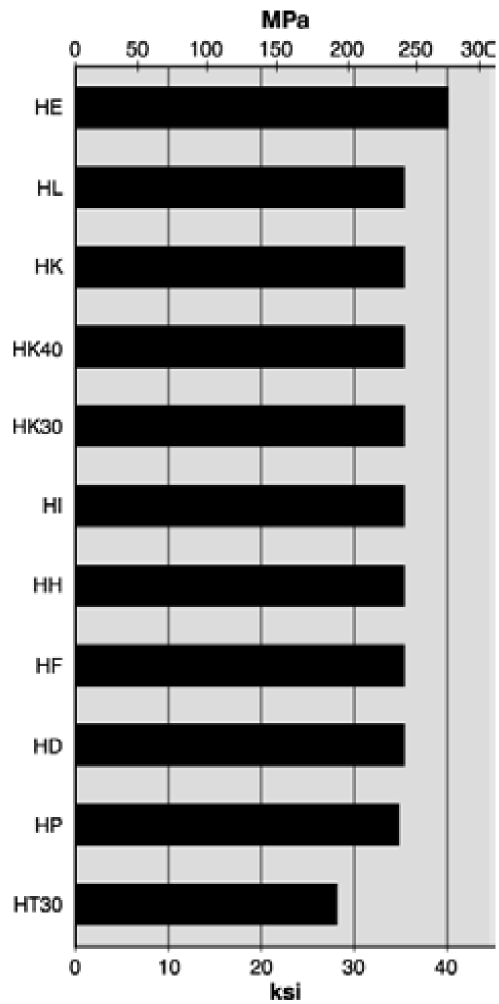


Nickel and chromium additions are beneficial in heat-resistant castings. Nickel improves carburization resistance and lowers the coefficient of thermal expansion, which improves thermal fatigue resistance. Chromium provides resistance to oxidation and sulfur-containing and other corrosive atmospheres; contributes to high temperature creep and rupture strength; and, in some alloys, increases resistance to carburization.

Tables 20 and 21 provide the chemistries, designations, and ASTM specifications for these grades. *Table 22* provides the minimum strength requirements and *Figures 18* through *21* compare them with the strengths of heat-resistant nickel-base alloys. *Tables 23* through *25* provide additional mechanical property data at elevated temperatures and *Table 26* provides hardness data. Physical properties are shown in *Table 27*.

The most commonly used grades of heat-resistant stainless steels are HD, HF, HH, and HK. However, HK has been replaced in many plants by proprietary versions of HP that have higher creep strengths and are resistant to sigma formation (see the nickel-base alloy section for more information on HP). When small quantities of castings are required, designers should consider specifying one of the more popular compositions to ensure faster deliveries.

Figure 19 Relative yield strength of heat-resistant stainless steel nickel-base alloy castings



HD (Mr-5Ni) UNS J93005
HD50 UNS J93015

The microstructure of HD is primarily austenitic with some ferrite, and is weakly magnetic. It is not age hardenable. HD provides excellent oxidation and sulfur resistance as well as good weldability. It is used for load-bearing applications where temperatures do not exceed 1200°F (649°C) and for light loads up to 1900°F (1040°C). Exposure to temperatures between 1300-1500°F (705-815°C) for long times may result in hardening and significant loss of room temperature ductility due to sigma phase formation. Ductility can be restored by uniformly heating the casting to 1800°F (980°C) followed by a rapid cool to below 1200°F (650°C).

HD50 is a variation of HD and is used in centrifugal casting. The chemistries are equivalent except for the carbon and silicon compositions. HD has a maximum of 0.50% carbon and 2.00% silicon. HD50 specifies 0.45-0.55% carbon and 0.50-2.00% silicon. These modifications were made to control high-temperature strength and carburization and oxidation resistance.

HD has been used by the copper, glass, heat treating, oil refining, ore processing, and steel industries for brazing furnace components, cracking equipment, furnace blowers, pouring spouts, gas burner parts, holding pots, pouring spouts, roaster furnace rabble arms and blades, recuperater sections, salt pots, and cement kiln ends. It has been used to handle combustion gases, flue gases, high-sulfur atmospheres, molten copper and copper alloys, and molten neutral salts. Section thicknesses of 0.2 inch (5 mm) and above can be cast satisfactorily. Designs with large changes in section thickness should be avoided.

Figure 20 Relative elongation of heat resistant stainless steel nickel-base alloy castings

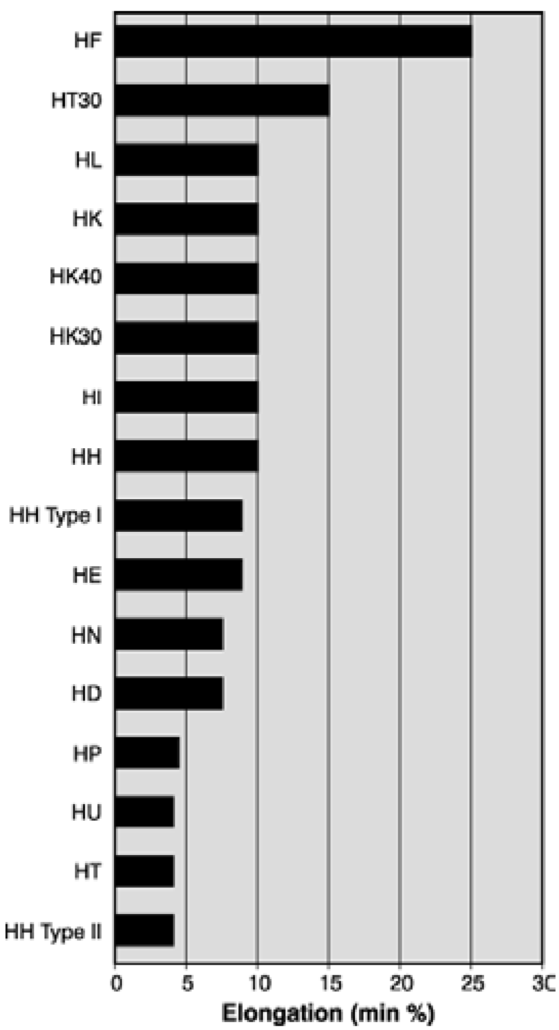


Figure 21 Relative elasticity of heat resistant stainless steel and nickel-base alloy castings

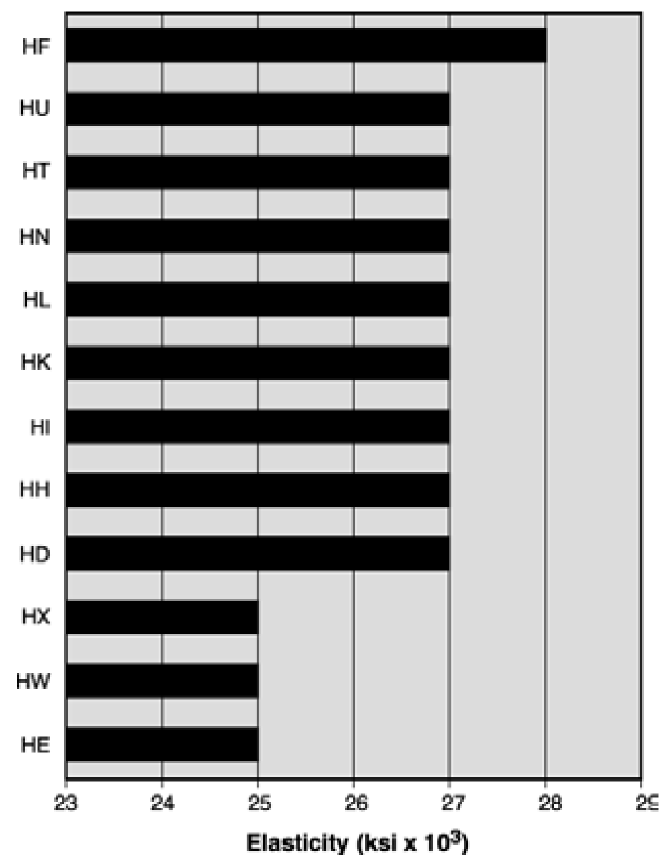


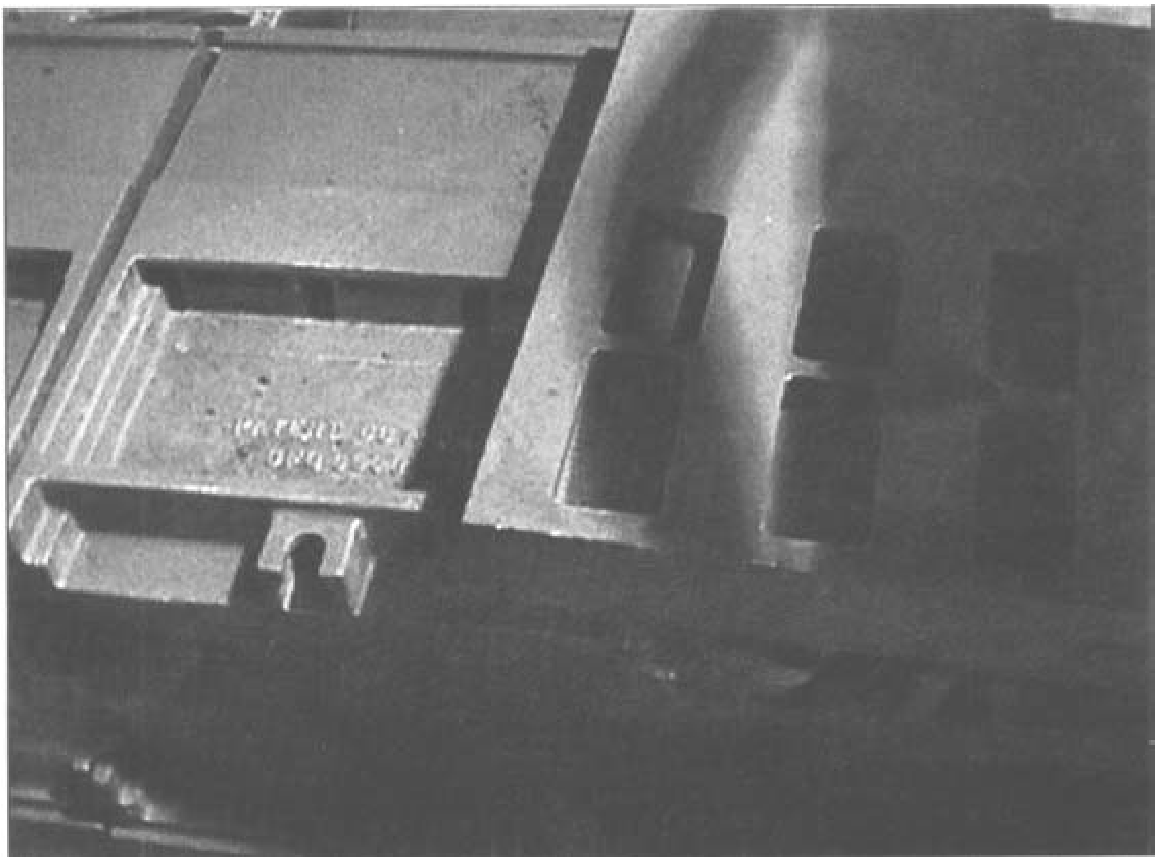
Table 20 UNS designations and compositions for heat resistant stainless steel castings

UNS	ACI	C	Cr	Mn	Mo	Ni	P	S	Si
J93005	HD	0.50	26.0-30.0	1.50	0.50	4.0-7.0	0.04	0.04	2.00
J93015	HD50	0.45-0.55	26.0-30.0	1.50	0.50	4.0-7.0	0.04	0.04	0.50-2.00
J93403	HE	0.20-0.50	26.0-30.0	2.00	0.50	8.0-11.0	0.04	0.04	2.00
J93413	HE35	0.30-0.40	26.0-30.0	1.50	0.50	8.0-11.0	0.04	0.04	0.50-2.00
J92603	HF	0.20-0.40	18.0-23.0	2.00	0.50	8.0-12.0	0.04	0.04	2.00
J92803	HF30	0.25-0.35	19.0-23.0	1.50	0.50	9.0-12.0	0.04	0.04	0.50-2.00
J93303[1]	HH	0.20-0.45	23.0-28.0	2.5	• • •	10.0-14.0	0.05	0.05	1.75
J93503	HH	0.20-0.50	24.0-28.0	2.00	0.50	11.0-14.0	0.04	0.04	2.00
J93513	HH30	0.25-0.35	24.0-28.0	1.50	0.50	11.0-14.0	0.04	0.04	0.50-2.00
J93633	HH33	0.28-0.38	24.0-26.0	1.50	0.50	12.0-14.0	0.04	0.04	0.50-2.00
J94003	HI	0.20-0.50	26.0-30.0	2.00	0.50	14.0-18.0	0.04	0.04	2.00
J94013	HI35	0.30-0.40	26.0-30.0	1.50	0.50	14.0-18.0	0.04	0.04	0.50-2.00
J94224	HK	0.20-0.60	24.0-28.0	2.00	0.50	18.0-22.0	0.04	0.04	2.00
J94203	HK30	0.25-0.35	23.0-27.0	1.50	• • •	19.0-22.0	0.040	0.040	1.75
J94204	HK40	0.35-0.45	23.0-27.0	1.50	• • •	19.0-22.0	0.040	0.040	1.75
J94213	HN	0.20-0.50	19.0-23.0	2.00	0.50	23.0-27.0	0.04	0.04	2.00
J94214	HN40	0.35-0.45	19.0-23.0	1.50	0.50	23.0-27.0	0.04	0.04	0.50-2.00

1) Other, N 0.20 max.

Table 21 Heat resistant stainless steel casting specifications

UNS	ACI	ASTM Specification
J93005	HD	A 297
J93015	HD50	A 608
J93403	HE	A 297
J93413	HE35	A 608
J92603	HF	A 297
J92803	HF30	A 608
J93303	HH	A 447
J93503	HH	A 297
J93513	HH30	A 608
J93633	HH33	A 608
J94003	HI	A 297
J94013	HI35	A 608
J94224	HK	A 297
J94203	HK30	A 351, A 608
J94204	HK40	A 351, A 608
J94213	HN	A 297
J94214	HN40	A 608



HH was used for these cement cooler grates.

The Carondelet Corporation, Pevely, Missouri

Dorrenberq, Engelskirchen, Germanv

This is a side view of half of a rotary cement kiln entrance made from HD (GX40CrNiSi 27-4, 1.4823). It weighs 990-pounds (450 kg).

Credit: Junker, Simmerath, Germany

This rotary cement kiln entrance ring is made from proprietary stainless steel, G -X25 CrNiSi 20 14. The eighteen cover pieces are HD (GX40CrNiSi 27-4, 1.4823).

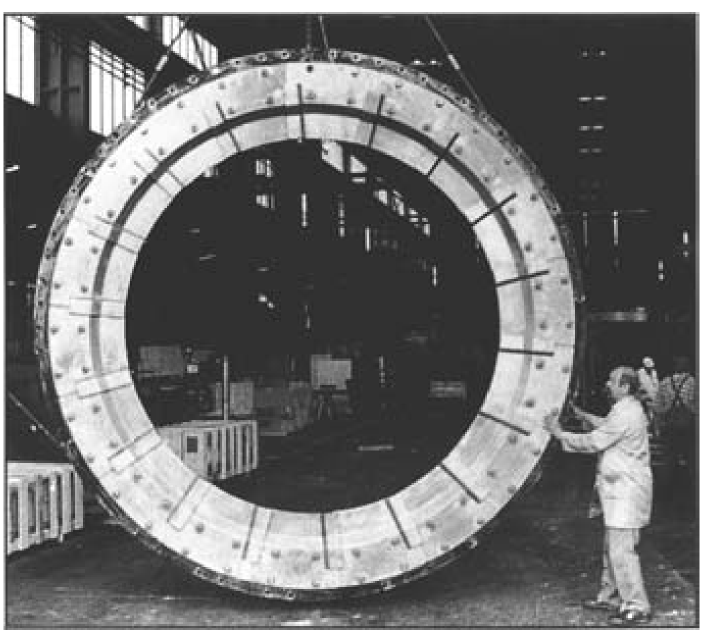


*Table 22 Minimum room temperature properties for heat resistant stainless steel castings**

UNS	Designation	Tensile Strength min		Yield Strength min		Elongation in 2 inch (50 mm), min %	Modulus of Elasticity in Tension x 10^3	
		ksi	MPa	ksi	MPa		ksi	MPa
J93005	HD	75	515	35	240	8[1]	27	186
J93403	HE	85	585	40	275	9[1]	25	172
J92603	HF	70	485	35	240	25[1]	28	193
J93303	HH Type I[2]	80	550	•••	•••	9	•••	•••
	HH Type II[2]	80	550	•••	•••	4	•••	•••
J93503	HH	75	515	35	240	10[1]	27	186
J94003	HI	70	485	35	240	10[1]	27	186
J94224	HK	65	450	35	240	10[1]	27	186
J94203	HK30	65	450	35	240	10.0	•••	•••
J94204	HK40	62	425	35	240	10.0	•••	•••
J94213	HN	63	435	•••	•••	8[1]	27	186

* ASTM A 297, A 351, and A 447

1) When ICI test bars are used in tensile testing as provided for in this specification, the gage length to reduced section diameter ratio shall be 4 to 1.

2) ASTM A 447 after aging for 24 hours at 1400 ± 25°F (760 ± 14°C) cool to at least 400°F (205°C) no faster then 200°F (110°C)/hour.

