STEEL
CASTINGS
HANDBOOK

Supplement 9
High Alloy Data Sheets
Heat Series

Steel Founders' Society of America
2004

Heat Resistant Type HA

Description

Type HA is an iron-chromium-molybdenum allow containing sufficient chromium to provide good resistance to oxidation at temperatures up to about 1200°F (699°C). The molybdenum content contributes desirable strength properties to the alloy at moderate temperatures. Castings of type HA alloy are widely used in oil refinery service.

The alloy has a ferritic structure with carbides in pearlitic areas or agglomerated particles depending on prior heat treatment. Hardening of the alloy occurs on cooling in air from temperatures above 1500°F (816°C). In the normalized and tempered condition, the allow exhibits satisfactory toughness throughout its useful temperature range.

Castings of type HA alloy have fairly good machining and welding properties if proper techniques are employed. The alloy is magnetic and has a low coefficient of thermal expansion comparable to carbon steel.

At room temperature, the thermal conductivity is only about half that of carbon steel and the electrical resistivity is seven times higher. With increasing temperature, these differences decrease and, above about 1600°F (871°C), these differences are practically negligible.

Heat treatment

To obtain maximum softness, type HA castings should be annealed by heating to 1625°F (885°C) or slightly higher, and then slowly cooling in the furnace at about 50°F (10°C) per hour to below 1300° F (996°C) and then air cooling to below 1300°F (709°C) followed by tempering at about 1250°F (677°C).

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.		0.35				0.90	8		
max.	0.20	0.65	1.00	0.04	0.045	1.20	12	-	bal

Physical properties

Modulus of elasticity, psi x 10^6	29
Density, lb/in^3	0.279
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, µΩ.m, at 70 °F	0.70
Melting point, approximate °F	2750
Magnetic permeability	Ferromagnetic

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion µ in./(in. °F)	
At 212 °F	15.0	70 - 212 °F	6.1
At 600 °F	15.4	70 - 600 °F	6.5
At 1000 °F	15.7	70 - 1000 °F	7.1
At 1200 °F	15.8	70 - 1200 °F	7.5

Mechanical properties at room temperature

	Representative values		Minimum tensile
	Annealed	Normalized 1825 °F Tempered 1250 °F	requirements ASTM A217
Tensile strength, ksi	95.0	107.0	90.0
Yield strength, 0.2% offset, ksi	65.0	81.0	60.0
Elongation, in 2in., %	23	21	18
Reduction in area, %	-	56	35
Brinell hardness (HBW)	180	220	-
Charpy V-notch, keyhole, ft.lbs	-	32	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %	Reduction of area, %
1000 °F	67.0	42.0	-	71
1100 °F	44.0	32.0	36	58

Creep rupture properties

Representative values[1] - long time	Limiting creep stress, ksi 0.0001%/h	Stress to rupture 10h	100h	1000h
1000 °F	16.0	45.0	37.0	27.0
1100 °F	7.2	-	-	-
1200 °F	3.1	-	-	-

[1]For constant temperature, for cyclic temperature lower values would apply

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HA alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Glass, Oil Refining

Castings Fan blades, furnace rollers, Lehr rolls, refinery fittings, trunnions

Environment Air, flue gases, petroleum, steam

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HA. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design considerations

Section thicknesses from 3/16 inch up can be cast satisfactory in HA alloy. Somewhat lighter sections are feasible depending on casting design and pattern equipment. Drastic changes in section should be avoided, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allowance for this alloy is 1/4 inch per foot.

Fabricating considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HA castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. It is generally considered that metal-arc welding is more satisfactory for high temperature applications of this alloy than oxyacetylene welding.

Castings should be heated to 450-550°F (232-288°C) before welding. After welding, castings should be heated to 1200-1300°F (699-709° C), depending on the original draw temperature, held sufficiently long to ensure uniform heating throughout the area and section involved, and then air cooled rapidly. Other welding procedures that are described under Alloy CA-15 are applicable to Alloy HA.

Machining Most machining operations can be performed satisfactorily on castings of HA alloy. The work-hardening rate of this grade is much lower than that of the iron-chromium-nickel types, but it is advisable in all cases that the tool be kept continually entering into the metal. Slow feeds, deep cuts and powerful, rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are stringy.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Other castings designations, specifications, and corresponding wrought alloy

The wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast ASTM: A217(C12), A426(CP9)

Wrought ASTM: A199(T9), A200(T9)

Heat Resistant Type HC (UNS S92605)

Description

Type HC is an iron-chromium allow containing about 28 percent chromium and up to 4 percent nickel. It provides excellent resistance to oxidation and high-sulfur-containing flue gases at temperatures as high as 2000°F (1093°C). This grade is limited to applications where strength is not a consideration, or for moderate load bearing service around 1200°F (699°C). It is also used where appreciable nickel cannot be tolerated, as in very high sulfur atmospheres, or where nickel tends to crack hydrocarbons through catalytic action.

The alloy has a ferritic structure at all temperatures and for this reason is not hardened by heat treatment. The ductility and impact strength are very low at room temperature, and the creep strength very low at elevated temperature, unless some nickel is present. In the HC type alloy containing over 2 percent nickel, substantial improvement in these properties is obtained by increasing the nitrogen content to 0.15 percent or more.

Heating in the range 800 to 1050°F (427 to 566°C) will result in a loss of room temperature ductility and toughness. This loss is the so-called "885°F (475°C) embrittlement." In addition, this alloy is susceptible to sigma phase formation when heated for extended periods of time in the range 1100 to about 1600°F (593 to 871°C).

Castings of type HC alloy are readily machinable. They can be welded successfully if proper technique is employed. The alloy is magnetic and has a lower coefficient of thermal expansion than to carbon steel.

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.							26		
max.	0.50	1.00	2.00	0.04	0.04	0.5[1]	30	4	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	29
Density, lb/in^3	0.272
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, µΩ.m, at 70 °F	0.77
Melting point, approximate °F	2725
Magnetic permeability	Ferromagnetic

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion µ in./(in. °F)			
At 212 °F	12.6	70 - 1000 °F	6.3	70 - 1800 °F	7.4
At 600 °F	15.4	70 - 1200 °F	6.4	70 - 2000 °F	7.7
At 1000 °F	15.7	70 - 1400 °F	6.6	1200 - 1600 °F	8.7
At 1200 °F	15.8	70 - 1600 °F	7.0	1200 - 1800 °F	9.3

Mechanical properties at room temperature

	Representative values			Minimum tensile requirements ASTM A297
	As cast (a)	Aged 24h at 1400 °F Furnace cooled (b)	(b)	
Tensile strength, ksi	70.0	110.0	115.0	55.0
Yield strength, 0.2% offset, ksi	65.0	75.0	80.0	-
Elongation, in 2in., %	2	19	18	-
Brinell hardness (HBW)	190	223	-	-

At elevated temperatures - Creep rupture properties

Representative values[2] - long time	Limiting creep stress, ksi 0.0001%/h	Stress to rupture 10h	100h	1000h
	(b)	(b)	(b)	
1400 °F	1.30	4.6	3.30	2.30
1600 °F	0.75	2.0	1.70	1.30
1800 °F	0.36	1.1	0.85	0.62

[2]For constant temperature, for cyclic temperature lower values would apply
(a) <1.0% Ni, low N
(b) >2.0% Ni, 0.15% min. N

At room temperature, the thermal conductivity is only about half that of carbon steel and the electrical resistivity is about eight times higher. With increasing temperature, these differences decrease and, above about 1600°F (871°C), these differences are practically negligible.

Heat Treatment

Type HC castings are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HC alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Cement, Glass, Heat Treating, Industrial Furnace, Oil Refining, Ore Processing, Paper, Power, Zinc Refining.

Castings Boiler baffles, electrodes, furnace grate bars, gas outlet dampers, kiln parts, lute rings, rabble blades and holders, recuperators, salt pots, soot blower tubes, support skids, tuyers.

Environment Air, combustion gases, flue gases, high sulfur, molten neutral salts.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HC. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HC alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Some difficulty is encountered in running thin sections, however, and designs involving appreciable changes in section should be avoided. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allowance for this alloy is 7/22 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding

Type HC castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. It is generally considered that metal-arc welding is more satisfactory for high temperature applications of this alloy than oxyacetylene welding.

Castings should be heated to 400-800°F (232-427°C) before welding. After welding, castings should be heated to 1550°F (843° C),held sufficiently long to ensure uniform heating throughout the area and section involved, and then air cooled rapidly. Welding procedures utilizing SMAW and GTAW techniques are described in this section.

Machining

Most machining operations can be performed satisfactorily on castings of HC alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful, rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curler and breaker tools are recommended.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

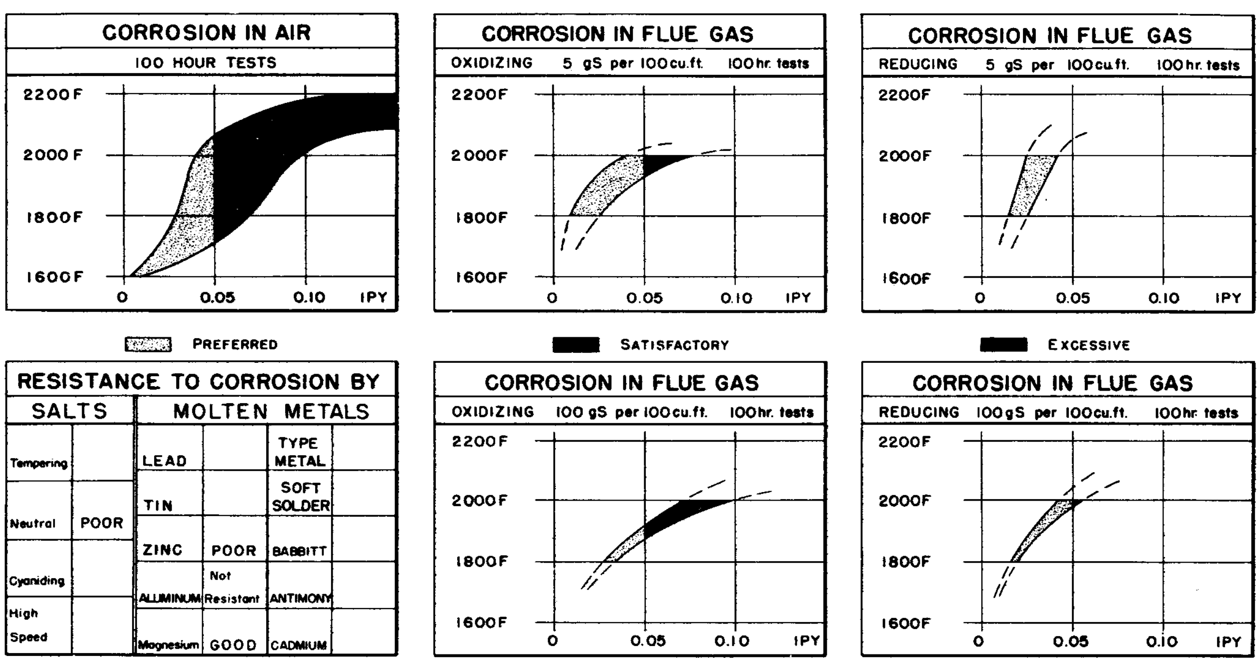
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast ASTM: A297(HC), A608(HC30), S A E 70446

Wrought AISI 446



Heat Resistant Type HD (UNS J93005)

Description

Type HD is an iron-chromium-nickel alloy very similar in general properties to the 28 percent chromium HC type, but containing about 5 percent nickel. Its high chromium content makes this grade suitable for use in high-sulfur atmospheres, and the addition of nickel provides somewhat greater strength at high temperatures for type HD than exhibited by the other "straight chromium" alloys with which it is frequently grouped.

The alloy has a two-phase, ferrite plus austenite structure that is non-hardenable by customary heat treating procedure. Long exposure to temperatures in the range 1300 to 1500°F (704 to 816°C), however, may result in considerable hardening of the alloy accompanied by severe loss of room temperature ductility through formation of the sigma phase. Restoration of ductility may be accomplished by heating the alloy to a uniform temperature of 1800°F (982°C) or higher, and then cooling rapidly to below 1200°F (699°C).

Castings of type HD alloy have good machining and welding properties. Electrical resistivity and thermal conductivity are similar to type HC, but thermal expansion coefficients are about 20 percent higher. The alloy is magnetic.

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.							26	4	
max.	0.50	1.00	2.00	0.04	0.04	0.5[1]	30	7	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27
Density, lb/in^3	0.274
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, μΩ.m, at 70 °F	0.81
Melting point, approximate °F	2700
Magnetic permeability	Ferromagnetic

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	12.6	70 - 1000 °F	7.7	70 - 1800 °F	6.1
At 1000 °F	17.9	70 - 1200 °F	8.0	70 - 2000 °F	6.5
At 1500 °F	20.3	70 - 1400 °F	8.3	1200 - 1600 °F	7.1
At 2000 °F	24.2	70 - 1600 °F	8.6	1200 - 1800 °F	7.5

Mechanical properties at room temperature

	Representative values As cast	Minimum tensile requirements ASTM A297
Tensile strength, ksi	85.0	75.0
Yield strength, 0.2% offset, ksi	48.0	35.0
Elongation, in 2in., %	16	8
Brinell hardness (HBW)	190	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	36.0	-	14
1600 °F	23.0	-	18
1800 °F	15.0	-	40

Creep rupture properties

Representative values[2] - long time	Limiting creep stress, ksi 0.0001%/h	Stress to rupture 10h	100h	1000h
1400 °F	3.5	14.0	10.0	7.0
1600 °F	1.9	-	5.0	-
1800 °F	0.9	-	2.5	-
1600 °F	0.2	-	-	-

[2]For constant temperature, for cyclic temperature lower values would apply

Heat Treatment

Type HD castings are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HD alloy has been employed successfully; they are not comprehensive nor are they intended as guides to alloy selection for specific end uses.

Industries Copper, Glass, Heat Treating, Oil Refining, Ore Processing, Steel.

Castings Brazing furnace parts, cracking equipment, furnace blowers, gas burner parts, holding pots, kiln parts, pouring spouts, rabble shoes and arms, recuperator sections, salt pots.