Table 23 Short-time high-temperature properties of heat resistant stainless steel castings[Ref. 1]

	Temperature		Tensile Strength		Yield Strength 0.2%	Offset
ACI	°F	°C	ksi	MPa	ksi	MPa
HD	1400	760	36	248	•••	•••
	1600	870	23	158	•••	•••
	1800	980	15	103	•••	•••
HF	1200	650	57	393	31.5	217.2
	1400	760	35	241	21.55	148.6
	1600	870	22	152	15.5	106.9
HH, Type 1	1400	760	33	227	17	117
	1600	870	18.5	127	13.5	93.1
	1800	980	9	62	6.3	43.4
HH Type 2	1400	760	35	241	18	124
	1600	870	22	152	14	96
	1800	980	11	76	7	48
HI	1400	760	38	262	•••	•••
	1600	871	26	179.3	•••	•••

Table 24 Tensile strength and elongation values for centrifugally cast heat resistant alloy tubing*

Properties	HD50	HF30	HH30	HH33	HI35	HK30	HK40
1400°F (760°C)							
Tensile Strength							
ksi	7.45	26.0	•••	•••	•••	26.0	29.0
MPa	51.4	179	•••	•••	•••	179	200
Elongation (%)	•••	7.0	•••	•••	•••	•••	7.0
1600°F (870°C)							
Tensile Strength							
ksi	2.6	14.5	7.6	20.0	20.0	14.0	16.5
MPa	17.7	99.9	52.7	138	138	96.5	114
Elongation (%)	•••	9.0	12.0	8.0	8.0	9.0	6.0
1800°F (980°C)							
Tensile Strength							
ksi	•••	•••	•••	4.0	•••	3.6	4.2
MPa	•••	•••	•••	27.6	•••	24.8	28.9
Elongation (%)	•••	•••	•••	20.0	•••	24.0	22.0

*ASTM A 297, A 351, AND A 447

Table 25 Minimum time to rupture values for centrifugally cast heat-resistant alloy tubing from ASTM A 608

Minimum Rupture Life, hours	HF30	HH33	HK30	HK40	HK50
1600°F (870°C) at 10 ksi (69 MPa)	6.0	5.0	7.0	25	47
1600°F (870°C) at 8 ksi (55 MPa)	18	17	24	•••	•••
1600°F (870°C) at 6 ksi (41 MPa)	•••	3.0	4.0	11	20
1600°F (870°C) at 4 ksi (28 MPa)	•••	20	34	•••	•••

Table 26 Typical Brinell hardness of as-cast and aged heat resistant stainless steel castings Ref. 10

UNS	Designation	Brinell hardness As-cast	Brinell hardness Aged[1]
J93005	HD	190	
J93403	HE	200	270
J92603	HF	165	190
J93303	HH, Type I	185	200
	HH, Type II	180	200
J93503	HH		
J94003	HI	180	200
J94224	HK	170	190
J94203	HK30		
J94204	HK40		
N08604	HL	160	
J94213	HN	160	

1) Aged 24 hours at 1400°F (760°C) and furnace cooled

Table 27 Physical properties of heat resistant stainless steel castings Ref. 10,11

UNS	ACI	Melting Point		Density		Electrical Resistivity, 70°F		Specific Heat 32-212°F (0-100°C)	
		°F	°C	lb/in³	gm/cm³	Ω/cir mil/ft	microhm/ cm²/cm	Btu/lb•°F	J/kg•K
J93005	HD	2700	1482	0.274	7.58	487	81	0.12	502
J93403	HE	2650	1454	0.277	7.67	511	85	0.14	586
J92603	HF	2550	1399	0.280	7.75	481	80	0.12	502
J93503	HH	2500	1371	0.279	7.72	451-511	75-85	0.12	502
J94003	HI	2550	1399	0.279	7.72	511	85	0.12	502
J94224	HK	2550	1399	0.280	7.75	541	90	0.12	502
J94213	HN	2500	1371	0.283	7.83	596	99.1	0.11	461

HE (Mr-9Ni) UNS J93403
HE35 UNS J93413

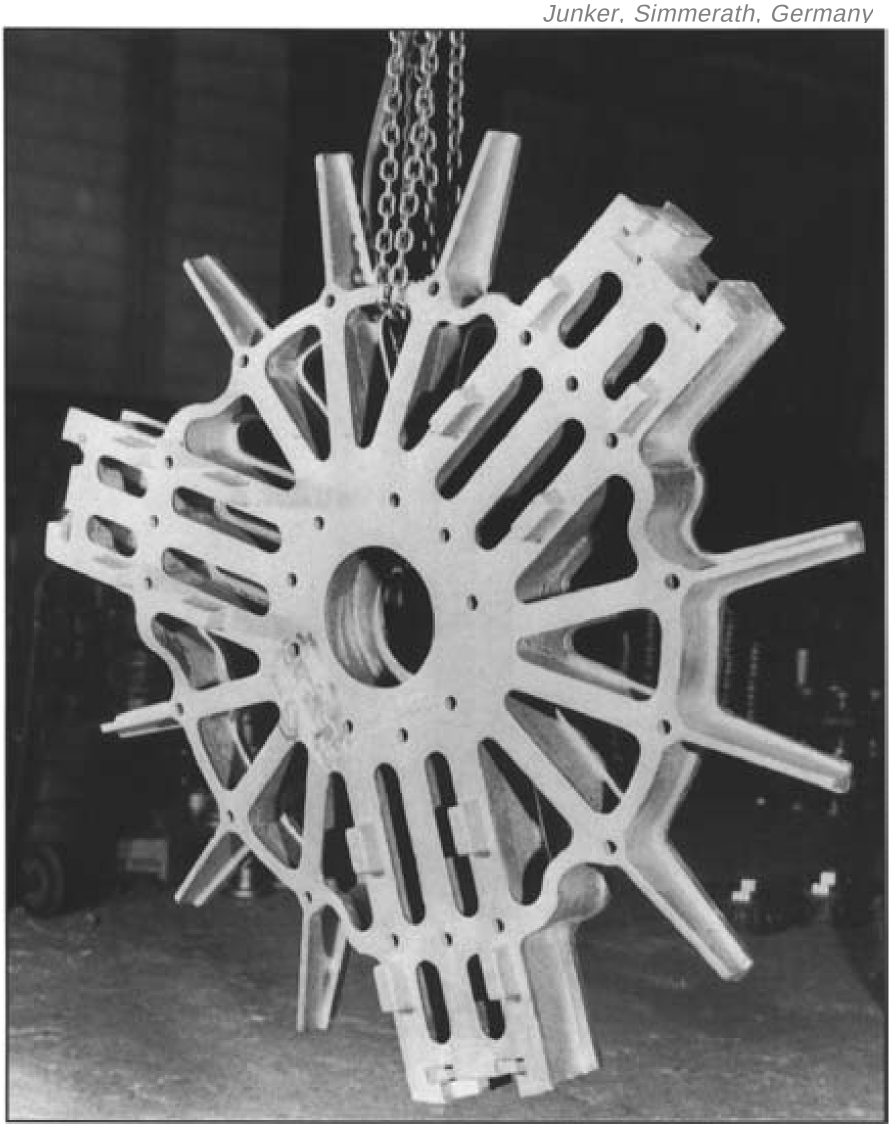
HE has a primarily austenitic microstructure with some ferrite and is weakly magnetic. It provides better high-temperature oxidation and sulfur resistance than HD. HE is used up to 2000°F (1095°C), but sigma phase formation and embrittlement may occur after prolonged exposure to temperatures around 1500°F (815°C). If this occurs, ductility can be improved somewhat by heating the casting to 2000°F (1095°C) followed by rapid cooling.

This is the strongest stainless steel casting grade with good resistance to high sulfur content, high-temperature gases (300 to 500 grains of sulfur per 100 cubic feet) making it a common choice for ore-roasting equipment. It is also used for billet skids, burner nozzles, dampers, furnace chains and conveyors, furnace door frames, oil burner oars, rabble arms and blades, recuperaters, rotating shafts, soot blower elements, steam generator parts, and tube supports in the oil refining, power, and steel industries.

Section thicknesses of 0.2 inch (5 mm) and above can be cast satisfactorily. Designs with large changes in section thickness should be avoided. It can be cast into intricate shapes.

HE35 is a variation of HE developed for centrifugal casting. Their chemistries are similar except that HE35 has a tighter carbon range, lower maximum manganese level, and a silicon range rather than a maximum to control its strength and resistance to carburization and oxidation.

Junker, Simmerath, Germany



This HF (EN GX40CrNiSi22-10) heat treating furnace grate is about 90-inches in diameter and 4-inches thick (2,300 mm diameter by 100 mm).

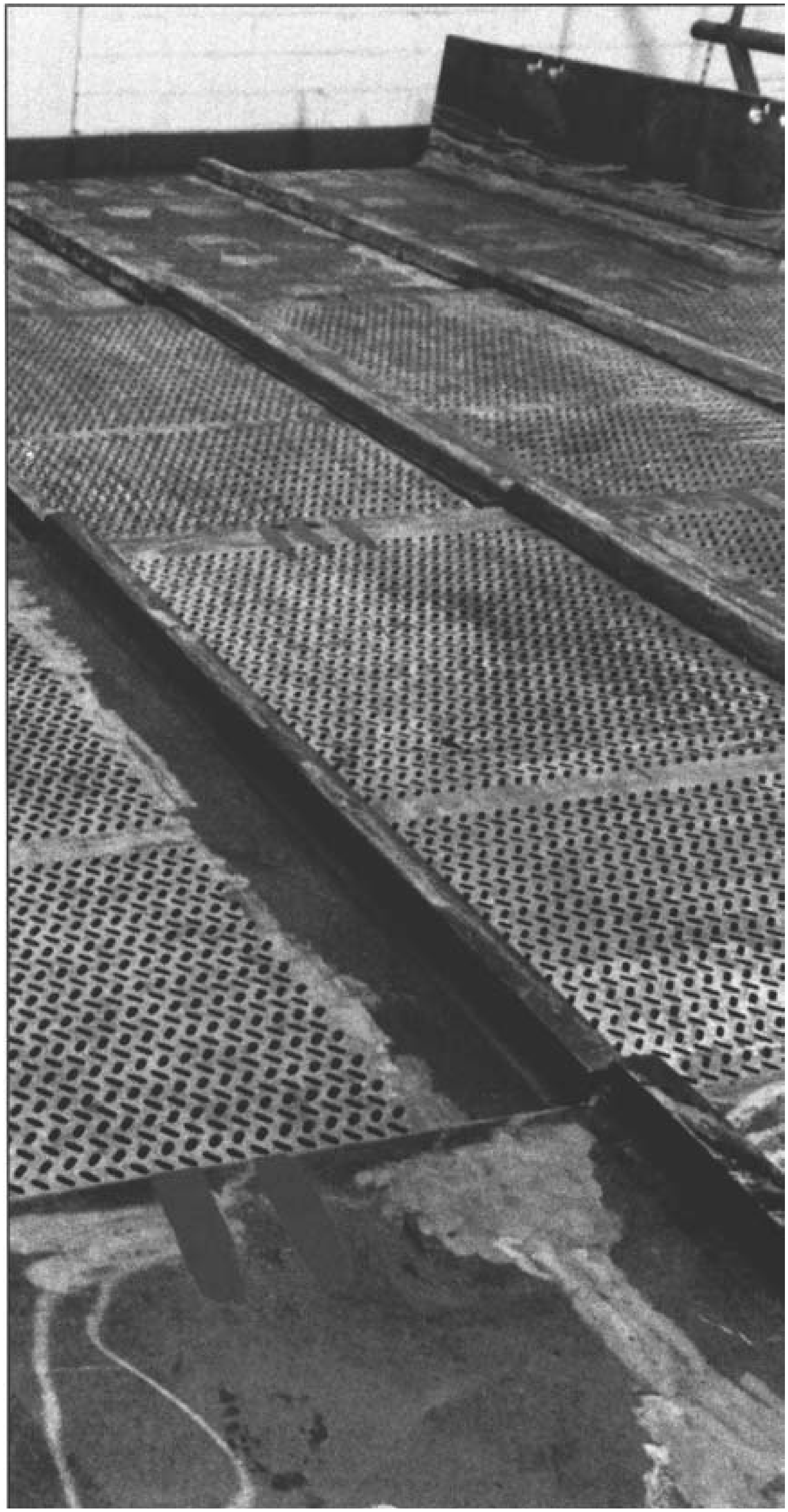
HF (Mr-9Ni) UNS J92603
HF30 UNS J92803

The higher nickel and carbon levels of HF ensure an austenitic structure. If the composition is not properly balanced, the microstructure may contain some ferrite in the as-cast condition which would make it more susceptible to embrittlement after prolonged exposure to temperatures of 1400-1500°F (760-815°C). Castings are normally used in the as cast condition, but if the casting will be subjected to cyclical heating and cooling during use, performance may be improved by prior heat treating at 1900°F (1038°C) for six hours followed by a furnace cool.

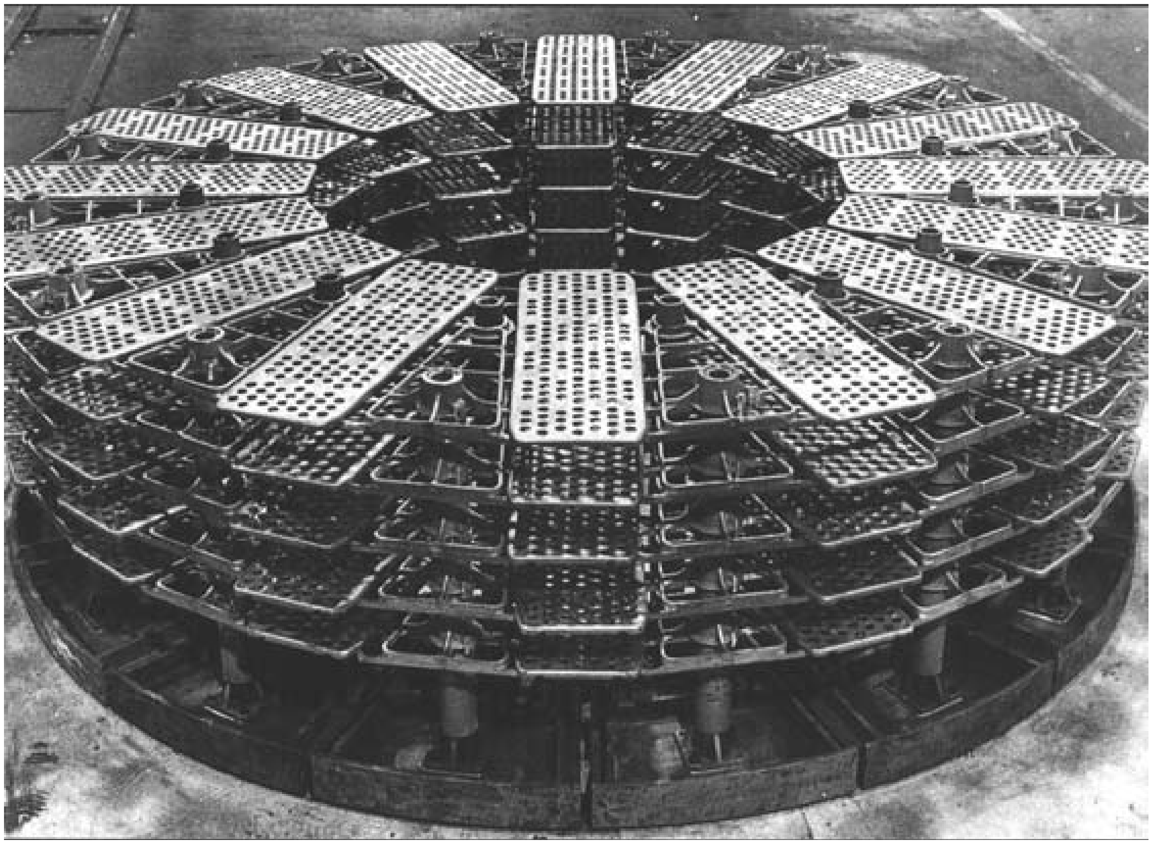
HF is used for applications where strength and corrosion resistance are needed for operating temperatures of 1200-1600°F (650-870°C). It is used most commonly in oil refineries and heat-treating furnaces. Other applications include arc furnace electrode arms; annealing boxes, trays, and baskets; brazing channels; burner tips; conveyor belts and chains; fan housings; furnace rails; gas burner rings; tempering baskets; soaking pit dampers; burnishing and coating rolls; and wear plates.

HF30 is a variation of HF used in centrifugal casting. It has tighter carbon, chromium, and nickel ranges; a lower maximum manganese level; and a silicon range of 0.5 to 2.0% rather than a maximum of 2.0%.

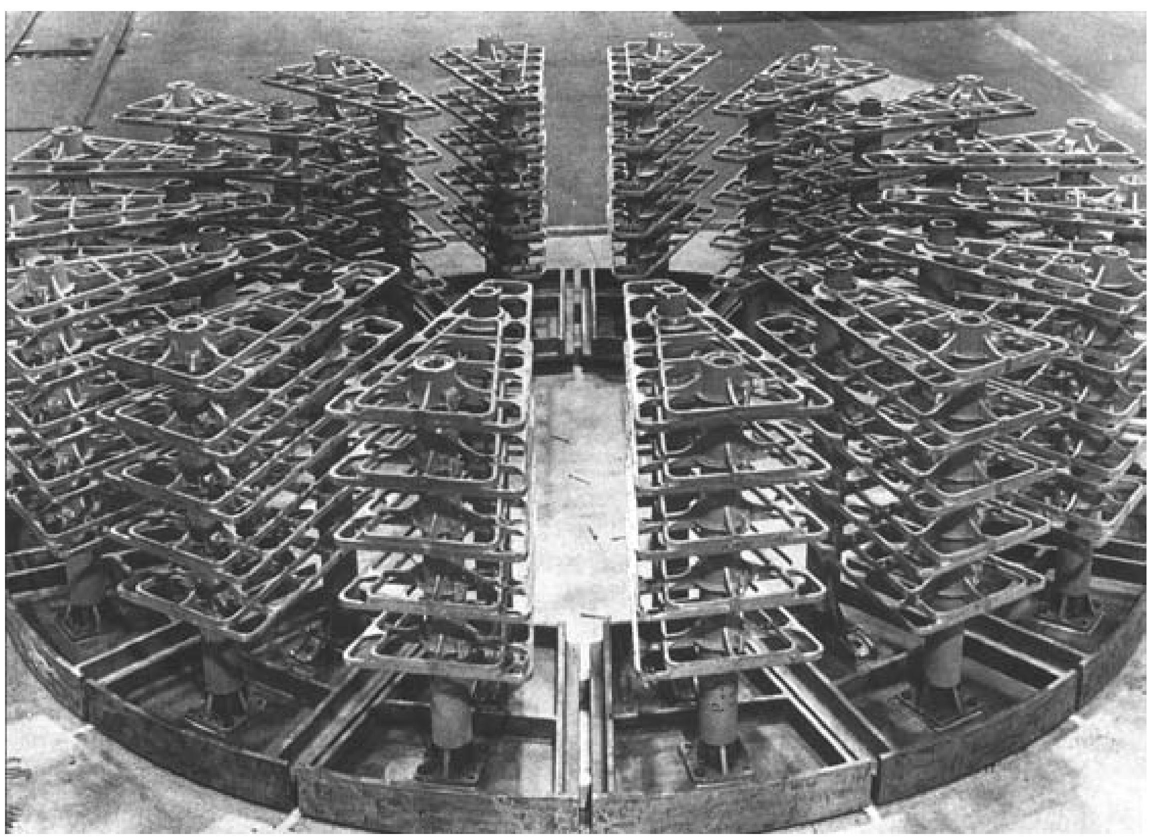
HF (EN GX25CrNiSi 18-9, 1.4825) was used for these 770 to 990 pound (350 to 450 kg) plates for sintering iron ore.



Dorrenberg, Engelskirchen, Germany

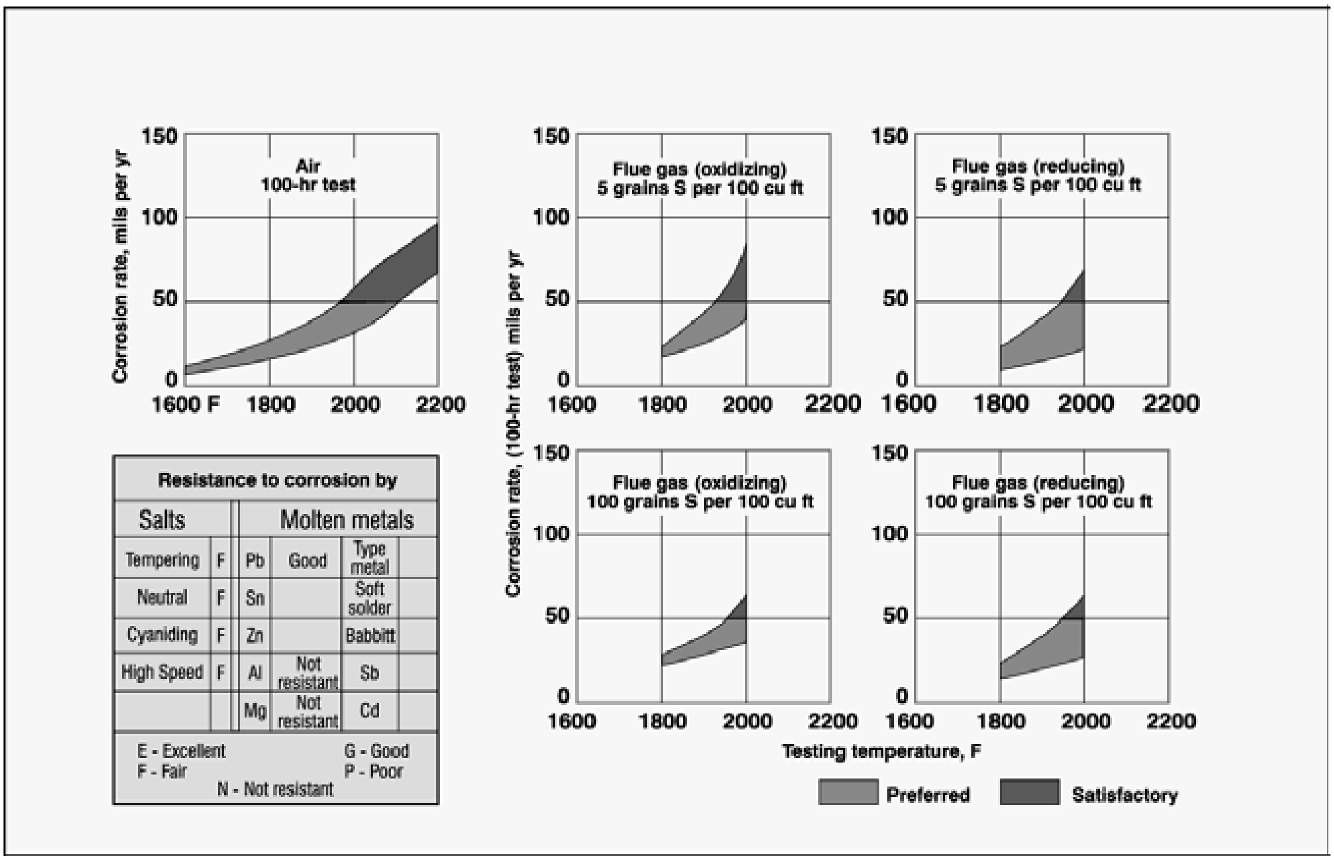


Pose-Marre, Erkrath, Germany



This charging system for an automatic rotary hearth furnace is shown with and without shelves. It is made from a proprietary stainless steel, G -X 40 NrCrNb 35-25 and operates at 500°F (930°C).

Figure 22 Corrosion characteristics of alloy HH (Fe-26Cr-12Ni) castings [Ref.2]



HH (25Cr-12Ni) UNS J93303/J93503

HH30-UNS J93513

HH33-UNS J93633

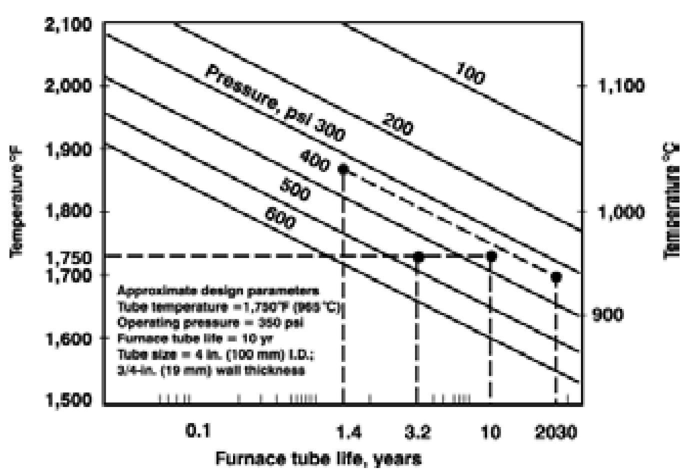
Both J93503 (ASTIVI A 297) and J93303 (ASTIVI A 447) are called HH in industry literature. They have similar compositions. Both grades are usually used in the as-cast condition. Two distinct grades (Type I and Type II) can be obtained while staying within the J93303 chemistry range by varying the chromium-to-nickel ratio.

Type I is primarily austenitic with some ferrite and has a maximum magnetic permeability of 1.70. It has a relatively low creep stress between 1500-2000°F (815-1095°C) and relatively high ductility at room temperature after aging for a short time between 1300-1500°F (705-815°C). It is more prone to sigma phase formation between 1200-1600°F (650-870°C) than Type II.

Type II is austenitic with a maximum permeability of 1.05. It has a relatively high creep strength, and its ductility may be relatively low after aging for short periods of time between 1350-1500°F (705-815°C). Type II is used for components with relatively high constant load conditions between 1200-1800°F (650-980°C). HH provides good resistance to surface corrosion under a variety of conditions but is not used in carburizing environments because of the potential for embrittlement. Although HH can withstand repeated temperature changes, it is not suggested for applications where severe cyclic temperature changes occur. The chromium content is high enough to provide good scaling resistance in air up to 2000°F (1095°C). Corrosion data for HH in oxidizing and reducing flue gas and air can be found in Figure 22.

Applications for HH include annealing trays, tube supports, carburizing boxes, exhaust manifolds, radiant tubes, retorts, structural elements, containers, and supports for electric furnaces, petroleum still tube supports, and similar applications. The manufacturer should be notified if the service temperature will be near 1800°F (980°C) so that the ferrite and austenite levels can be modified to meet the strength and ductility levels of the application. An austenite structure provides higher strength but lower ductility at this temperature, while a ferrite and austenite mixture provides better ductility but lower strength. HH30 and HH33 are variations of HH developed for centrifugal casting.

Figure 23 HK40 tubes in steam-methane reforming furnace. Tube life is greatly affected by small changes in pressure and temperature [Ref. 12]



HI (Mr-15Ni) UNS J94003
H135 UNS J94013

HI has more uniform high temperature properties than the lower alloyed grades in this group because it is more likely to be completely austenitic. It is similar to HH with a higher chromium content for improved oxidation resistance up to 2150°F (1180°C). It is weldable by all common methods. No preheat or postheat is required.

It is primarily used for retorts for calcium and magnesium production. Other applications include furnace fixtures, furnace skids, hearth plates, billet skids, conveyor rollers, furnace rails, lead pots, hearth plates, and tube spacers.

HK (25Cr-20Ni) UNS J94224
HK30 UNS J94203
HK40 UNS J94204

HK has high creep and rupture strengths and can be used in structural applications up to 2100°F (1150°C). It has excellent resistance to hot gas corrosion, including sulfur-bearing hot gas, under both oxidizing and reducing conditions. HK is ordinarily used in the as-cast condition. It is weldable by all common methods. No preheat or post-heat is required. Its machinability is good.

HK is most commonly used for furnace tubes and calcining. It is also used for handling air, ammonia, hydrogen, and molten neutral salts. Other applications include furnace rolls, and steam hydrocarbon reformer and ethylene pyrolysis tubing, billet skids, and furnace trays and fixtures. In most plants, HK has been replaced with proprietary versions of HP which have higher creep strengths and are resistant to sigma formation (see the nickel-base alloy section for more information on HP).

HK30 and HK40 are variations of HK and are used for pressure-containing parts used in elevated temperature and corrosive service (ASTIVI A 351) and centrifugally cast parts (A 608).

HK40 is used in reforming and ethylene cracking tubes, fittings, and tubesheets. It provides creep resistance up to 1800°F (980°C). HK40 tube life can be dramatically shortened by overheating by 100°F (55°C) and higher pressure levels as shown in Figure 23. A comparison of allowable creep-rupture stress levels for HK40, HPN6, and HP modifications is shown in *Figure 24*. A comparison with several nickel-base alloys of the level of carburization is shown in *Figure 25.*

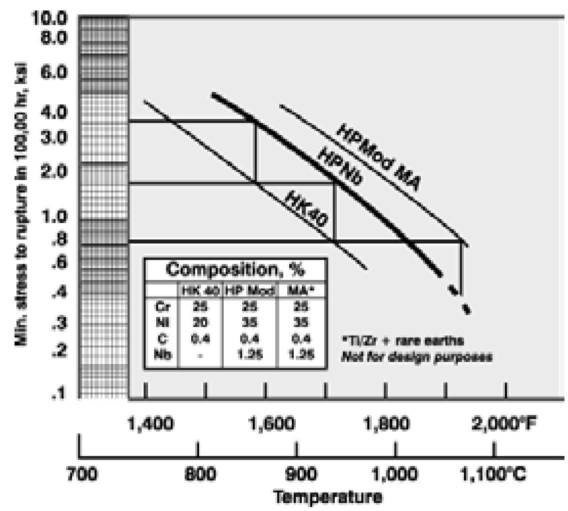
HN (20Cr-25Ni) UNS J94213

HN40 UNS J94214

HN has properties similar to those of HK. It is resistant to oxidizing and reducing flue gases and provides very high strength at high temperatures. HN is primarily used for brazing fixtures and furnace rolls. Other applications include furnace chains, radiant tubes, trays, beams, and other parts. Its machinability is good and it is weldable by all common methods. No preheat or post-heat is required.

HN40 is a variant of HN developed for improved centrifugal casting.

Figure 24 Generalized comparison of allowable creep-rupture stress for HK40, HPNb and HPMod micro alloys *Ref. 12*



NICKEL-BASE ALLOYS Nickel-base alloys are generally classified as "heat-resistant" when capable of continuous or intermittent use for sustained periods of time above 1200°F (650°C). Carbon content is usually a distinguishing factor between the heat and corrosion-resistant alloys, but this dividing line can be vague, particularly for alloys used in the 900-1200°F (480 to 650°C) range.

Nickel and chromium have the greatest influence on heat-resistant castings by improving creep strength, corrosion resistance, and thermal fatigue, which are important characteristics in the selection of high-temperature nickel-base alloys. Chemistry, grain boundary area, and the alignment of grain boundaries relative to applied stresses control thermal fatigue resistance. Boron, zirconium, carbon, and hafnium strengthen grain

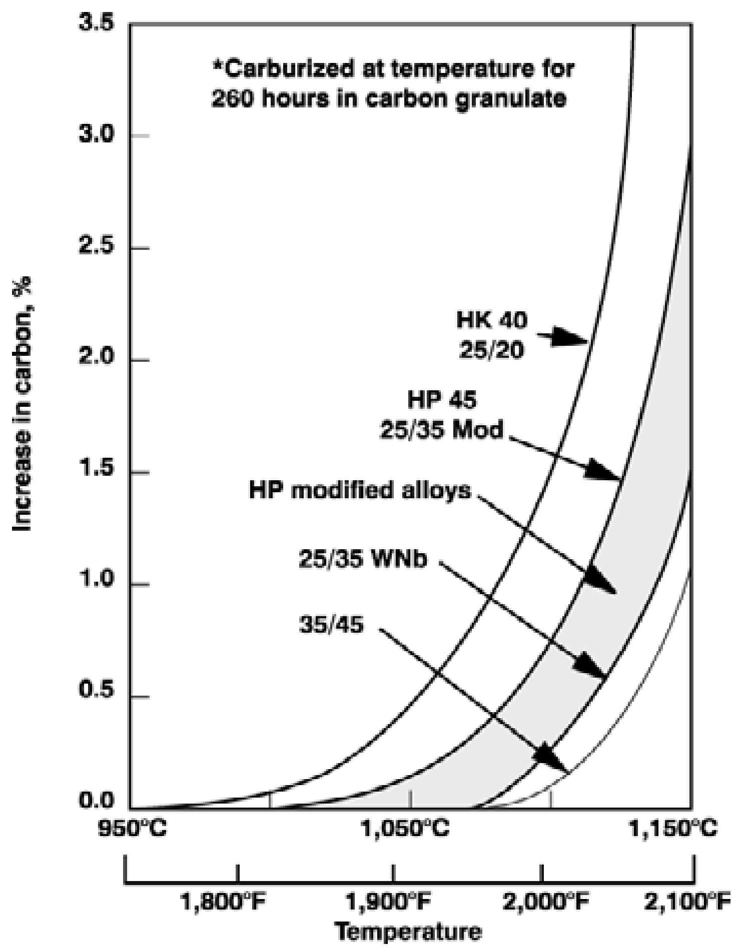
The most commonly used heat-resistant nickel-base alloy castings are HP HU, HX, and micro-alloyed proprietary versions of HP. Some of the nickel-chromium-iron alloys, which are classified as corrosion-resistant alloys, are also used in high temperature applications. When castings are required in small quantities, designers should consider specifying the most commonly used alloys rather than alloys that may be difficult to obtain.

Alloy designations, compositions, and specifications are provided in *Tables 28 and 29.* The mechanical properties are shown in Tables *30 and 31.* The mechanical properties for both the heat-resistant stainless steel and nickel-base castings are compared in *Figures 18 through 21, Table 32* shows the physical properties, and *Table 33* provides typical hardness values. Stress rupture data is often valuable when used in conjunction with creep strength when establishing allowable design stresses. *Figures 26 and 27* show the creep strength of the heat-resistant nickel-base alloy castings. *Figures 28 and 29* show 1,000-hour stress rupture data and *Figures 30 and 31* show 10,000- and 100,000-hour stress rupture data for the same alloys. The stress rupture tests rank the alloys in an order similar to the creep tests.

CT15C (32Ni-Cr-ICb) UNS N08151

Although the "C" in its name indicates that CT15C is designed for corrosion-resistant applications, it is primarily used in heat-resisting applications at temperatures up to 1600°F (870°C) for tubes, manifolds, and fittings in reformer, ethylene plant, and other high-temperature petrochemical processes. It retains good ductility and weldability and can be used in applications where there is severe thermal cycling.

Figure 25 Increase in alloy carburization with tube-metal temperature increase *Ref. 10*



These statically cast tube trees are made from proprietary version of HP.

Duraloy Technologies Inc., Scottdale, Pennsylvania

HL (Cr-20Ni) UNS N08604
HL30 UNS N08613
HL40 UNS N08614

HL has properties similar to HK but provides improved sulfur resistance, especially where excessive scaling must be avoided. It is resistant to corrosion in high-sulfur environments to 1800°F (980°C) and is often used for gas dissociation equipment. Other applications include carrier fingers, furnace skids, radiant tubes, and stack dampers. HL has good machinability and it is weldable by all common methods. No preheat or post-heat is required.

The compositions of the HL30 and HL40 were developed for centrifugal casting. Their compositions are identical except that HL40 has a higher carbon range. Both have narrower ranges than HL for carbon, nickel, and silicon and lower maximum manganese levels.

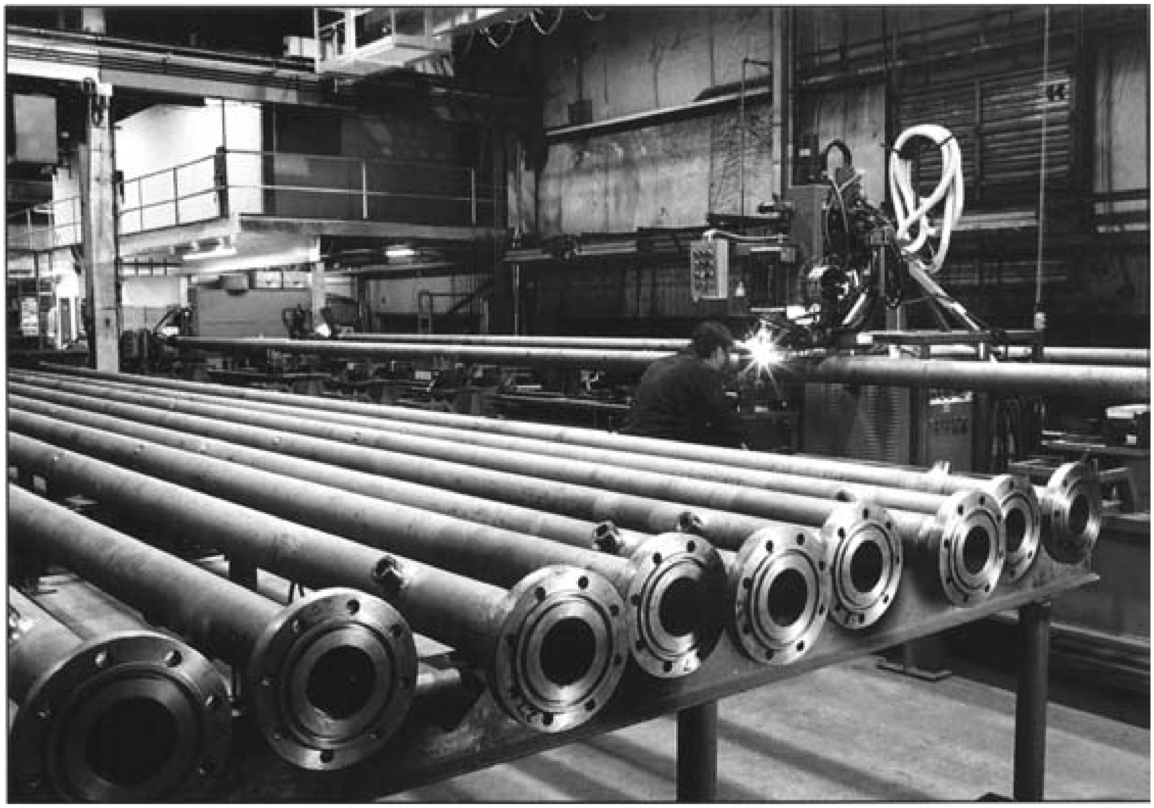
Table 28 UNS designations and compositions* for heat resisting nickel-base alloy castings

UNS	ACI	C	Cr	Fe	Mn	Mo	Ni	P	S	Si
N08151[1]	CT15C	0.05-0.15	19.0-21.0	rem	0.50-1.50	• • •	31.0-34.0	0.03.	0.03	0.50-1.50
N08604	HL	0.20-0.60	28.0-32.0	rem	2.00	0.50	16.0-22.0	0.04	0.04	2.00
N08613	HL30	0.25-0.35	28.0-32.0	rem	1.50	0.50	18.0-22.0	0.04	0.04	0.50-2.00
N08614	HL40	0.35-0.45	28.0-32.0	rem	1.50	0.50	18.0-22.0	0.04	0.04	0.50-2.00
N08705	HP	0.35-0.75	24.0-28.0	rem	2.00	0.50	35.0-37.0	0.04	0.04	2.50
N08605	HT	0.35-0.75	15.0-19.0	rem	2.00	• • •	33.0-37.0	0.04	0.04	2.50
N08030	HT30	0.25-0.35	13.0-17.0	rem	2.00	0.50	33.0-37.0	0.040	0.040	2.50
N08050	HT50	0.40-0.60	15.0-19.0	rem	1.50	0.50	33.0-37.0	0.04	0.04	0.50-2.00
N08004	HU	0.35-0.75	17.0-21.0	rem	2.00	0.50	37.0-41.0	0.04	0.04	2.50
N08001	HW	0.35-0.75	10.0-14.0	rem	2.00	0.50	58.0-62.0	0.04	0.04	2.50
N08006	HW50	0.40-0.60	10.0-14.0	rem	1.50	0.50	58.0-62.0	0.04	0.04	0.50-2.00
N06006	HX	0.35-0.75	15.0-19.0	rem	2.00	0.50	64.0-68.0	0.04	0.04	2.50
N06050	HX50	0.40-0.60	15.0-19.0	rem	1.50	0.50	64.0-68.0	0.04	0.04	0.50-2.00

1) Other =0.50-1.50 Nb

* Maximum unless a range is given.