Environment Air, combustion gases, flue gases, high sulfur, molten copper and copper alloys, molten neutral salts.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HD. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thickness from 3/16 inch up can be cast satisfactorily in HD alloy. Somewhat lighter sections are feasible depending on casting design and pattern equipment. Some difficulty is encountered in running thin sections, however, and designs involving appreciable changes in section should be avoided. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allowance for this alloy is 7/22 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding .
Type HD castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. It is generally considered that metal-arc welding is more satisfactory for high temperature applications of this alloy than oxyacetylene welding. The welding procedures outlined for Alloy HC are applicable for Alloy HD. Welding procedures utilizing SMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HD alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful, rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curler and breaker tools are recommended.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

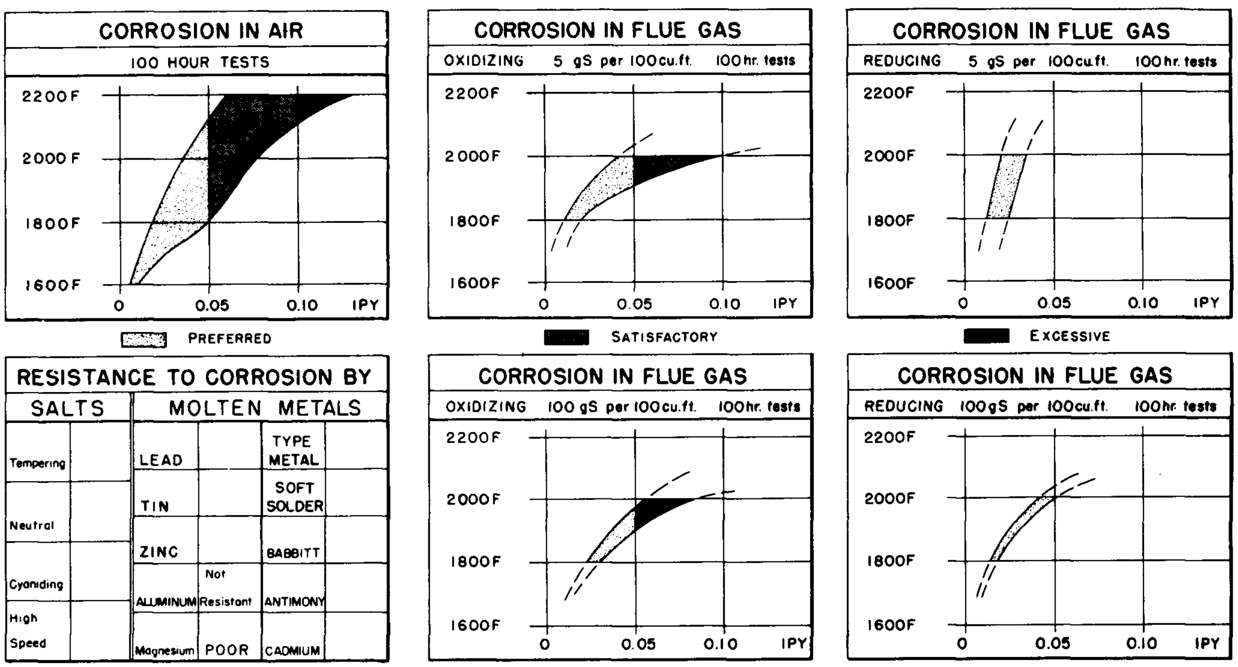
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6^{th} Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast ASTM: A297(HD), A608(HD30), S A E 70327

Wrought AISI 327



Heat Resistant Type HE (UNS J93403)

Description

Type HE is an iron-chromium-nickel alloy containing enough chromium to be suitable for service up to 2000°F (1093°C) but also having sufficient nickel to make it stronger and more ductile than the "straight chromium" types at room temperature in the as-cast condition. At high temperatures, the alloy has excellent corrosion resistance, good ductility and moderate strength. It is the strongest grade having good resistance to very-high-sulfur-content gases (300 to 500 grains sulfur per 100 cubic feet of gas) at high temperatures. For this reason, type HE castings are used extensively in ore-roasting equipment.

In the as-cast condition the alloy has a two-phase, austenite plus ferrite structure containing carbides. Type HE castings cannot be hardened by heat treatment, but, like the HD grade, long exposure to temperatures around 1500°F (816°C) will promote formation of the sigma phase with consequent embrittlement of the alloy at room temperature. Ductility of this grade can be improved somewhat by quenching the alloy from about 2000°F (1093°C).

Castings of type HE alloy have good machining and welding properties. At room temperature, thermal expansion is about 50 percent greater than for carbon steel or the iron-chromium HC type. Also, at room temperature, thermal conductivity is much lower than for types HD or HC, but electrical resistivity is about the same. The alloy is weakly magnetic.

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						26	8	
max.	0.50	2.00	2.00	0.04	0.04	0.5[1]	30	11	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	25.0
Density, lb/in^3	0.277
Sp. Heat, Btu/lb.°F, at 70 °F	0.14
Electrical resistivity, μΩ.m, at 70 °F	0.85
Melting point, approximate °F	2650
Magnetic permeability	1.3 - 2.5

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)	
At 212 °F	8.5	70 - 1000 °F	9.6
At 600 °F	10.5	70 - 1200 °F	9.9
At 1000 °F	12.4	70 - 1400 °F	10.2
At 1200 °F	13.5	70 - 1600 °F	10.5
At 1400 °F	14.6	70 - 1800 °F	10.8
At 1600 °F	15.9	70 - 2000 °F	11.1
At 1800 °F	16.9	1200 - 1600 °F	12.2
At 2000 °F	18.2	1200 - 1800 °F	12.5

Mechanical properties at room temperature

	Representative values: As cast	Representative values: Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	95.0	90.0	85.0
Yield strength, 0.2% offset, ksi	45.0	55.0	40.0
Elongation, in 2in., %	20	10	9
Brinell hardness (HBW)	200	270	-
Charpy keyhole, ft.lbs	10	-	-

At elevated temperatures

Creep rupture properties

Representative values[2] - long time	Limiting creep stress, ksi 0.0001%/h	Stress to rupture, ksi 100h
1400 °F	4.0	11.0
1600 °F	1.9	5.3
1800 °F	0.9	2.5
1600 °F	0.2	-

[2]For constant temperature, for cyclic temperature lower values would apply

Heat Treatment

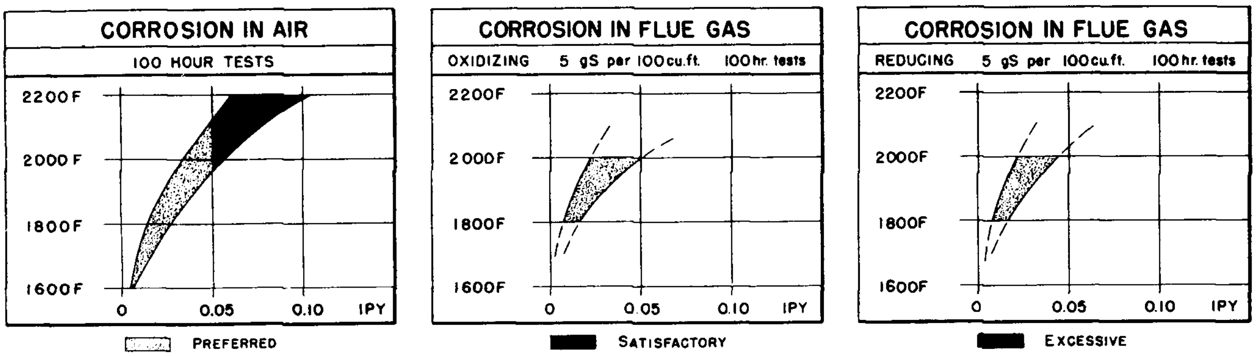
Type HE castings are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HE alloy has been employed successfully; they are not comprehensive nor are they intended as guides to alloy selection for specific end uses.

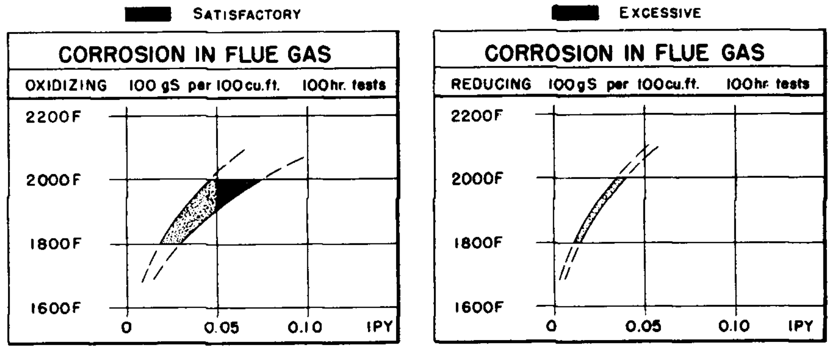
Industries

Oil Refining, Power, Smelting, Steel.



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering		LEAD		TYPE METAL	
Neutral		TIN		SOFT SOLDER	
Cyaniding		ZINC		BABBITT	
High Speed		ALUMINUM	Not Resistant	ANTIMONY	
		Magnesium	Not Resistant	CADMIUM	



Castings

Billet skids, burner nozzles, dampers, furnace chains and conveyors, furnace door frames, oil burner parts, rabble arms and blades, recuperators, rotating shafts, soot blower elements, steam generator parts, tube supports.

Environment Air, flue gases, high sulfur, steam.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HE. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HE alloy. Somewhat lighter sections are feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allowance for this alloy is 9/22 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HE castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. Metal-arc welding is generally preferred for high temperature applications of this alloy. Lime coated electrodes of similar composition (AWS E312-15) are suggested for arc welding. Neither preweld nor postweld heat treating is required.

Additional details of welding procedures described for Alloy HH are applicable for Alloy HE. Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HE alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful, rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curler and breaker tools are recommended.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast	ASTM: A297(HE), A608(HE30), S A E 70312
Wrought	AISI 312

Heat Resistant Type HF (UNS J92603)

Description

Type HF is an iron-chromium-nickel alloy similar to the well-known type CF corrosion resistant composition (19 Cr. 9 Ni), but containing somewhat more chromium and nickel, and substantially more carbon. The increased chromium content confers added resistance to oxidation at elevated temperature, and the higher nickel and carbon levels ensure an austenitic structure; accordingly, this grade is suitable for applications requiring high strength and corrosion resistance in the range 1200 to 1600°F (649 to 871°C). It is used extensively in oil refinery and heat treating furnaces.

As cast, the alloy has an austenitic matrix containing interdendritic eutectic carbides and occasionally an unidentified lamellar constituent. Aging at service temperatures is usually accompanied by precipitation of finely dispersed carbides resulting in higher room temperature strength and some loss of ductility. Improperly balanced alloys may be partially ferritic as cast, and such materials are susceptible to embrittlement from sigma phase formation after long exposure at 1400 to 1500°F (760 to 816°C).

Castings of type HF alloy have good welding and machining properties. At room temperature, thermal expansion is about 40 percent greater than carbon steel or iron-chromium alloy types HA, HC and HD, and heat conductivity is 25 to 60 percent less. The alloy has

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						18	8	
max.	0.40	2.00	2.00	0.04	0.04	0.5[1]	23	12	bal

1 Mo not intentionally added.

Physical properties	
Modulus of elasticity, psi x 10^6	28.0
Density, lb/in^3	0.280
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, μΩ.m, at 70 °F	0.80
Melting point, approximate °F	2550
Magnetic permeability	1.00

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	8.3	68 - 200 °F	8.96	68 - 1400 °F	10.30
At 600 °F	10.5	68 - 400 °F	9.26	68 - 1600 °F	10.46
At 1000 °F	12.3	68 - 600 °F	9.51	68 - 1800 °F	10.61
At 1200 °F	13.3	68 - 800 °F	9.74	68 - 2000 °F	10.74
At 1400 °F	14.6	68 - 1000°F	9.94	1200 - 1400 °F	11.00
At 1600 °F	15.9	68 - 1200°F	10.13	1200 - 1600 °F	11.50

Mechanical properties at room temperature

	Representative values: As cast	Representative values: Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	92.0	100.0	70.0
Yield strength, 0.2% offset, ksi	45.0	50.0	35.0
Elongation, in 2in., %	38	25	25
Brinell hardness (HBW)	165	190	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	60.0	31.5	10
1400 °F	38.0	25.0	16
1600 °F	21.0	15.5	16

Creep rupture properties

Representative values[2] - long time	Limiting creep stress, ksi: 0.0001%/h	Limiting creep stress, ksi: 1% total creep in 100,000 h	Stress to rupture in hours: 100	1000	10,000	100,000
1200 °F	18.0	11.3	33.0	25.0	16.5	11.0[3]
1400 °F	6.8	4.4	13.5	9.1	6.1	4.0[3]
1600 °F	3.9	0.9	7.2	4.4	2.7	1.7[3]

[2] For constant temperature, for cyclic temperature lower values would apply
[3] Extrapolated

about five times the electrical resistance of carbon steel. It is normally non-magnetic.

Heat Treatment

Castings of type HF alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment, but, if service conditions involve repeated heating and cooling, improved performance may be obtained by heating castings at 1900°F (1038°C) for six hours followed by furnace cooling prior to placing in service.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HF alloy has been employed successfully; they are nor comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Aluminum, Cement, Glass, Heat Treating, Industrial Furnace, Oil Refining, Steel.

Castings Arc furnace electrode arms, annealing boxes and trays, baskets, brazing channels, burner tips, burnishing rolls, conveyor belts and chains, fan housings, furnace rails, gas burner rings, hardening retorts, hearth plates, Lehr rolls, pier caps, soaking pit dampers, tempering baskets, wear plates.