These HP and modified HP steam reformer furnace tube assemblies are used in the production of nitrogen fertilizers, methanol, and refining oil.



Wisconsin Centrifugal, Waukesha.

HP (26Cr-35Ni) UNS N08705

HP is extremely resistant to high-temperature oxidizing and carburizing atmospheres. It provides good strength in the 1650-2000°F (900-1095°C) temperature range and is often used for heat treatment fixtures, radiant tubes, and coils for ammonia furnaces and for ethylene pyrolysis heaters, where it has replaced HK. *Figure 24* compares the allowable creep-rupture stress of HP modifications with HK. It has good machinability and is weldable by all common methods. No preheat or post-heat is required. Although this is a widely used grade, HP is rarely purchased to the chemistries listed in UNS N08705 or ASTIVI A 297. Proprietary versions with niobium additions and further micro-alloying element additions are used to improve rupture properties. These proprietary variations on HP are used extensively for reformers, ethylene furnaces, methanol furnaces, and similar applications. For most of these applications, HP is centrifugally cast. *Figure 25* compares various modifications of HP with HK40 and 35Cr-45Ni alloy carburization with increasing temperature.

Table 29 Heat resistant nickel-base alloy specifications

UNS	ACI	ASTM
N08151	CT15C	A 351
N08604	HL	A 297
N08613	HL30	A 608
N08614	HL40	A 608
N08705	HP	A 297
N08605	HT	A 297
N08030	HT30	A 351
N08050	HT50	A 608
N08004	HU	A 297
N08005	HU50	A 608
N08001	HW	A 297
N08006	HW50	A 608
N06006	HX	A 297
N06050	HX50	A 608

Table 30 Room temperature properties for heat resistant nickel-base alloy castings

UNS	Designation	Tensile Strength min		Yield Strength min		Elongation in 2 inch (50 mm), min %	Modulus of Elasticity in Tension x 10³	
		ksi	MPa	ksi	MPa		ksi	MPa
N08151[1]	CT15C	63	435	25	170	20	•••	•••
N08604	HL	65	450	35	240	10[2]	27	186
N08705	HP	62.5	430	34	235	4.5[2]	•••	•••
N08605	HT	65	450	•••	•••	4[2]	27	186
N08030	HT30	65	450	28	195	15.0	•••	•••
N08004	HU	65	450	•••	•••	4[2]	27	186
N08001	HW	60	415	•••	•••	•••	25	172
N06006	HX	60	415	•••	•••	•••	25	172

Except as noted, these are the minimum properties listed in ASTM A 297 and A 351.

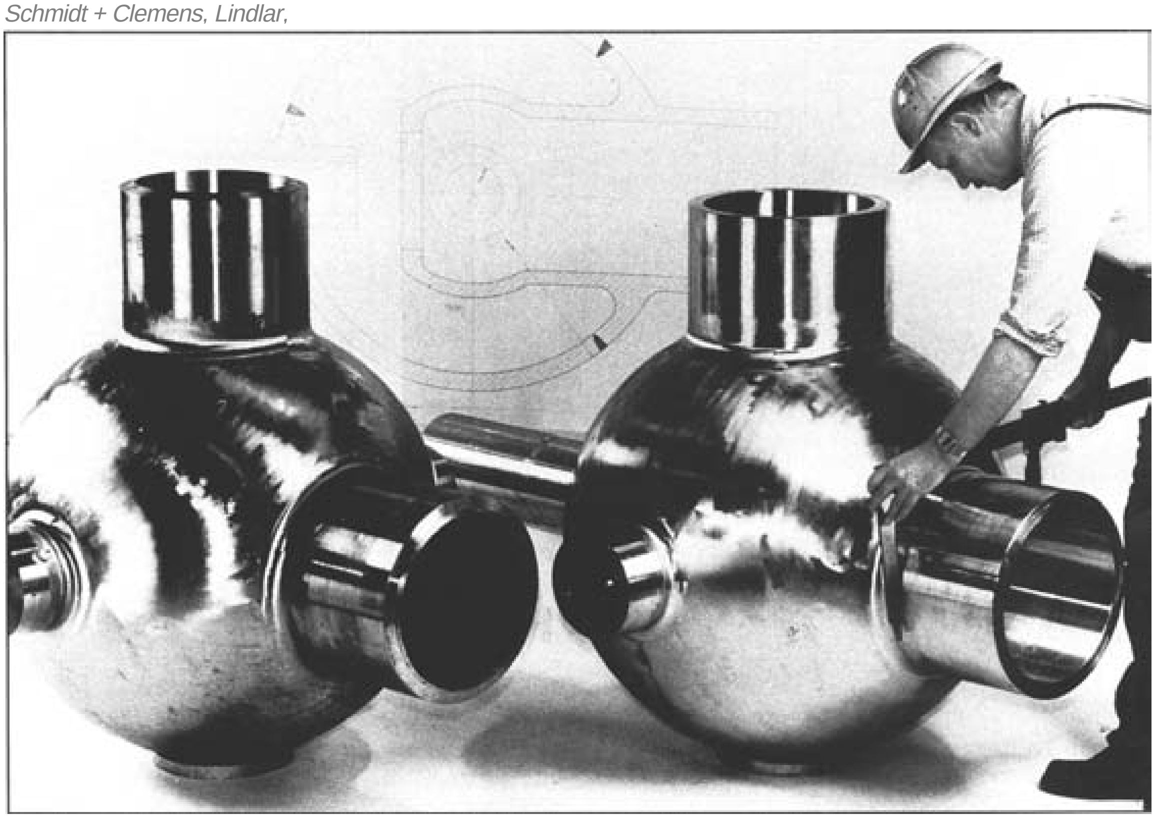
1) Minimum requirements from ASTM A 351

2) When ICI test bars are used in tensile testing as provided for in this specification, the gage length to reduced section diameter ratio shall be 4 to 1.

Table 31 Short-time high-temperature properties of heat resistant nickel-base alloy castings[1]

ACI	Temperature		Tensile Strength		Yield Strength 0.2% Offset	
	°F	°C	ksi	MPa	ksi	MPa
HL	1400	760	50	345	•••	•••
	1600	871	30	210	•••	•••
	1800	982	19	129	•••	•••
HT	1200	649	42	292	28	193
	1400	760	35	241	26	179
	1600	871	19	130	15	103
	1800	982	11	76	8	55
	2000	1093	6	41	•••	•••

Schmidt + Clemens, Lindlar,



These CT15C (EN GX10NiCrNb 32-20) ball valve housings were fabricated from several centrifugally cast parts for the petrochemical industry. The ball diameter is about 35 inches (880 mm) and the length is about 65 inches (1640 mm).

Table 32 Physical properties of heat resistant nickel-base alloy castings[Ref.10]

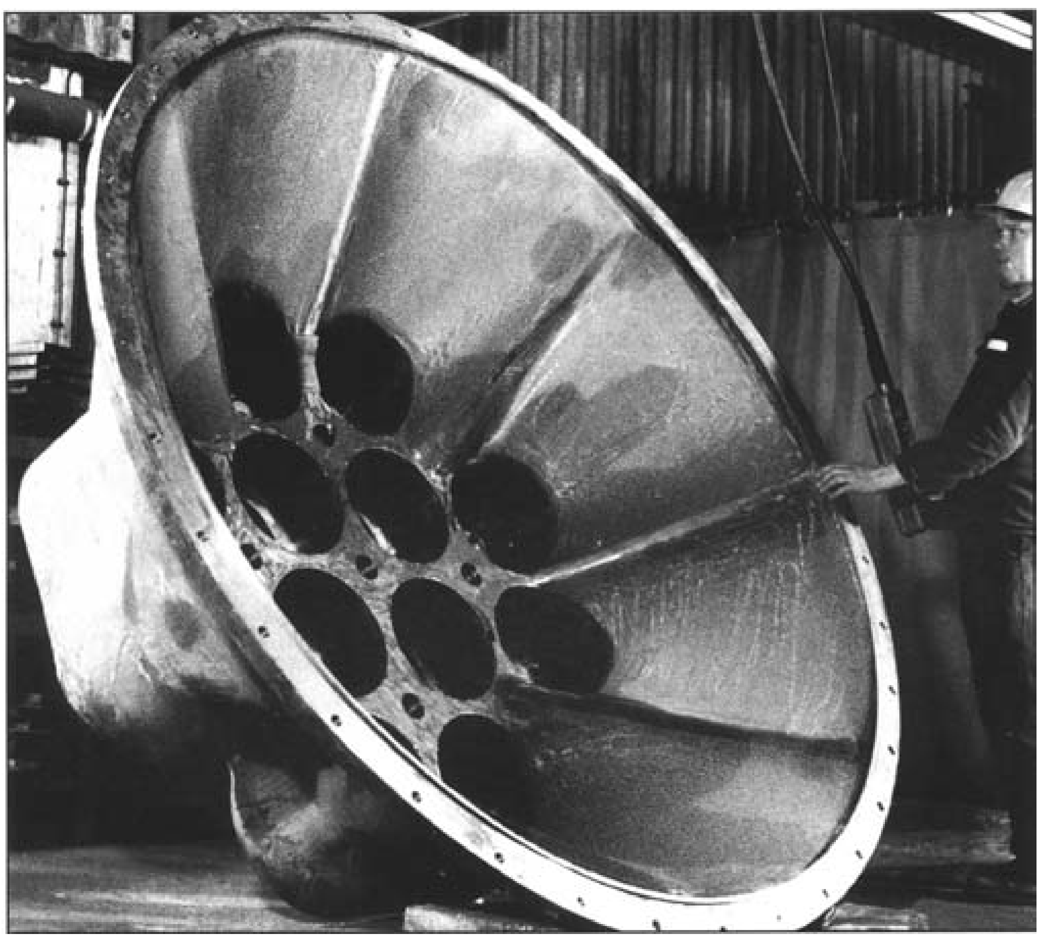
UNS	ACI	Melting Point		Density		Electrical Resistivity, 70°F		Specific Heat 32-212°F (0-100°C)	
		°F	°C	lb/in³	gm/cm³	Ω/cir mil/ft	microhm/c m²/cm	Btu/lb•°F	J/kg•°K
N08604	HL	2600	1427	0.279	7.72	565	94	0.12	5.02
N08705	HP	2450	1343	0.284	7.83	614	102	0.11	461
N08605	HT	2450	1343	0.286	7.92	602	100	0.11	461
N08004	HU	2450	1343	0.290	8.03	632	105	0.11	461
N08001	HW	2350	1288	0.294	8.14	674	112	0.11	461
N06006	HX	2350	1288	0.294	8.14	698	116	0.11	461

Table 33 Typical Brinell hardness of as-cast and aged hear resistant nickel-base alloy castings[Ref. 10]

UNS	Designation	Brinell hardness As-cast	Aged [1]
N08604	HL	192	
N08705	HP		
N08605	HT	180	200[1]
N08030	HT30		
N08004	HU	170	190[2]
N08001	HW	185	205[3]
N06006	HX	176	185[2]

1) Aged 24 hours at 1400°F (760°C) and air cooled
2) Aged 48 hours at 1800°F (980°C) and air cooled.
3) Aged 48 hours at 1800°F (980°C) and furnace cooled

Junker, Simmerath, Germanv



CT15C (EN GX10NiCrNb 32-20) was used for this conical industrial furnace end. It weighs 5,280 pounds (2,400 kg) and is 98 inches (2,500 mm) in diameter and 20 inches (500 mm) deep.

Figure 26 Heat resistant casting creep strength Ref. 10

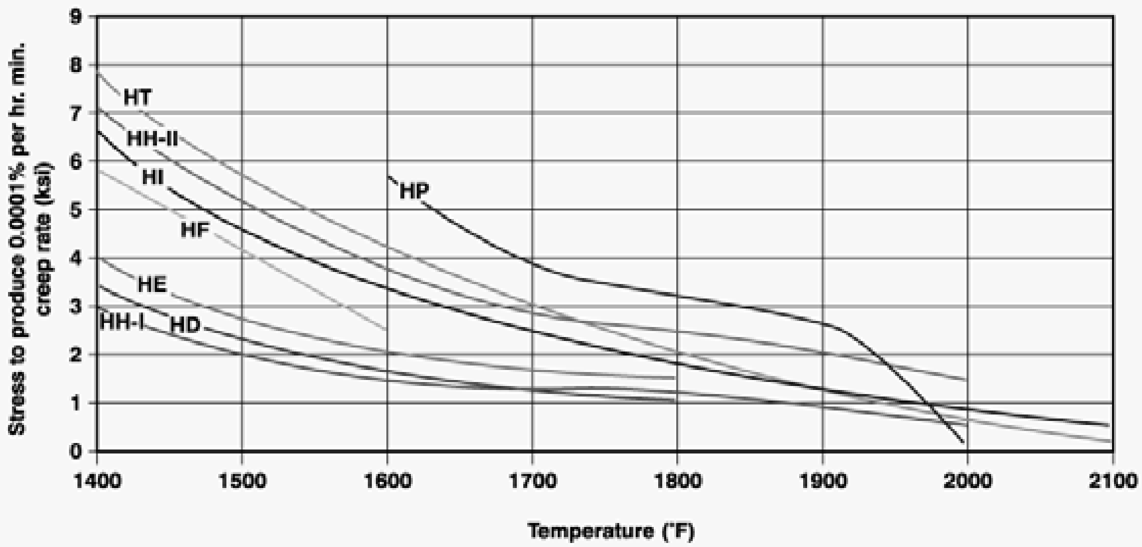


Figure 27 Heat resistant casting creep strength Ref. 10

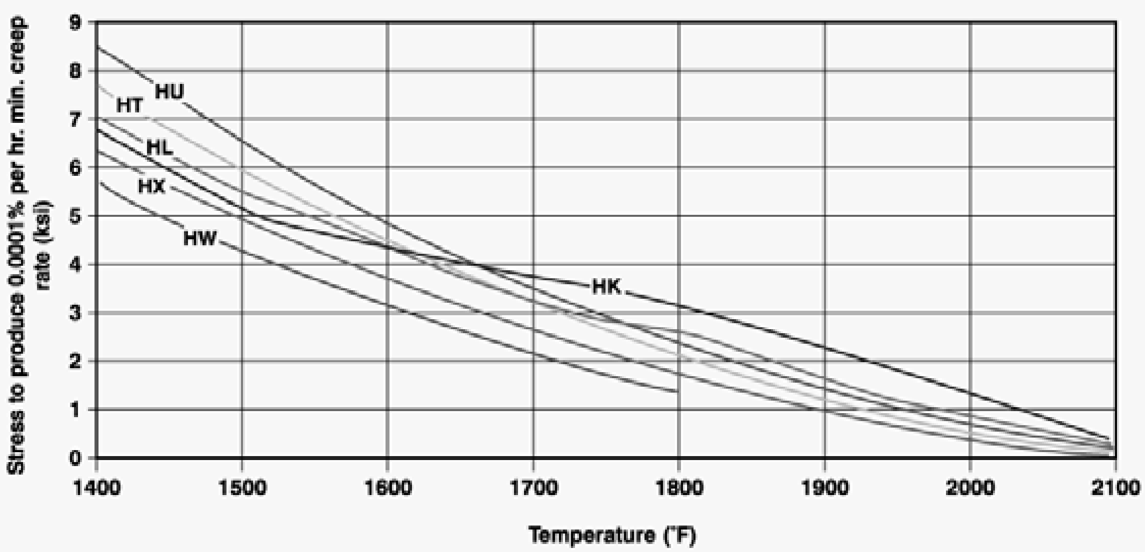


Figure 28 Heat resistant casting stress rupture data (1,000 hours)[Ref. 10]

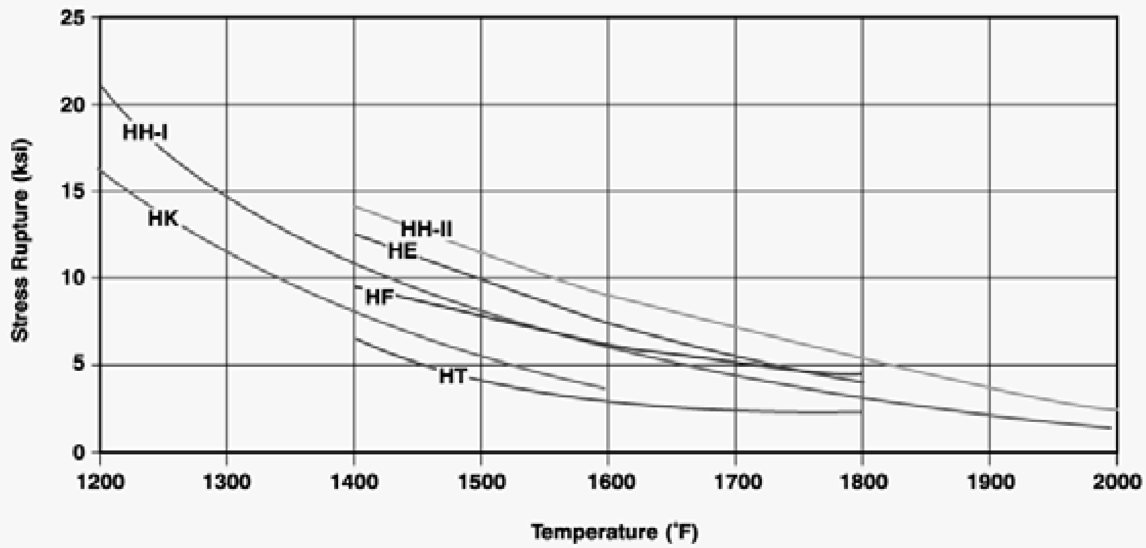


Figure 29 Heat resistant casting stress rupture dats (1,000 hours)[Ref. 10]

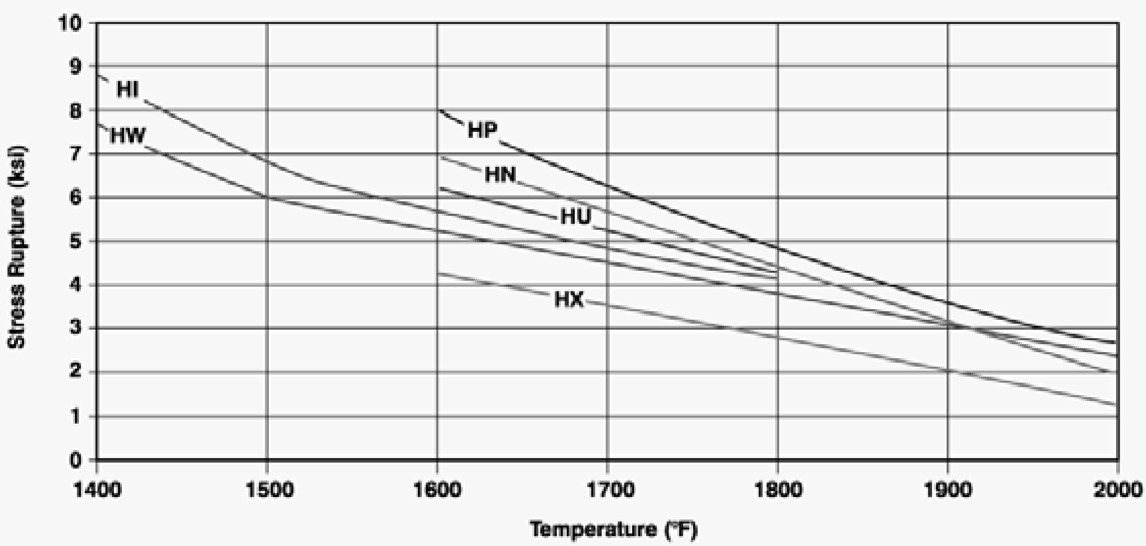


Figure 30 Heat resistant casting stress rupture data (10,000 hours) [Ref. 10]

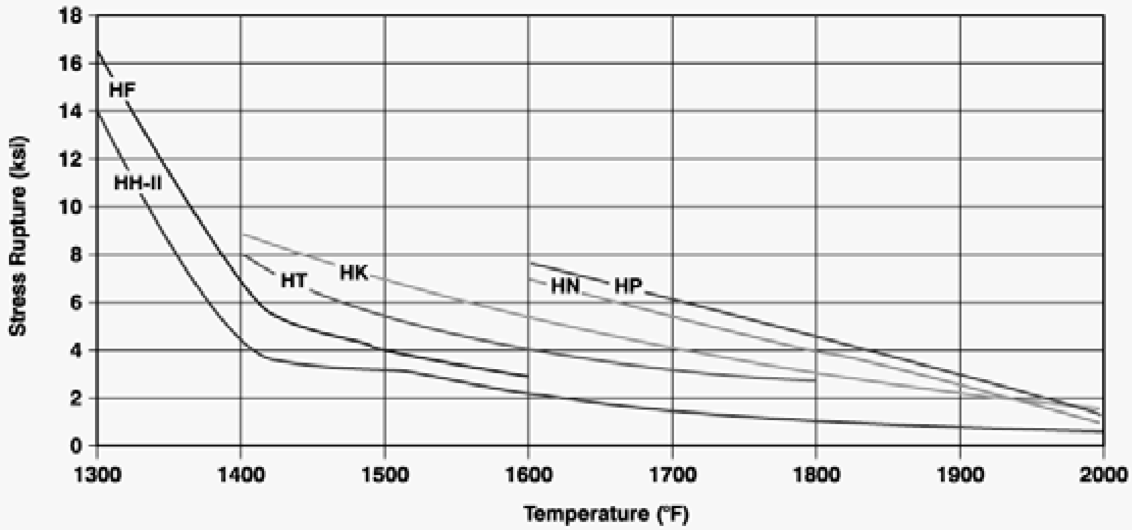
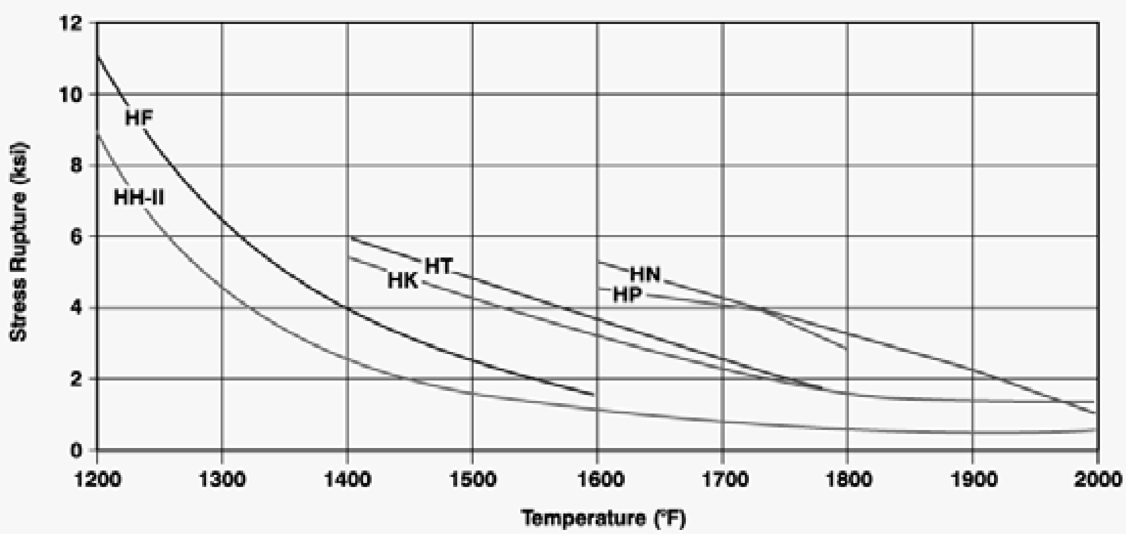


Figure 31 Heat resistant casting stress rupture data (100,000 hours) [Ref. 10]

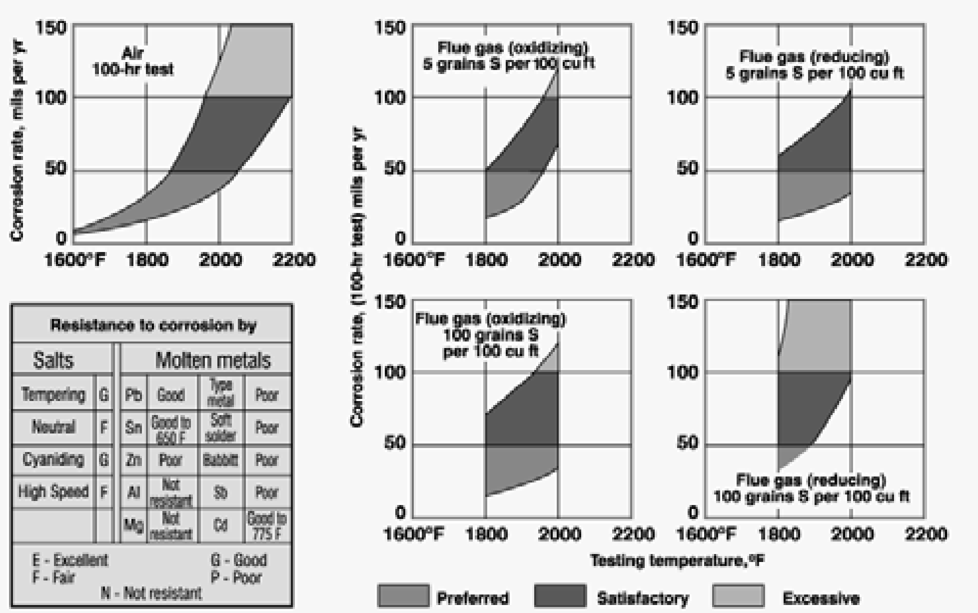


HT (15Cr-35Ni) UNS N08002
HT30 UNS N08030
HT50 UNS N08050

HT is usually used in the as-cast condition and is the cast equivalent of wrought Type 330 (N08330). It can withstand oxidizing conditions to 2100°F (1150°C) and reducing conditions to 2000°F (1095°C), provided that limiting creep stress values are not exceeded. It is resistant to air, oxidizing and reducing flue gases, carburizing gases, salts, and molten metals (Figure 32). It is widely used for heat treatment furnace parts that are subject to cyclic heating such as rolls, roller rails, disks, chains, boxes, pots, and fixtures. It is also used for glass rolls, enameling racks, radiant tubes, salt pots, fan blades, hearth plates, trays, idler drums, muffles, and retorts. It is weldable by all common methods and has good machinability.

HT30 (A 351) is a grade variation for pressure-containing parts used for elevated temperature and corrosive service. HT50 (A 608) is a grade variation developed for centrifugal cast parts.

Figure 32 Corrosion characteristics of alloy HT (Fe-35Ni-17Cr) castings



Resistance to corrosion by						
Salts		Molten metals				
Tempering	G	Pb	Good	Type metal	Poor
Neutral	F	Sn	Good to 650 F	Soft solder	Poor
Cyaniding	G	Zn	Poor	Babbitt	Poor
High Speed	F	Al	Not resistant	Sb	Poor
		Mg	Not resistant	Cd	Good to 775 F

E - Excellent G - Good
F - Fair P - Poor
N - Not resistant

HU (Mr-39Ni) UNS N08004
HU50 UNS N08005

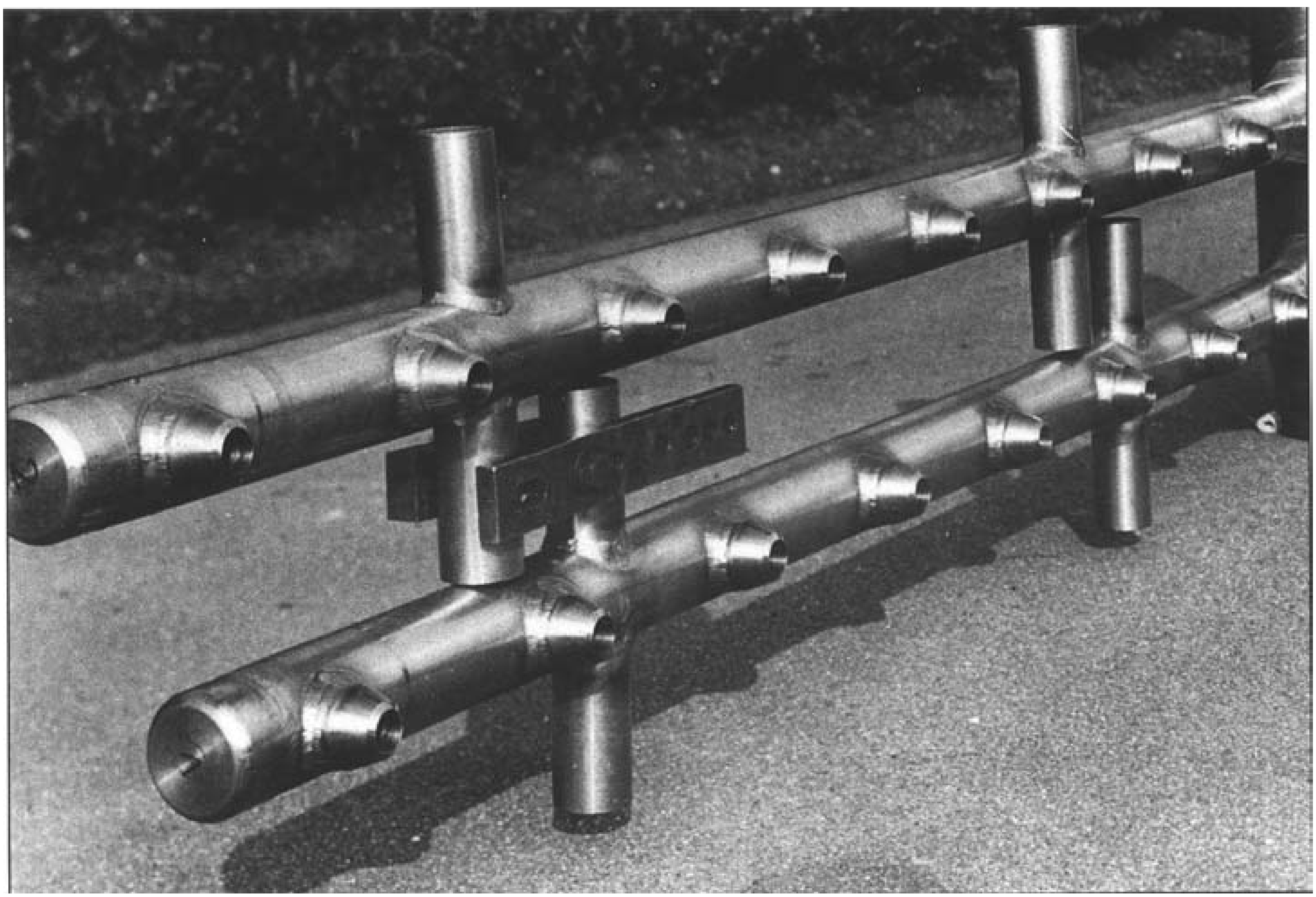
HU has higher hot strength than HT and provides excellent resistance to carburizing atmospheres, hot gas corrosion, and thermal fatigue. It is often used for severe service applications such as burner tubes, lead and cyanide pots, retorts, and furnace rolls. Other applications include salt pots, muffles, chains, and radiant tubes. It has good machinability and is weldable by all common methods. No preheat or post-heat is required.

HW (12Cr-60Ni) UNS N08001
HW50 UNS N08006

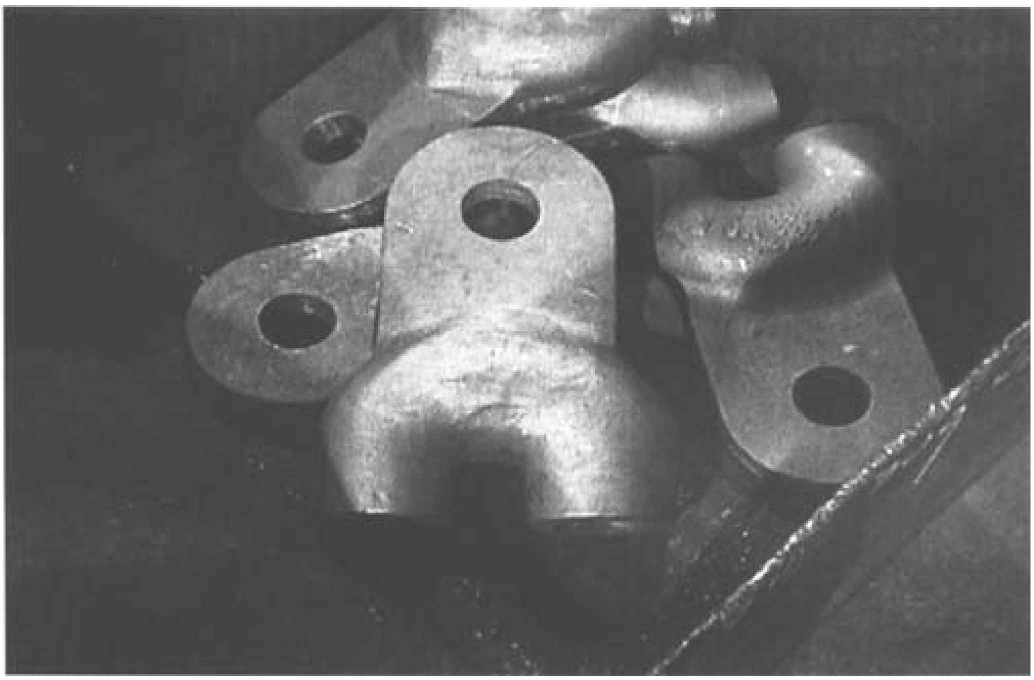
In the as-cast condition, the microstructure of HW is a continuous, interdendritic network of elongated eutectic carbides. With the exception of the immediate vicinity of the eutectic carbides, the microstructure becomes austenitic with a uniform distribution of small carbide particles after exposure to service temperatures. The structure change increases room temperature strength but does not affect ductility. HW50 is an HW grade variation which is used for centrifugal casting.

This 276 inch (7,000 mm), 2640 pound (1200 kg) reformer furnace exit collector was fabricated from sand and centrifugally cast CT15C (ENGX10NiCrNb32-20) and other heat-resistant grades.