Environment Air, combustion gases, flue gases oxidizing and reducing, steam.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HF. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thickness from 3/16 inch up can be cast satisfactorily in HF alloy. Somewhat lighter sections are feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allowance for this alloy is 1/22 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HF castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. Metal-arc welding is generally preferred for high temperature applications of this alloy. Neither preweld nor postweld heat treating is required.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HF alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curler and breaker tools are recommended.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

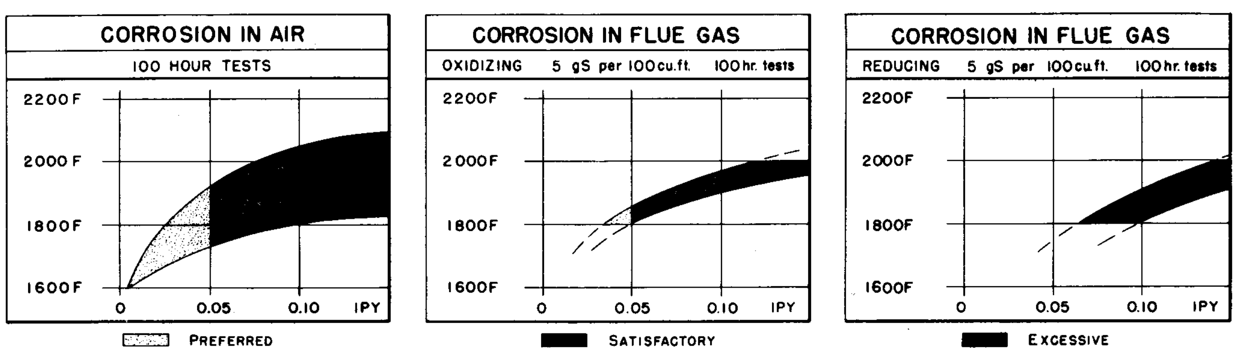
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

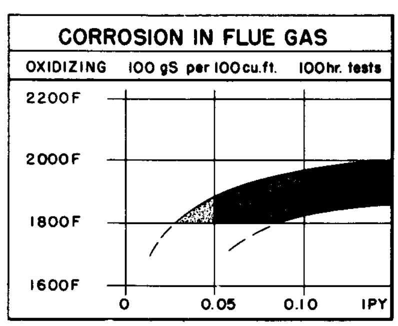
Cast ASTM: A297(HF), A608(HF30), S A E 70308, MIL-S-17509(SHIPS)

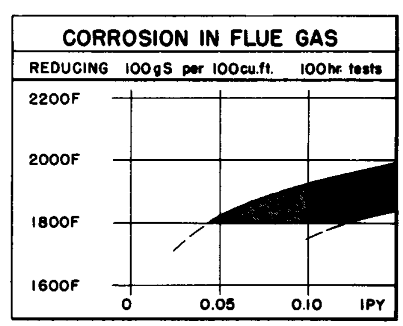
Wrought AISI 302B



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering		LEAD		TYPE METAL	
Neutral		TIN	GOOD to 650F	SOFT SOLDER	
		ZINC	POOR	BABBITT	
Cyaniding		ALUMINUM	Not Resistant	ANTIMONY	GOOD to 1300F
High Speed		Magnesium	Not Resistant	CADMIUM	GOOD to 775F





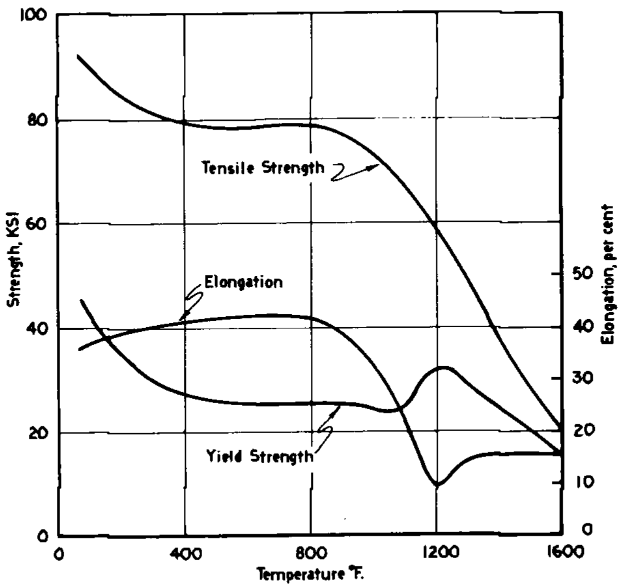


Fig. 1 Effect of temperature on short-time tension test properties of Type HF alloy.

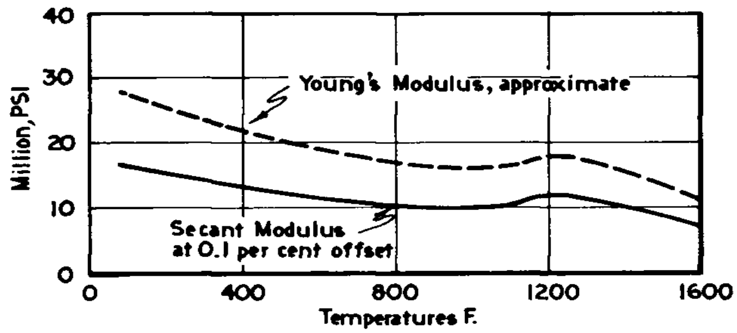


Fig. 2 Effect of temperature of tension test on approximate modulus elasticity of Type HF alloy.

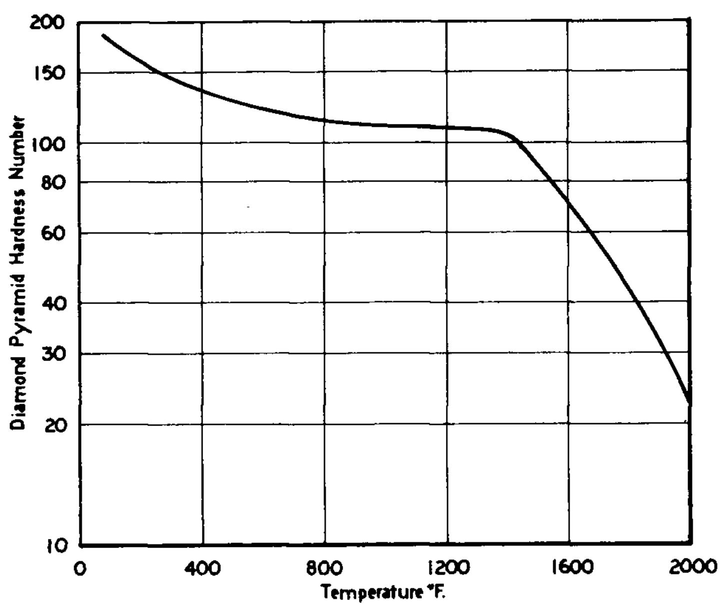


Fig 3 Effect of temperature on hardness of Type HF alloy.

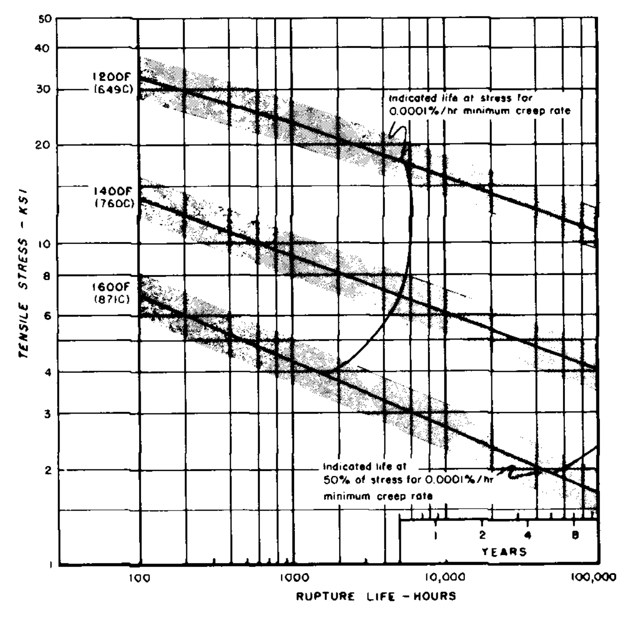


Fig. 4. Creep-rupture properties of Type HF alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits. Scatter of values may be much wider, particularly at the longer times and higher temperatures.

Heat Resistant Type HH (UNS J93503)

Description

Type HH is an iron-chromium-nickel alloy containing the minimum quantities of chromium and nickel in proportions to supply a useful combination of properties for elevated temperature service. The chromium range is high enough to ensure good scaling resistance up to 2000°F (1093°C) (and sometimes higher) in air or normal combustion gases. Sufficient nickel is present, aided by carbon, nitrogen and manganese, to maintain austenite as the major phase; but the alloy is borderline in character and its microstructure is very sensitive to composition balance. For high ductility near 1800°F (982°C) a structure exhibiting both austenite and ferrite is appropriate. Such an alloy is relatively weak, however, and if high strength is needed, and lower ductility can be tolerated, a composition balanced to be wholly austenitic is desirable. Fortunately, two distinct grades of material can be obtained within the stated chemical composition range of the type HH alloy. These grades are defined as Type I and Type II in ASTM Specification A447. The various useful properties obtainable in the type HH alloy make it suitable for a wide range of high temperature applications and, for this reason, it is used in greater quantity than any other heat resistant grade.

The alloy is basically austenitic and holds considerable carbon in solid solution, but carbides, ferrite (soft, ductile and magnetic) and sigma (hard, brittle and non-magnetic) also may be present in the micro-structure. The amounts of the various structural constituents present depend on the chemical composition and the thermal history of the sample under consideration. Near 1600°F (871°C) the partially ferritic alloys tend to embrittle from development of the sigma phase, while around 1400°F

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						24	11	
max.	0.50	2.00	2.00	0.04	0.04	0.5[1]	28	14	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Density, lb/in^3	0.279
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, μΩ.m, at 70 °F	0.75 - 0.85
Melting point, approximate °F	2500
Magnetic permeability	1.00 - 1.9

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	8.2	70 - 1000 °F	9.5	70 - 1800 °F	10.5
At 600 °F	10.1	70 - 1200 °F	9.7	70 - 2000 °F	10.7
At 1000 °F	12.0	70 - 1400 °F	9.9	1200 - 1600 °F	11.4
At 1200 °F	13.0	70 - 1600 °F	10.2	1200 - 1800 °F	11.7
At 1400 °F	14.1				
At 1600 °F	15.3				
At 1800 °F	16.3[2]				
At 2000 °F	17.5[2]				

[2] Estimated

Type I - Partially ferritic

Mechanical properties at room temperature

	Representative values As cast	Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	85.0	86.0	75.0
Yield strength, 0.2% offset, ksi	50.0	55.0	35.0
Elongation, in 2in., %	25	11	10
Brinell hardness (HBW)	185	200	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	-	-	-
1400 °F	33.0	17.0	18
1600 °F	18.5	13.5	30
1800 °F	9.0	6.3	45

Creep rupture properties

Representative values[3] - long time	Limiting creep stress, ksi (rate 0.0001%/h)	Stress to rupture in hours 10	100	1,000
1400 °F	3.0	-	14.0	6.5
1600 °F	1.7		6.4	3.8
1800 °F	1.1	4.7	3.1	2.1
2000 °F	0.3	-	1.5	-

For constant temperature, for cyclic temperature lower values would apply

(760°C) carbide precipitation may cause a comparable loss of ductility. Such possible embrittlement suggests that 1700 to 2000°C (927 to 1093°C) is the best service temperature range, but this is not critical for steady temperature conditions in the absence of unusual thermal or mechanical stresses.

A serious cause of embrittlement is absorption of carbon from the service environment. Accordingly, the HH type alloy is seldom used for carburizing applications. High silicon content (over 1.5 percent) will fortify the alloy against carburization under mild conditions but will promote ferrite formation and possible sigma embrittlement. Thus, although the HH type alloy can give satisfactory service in carburizing atmospheres, types HT, HU, HW and HX are considered superior and are generally preferred for such application, particularly where thermal shock is involved.

The partially ferritic (Type I) HH alloy is frequently considered best adapted to operating conditions which are subject to changes in temperature level and applied stress. A plastic extension in the weaker, ductile ferrite under changing load tends to occur more readily than in the stronger austenitic phase, thereby reducing unit stresses and stress concentrations and permitting rapid adjustment to suddenly applied overloads without cracking. Where load and temperature conditions are comparatively constant, the wholly austenitic (Type II) HH alloy provides the highest creep strength and permits use of maximum design stress. The stable austenitic alloy is also favored for cyclic temperature service that might induce sigma phase formation in the partially ferritic type.

Type II - Wholly austenitic

Mechanical properties at room temperature

	Representative values: As cast	Representative values: Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297	
Tensile strength, ksi	80.0	92.0	75.0	80.0
Yield strength, 0.2% offset, ksi	40.0	45.0	35.0	-
Elongation, in 2in., %	15	8	10	4
Brinell hardness (HBW)	180	200	-	-
Impact, Charpy keyhole (see Fig. 1)				

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	60.5	32.2	14
1400 °F	37.4	19.8	16
1600 °F	21.5	16.0	18
1800 °F	10.9	7.3	31
2000 °F	5.5	-	-

Creep rupture properties
Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	1% creep in, ksi 100,000	Stress to rupture in stress, ksi hours 100	1,000	10,000	100,000
1200 °F	18.0	9.5	35.0	22.00	14.00	9.00[4]
1400 °F	6.3	2.0	14.0	8.00	4.80	2.80[4]
1600 °F	3.9	1.1	6.8	3.80	2.15	1.20[4]
1800 °F	2.1	-	3.2	1.65	0.86[4]	0.44[4]
2000 °F	0.8	-	1.4	0.68	0.34[4]	0.15[4]

[3] For constant temperature, for cyclic temperature lower values would apply
[4] Extrapolated

Castings of type HH alloy have good weldability and fair machining characteristics. At room temperature, thermal expansion is about 40 percent greater than carbon steel or iron-chromium alloy types HC or HD and almost 10 percent more than the nickel-predominant types such as HT or HW. Also, at room temperature, electrical resistance is about five times that of carbon steel.

The alloy varies from non-magnetic to weakly magnetic. The magnetic permeability increases with the amount of the ferrite phase present, but decreases if the ferrite is converted to sigma phase. Thus, this property can be used to indicate constitution and, under the proper conditions, to estimate high temperature strength.

Heat Treatment

Castings of type HH alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment. For alloys of medium carbon content (about 0.30%) in applications involving thermal fatigue from rapid heating and cooling, improved performance sometimes may be obtained by heating castings at 1900°F (1038°C) for 12 hours followed by furnace cooling prior to placing in service.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HH alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Cement, Chemical, Furnace, Construction, Glass, Heat Treating, Oil Refining, Ore Refining, Steel.

Castings Annealing trays, billet skids, burner nozzles, carburizing boxes, convection tube supports, dampers exhaust manifolds, flue gas stacks, grate supports, hardening trays, kiln nose ring segments, muffles, normalizing discs, pier caps, quenching trays, rabble arms and blades, radiant tubes and supports, refractory supports, retorts, roller hearths and rails, stoker parts, tube hangers.

Environment Air, ammonia, carburizing gas, combustion gases, flue gases oxidizing and reducing, high sulfur gases, molten cyanide, steam, tar.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HH. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HH alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HH castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. Metal-arc welding is generally preferred for high temperature applications of this alloy. Neither preweld nor postweld heat treating is required.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HH alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

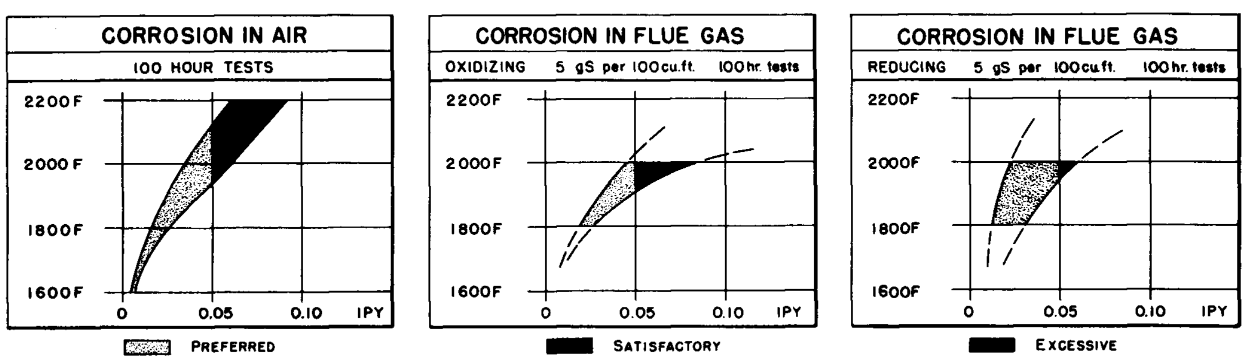
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

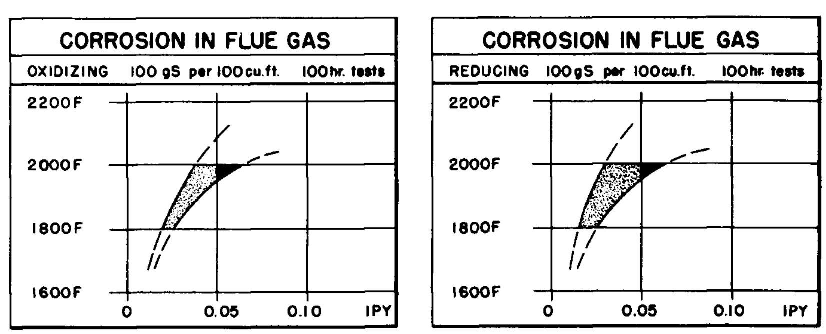
Cast ASTM: A297(HH), A447, A608(HH33), SAE 70309

Wrought AISI 309



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering	FAIR	LEAD	GOOD	TYPE METAL	
Neutral	FAIR	TIN		SOFT SOLDER	
		ZINC		BABBITT	
Cyaniding	FAIR	ALUMINUM	Not Resistant	ANTIMONY	
High Speed	FAIR	Magnesium	Not Resistant	CADMIUM	



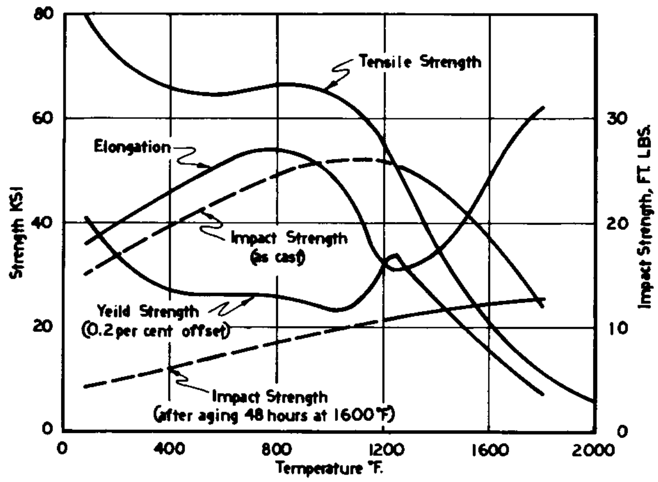


Fig 1 Effect of temperature on short time tension test and Charpy impact properties of wholly austenitic Type HH alloy.

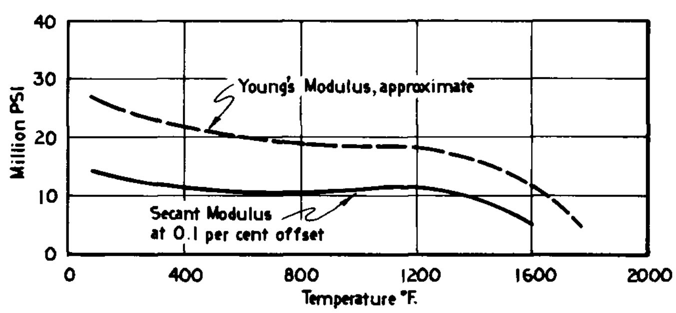


Fig. 2 Effect of temperature of tension test on approximate modulus of elasticity of Type HH alloy

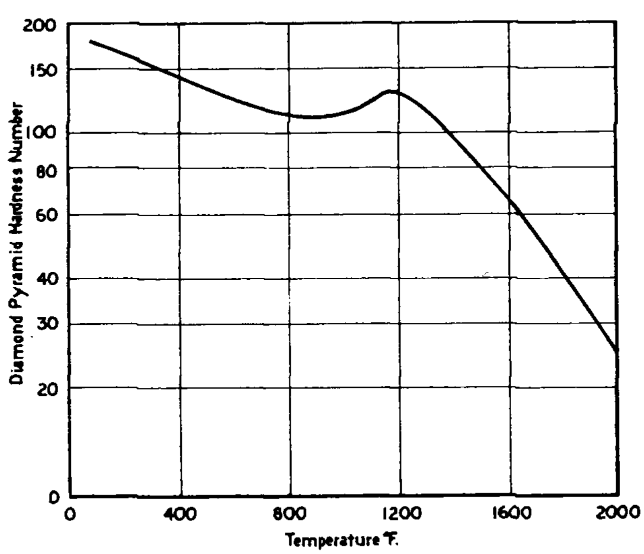


Fig 3 Effect of temperature on hardness of wholly austenitic Type HH alloy.

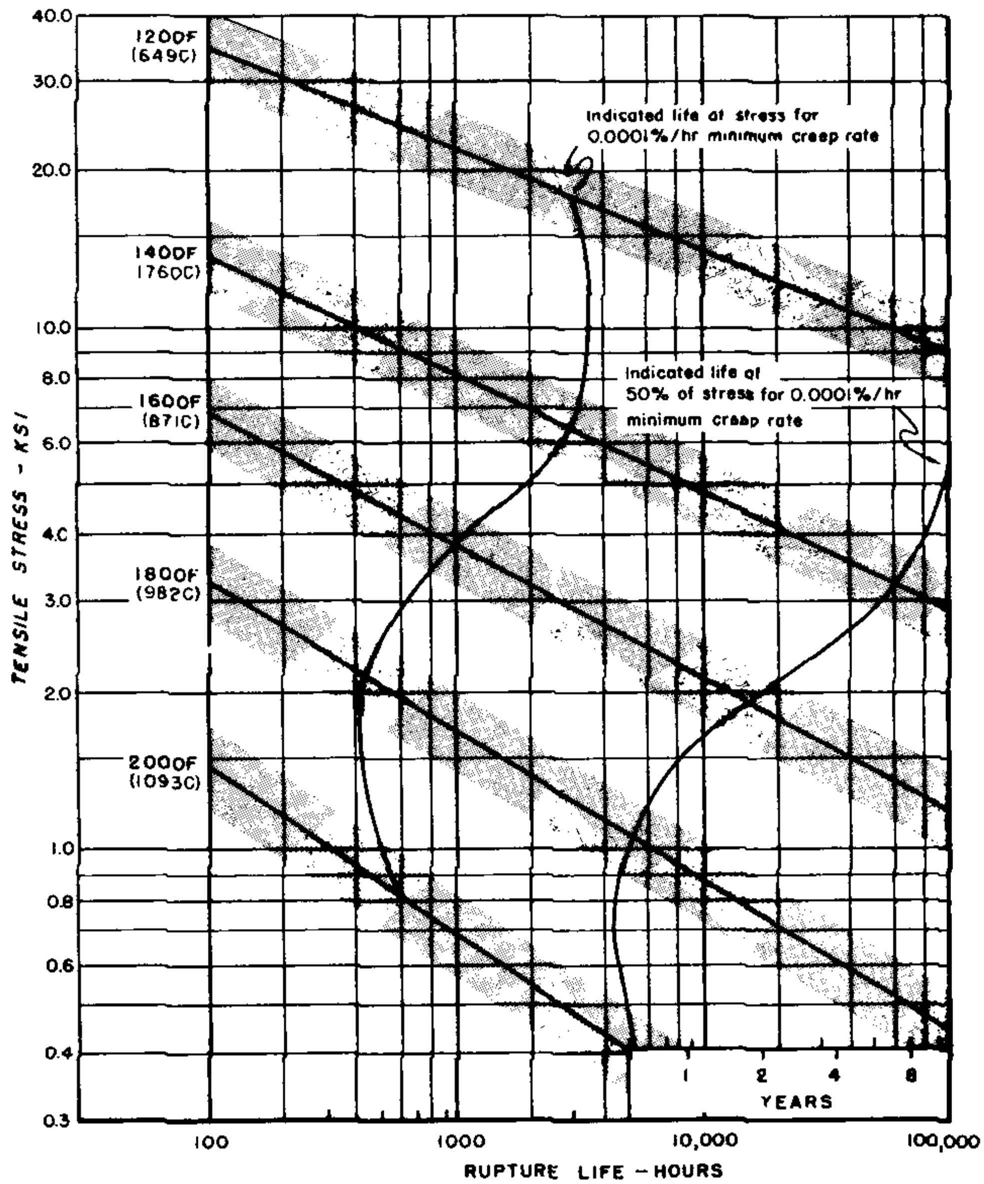


Fig. 4. Creep-rupture properties of Type HH (wholly austenitic) alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits. Scatter of values may be much wider, particularly at the longer times and higher temperatures.

Heat Resistant Type HI (UNS J94003)

Description

Type HI is an iron-chromium-nickel alloy similar to type HH, but containing more nickel and chromium. The increased chromium content makes this grade more resistant to oxidation than the HH type and the additional nickel serves to maintain good strength of high temperature. Exhibiting adequate strength, ductility and corrosion resistance, this alloy has been used extensively for retorts operating with an internal vacuum at continuous temperature of 2150°F.

The alloy has a predominantly austenitic structure containing carbides and, depending on the exact composition balance, may or may not contain small amounts of ferrite. Aging at 1400 to 1600°F (760 to 871°C) is accompanied by precipitation of finely dispersed carbides which tend at room temperature to increase mechanical strength and to decrease ductility. Following service at temperatures to increase the room temperature mechanical strength and to decrease the ductility above 2000°F (1093°C), however, such carbides remain in solution and room temperature ductility is not impaired.

Castings of type HI alloy have good weldability and fair machining characteristics. At room temperature, thermal expansion is about 50 percent greater than carbon steel or iron-chromium alloy types HC and HD, and heat conductivity is about 40 percent less. The alloy is virtually non-magnetic.

Heat Treatment

Castings of type HI alloy are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HI alloy has been employed

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						26	14	
max.	0.50	2.00	2.00	0.04	0.04	0.5[1]	30	18	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Density, lb/in^3	0.279
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, µΩ.m, at 70 °F	0.85
Melting point, approximate °F	2550
Magnetic permeability	1.00 - 1.7

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion µ in./(in. °F)	
At 212 °F	8.2	70 - 1000 °F	9.9
At 600 °F	10.1	70 - 1200 °F	10.0
At 1000 °F	12.0	70 - 1400 °F	10.1
At 1200 °F	13.0	70 - 1600 °F	10.3
At 1400 °F	14.1	70 - 1800 °F	10.5
At 1600 °F	15.3	70 - 2000 °F	10.8
At 1800 °F	16.3	1200 - 1600 °F	11.0
At 2000 °F	17.5	1200 - 1800 °F	12.0

Mechanical properties at room temperature

	Representative values		Minimum tensile requirements
	As cast	Aged 24h at 1400 °F Furnace cooled	ASTM A297
Tensile strength, ksi	80.0	90.0	70.0
Yield strength, 0.2% offset, ksi	45.0	65.0	35.0
Elongation, in 2in., %	12	6	10
Brinell hardness (HBW)	180	200	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	38.0	-	6
1400 °F	26.0	-	12

Creep rupture properties

Representative values[3] - long time	Limiting creep stress, ksi (rate 0.0001%/h)	Stress to rupture in hours 100	1,000
1400 °F	6.60	13.0	8.50
1600 °F	3.60	7.5	4.80
1800 °F	1.90	4.1	2.60
2000 °F	0.80	1.9	1.25
2150 °F			

[2] For constant temperature, for cyclic temperature lower values would apply

successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Heat Treating, Magnesium Reducing, Steel.

Castings Billet skids, brazing fixtures, conveyor rollers, furnace rails, hearth plates, lead pots, pier caps, retorts, tube spacers.

Environment Air, flue gases oxidizing and reducing, molten lead.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HI. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HI alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding The welding procedures outlined for Alloy HH are applicable for Alloy HI. Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HI alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

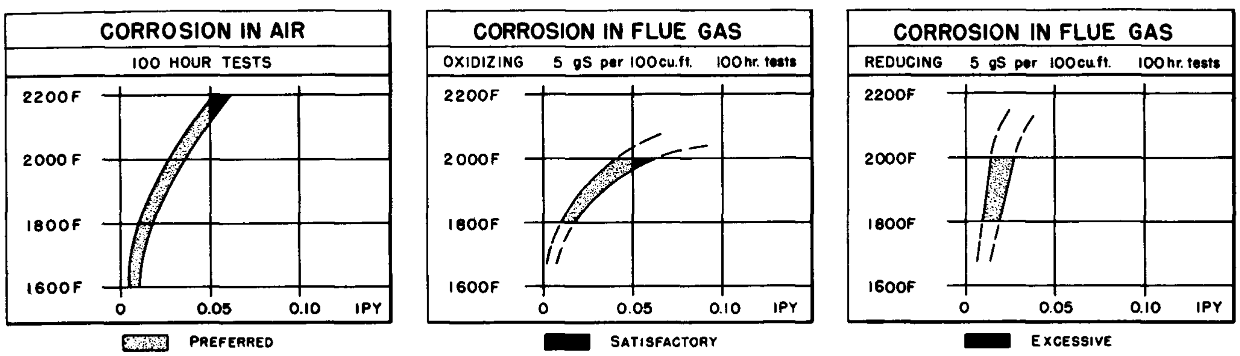
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

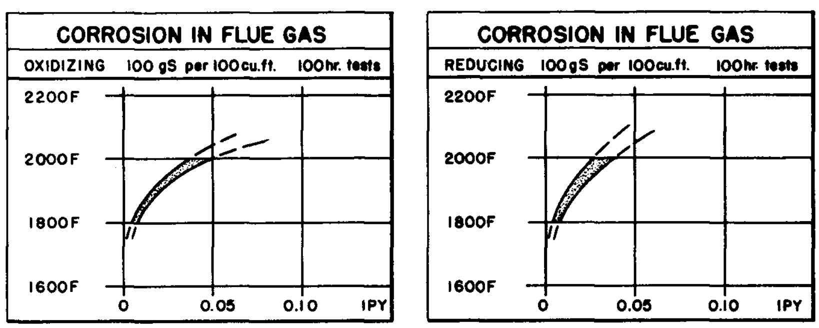
The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast ASTM: A297(HI), A608(HI35)

Wrought None



RESISTANCE TO CORROSION BY					
SALTS		MOLTEN METALS			
Tempering	FAIR	LEAD	GOOD	TYPE METAL	
Neutral	POOR	TIN		SOFT SOLDER	
		ZINC	POOR	BABBITT	
Cyaniding	GOOD	ALUMINUM	Not Resistant	ANTIMONY	
High Speed	POOR	Magnesium	Not Resistant	CADMIUM	



Heat Resistant Type HK (UNS J94224)

Description

Type HK is an iron-chromium-nickel alloy somewhat similar to a wholly austenitic type HH in general characteristics and mechanical properties. Although not quite as resistant to oxidizing gases as types HC, HE, OR HI, the HK alloy has chromium content high enough to ensure good resistance to corrosion by hot gases, in both oxidizing or reducing conditions. The high nickel content helps to make the HK grade one of the strongest heat resistant casting alloys at temperatures above 1900°F (1038°C). Accordingly, HK type castings are widely used for stressed parts in structural applications up to 2100°F (1149°C).