Pose-Marre, Erkrath, Germany

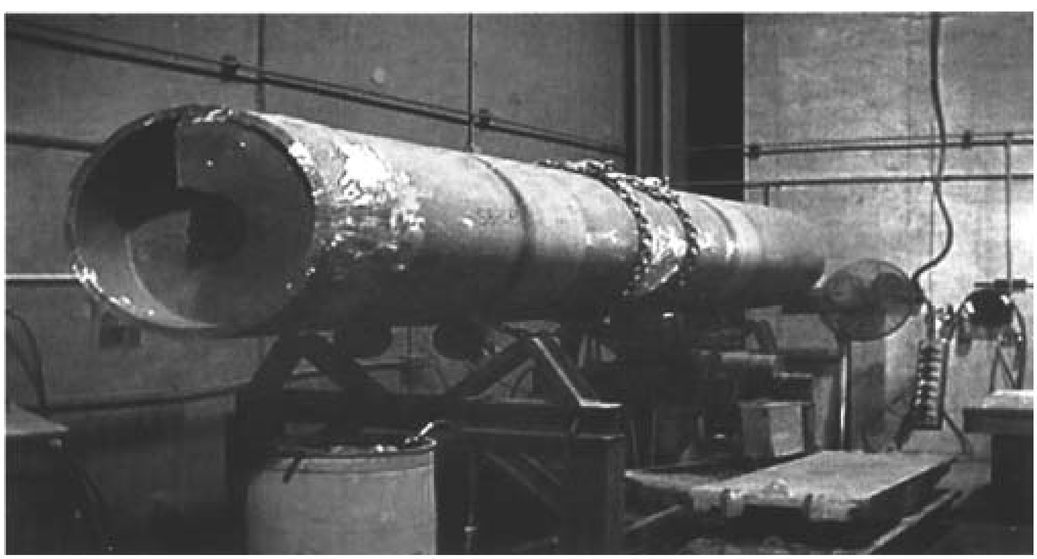


These elbows are HP modified with Nb.



These fittings were cast from HP modified with Nb.

The Carondelet Corporation, Pevely, Missouri



This retort was cast in HT.

HW is extremely resistant to oxidation, thermal shock, and fatigue and is an excellent choice for applications with wide and/or rapid temperature fluctuations. It is used in temperatures up to 2050°F (1120°C) in strongly oxidizing atmospheres and up to 1900°F (1040°C) in the oxidizing or reducing products of combustion if sulfur is not present; HW should not be used in reducing gases that contain sulfur. It is also highly resistant to carburization from tempering and cyaniding salts.

HW is used for electrical heating elements because of its high electrical resistivity. It is also used for intricate heat treating furnace fixtures, hearths, muffles, retorts, trays, burner parts, enameling fixtures, quenching fixtures, cyanide pots, and containers for molten lead. It has good machinability and is weldable by all common methods. No preheat or post-heat is required.

HX (Mr-66Ni) UNS N06006
HX50 UNS N06050

HX is extremely resistant to oxidation, thermal shock, and fatigue. It is highly resistant to carburization when in contact with tempering and cyaniding salts. The higher nickel and chromium content provide better resistance to hot gas corrosion than HW, particularly in reducing gases containing sulfur. It is used for severe service up to 2100°F (1150°C). HX50 is a variation that is used for centrifugal casting.

HX is used for cast electrical heating elements because of its high electrical resistivity. It is used for furnace hearths, muffles, retorts, trays, burner parts, enameling fixtures, quenching fixtures, and containers for molten lead.

Centrifugally cast CT15C was used for these bullhead tee and transition cone assemblies. They are used in the outlet manifold section of steam reformer furnaces when producing nitrogen fertilizers, methanol, and in oil refining.

Wisconsin Centrifugal, Waukesha, Wisconsin

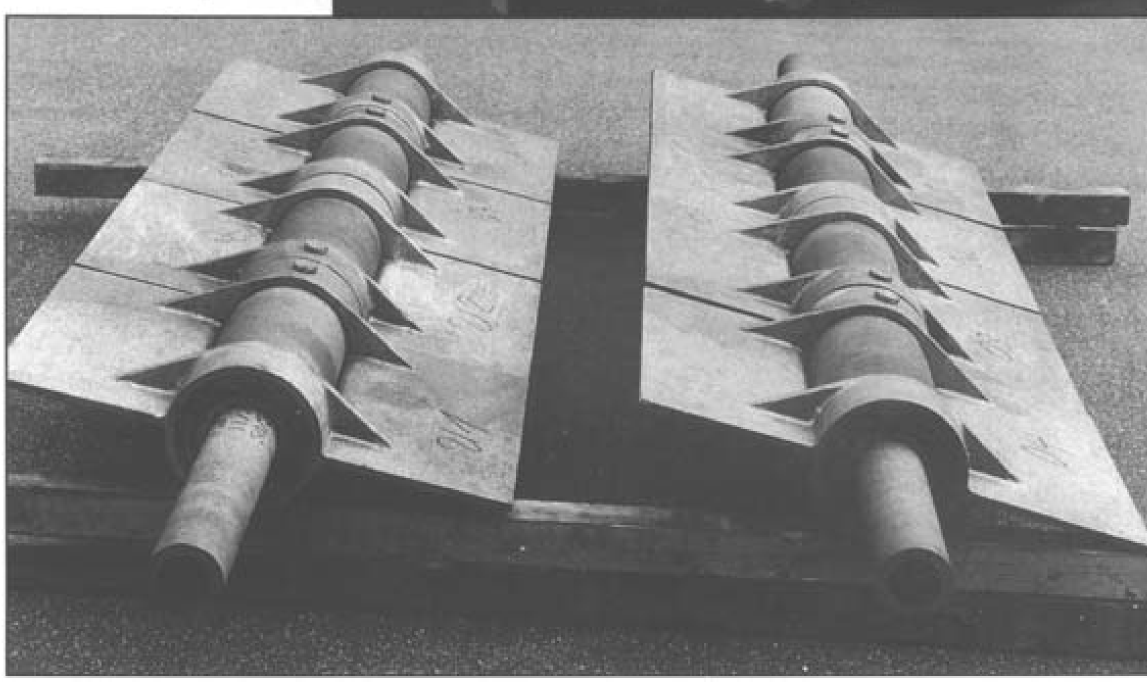
Cr-Ni ALLOY AND HIGH PERFORMANCE NICKEL-BASE ALLOY CASTINGS FOR HEAT-RESISTING AND ELEVATED-TEMPERATURE CORROSION APPLICATIONS

Chromium-nickel alloys are usually produced in electric arc or induction furnaces and poured into sand, shell, investment or centrifugal molds. They are becoming more important for structural members, containers, supports, hangers, spacers, and similar product forms used in corrosive environments up to 2000°F (1090°C).

There are numerous proprietary 35Cr-45Ni alloy compositions that do not have UNS numbers and are not covered by an ASTM specification. These alloys resist most severe ethylene cracking conditions and have high nickel contents to ensure very high resistance to carburization. The high chromium content aids in the formation of a protective oxide film, which is expected to be self-healing in de-coking. Niobium increases the creep strength and the controlled micro-alloy addition ensures further strength and carburization improvement. The 35Cr-45Ni alloys provide excellent resistance to

Duraloy Technologies, Inc., Scottdale, Pennsylvania

These slab reheat or "Tunnel" furnace rolls are made from Super 22H.



Pose-Marre, Erkrath, Germany

Flue gas dampers made of 50Cr-50NiNb (EN G-NiCr50Nb or G-NiCr 28W). The four cast flaps are assembled over a centrifugally cast tubular axle.

carburization at cracking temperatures up to 2100°F (1150°C) and high rupture strength. Figure 25 compares the increase in carburization of various modifications of HP, HK40, and an 35Cr-45Ni with tube-metal temperature increase.

The proprietary alloys with compositions of approximately 30Cr-50Ni are used for extended service in the 1950 to 2250°F (1065 to 1230°C) range for furnace rolls, radiant tubes, retorts, muffles, and severe service applications. Super 22H® is sometimes used generically to refer to this alloy family, but it is a proprietary alloy. These alloys provide high strength in this temperature range, excellent oxidation and carburization resistance, excellent resistance to chloride and polythionic acid stress corrosion cracking, excellent resistance to thermal shock, and dimensional stability.

The US Navy and some refineries where corrosive waste crude oil is burned for boilers and furnaces use 50Cr-50Ni (UNS R20500) and 50Cr-50NiNb. The niobium-modified version, 50Cr-50NiNb, provides improved creep and stress rupture properties for the petroleum and power industries. The catastrophic corrosion of 25Cr-20Ni and other stainless steels is often referred to as "Fuel Ash Corrosion" or vanadium-sodium attack. 35Cr-45Ni and the 50Cr-50Ni alloys have shown satisfactory performance under these conditions. The 35/45 alloy is mainly used for tubulars and the 50/50 alloys for tube sheet brackets and radiant coil hangers.

Some of the nickel-base superalloys that were originally developed for aerospace applications are starting to be used for other applications. One example is Alloy 713C, which was developed for turbine rotors and is now being used for diesel turbo-charger wheels, high temperature fasteners, and other high temperature components. Similar applications are being developed for other alloys in this family; however, the current application volume is small.

The compositions and mechanical properties of the Cr-Ni alloys and Alloy 713C are shown in *Tables 34 and 35*

Table 34 Designations and compositions for Cr-Ni Alloy and high performance nickel-base alloy castings

UNS	Common or Trade Names	C	Mn	Si	S	P	N	N+C	Fe	Ti	Co	W	Al	Nb	Cr	Ni
•••	Alloy 713C[2]	0.12	•••	•••	•••	•••	•••	•••	•••	0.8	•••	•••	6.1	2.2	12.0-14.0	rem
•••	35Cr-45Ni[1]	0.40-0.60	1.00-2.00	1.00-2.00	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	34.0-37.0	43.0-48.0
•••	Super 22H	0.40-0.55	•••	•••	•••	•••	•••	•••	•••	•••	2.5-4.0	4.0-6.0	•••	•••	26.0-30.0	46.0-50.0
R20500	50 Cr-50Ni[3]	0.10	0.30	1.00	0.02	0.02	0.30	•••	1.00	0.50	•••	•••	0.25	•••	48.0-52.0	rem
•••	50 Cr-50Ni-Nb, Alloy 657[3]	0.10	0.30	0.50	0.02	0.02	0.16	0.20	1.00	0.50	•••	•••	0.25	1.4-1.7	47.0-52.0	rem

1) Other: Nb, Ti, and others 2) Other: 4.2 Mo, 0.012 B, 0.1 Zr 3) ASTM A 560

Table 35 Room temperature tensile and charpy requirements for Cr-Ni alloy and high performance nickel-base alloy castings

Common or Trade Name	Tensile Strength min		Yield Strength min		Elongation in 2 inch (50 mm), min %	Impact Unnotched Charpy, min	
	ksi	MPa	ksi	MPa		ft-lb	J
35Cr-45Ni	65-66.4	448-450	35.5	245	4%	•••	•••
Alloy 713C[1]	123	847	106	730	8.0	10[2]	14[2]
Super 22H	75	517	45	310	4.0	•••	•••
50 Cr-50 Ni[1]	80	550	50	340	5.0	50	78
50 Cr- 50 Ni-Nb, Alloy 657[1]	80	550	50	345	5.0	•••	•••

1) ASTM A 560 M 2) Notched charpy data

FABRICATION CASTING METHODS

Stainless steel and nickel-base alloy castings are produced by centrifugal, sand, shell-mold, ceramic-mold, and investment casting. Nickel-base alloys containing more than about 0.2% aluminum, titanium, zirconium or other reactive elements should not be melted or cast in oxidizing environments such as air. *Table 36* provides a comparison of the shrinkage allowance for several families of cast stainless steels, nickel alloys, and other cast metals.

Table 36 Typical liquid metal casting shrinkage allowances[1,13]

Metal	Shrinkage Allowance in./ft.	Shrinkage Allowance mm/m
Aluminum	0.156	13.0
Aluminum bronze	0.250	20.8
Brass	0.156	13.0
Gray cast iron*	0.1-0.156	8.3-13.0
White cast iron	0.250	20.8
Magnesium	0.187	15.6
Nickel alloys, nominal	0.250	20.8
HW. HX	0.28	23.3
HL, HP, HT, HU	0.31	25.8
Alloy steel	0.25	20.8
Carbon steel	0.20	16.7
Stainless steel, nominal	0.30	25.0
CA6NM, CD4MCu	0.25	20.8
CF3, CF8, CF3M, CF8M, CF16F, CG8M, CH20, CK20, CN7M, HH, HI HK, HN	0.31	25.8
CF8C	0.34	28.3

* Cast iron shrinkage depends on cooling speeds. Slower cooling reduces shrinkage.

Sand Casting

There are three sand casting processes: green sand, chemically bonded sand, and shell casting. Green sand casting is a clay-bonded system and produces the roughest surface finish of the three processes. Shell casting uses sand that is coated with a binder system and heated. It produces the smoothest finish of these three processes.

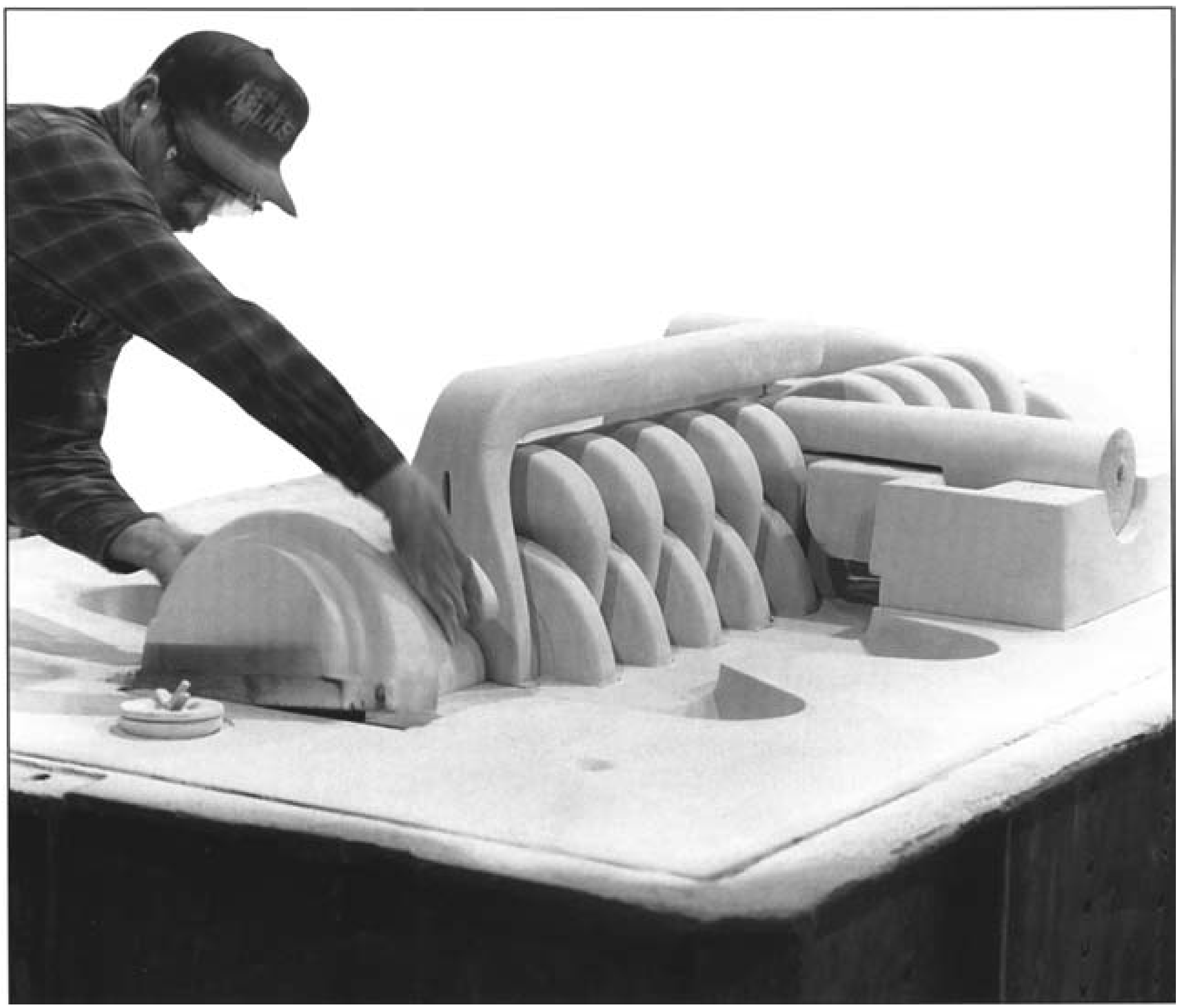
Atlas Foundry & Machine Company, Tacoma, Washington

The heat of CF8 is being tapped from the AOD vessel into a pouring ladle.

Investment Casting

Investment casting uses wax or foam patterns that are removed prior to casting. A ceramic slurry is applied over a disposable pattern to form a mold. This process provides increased dimensional precision and a higher level of detail. The aircraft and aerospace industries use investment castings for nickel-base alloy turbine blades, vanes, and structural components, and stainless steel structural components such as fan exit cases and struts. Stainless steel investment castings are used for valves and fittings, sporting goods, pumps, engines and turbines, military and small arms applications, airframes, missile controls, medical equipment, machine tools, and office machines. Appearance and elimination of machining are the most common reasons for selecting investment casting.

These stage cores are being assembled into a drag mold for a CA6NM stainless steel multistage pump.



Atlas Foundry & Machine Company, Tacoma, Washington

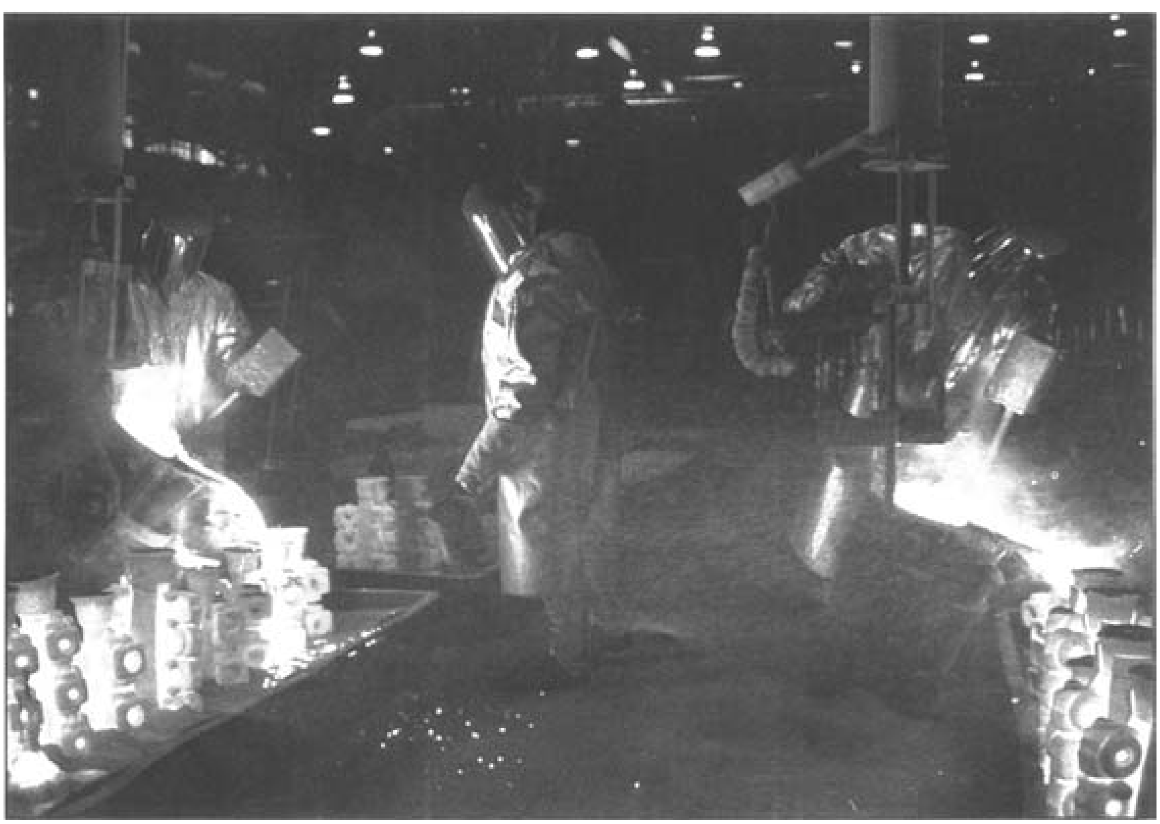
Ceramic Mold Casting

Ceramic mold casting is similar to investment casting. It is used for castings that are too large for wax or plastic patterns or where quantities are limited. It produces high quality castings with fine detail, good surface finish and soundness, freedom from non-metallic inclusions, and a high degree of dimensional accuracy. The surface roughness of ceramic mold and investment castings is comparable. Zirconia, alumina, or fused silica are used in lieu of sand with minimal organic binders (usually alcohol) to reduce the potential for carbon contamination. Stainless steel components made with this process include food machinery components; valves for the chemical, pharmaceutical, and petroleum industries; glass molds; aircraft structural components; and hardware for atomic reactors and aerospace vehicles.