As normally produced, the HK alloy type is stable austenitic over its entire temperature range of application. The as-cast microstructure consists of an austenite matrix containing massive carbides as scattered islands or networks. After aging at service temperature, the alloy exhibits a dispersion of fine, granular carbides within the austenite grains, with subsequent agglomeration if the temperature is high enough. These fine, dispersed carbides contribute to the creep strength of the alloy. A lamellar constituent tentatively identified as an austenite, carbonitride eutectoid resembling pearlite also is frequently observed in HK alloys but its exact nature is in doubt. Except when present in excessive amounts, however, it is not associated with loss of hot strength. Unbalanced compositions are possible within the stated chemical ranges of this grade, and in this event some ferrite may be present in the austenite matrix. Such ferrite will transform to the brittle sigma phase if the alloy is held for more than short times around 1500°F (816°C) with consequent weakening at this temperature and embrittlement

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						24	18	
max.	0.60	2.00	2.00	0.04	0.04	0.5[1]	28	22	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	
Equiaxed grains	27.0
Columnar grains	20.0
See Fig. 1 for variation with temperature	
Poisson's ratio (See Fig. 1 for variation with temperature)	0.30
Density, lb/in^3	0.280
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, µΩ.m, at 70 °F	0.90
Melting point, approximate °F	2550
Magnetic permeability	1.02

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion µ in./(in. °F)			
At 212 °F	7.9	70 - 1000 °F	9.4	70 - 1800 °F	10.2
At 600 °F	9.8	70 - 1200 °F	9.6	70 - 2000 °F	10.4
At 1000 °F	11.8	70 - 1400 °F	9.8	1200 - 1800 °F	11.4
At 1200 °F	12.9	70 - 1600 °F	10.0	1200 - 2000 °F	11.7
At 1400 °F	14.2				
At 1600 °F	15.7[2]				
At 1800 °F	17.1[2]				
At 2000 °F	18.6[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values: As cast	Representative values: Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	75.0	85.0	65.0
Yield strength, 0.2% offset, ksi	50.0	50.0	35.0
Elongation, in 2in., %	17	10	10
Brinell hardness (HBW)	170	190	-
Charpy keyhole, ft lbs 21.5			

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	37.5	24.4	12
1600 °F	23.3	14.7	16
1800 °F	12.4	8.7	42
1900 °F	9.1	6.8	54
2000 °F	5.6	5.0	55

Creep rupture properties
Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	1% creep stress, ksi, in 100,000	Stress to rupture in ksi, hours 100	1,000	10,000	100,000
1400 °F	10.20	6.30[4]	15.55	12.00	8.80	6.20[4]
1600 °F	6.00	2.50[4]	9.20	6.00	3.80	2.50[4]
1800 °F	2.50	0.90[4]	4.75	2.80	1.70	1.00[4]
1900 °F	1.40	0.39[4]	3.20	1.90	1.10[4]	0.66[4]
2000 °F	0.65	0.23[4]	2.20	1.25	0.72[4]	0.42[4]

[3] For constant temperature, for cyclic temperature lower values would apply
[4] Extrapolated

at room temperature. Formation of sigma phase in HK type alloy can occur directly from austenite in the range 1400 to 1600°F (760 to 871°C) particularly at the lower carbon level (0.20-0.30 percent), and for this reason a considerable scatter in properties at intermediate temperatures is observed for this grade. Silicon is helpful in conferring resistance of the alloy to carburization, but is normally held to 2.00 percent maximum because higher amounts promote sigma formation.

Minimum creep rate and average rupture life are influenced strongly by variations in the carbon content of the HK alloy. Under the same conditions of temperature and load, alloys with higher carbon content have reduced creep rates and longer lives than those with lower carbon contents. Room temperature properties after aging at elevated temperatures are affected also: the higher the carbon the lower the residual ductility. For these reasons, within the chemical composition required by ASTM Specification A297 for the general HK alloy type shown in the Summary of Properties, three grades with narrower carbon ranges are recognized. These are the HK-30, HK-40 and HK-50 grades, in which the number following the alloy type designation indicates the midpoint of a +0.05 percent carbon range. In addition to the carbon limitation, a nitrogen range of 0.05 to 0.15 percent is specified for grades HK-40 and HK-50 in ASTM Specification A567. Nitrogen and molybdenum are not specified for grades HK-30 and HK-40 in ASTM Specification A351 but the manganese and silicon limits are lowered to 1.50 and 1.75 maximum, respectively, the chromium range is lowered to 23 to 27 percent and the nickel range is narrowed to 19 to 22 percent for each grade. An extended discussion of the influence of chemical composition variations on the mechanical properties of the HK type alloys is given in ALLOY CASTING BULLETIN No. 17, October 1961. Of the three grades, the HK-40 alloy of Specification A351 has become the most widely used. It has found extensive application in the petroleum and petro-chemical industries for process equipment operating at high temperatures.

Castings of type HK alloy have good weldability and machining characteristics. Thermal expansion is about 40 percent greater than carbon steel or iron-chromium alloy types HC and HD, and heat conductivity is about 40 percent less. At room temperature, electrical resistance is about six times that of carbon steel, and the alloy is virtually non-magnetic.

Heat Treatment

Castings of type HK alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HK alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Aircraft, Cement, Fertilizer, Heat Treating, Ore Refining, Petrochemical, Petroleum, Steel.

Castings Billet skids, brazing fixtures, calcining tubes, cement kiln nose segments, conveyor rolls, furnace door arches and lintels, heat treating trays and fixtures, pier caps, rabble arms and blades, radiant tubes, reformer tubes, retorts, rotating shafts, skid rails, sprockets, stack dampers.

Environment Air, ammonia, carburizing gases, combustion gases, flue gases oxidizing and reducing, hydrogen, molten neutral salts.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HK. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HK alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HK castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. Metal-arc welding is generally preferred for high temperature applications of this alloy. Neither preweld nor postweld heat treating is required.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HK alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

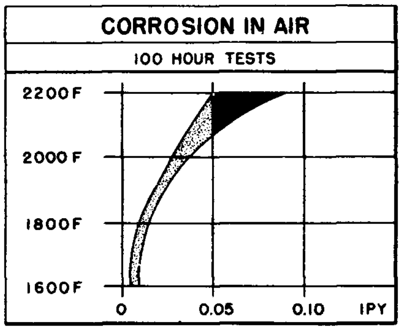
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

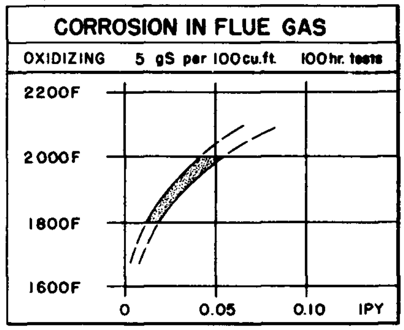
Casting designations, specifications, and corresponding wrought alloy

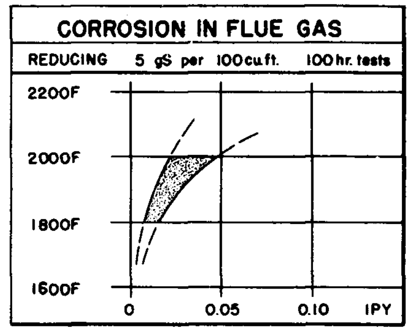
The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

Cast ASTM: A297(HK), A351(HK30, HK40), A567(HK40, HK50), A608(HK30, HK40), SAE 70310, AMS 5365

Wrought AISI 310



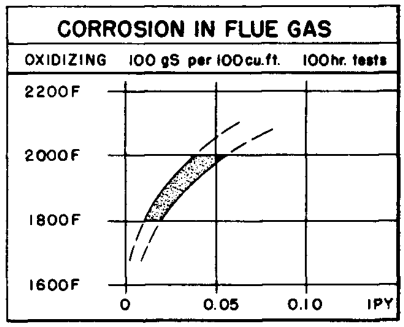


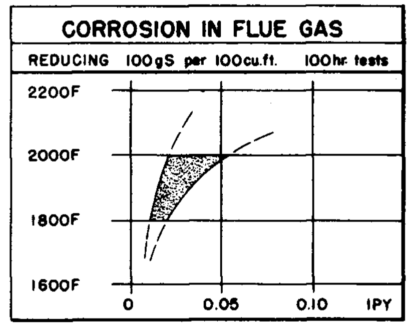


PREFERRED SATISFACTORY EXCESSIVE

RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering	GOOD	LEAD		TYPE METAL	
Neutral	GOOD	TIN		SOFT SOLDER	
		ZINC		BABBITT	
Cyaniding	GOOD	ALUMINUM	Not Resistant	ANTIMONY	
High Speed	GOOD	Magnesium	Not Resistant	CADMIUM	





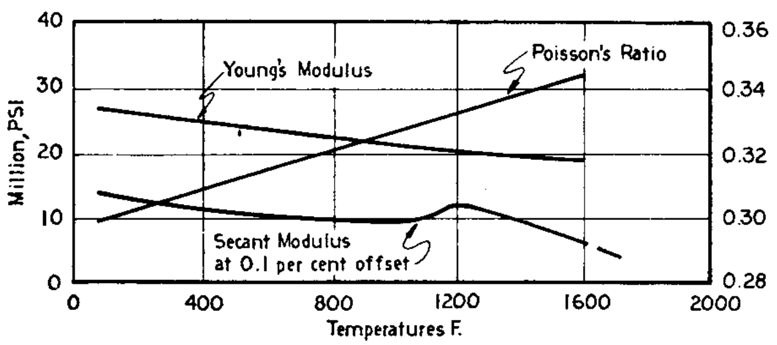


Fig. 1. Effect of temperature of tension test on elastic moduli and Poisson's Ratio of equiaxed grain Type HK 40 alloy.

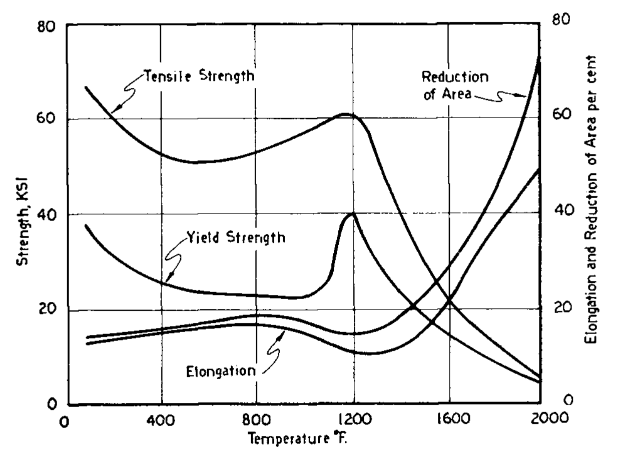


Fig. 2. Effect of temperature on short-time tension test properties of Type HK 40 alloy.

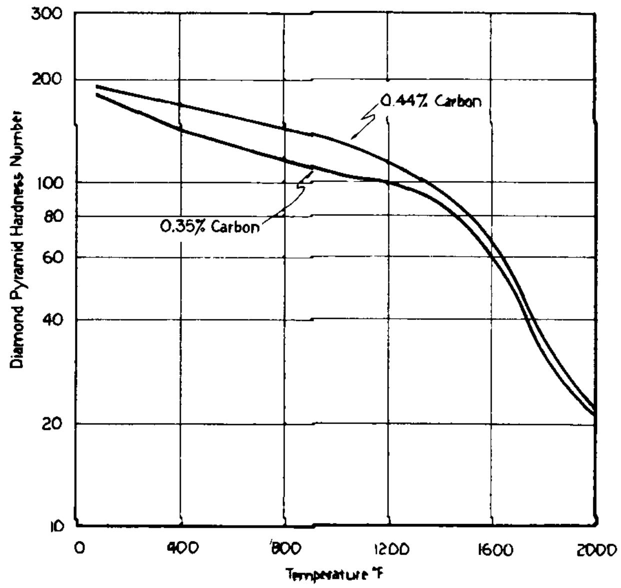


Fig. 3. Effect of temperature on hardness of Type HK 40 alloy.

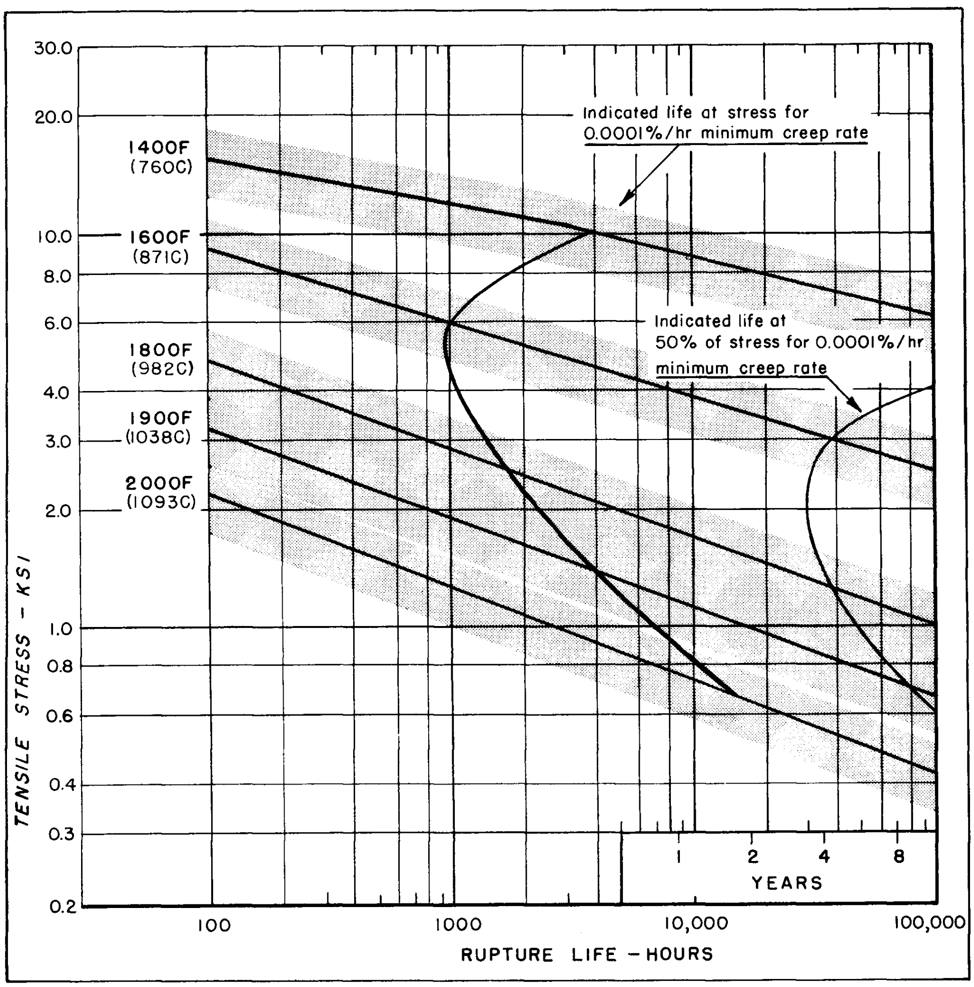


Fig. 4. Creep-rupture properties of Type HK-40 alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits. Scatter of values may be much wider, particularly at the longer times and higher temperatures.

Heat Resistant Type HL (UNS J94604)

Description

Type HL is an iron-chromium-nickel alloy similar to type HK, but its higher chromium content gives this grade greater resistance to corrosion by hot gases, particularly those containing appreciable amounts of sulfur. Because essentially equivalent high temperature strength can be obtained with either the HK or HL grades, the improved corrosion resistance of the HL alloy makes it especially useful for severe service where excessive scaling must be avoided.

The as-cast and aged microstructures of type HL alloy, as well as its physical properties and fabricating characteristics are about the same as those of the HK grade.

Heat Treatment

Castings of type HL alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HL alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Steel, Vitreous Enamel.

Castings Carrier fingers, enameling furnace fixtures, furnace skids for slabs and bars, radiant tubes, stack dampers.

Environment Air, flue gases.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						28	18	
max.	0.60	2.00	2.00	0.04	0.04	0.5[1]	32	22	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	29.0
Density, lb/in^3	0.279
Sp. Heat, Btu/lb.°F, at 70 °F	0.12
Electrical resistivity, μΩ.m, at 70 °F	0.94
Melting point, approximate °F	2600
Magnetic permeability	1.01

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	8.2	70 - 1000 °F	9.2	70 - 1800 °F	9.9
At 600 °F	10.2	70 - 1200 °F	9.4	70 - 2000 °F	10.1
At 1000 °F	12.2	70 - 1400 °F	9.6	1200 - 1600 °F	10.5
At 1200 °F	13.4	70 - 1600 °F	9.7	1200 - 1800 °F	10.7
At 1400 °F	14.7				
At 1600 °F	16.3				
At 1800 °F	17.7				
At 2000 °F	19.3				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Minimum tensile requirements ASTM A297
Tensile strength, ksi	82.0	65.0
Yield strength, 0.2% offset, ksi	50.0	35.0
Elongation, in 2in., %	19	10
Brinell hardness (HBW)	192	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	50.0	-	-
1600 °F	30.4	-	-
1800 °F	18.7	-	-

Creep rupture properties
Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	Stress to rupture, stress, ksi,hours 100	1,000	10,000
1400 °F	7.0	15.0	12.00	8.80
1600 °F	4.3	9.2	6.00	3.80
1800 °F	2.2	5.2	2.80	1.70

[3] For constant temperature, for cyclic temperature lower values would apply

the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HL. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HL alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding The welding procedures outlined for Alloy HK are applicable for Alloy HL. Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HL alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully.

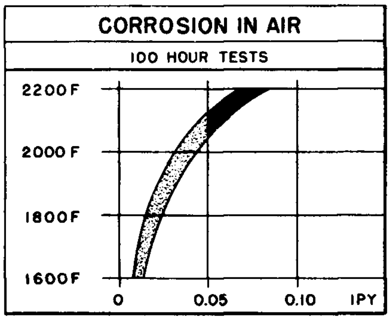
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

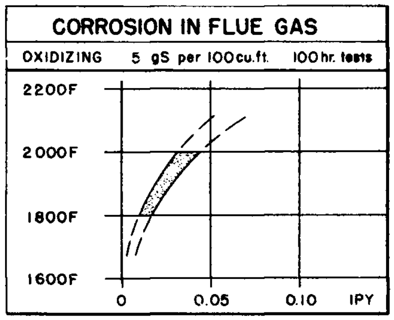
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

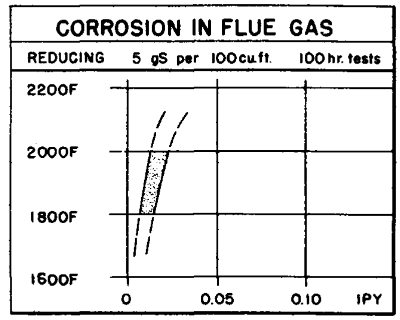
Casting designations, specifications, and corresponding wrought alloy

Cast ASTM: A297(HL), A608(HL30, HL40), SAE 70310A

Wrought None



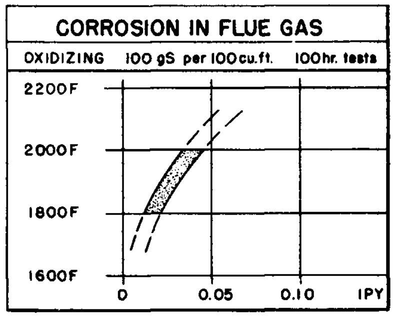


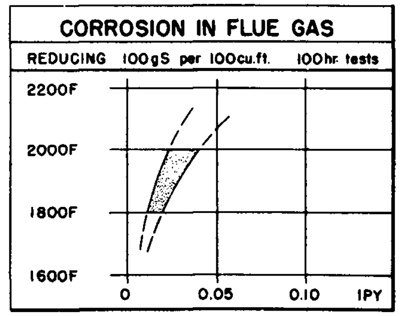


PREFERRED   SATISFACTORY   EXCESSIVE

RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering		LEAD		TYPE METAL	
Neutral		TIN		SOFT SOLDER	
Cyaniding		ZINC		BABBITT	
High Speed		ALUMINUM	Not Resistant	ANTIMONY	
		Magnesium	Not Resistant	CADMIUM	





Heat Resistant Type HN (UNS J94213)

Description

Type HN is an iron-chromium-nickel alloy containing sufficient chromium for good high temperature corrosion resistance and with a nickel content in excess of the chromium content. The alloy has properties somewhat similar to the much more widely used type HT alloy but with better ductility. It is used for highly stressed components in the 1800-2000°F (982 to 1093°C) temperature range. In several specialized applications, notably brazing fixtures, it has given satisfactory service at temperatures of 2000 to 2100°F (1093 to 1149°C).

The alloy has an austenitic structure at all temperatures, and lies well within the stable austenite field. In the as-cast condition carbide areas are present and additional fine carbides precipitate on aging. The alloy is not susceptible to sigma phase formation, nor is increased carbon content especially detrimental to ductility.

Castings of type HN alloy have good machining and welding properties if proper techniques are employed.

Heat Treatment

Castings of type HN alloy are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HN alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Aircraft, Automotive, Petroleum, Petrochemical, Power.

Castings Brazing fixtures, chain,

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.20						19	23	
max.	0.50	2.00	2.00	0.04	0.04	0.5[1]	23	27	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Density, lb/in^3	0.283
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, μΩ.m, at 70 °F	0.991
Melting point, approximate °F	2500
Magnetic permeability	1.10

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	7.5	70 - 1000 °F	9.3	70 - 1800 °F	10.1
At 600 °F	9.2	70 - 1200 °F	9.5	70 - 2000 °F	10.2
At 1000 °F	11.0	70 - 1400 °F	9.7	1200 - 1800 °F	11.0
At 1200 °F	12.1	70 - 1600 °F	9.9	1200 - 2000 °F	11.1
At 1400 °F	13.2				
At 1600 °F	14.5				
At 1800 °F	15.7[2]				
At 2000 °F	17.0[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Minimum tensile requirements ASTM A297
Tensile strength, ksi	68.0	63.0
Yield strength, 0.2% offset, ksi	38.0	38.0
Elongation, in 2in., %	13	8
Brinell hardness (HBW)	160	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1600 °F	20.250	14.50	37
1800 °F	11.950	9.675	51
1900 °F	8.500	5.500	53
2000 °F	6.165	4.925	55

Creep rupture properties
Representative values[3] - long time

	Limiting stress,ksi, creep rate 0.0001%/h	1% creep stress, in, ksi 100,000	Stress to rupture in ksi hours 100	1,000	10,000	100,000
1600 °F	6.30	3.00[4]	11.0	7.40	4.80	3.20[4]
1800 °F	2.40	1.10[4]	5.6	3.40	2.10	1.30[4]
1900 °F	1.60	0.45[4]	4.6	2.10	0.96[4]	0.44[4]
2000 °F	1.04	0.17[4]	2.9	1.25	0.52[4]	0.22[4]

[3] For constant temperature, for cyclic temperature lower values would apply
[4] Extrapolated

furnace beams and parts, pier caps, radiant tubes and tube supports, sill plate brackets, torch nozzles, trays, tubes.

Environment Air, flue gases oxidizing and reducing.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HN. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HN alloy. Somewhat lighter sections are feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding The welding procedures outlined for Alloy HK are applicable for Alloy HN. Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HN alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

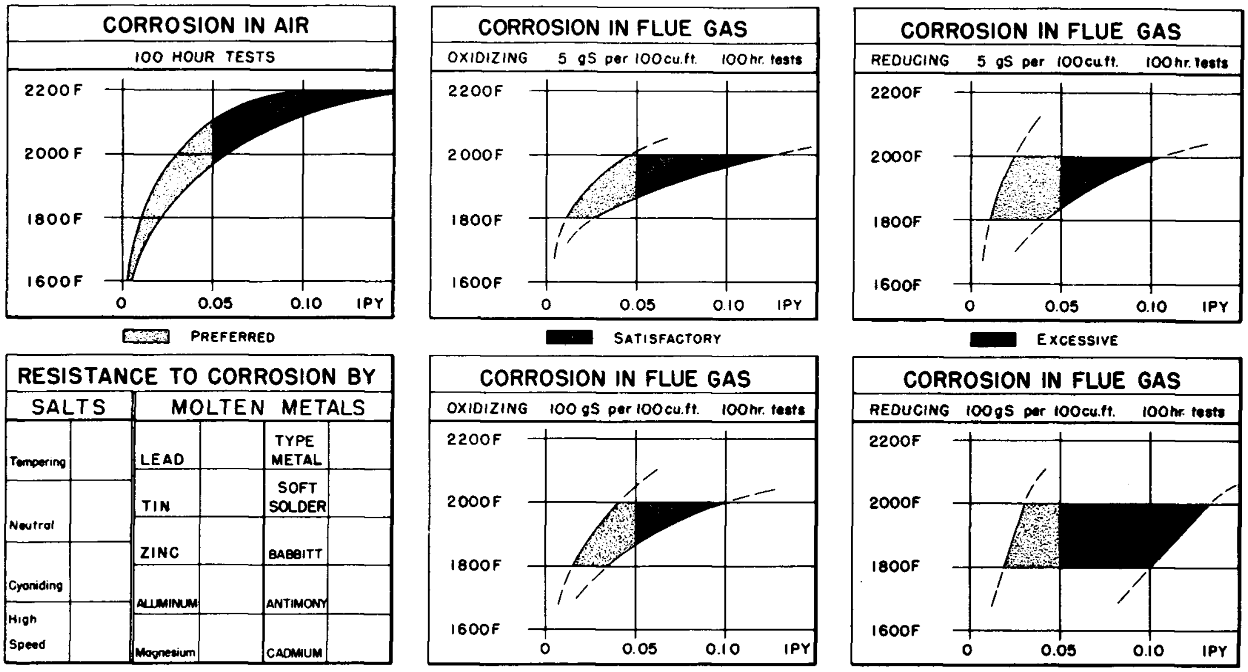
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

Cast ASTM: A297(HN), A608(HN40)

Wrought None



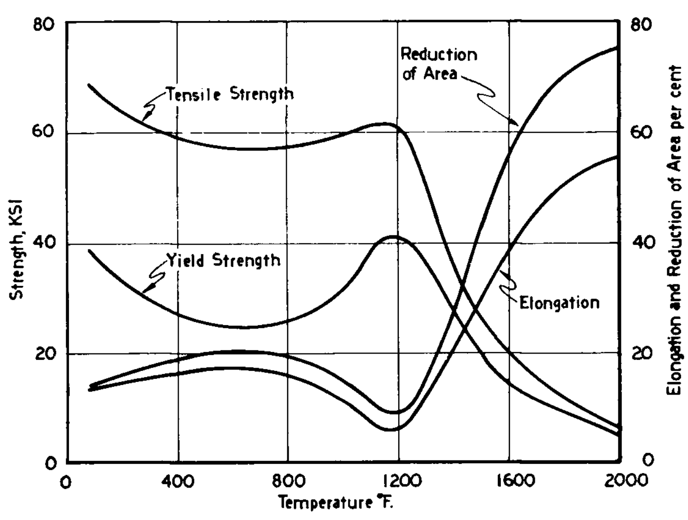


Fig. 1. Effect of temperature on short-time tension test properties of Type HN alloy.

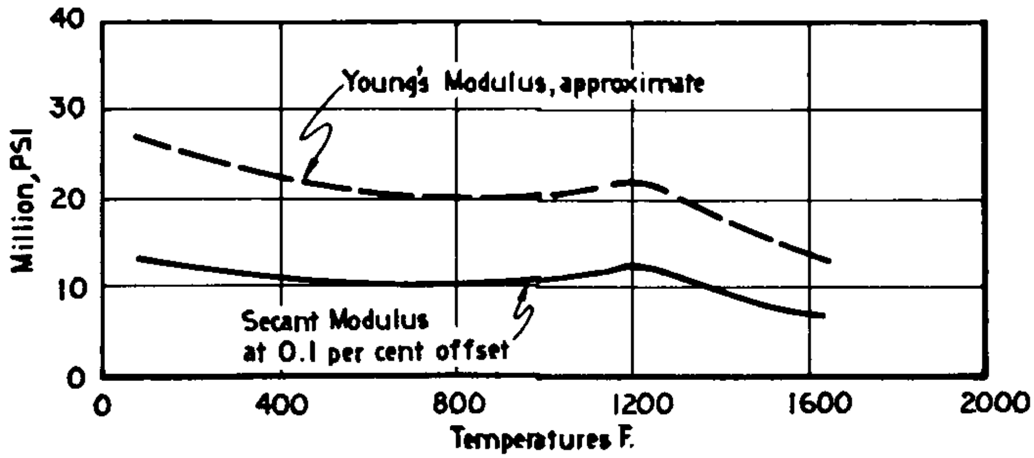


Fig. 2. Effect of temperature of tension test on approximate modulus elasticity of Type HN alloy.