Centrifugal Casting

Centrifugal casting can be used for any stainless steel or nickel-base alloy that can be statically cast. There are two types of centrifugal casting, vertical and horizontal. Horizontal centrifugal casting is used to produce pipe, tube, bushings, cylinder sleeves, and other cylindrical and tubular castings. Bimetallic tubes using stainless steel or nickel-base alloys are also produced using this method. Vertical centrifugal casting of stainless steel and nickel-base alloys can be used to produce cylindrical, non-cylindrical, or asymmetrical shapes. The high force level and directional solidification of centrifugal casting may produce castings with better cleanliness and density than static castings. The desired shape, quality, and quantity of castings needed determine the type of mold (sand, semi-permanent, or permanent).

Flowserve Corp., Provo, Utah



Pouring molten stainless steel into molds.

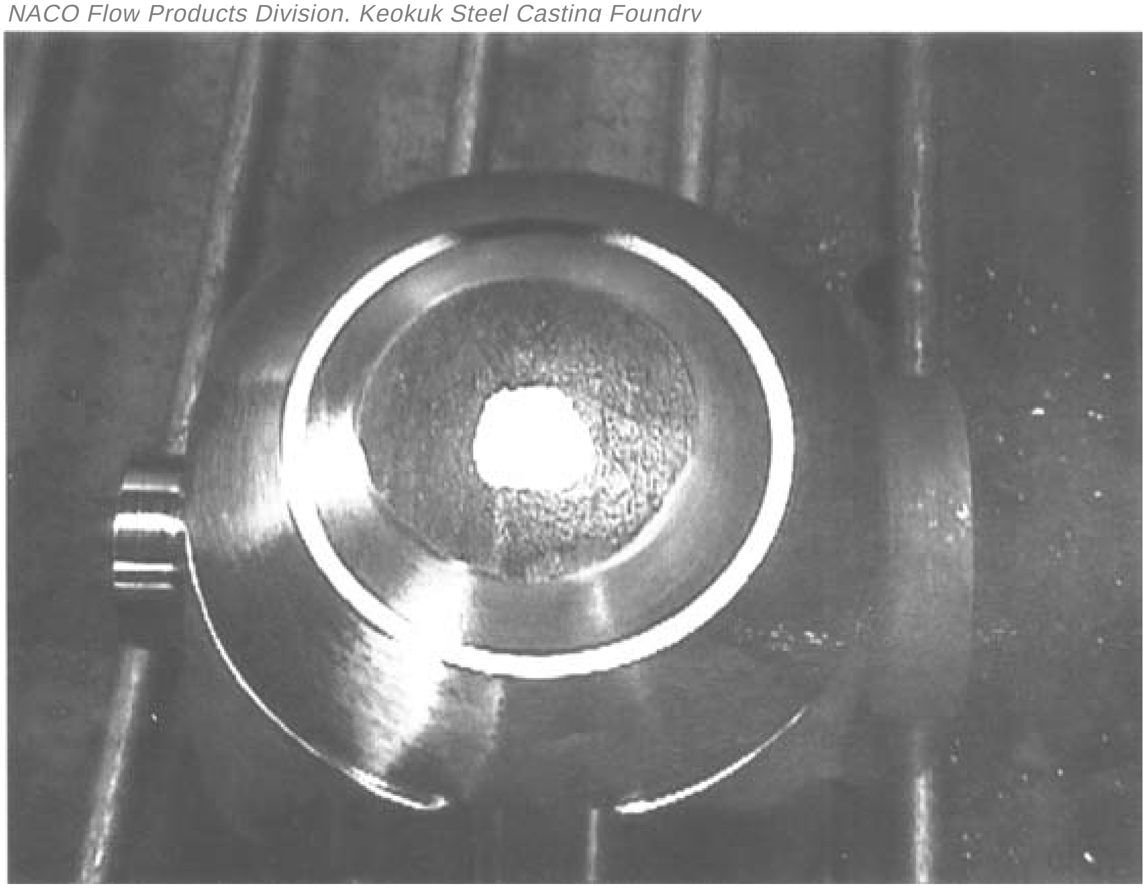
Other Casting Methods

Several newer and less widely used casting methods include counter-gravity, low-pressure casting using vacuum-melted (CLV) or air-melted (CLAS) alloys. The CLV process is used for alloys that contain reactive metals, especially superalloys, which contain aluminum, titanium, zirconium, and hafnium. The process can produce relatively large castings with wall thicknesses down to 0.02 inches (0.5 mm) that are free of small oxides. It has been used to make gas turbine engine parts from nickel-base superalloys such as Alloy 713C. The CLAS process uses sand molds and low vacuum levels. This has been used for thin-walled components such as stainless steel exhaust manifolds and truck wheel centers.

When castings are used in demanding applications where the stresses are unidirectional rather than isotropic, directional solidification and monocrystal (single-crystal) casting are used. Gas turbine engine blades and other components that are subjected to high stresses along their major axes and high temperatures are typical applications for nickel-base directional and monocrystal castings.

Lost foam casting, also referred to as evaporative pattern casting (EPC), consists of coating molded polystyrene foam with a refractory and placing it in a container surrounded by unbonded silica sand. Molten metal is poured into the mold and vaporizes the foam. It can produce complex castings and short runs of large castings. It may be used for selected applications where potential carbon pick-up is not considered a problem.

NACO Flow Products Division, Keokuk Steel Casting Foundry



A CW6MC valve core assembly prior to machining.

MACHINING

Stainless steel and nickel-base castings are more difficult to machine than carbon steel and require comparatively slow speeds and moderate feeds. Cutting speeds and feeds for high speed steel tooling are shown in *Table 37* for some corrosion and heat-resistant castings. If carbide tooling is used, the speeds should be increased by a factor of two or three.

Successful machining is dependent on avoiding work hardening of the metal ahead of the cutting tool. Techniques that minimize work hardening include sharp-cutting tool edges, positive rake angles, adequate clearance angles, avoidance of dwelling, and machines and setups with sufficient power and rigidity to keep vibration to a minimum. Feed rate and cutting depth should be set so that subsequent passes are below the previously work hardened layer.

Table 37 Machining with high speed steel tooling [Ref. 10]

Grade	Rough Turning		Finish Turning		Drilling [1]	Tapping
	Speed, sfm	Feed, ipr	Speed, sfm	Feed, ipr	Speed, sfm	Speed, sfm
CA6NM	40-50	0.10-0.030	80-100	0.005-0.010	20-50	10-20
CD4MCu	40-50	0.020-0.025	80-100	0.005-0.010	20-40	10-20
CF3	25-35	0.020-0.025	50-70	0.005-0.010	20-40	10-20[2]
CF8	25-35	0.020-0.025	50-70	0.005-0.010	20-40	10-20[2]
CF3M	25-35	0.020-0.025	50-70	0.005-0.010	20-50	10-20[2]
CF8M	25-35	0.020-0.025	50-70	0.005-0.010	20-40	10-20[2]
CF8C	30-40	0.020-0.025	60-80	0.005-0.010	30-60	10-25[2]
CF16F	45-55	0.020-0.025	90-110	0.005-0.010	30-80	15-30
CG8M	25-35	0.020-0.025	50-70	0.005-0.010	20-50	10-20[2]
CH20	25-35	0.020-0.025	50-70	0.005-0.010	20-50	10-20[2]
CK20	25-35	0.020-0.025	50-70	0.005-0.010	20-40	10-20[2]
CN7M	45-55	0.020-0.025	90-110	0.005-0.010	30-60	10-25
HD	40-50	0.025-0.035	80-100	0.005-0.010	40-60	10-25[2,3]
HE	30-40	0.020-0.025	60-80	0.005-0.010	30-60	10-25[3]
HF	25-35	0.015-0.020	50-70	0.005-0.010	20-40	10-20[3,4]
HH	25-35	0.015-0.020	50-70	0.005-0.010	20-40	10-20[3,4]
HI	25-35	0.015-0.020	50-70	0.005-0.010	20-40	10-20[3,4]
HK	25-35	0.020-0.025	50-70	0.005-0.010	20-40	10-20[3,4]
HN	35-45	0.020-0.025	70-90	0.005-0.010	40-60	5-15[3,4]
HP	35-45	0.020-0.025	70-90	0.005-0.010	40-60	5-15
HT	40-45	0.025-0.035	80-90	0.005-0.010	40-60	5-15[3,4]
HU	40-45	0.025-0.035	80-90	0.005-0.010	40-60	5-15[3,4]
HW	40-45	0.025-0.035	80-90	0.005-0.010	40-60	5-15[3,4]
HX	40-45	0.025-0.035	80-90	0.005-0.010	40-60	5-15[3,4]

1) Drilling Feeds: Drill Diameter inches/Feed, ipr: under 1/8/0.001-0.002; 1/8- 1/4/0.002-0.004; 1/4-1/2/0.004-0.007; 1/2- 1/0.007-0.015; over 1/0.015-0.025
2) Use Chip Curler
3) Chips are tough and stringy
4) Use chip curler and breakers

WELDING

Welding is used to upgrade the quality of castings as well as during fabrication of assemblies that are too large or complicated to be produced as a one-piece casting. Welding is also used to improve the surface and eliminate shrinkage voids. If the welding is done properly, it will not adversely affect the performance of the casting. Grade, filler metal, surface preparation, welding process, heat treatment, and testing weld quality should be considered when evaluating welding techniques. Castings have equal or better weldability than their wrought equivalents, but there are variations in weldability from grade to grade.

The Steel Founders' Society of America (SFSA) has comprehensive publications on welding stainless steel and nickel-base alloys.

Atlas Foundry & Machine Company, Tacoma, Washington

This CF8 stainless steel cover flange is part of a vertical pump assembly and is shown in the rough machining condition.

PURCHASING CONSIDERATIONS

When ordering corrosion and heat-resistant stainless steels and nickel-base alloys, it is important to remember that high-performance castings are custom-made products for demanding environments. A high level of communication between the foundry and purchaser has a significant influence on achieving timely delivery of cost-effective castings capable of meeting application requirements.

Even if the casting will be used in conjunction with wrought components, it should not be specified based on its wrought equivalent. For example, specifying "cast Type 304" is inappropriate because of chemistry and property differences. Unified Numbering System (UNS), American Casting Institute (ACI), and other standard designations for cast materials, and casting specifications should be referenced.

During the bidding and design process, the foundry should be provided with details of the service environment (temperature, corrosive environment, loading), planned fabrication techniques (welding, machining), and finished component specification or code requirements. If a component were previously designed based on forgings or welded assemblies, the cast design can usually be optimized to improve performance and reduce costs. It is important that the engineers at both the foundry and the purchaser begin consultation at an early stage and that the complete design details and dimensions be provided.

Unusual and unnecessary tests delay delivery and increase cost. The best assurance of timely delivery and quality is to work with a foundry that is experienced with the application and the alloy. See NiDI publication Procurement of Quality Stainless Steel Castings, No. 10 021, for additional information on purchasing considerations.

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Feritscope is a trademark of Fischer Technology

ZERON100 is a trademark of
Weir Materials Ltd.

Super 22H is a trademark of
Duraloy Technologies, Inc.

SUGGESTED ADDITIONAL READING

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APPENDIX A

UNS NUMBER CROSS REFERENCE TO INTERNATIONAL STAINLESS STEEL AND NICKEL-BASE ALLOYS SPECIFICATIONS WITH SIMILAR CHEMICAL COMPOSITIONS

UNS Number	***International Specification***
J91540 .	ASTM: A487 (CA-6NM), A352 (CA-6NM), A356 (CA-6NM); DIN: 1.4313, G-X5CrNi134; 1.4414, G-X4CrNiMo134 ; UNI: 3161 GX6CrNi13 04; BS: 1504425C11; 3100425C11; JIS: G5121 SCS5
J92180	ASTM: A747 (CB7Cu-1); DIN: 1.4542, X5CrNiCuNb17 4 ; JIS: G5121 SCS24
J92500	ASTM: A351 (CF3, CF-3A), A451 (CPF3, CPF3A), A743 (CF-3), A744 (CF-3); ACI: CF-3; BIDS: 6738 OOOCh18N11; DIN: 1.4306, G-X2CrNi18 9; BS: 1504304C12; 3100304C12; JIS: G5121 SCS19; G5121 SCS19A; UNI: 3161 GX2CrNi1910; UNE: 36-257 F8412 AM-X2CrNi19 10; AFNOR NF: Z2CN18.10M; Z3CN19.10M; Z3CN19.9M
J92590	ASTM: A 452 (TP304H), A351 (CF-10); AFNOR NF: Z6CN18.10M; Z6CN19.9M ; DIN: 1.4308, G-X6CrNi18 9; STAS: 10718 T6NiCr180; JIS: G5121 SCS13; BS: 1504304C15; 3100304C15; MSZ: 21053 AoX7CrNi18 9 ; UNE: 36-257 F8411 AM-X7CrN20 10
J92600	ASTM: A351 (CF-8, CF-8A), A451 (CPF8, CPF8A), A743 (CF-8), A744 (CF-8); AFNOR NF: Z6CN18.10M; Z6CN19.9M ; BIDS: 9631 OCh18N9L; STAS: 10718 T6NiCr180; MSZ: 21053 AoX7CrNi18 9; DIN: 1.4308, G-X6CrNi18 9; 1.4815, G-X8CrNi19 10; BS: 1504304C15; 3100 304C15; UNE: 36-257 F8411 AMX7CrNi20 10; JIS: G5121 SCS13, G5121 SCS13A
J92603	ASTM: A297 (HF); CSN: 422932; 422934; JIS: G5122 SCH12; UNI: 3159 GX30CrNi20 10; BS: 3100 302C35; UNE: 36-258 F8450 AM-X30CrN20 10 ; DIN: 1.4825, G-X25CrNiSi18 9; 1.4826, G-X40CrNiSi22 9
J92700	ASTM: A351 (CF-3MN); AFNOR NF: Z2CND18.12M; Z3CND20.10M; BS: 1504316C12; 3100316C21; JIS: G5121 SCS16; G5121 SCS16A; DIN: 1.4435, X2CrNiMo18 14 3; LINE: 36-257 F8415 AM-X2CrNiNbMo19 11
J92701	ASTM: A743 (CF-16F); BIDS: 9631 Ch18N9L; JIS: G5121 SCS12; STAS: 6855 T15NiCr180; 6855 T15NiCr180X; AMS: 5341; AFNOR NF: Z10CN18.9M; PN: 83158 LH18N9 ; BS: 3100 302C25; 3146 ANC3; CSN: 42 2931; MSZ: 21053 AoX12CrNi18 9; DIN: 1.3955, G-X12CrNi18 11; 1.4312, G-X10CrNi18 8
J92710	ASTM: A351 (CF-8C), A451 (CPF8C), A743 (CF-8C), A744 (CF-8C); JIS: G5121 SCS13; G5121 SCS13A; UNE: 36-257 F8411 AM-X7CrNi20 10; AFNOR NF: Z6CN18.10M; Z6CN19.9M; MSZ:

21053 AoX7CrNi18 9; STAS: 10718 T6NiCr180; BS: 1504 304C15; 3100304C15; BIDS: 9631 0Ch18N9L; DIN: 1.4308, G-X6CrNi18 9; 1.4815, G-X8CrNi19 10

J92800 ASTM: A351 (CF-3M, CF-3MA), A451 (CPF-3M), A744 (CF-3M); UNI: 3161 GX2CrNiMo19 11; JIS: G5121 SCS16; G5121 SCS16A; UNE: 36-257 F8415 AM-X2CrNiMo19 11; BIDS: 6738 000Ch17N14M2; BS: 1504 316C12; 3100316C12; AFNOR NF: Z2CND18.12M; Z3CND19.10M; Z3CND20.10M; DIN: 1.4404, G-X2CrNiMo18 10; 1.4435, X2CrNiMo18 14 3

J92803 ASTM: A608 (HF30); UNI: 3159 GX30CrNi20 10; BS: 3100 302C35; UNE: 36-258 F8450 AM-X30CrNi2010; DIN: 1.4825/ 1.4826

J92804 ASTM: A351, A743 (CF-3MN); DIN: 1.4404

J92900 ASTM: A351 (CF-8M), A451 (CPF8M), A473 (CF-8M), A744 (CF8M); LINE: 36-257 F8414 AM-X7CrNiMo20 10; JIS: G5121 SCS14; STAS: 10718 T6MoNiCr180; BIDS: 9631 0Ch18NTM2L; 9631 Ch18N10M2L; DIN: 1.4408, G-XCrN!Mo18 10; NI: 3161 GX6CrNiMo20 11; MSZ: 21053 AoX7CrNiMo18 10; PN: 83158 L0H18N19M; 83158 LH18N10M; AFNOR NF: Z5CND20.10M; Z5CND20.8M; Z6CND18.12M; BS: 1504315C16; 1504316C16, 3100 315C71, 3100316C16, 3146 ANC4