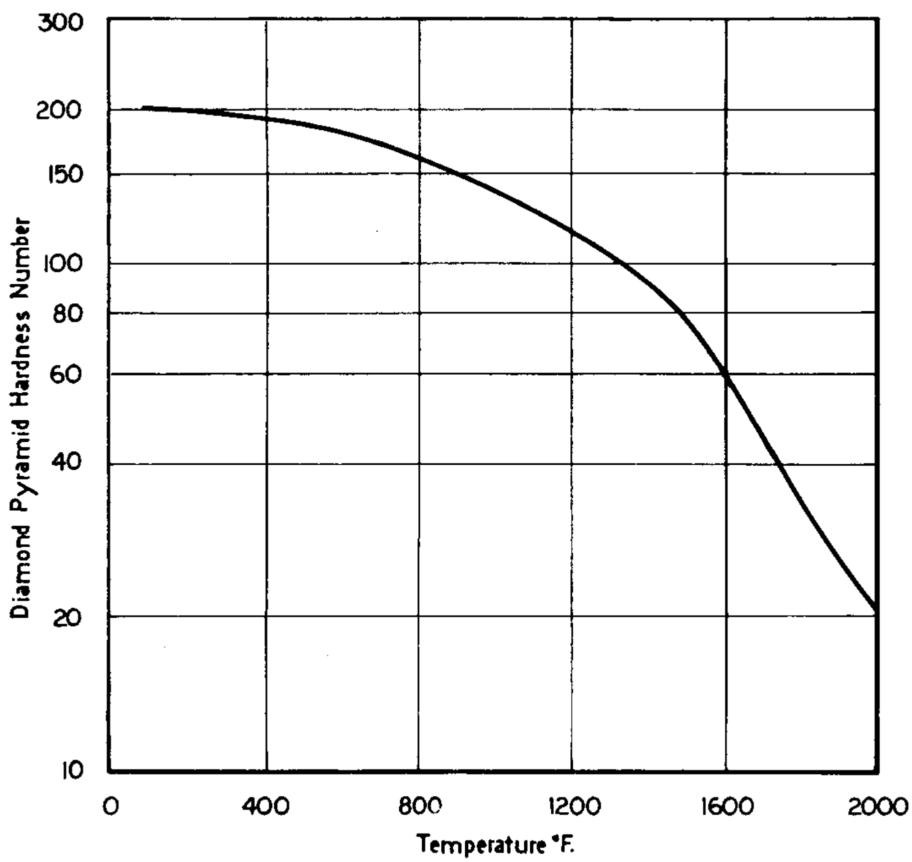


Fig. 3. Effect of temperature on hardness of Type HN alloy.

TYPE HN

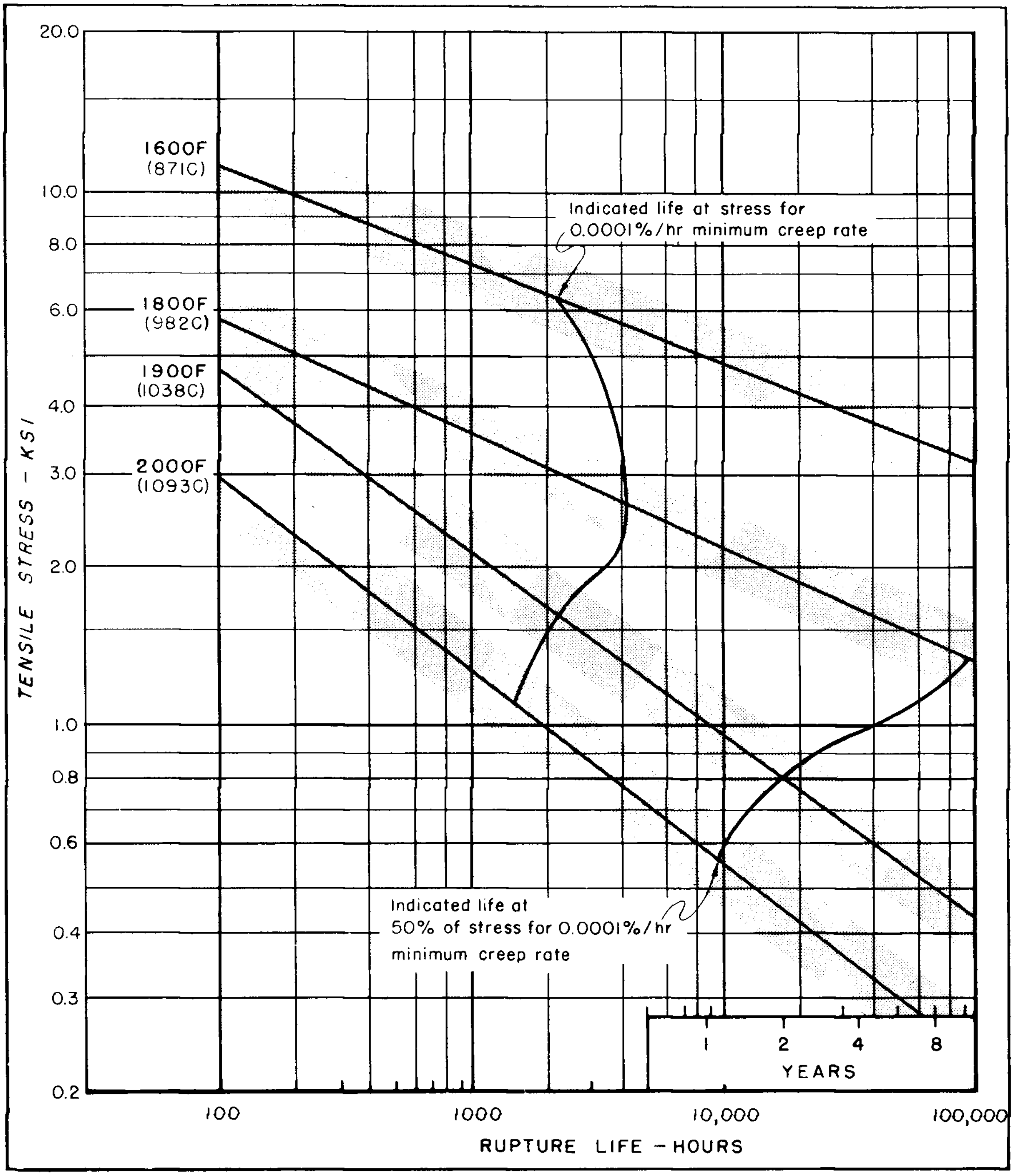


Fig. 4. Creep-rupture properties of Type HN alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits. Scatter of values may be much wider, particularly at the longer times and higher temperatures.

Heat Resistant Type HP (UNS J95705)

Description

Type HP is an iron-chromium-nickel alloy that is related to the HN and HT types but is higher in alloy content than either of those grades. It has the same chromium but more nickel than the HN type, and the same nickel but more chromium than the HT alloy. This combination of elements makes the HP composition resistant to both oxidizing and carburizing atmospheres at high temperatures. The alloy has good creep-rupture properties in the 1800 to 2000°F (982 to 1093°C) temperature range comparable to, or better than, the HK-40 and HN alloy types. The HP alloys have many modifications, to the extent that unmodified grades form a very small proportion of "HP" alloys supplied to purchasers. There are essentially two groups of alloy modifications. The first relies on the addition of such elements as Nb and W to improve creep rupture properties and the second makes a further addition of microalloys such as Ti. These microalloyed grades have even greater rupture properties than the first stage of modification. Within this group of alloy types the Si levels may be increased for applications in carburizing environments. The addition of Si usually causes a drop in the creep rupture properties when compared to the grades not used in carburizing applications.

Because of its high nickel content, the alloy is not susceptible to sigma phase formation. The microstructure consists of massive primary carbides in an austenitic matrix together with fine carbides which are precipitated within the austenite grains after aging at elevated temperature.

Castings of type HP alloy have good machining and welding properties similar to the HT type.

Heat Treatment

Castings of type HP alloy are normally supplied in the as-cast condition.

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.35						24	33	
max.	0.75	2.00	2.00	0.04	0.04	0.5[1]	28	37	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Poisson's ratio	0.3
Density, lb/in^3	0.284
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, μΩ.m, at 70 °F	1.02[2]
Melting point, approximate °F	2450
Magnetic permeability	1.02 - 1.25

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	7.5	70 - 1000 °F	9.2[2]	70 - 1800 °F	10.6[2]
At 600 °F	9.2[2]	70 - 1200 °F	9.5	70 - 2000 °F	11.4[2]
At 1000 °F	11.0[2]	70 - 1400 °F	9.8[2]	1200 - 1800 °F	11.9[2]
At 1200 °F	12.1[2]	70 - 1600 °F	10.0[2]	1200 - 2000 °F	12.2[2]
At 1400 °F	13.2[2]	70 - 1800 °F	10.3[2]	1600 - 2000 °F	13.1[2]
At 1600 °F	14.5[2]				
At 1800 °F	15.7[2]				
At 2000 °F	17.0[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Minimum tensile requirements ASTM A297
Tensile strength, ksi	71.0	62.5
Yield strength, 0.2% offset, ksi	40.0	34.0
Elongation, in 2in., %	11.5	4.5

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	43.0	29.0	15
1600 °F	26.0	17.5	27
1800 °F	14.5	11.0	46
2000 °F	7.5	6.2	69

Creep rupture properties

Representative values[3] - long time

	Limiting stress,ksi, creep rate 0.0001%/h	1% creep in, ksi 100,000	Stress to rupture in stress, ksi hours 100	1,000	10,000	100,000
1600 °F	5.8	4.9	10.0	7.5	5.10	3.30[4]
1800 °F	2.8	2.1	5.9	3.6	2.20	1.10[4]
2000 °F	1.0	0.4	2.8	1.5	0.60	0.25[4]

[3] For constant temperature, for cyclic temperature lower values would apply
[4] Extrapolated

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HP alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Heat Treating, Petrochemical, Petroleum.

Castings Ethylene pyrolysis heaters, heat treat fixtures, radiant tubes, refinery tubes.

Environment Air, carburizing atmospheres, flue gases oxidizing and reducing.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HP. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HP alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HP castings can be welded by metal-arc, inert-gas arc, and oxyacetylene gas methods. Electric arc processes are most widely used. Neither preweld nor postweld heat treating is required.The welding procedures outlined for Alloy HK are applicable for Alloy HP.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HP alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts, and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

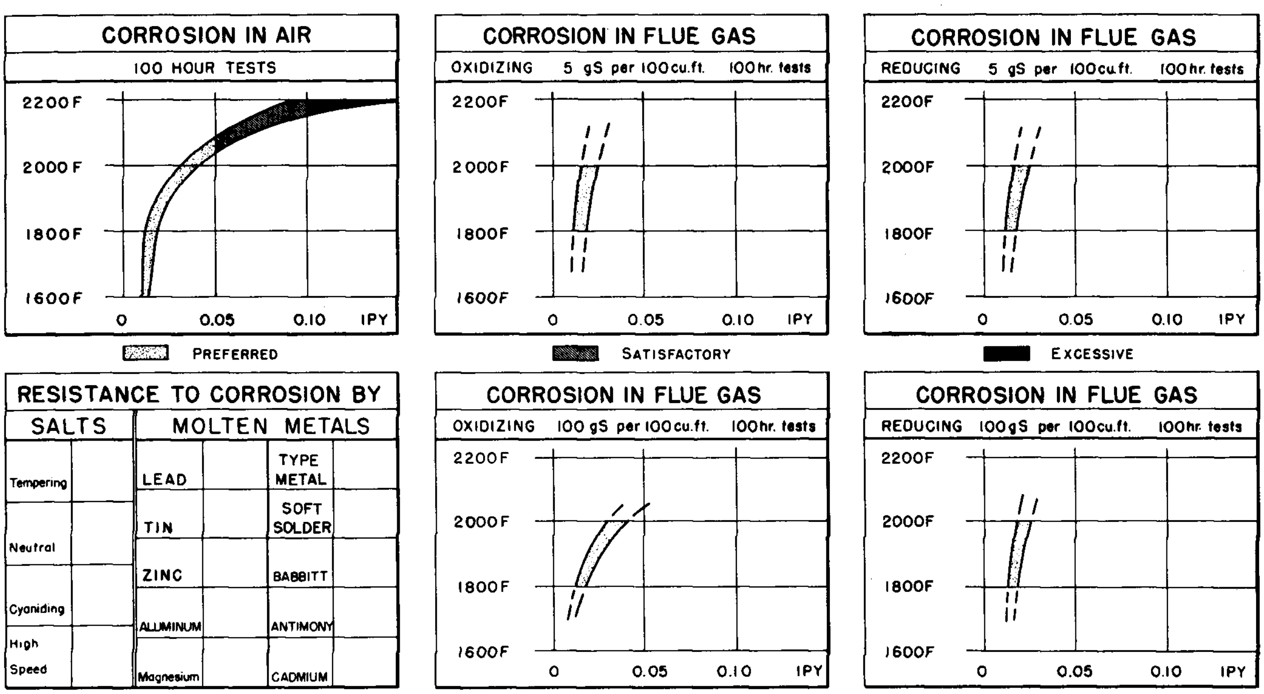
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

Cast ASTM: 297(HP)

Wrought None



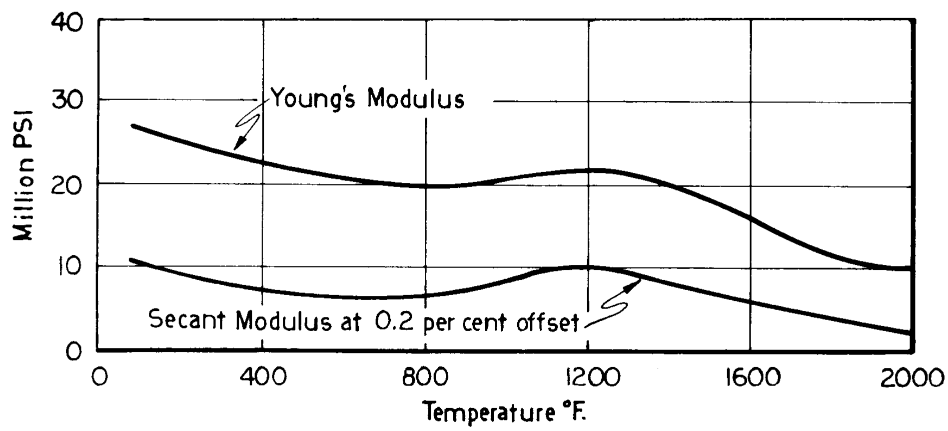


Fig. 1. Effect of temperature of tension test on elastic moduli of Type HP alloy.