J92920 ASTM: A452 (TP316H); BS: 1504 315C16; 3100 315C71; 3146 ANC4; AFNOR NF: Z6CND18.12M; DIN: 1.3952, GX4CrNiMoN18 4

J92971 ASTM: A351, A451; BS: 1504 318C17; 3100318C17; 3146 ANC4 Grade C; JIS: G5121 SCS22; AFNOR NF: Z4CNDNb18.12M; Z6CNDNb18.12M; UNI: 3161 GX6CrNiMoNb20 11; STAS: 10718 T10MoNiCr180; 9277 OTA10NbMoNiCr170; DIN: 1.4580, G-X10CrNiMoNb18 10; 1.4581, G-X5CrNiMoNb18 10; MSZ: 21053 AoX10CrNiMoNb18 12; 21053 AoX12CrNiMoNb18 10

J93000 ASTM: A351 (CG-8M); A743 (CG-8M); A744 (CG-8M); AFNOR: Z8CND18.10.3M; UNE: 36-257 F8416 AM-X7CrNiMo20 11; DIN: 1.4431, X12CrNiMo19 10 3; 1.4448, G-X6CrNiMo17 13; UNI: 3161 GX6CrNiMo20 1103; BS: 1504 317C16; 3100 317C16; 3146 ANC4 Grade A

J93001 ASTM: A743 (CG-12); DIN: 1.4947, G-X5CrNi22 10

J93005 ASTM: A297 (HD), DIN: 1.4823

J93303 ASTM: A447; DIN: 1.4339, G-X32CrNi28 10; 1.4846, X40CrNi25

21; UNI: 3159 GS35CrNi28 09; BS: 3100 309C32; 3100 309C35; JIS: G5122 SCH13; UNE: 36-258 F8451 AM-X35CrNi2512

J93370 ASTM: A744, A351, A890; AFNOR NF: Z3CNUD26.5M; BS: 3146 ANC21

J93400 ASTM: A351 (CH-8), A451 (CPH-8); DIN: 1.4833, X7CrNi23 14

J93402 ASTM: A351 (CH-20), A451 (CH-2, CPH-10, CPH-20), A743 (CH-20); UNI: 3161 GX16CrNi24 14

J93403 ASTM: A297; DIN: 1.4846, X40CrNi25 21; JIS: G5122 SCH13; G5122 SCH17; BS: 3100 309C32; 3100 309C35; 3100 309C40; UNE: 36-258 F8451 AMX35CrNi25 12

J93413 ASTM: A608 (HE-35); BS: 3100 309C32; 3100 309C40; JIS: G5122 SCH17; UNE: 36-258 F8451 AM-X35CrNi25 12

J93503 ASTM: A297 (HH); DIN: 1.4837, G-X40CrNiSi25 12; 1.4846, X40CrN!25 21; UNI: 3159 GX35CrNi25 12; JIS: G5121 SCS17; G5122 SCH13; CSN: 42 2936; STAS: 6855 T35NiCr260; 6855 T35NiCr260X; UNE: 36-258 F8451 AM-X35CrNi25 12; BS: 3100 309C30; 3100 309C32; 3100 309C35

J93513 ASTM: A608 (HH-30); UNE: 36258 F8451 AM-X35CrNi25 12; BS: 3100 309C32; 3100 309C35

J93633 ASTM: A608 (HH33); DIN: 1.4846, X40CrNi25; JIS: G5122 SCH13; BS: 3100 309C32; UNE: 36-258 F8451 AM-X35CrNi25 12; STAS: 6855 T35N!Cr260; 6855 T35NiCr260X

J93790 ASTM: A351 (CG6MMN); DIN: 1.3964, G-X4CrNiMnMoN19 16 5

J94003 ASTM: A297 (HI); UNI: 3159 GX35CrNi2816; JIS: G5122 SCH18; BS: 3100 309C32; 3100 309C35

J94013 ASTM: A608 (H135); UNI: 3159 GX35CrNi2816; JIS: G5122 SCH18; STAS: 6855 T35NiCr260; 6855 T35NiCr260X; BS: 3100 309C32

J94202 ASTM: A351 (CK 20), A451 (CPK20), A743 (CK20); UNI: 3161 GX16CrNi25 21; JIS: G5121 SCS18; DIN: 1.4840, G-X15CrNi25 20; 1.4843, CrNi25 20; PN: 83159 LH25N19S2; STAS: 6855 T25NiCr250; 6855 T25NiCr250X

J94203 ASTM: A351 (HK-30), A608 (HK30); JIS: G5122 SCH21

J94204 ASTM: A351 (HK-40), A608 (HK40); CSN: 42 2952; JIS: G5122 SCH22; DIN: 1.4846, X40CrNi25 21; 1.4848, G-X40CrNiSi25 20; UNI: 3159 GX40CrNi26 20; UNE: 36-258 F8452 AM-X40CrNi25 20; BS: 1504 310C40; 3100 310C40; 3100 310C45; 3146 ANC5 Grade A

J94213 ASTM: A297 (HN); UNI: 3159 GX35NiCr25 21; JIS: G5122 SCH19; BS: 3100 311C11; 3146 ANC5 Grade A

J94214	ASTM: A608 (HN40); UNI: 3159 GX35NiCr25 21; JIS: G5122 SCH19; BS: 3100 311C11; 3146 ANC5 Grade 5
J94224	ASTM: A297 (HK); DIN: 1.4848, G-X40CrNiSi25 20; UNI: 3159 GX40CrNi26 20; JIS: G5122 SCH21; G5122 SCH22; CSN: 42 2952; UNE: 36-258 F8452 AM-X40CrNi25 20; BS: 1504 310C40; 3100 310C40; 3100 310C45; 3146 ANC5 Grade A
J94650	ASTM: A744 (CN-7MS); AFNOR NF: Z6NCDU25.20.04M; UNI: 3161 GX5NiCrSiMoCu24 19; DIN: 1.4536, G-X2NiCrMoCuN25 20
N02100	ASTM: A494; DIN: 2.4170,GNi95
N06006	ASTM: A297 (HX); UNI: 3159 GX55NiCr6617; GOST: KH15N60S2
N06040	ASTM: A494 (CY40), DIN: 2.4816
N06050	ASTM: A608 (HX50); GOST KH15N60S2
N08001	ASTM: A297 (HW); UNI: 3159 GX55NiCr60-12; BS: 3100 334C11 (EN1648 grade K); BS: 3146 ANC5 grade C
N08004	ASTM: A297 (HU); DIN: 1.4849/ 1.4865, GX40NiCrSi38-18; UNI: 3159 GX50NiCr39-19; JIS: G5122 SCH20; BS: 3100 331C40 (EN4238 grade H2C); BS: 3100 331 C60 (EN1648 grade H2)
N08005	ASTM: A608 (HU50); DIN: 1.4849/ 1.4865, CSN 42 2955; BS: 3146 ANC5 grade B
N08007	ASTM: A351, A743 (CN-7M); DIN: 1.4500, GX7NiCrMoCuNb25-20; ABNT EMVAC 20, Alloy 20; UNI: 3161 GX5NiCrSiMoCu24-19; UNE: 36-257F.8517AM-X6NiCrMoCu29-20
N08030	ASTM: A351 (HT30); DIN: 1.4865; JIS: G5122 SCH16
N08151	ASTM: A351 (CT 15C); DIN: 1.4859
N08705	ASTM: A297 (HP); DIN: 1.4857
N24130	ASTM: A494 (M-30C); DIN: 2.4365
N26022	ASTM: A494 (CX2MW); DIN: 2.4602
N26455	ASTM: A494 (CW-2M); DIN: 2.4610
N26625	ASTM: A494 (CW-6MC); DIN: 2.4856

Specification Abbreviations by Country

Brazil	ABNT
Bulgaria	BIDS
Czechoslovakia	CSN
France	AFMOR NF
Germany, Fed. R.	Din Werkstoff Nr
Hungary	MSZ
Italy	UNI
Japan	JIS
Poland	PN
Rumania	STAS
Spain	UNE
United Kingdom	BS
USA	ASTM
USSR	GOST

Sources

International Metallic Materials Cross-Reference, Daniel L. Potts & John G. Gensure, Genium Publishing Corporation, Schenectady, NY 1988

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APPENDIX B

Draft Euronorm Standard for Chemical Composition* of Corrosion Resistant Stainless Steel and Nickel-Base Alloy Castings

	Name	Wk.N.	C	Si	Mn	P	S	Cr	Mo	Ni	N	Cu	Nb	W
Martensitic	GX12Cr12	-	0.15	1.00	1.00	0.035	0.025	11.50-13.50	0.50	1.00	-	-	-	-
	GX7CrNiMo12-1	1.4008	0.10	1.00	1.00	0.035	0.025	12.00-13.50	0.20-0.50	1.00-2.00	-	-	-	-
	GX4CrNi13-4	1.4317	0.06	1.00	1.00	0.035	0.025	12.00-13.50	0.70	3.50-5.00	-	-	-	-
	GX4CrNiMo16-5-1	1.4405	0.06	0.80	1.00	0.035	0.025	15.00-17.00	0.70-1.50	4.00-6.00	-	-	-	-
	GX4CrNiMo16-5-2	-	0.06	0.80	1.00	0.035	0.025	15.00-17.00	1.50-2.00	4.00-6.00	-	-	-	-
	GX5CrNiCu16-4	-	0.07	0.80	1.00	0.035	0.025	15.00-17.00	0.80	3.50-5.50	0.05	2.50-4.00	0.35	-
Austenitic	GX2CrNi19-11	1.4309	0.030	1.50	2.00	0.035	0.025	18.00-20.00	-	9.00-12.00	0.20	-	-	-
	GX5CrNi19-10	1.4308	0.07	1.50	1.50	0.040	0.030	18.00-20.00	-	8.00-11.00	-	-	-	-
	GX5CrNiNb19-11	1.4552	0.07	1.50	1.50	0.040	0.030	18.00-20.00	-	9.00-12.00	-	-	8 x % C # 1.00	-
	GX2CrNiMo19-11-2	1.4409	0.030	1.50	2.00	0.035	0.025	18.00-20.00	2.00-2.50	9.00-12.00	0.20	-	-	-
	GX5CrNiMo19-11-2	1.4408	0.07	1.50	1.50	0.040	0.030	18.00-20.00	2.00-2.50	9.00-12.00	-	-	-	
	GX5CrNiMoNb19-11-2	1.4581	0.07	1.50	1.50	0.040	0.030	18.00-20.00	2.00-2.50	9.00-12.00	-	-	8 x % C # 1.00	-
	GX5CrNiMo19-11-3	-	0.07	1.50	1.50	0.040	0.030	18.00-20.00	3.00-3.50	10.00-13.00	-	-	-	-
	GX2CrNiMoN17-13-4	-	0.030	1.00	1.50	0.040	0.030	16.50-18.50	4.00-4.50	12.50-14.50	0.12-0.22	-	-	
Fully Austenitic	GX2NiCrMo28-20-2	1.4458	0.030	1.00	2.00	0.035	0.025	19.00-22.00	2.00-2.50	26.00-30.50	0.20	2.00	-	-
	GX4NiCrCuMo30-20-4	-	0.06	1.50	1.50	0.040	0.030	19.00-22.00	2.00-3.00	27.50-30.50	-	3.00-4.00	-	-
	GX2NiCrMoCu25-20-5	-	0.025	1.00	2.00	0.035	0.020	19.00-21.00	4.00-5.00	24.00-26.00	0.20	1.00-3.00	-	-
	GX2NiCrMoN25-20-5	-	0.030	1.00	1.00	0.035	0.020	19.00-21.00	4.50-5.50	24.00-26.00	0.12-0.20	-	-	-
	GX2NiCrMoCuN29-25-5	-	0.030	1.00	2.00	0.035	0.025	24.00-26.00	4.00-5.00	28.00-30.00	0.15-0.25	2.00-3.00	-	-
	GXNiCrMoCuN25-20-6	-	0.025	1.00	2.00	0.035	0.020	19.00-21.00	6.00-7.00	24.00-26.00	0.10-0.25	0.50-1.50	-	-
	GX2CrNiMoCuN20-18-6	-	0.025	1.00	1.20	0.030	0.010	19.50-20.50	6.00-7.00	17.50-19.50	0.18-0.24	0.50-1.50	-	-
Duplex	GX6CrNiN26-7	1.4347	0.08	1.50	1.50	0.035	0.020	25.00-27.00	-	5.50-7.50	0.10-0.20	-	-	-
	GX2CrNiMoN22-5-3	1.4410	0.030	1.00	2.00	0.035	0.025	21.00-23.00	2.50-3.50	4.50-6.50	0.12-0.20	-	-	-
	GX2CrNiMoN25-6-3	1.4468	0.030	1.00	2.00	0.035	0.025	24.50-26.50	2.50-3.50	5.50-7.00	0.12-0.25	-	-	-
	GX2CrNiMoN25-6-3-3	1.4517	0.030	1.00	1.50	0.035	0.025	24.50-26.50	2.50-3.50	5.00-7.00	0.12-0.22	2.75-3.50	-	-
	GX2CrNiMoN25-7-3	-	0.030	1.00	1.50	0.030	0.020	24.00-26.00	3.00-4.00	6.00-8.50	0.15-0.25	1.00	-	1.00
	GX2CrNiMoN26-7-1	1.4469	0.030	1.00	1.00	0.035	0.025	25.00-27.00	3.00-5.00	6.00-8.00	0.12-0.22	1.30	-	-

*maximum unless range is given

APPENDIX C

Draft Euronorm Standard for Chemical Composition* of Heat Resistant Stainless Steel Casting

	Name	Wk.N.	C	Si	Mn	P	S	Cr	Mo	Ni	Nb	Co	Other
Ferritic and Duplex	GX30CrSi7	1.4710	0.20-0.35	1.00-2.50	1.00	0.035	0.030	6.00-8.00	0.15	0.50	-	-	-
	GX40CrSi13	1.4729	0.30-0.50	1.00-2.50	1.00	0.040	0.030	12.00-14.00	0.50	1.00	-	-	-
	GX40CrSi17	1.4740	0.30-0.50	1.00-2.50	1.00	0.040	0.030	16.00-19.00	0.50	1.00	-	-	-
	GX160CrSi18	1.4743	1.40-1.80	1.00-2.50	1.00	0.040	0.030	17.00-19.00	0.50	1.00	-	-	-
	GX40CrSi24	1.4745	0.30-0.50	1.00-2.50	1.00	0.040	0.030	23.00-26.00	0.60	1.00	-	-	-
	GX40CrSi28	1.4766	0.30-0.50	1.00-2.50	1.00	0.040	0.030	27.00-30.00	0.50	1.00	-	-	-
	GX130CrSi29	1.4777	1.20-1.40	1.00-2.50	0.50-1.00	0.035	0.030	27.00-30.00	0.50	1.00	-	-	-
	GX40CrNiSi27-4	1.4823	0.30-0.50	1.00-2.50	1.50	0.040	0.030	25.00-28.00	0.50	3.00-6.00	-	-	-
Austenitic	GX25CrNiSi8-9	1.4825	0.15-0.35	0.50-2.50	2.00	0.040	0.030	17.00-19.00	0.50	8.00-10.00	-	-	-
	GX40CrNiSi22-10	1.4826	0.30-0.50	1.00-2.50	2.00	0.040	0.030	21.00-23.00	0.50	9.00-11.00	-	-	-
	GX25CrNiSi20-14	1.4832	0.15-0.35	0.50-2.50	2.00	0.040	0.030	19.00-21.00	0.50	13.00-15.00	-	-	-
	GX40CrNiSi25-12	1.4837	0.30-0.50	1.00-2.50	2.00	0.040	0.030	24.00-27.00	0.50	11.00-14.00	-	-	-
	GX40CrNiSi25-20	1.4848	0.30-0.50	1.00-2.50	2.00	0.040	0.030	24.00-27.00	0.50	19.00-22.00	-	-	-
	GX40CrNiSiNb24-24	1.4855	0.30-0.50	1.00-2.50.	2.00	0.040	0.030	23.00-25.00	0.50	23.00-25.00	0.80-1.80	-	-
	GX35NiCrSi25-20	-	0.20-0.50	1.00-2.50	2.00	0.040	0.030	19.00-23.00	0.50	23.00-27.00	-	-	-
	GX40NiCrSi35-17	-	0.30-0.50	1.00-2.50	2.00	0.040	0.030	16.00-18.00	0.50	34.00-36.00	-	-	-
	GX40NiCrSiNb35-17	-	0.30-0.50	1.00-2.50	2.00	0.040	0.030	17.00-20.00	0.50	34.00-36.00	1.00-1.80	-	-
	GX40NiCrSi38-19	1.4865	0.30-0.50	1.00-2.50	2.00	0.040	0.030	18.00-21.00	0.50	36.00-39.00	-	-	-
	GX40NiCrSiNb38-19	1.4849	0.30-0.50	1.00-2.50	2.00	0.040	0.030	18.00-21.00	0.50	36.00-39.00	1.20-1.80	-	-
	GX10NiCrSiNb32-20	1.4859	0.05-0.15	0.50-1.50	2.00	0.040	0.030	19.00-21.00	0.50	31.00-33.00	0.50-1.50	-	-
	GX40NiCrSi35-26	1.4857	0.30-0.50	1.00-2.50	2.00	0.040	0.030	24.00-27.00	0.50	33.00-36.00	-	-	-
	GX40NiCrCo20-20-20	-	0.30-0.65	max. 1.00	2.00	0.040	0.030	19.00-22.00	2.50-3.00	18.00-22.00	0.75-1.25	18.50-22.00	W:2.00-3.00
	GX50NiCrCoW35-25-15-5	-	0.45-0.55	1.00-2.00	1.00	0.040	0.030	24.00-26.00	-	33.00-37.00	-	14.00-16.00	W:4.00-6.00
	GX40NiCrNb45-35	-	0.35-0.45	1.50-2.00	1.00-1.50	0.040	0.030	32.50-37.50	-	42.00-46.00	1.50-2.00	-	-
Nickel-or Cobalt-Base	G-NiCr28W	2.4879	0.35-0.55	1.00-2.00	1.50	0.040	0.030	27.00-30.00	0.50	47.00-50.00	-	-	Fe: REM W: 4.00-6.00
	G-CoCr28	2.4778	0.05-0.25	0.50-1.50	1.50	0.040	0.030	27.00-30.00	0.50	4.00	0.50	48.0-52.0	Fe: REM
	G-NiCr50Nb	2.4680	0.10	1.00	0.05	0.020	0.020	48.00-52.00	0.50	Rest	1.00-1.80	-	Fe: 1.00 N: 0.16
	G-NiCr15	-	0.35-0.65	1.00-2.50	2.00	0.040	0.030	12.00-18.00	1.00	58.00-66.00	-	-	Fe: REM

***maximum unless range is given**