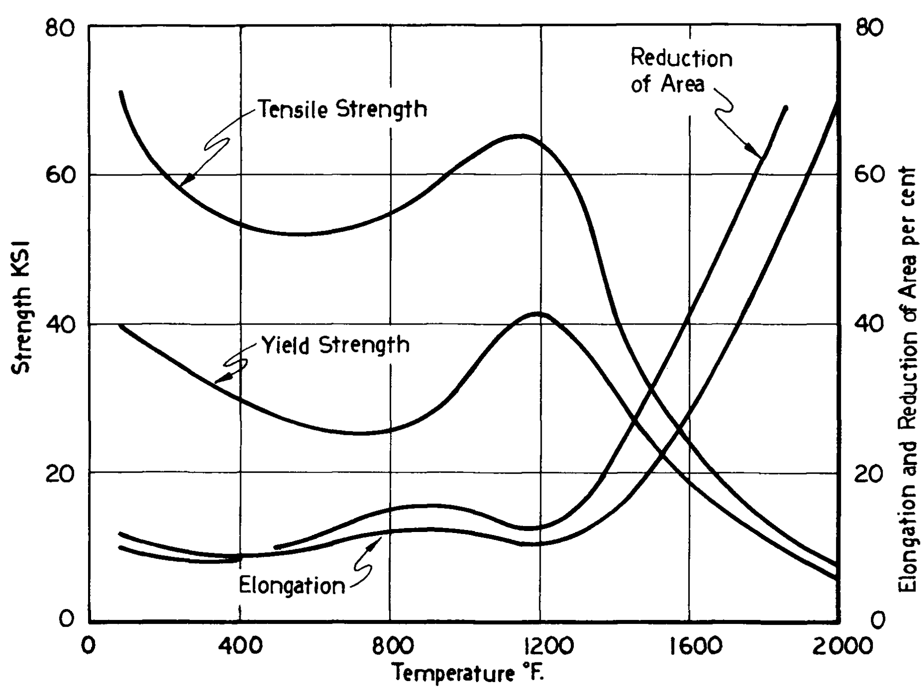


Fig. 2. Effect of temperature on short time tension test properties of Type HP alloy.

TYPE HP

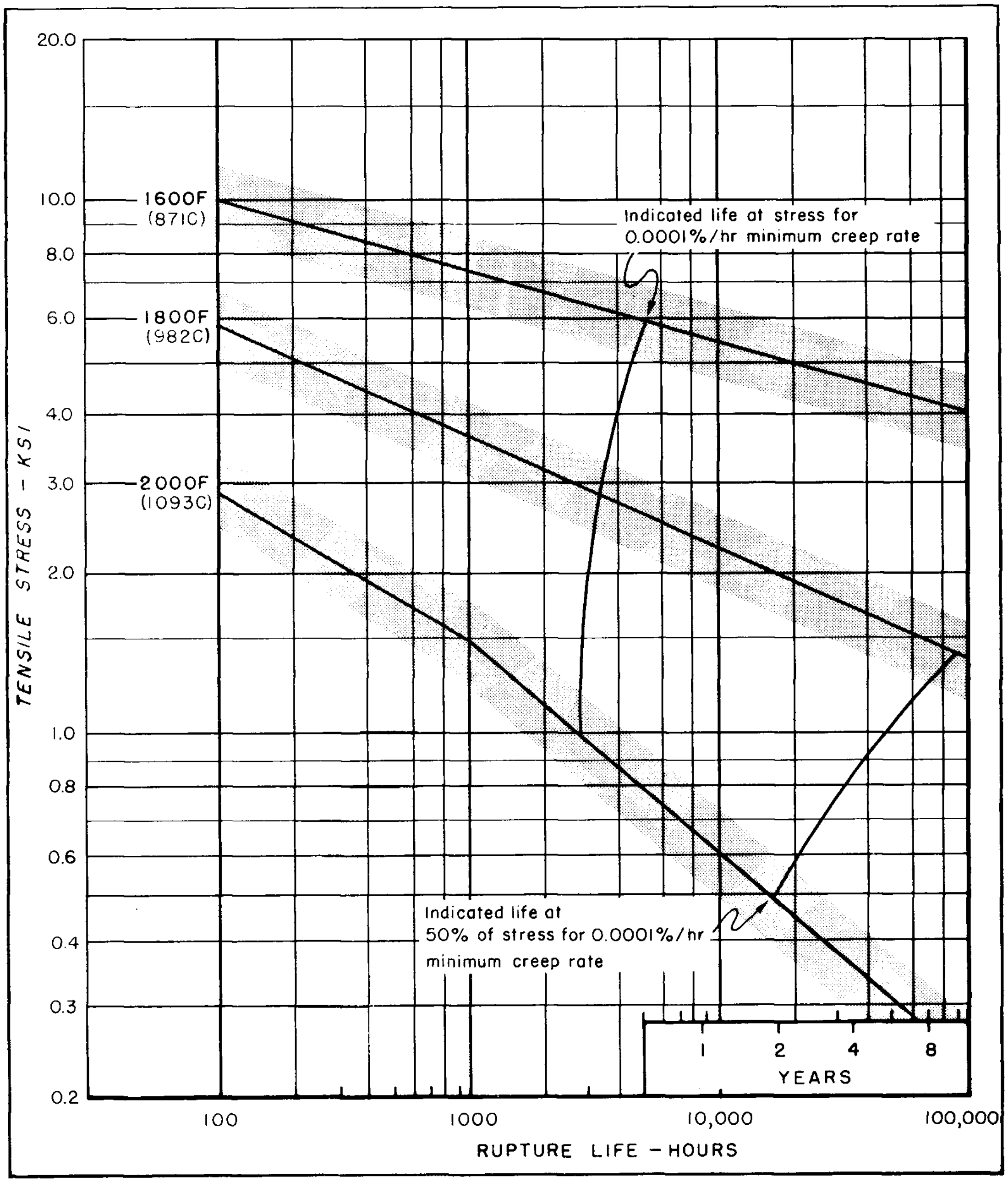


Fig. 3. Creep-rupture properties of Type HP alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits. Scatter of values may be much wider, particularly at the longer times and higher temperatures.

Heat Resistant Type HT (UNS J94605)

Description

Type HT is an iron-chromium-nickel alloy containing about equal amounts of iron and alloying elements. The high nickel content makes this grade useful in resisting the thermal shock of rapid heating and cooling. In addition the alloy is resistant at high temperature to oxidation and carburization, and has good strength at heat treating temperatures. Except in high sulfur gases, it performs satisfactorily up to 2100°F (1149°C) in oxidizing atmospheres and up to 2000°F (1093°C) in reducing atmospheres provided limiting creep stress values are not exceeded. This grade is widely used for general heat resistant applications in highly stressed parts.

The alloy has an austenitic structure containing varying amounts of carbides depending on the carbon content and thermal history. In the as-cast condition large carbide areas are present at the grain boundaries, but fine carbides precipitate within the grains after exposure at service temperatures with subsequent decrease in room temperature ductility. Increased carbon content does not significantly affect the high temperature ductility of the alloy; this characteristic makes it especially useful for carburizing fixtures or containers. Additional protection against carburization is obtained with silicon contents above about 1.6%, but at some sacrifice of hot strength.

Castings of type HT alloy have good machining and welding properties if proper techniques are employed. Thermal expansion is about one-third greater than carbon steel or iron-chromium alloy types HC or HD, and about ten percent less than iron-chromium-nickel alloy types HF and HH. Electrical resistance is over six times that of carbon steel and is characterized by a low temperature coefficient of resistivity (0.00017 per °F, 70-930°F) (0.000306 per °C, 21-499°C). The composition of type

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.35						15	33	
max.	0.75	2.00	2.50	0.04	0.04	0.5[1]	19	37	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Density, lb/in^3	0.286
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, μΩ.m, at 70 °F	1.0
Melting point, approximate °F	2450
Magnetic permeability	1.10 - 2.00

Thermal conductivity	Btu/(ft.h. °F)	Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	7.0	68 - 200 °F	7.90	68 - 1800 °F	9.33
At 600 °F	8.9	68 - 400 °F	8.14	68 - 2000 °F	9.56
At 1000 °F	10.8	68 - 600 °F	8.37	68 - 1800 °F	9.80
At 1200 °F	11.9	68 - 800 °F	8.61	68 - 2000 °F	10.04
At 1400 °F	12.9	68 - 1000 °F	8.85	1200 - 1600 °F	10.75
At 1600 °F	14.0	68 - 1200 °F	9.09	1200 - 1800 °F	11.00
At 1800 °F	15.3[2]				
At 2000 °F	16.3[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Representative values Aged 24h at 1400 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	70.0	75.0	65.0
Yield strength, 0.2% offset, ksi	40.0	45.0	-
Elongation, in 2in., %	10	5	4
Brinell hardness (HBW)	180	200	-
Charpy keyhole ft.lbs	4	-	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	42.4	28.0	5
1400 °F	35.0	26.0	10
1600 °F	18.8	15.0	26
1800 °F	11.0	8.0	28
2000 °F	6.0	-	-

Creep rupture properties

Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	Stress to rupture in stress, ksi hours 100	1,000	10,000	100,000
1400 °F	8.00	16.0	12.0	8.4	5.60[4]
1600 °F	4.50	8.9	5.8	3.7	2.40[4]
1800 °F	2.00	4.4	2.7	1.7	1.05[4]
1900 °F	0.50	2.1	1.3	-	-
2000 °F	0.15	-	-	-	-

[3] For constant temperature, for cyclic temperature lower values would apply

[4] Extrapolated

HT is such that the magnetic transformation of austenite occurs near room temperature. Minor shifts in constituents after service at high temperature or exposure to carburizing atmospheres may change as-cast magnetic permeability values considerably.

Heat treatment

Castings of type HT alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment, but for applications involving thermal fatigue from repeated rapid heating and cooling, improved performance may be obtained by heating castings at 1900°F (1038°C) for 12 hours followed by furnace cooling prior to placing in service.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HT alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Aluminum, Cement, Glass, Industrial Furnace, Heat Treating, Magnesium, Steel, Vitreous Enamel.

Castings Air ducts, brazing trays, carburizing containers, chain, cyanide pots, dampers, dippers, door frames, enameling bars and supports, fan blades, feed screws, gear spacers, glass molds, glass rolls, hearth plates, heat treating fixtures and trays, idler drums, kiln nose rings, lead pots, malleablizing baskets, muffles, oil burner nozzles, point bars, radiant tubes, resistor guides, retorts, roller rails, rolling mill guides, salt pots, tube supports.

Environment Air carburizing gas, flue gases oxidizing and reducing, molten metals, salts.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HT. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HT alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HT castings can be welded by metal-arc, inert gas-arc, and oxyacetylene gas methods.

Electric arc processes are most widely used, but satisfactory welds are also made with the oxyacetylene flame. The optimum balance between weld soundness and ductility is obtained if the Si to C ratio in the weld deposit is about the same as in the cast alloy, i.e. about 2:1.

Neither preweld nor postweld heat treating is required.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HT alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

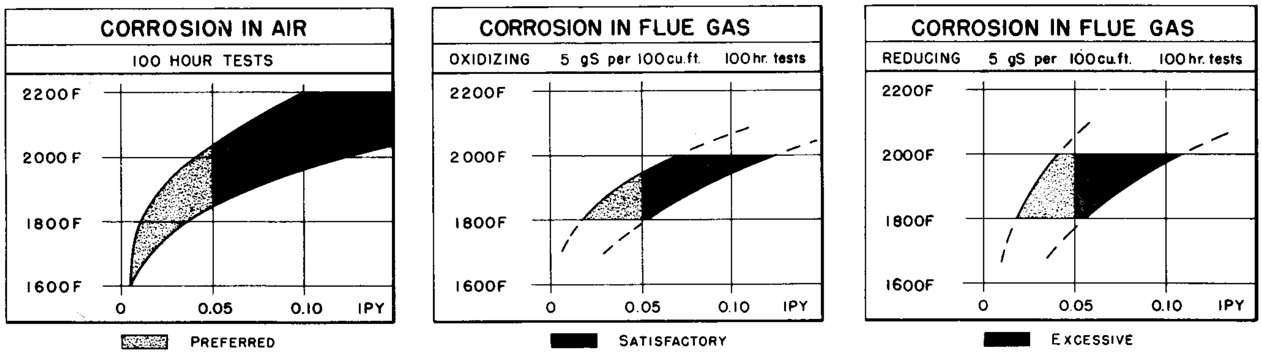
Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

The American Iron and Steel Institute wrought alloy designation is listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

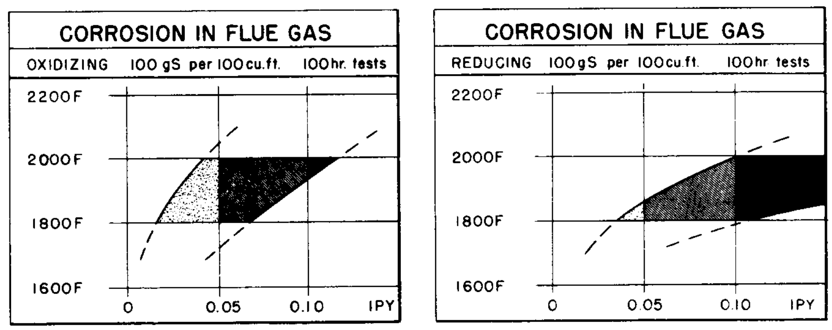
Cast ASTM: A297(HT), A608(HT50), SAE 70330

Wrought AISI 330



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering	GOOD	LEAD	GOOD	TYPE METAL	POOR
Neutral	FAIR with proper control	TIN	GOOD to 650F	SOFT SOLDER	POOR
		ZINC	POOR	BABBITT	POOR
Cyaniding	GOOD	ALUMINUM	Not Resistant	ANTIMONY	POOR
High Speed	FAIR	Magnesium	Not Resistant	CADMIUM	GOOD to 775F



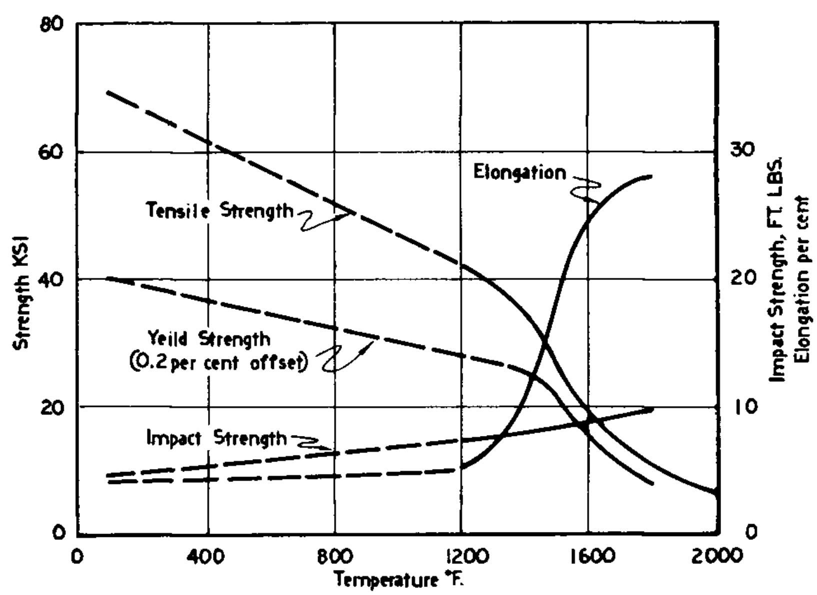


Fig I Effect of temperature on short time tension test and Charpy impact properties of Type HT alloy.

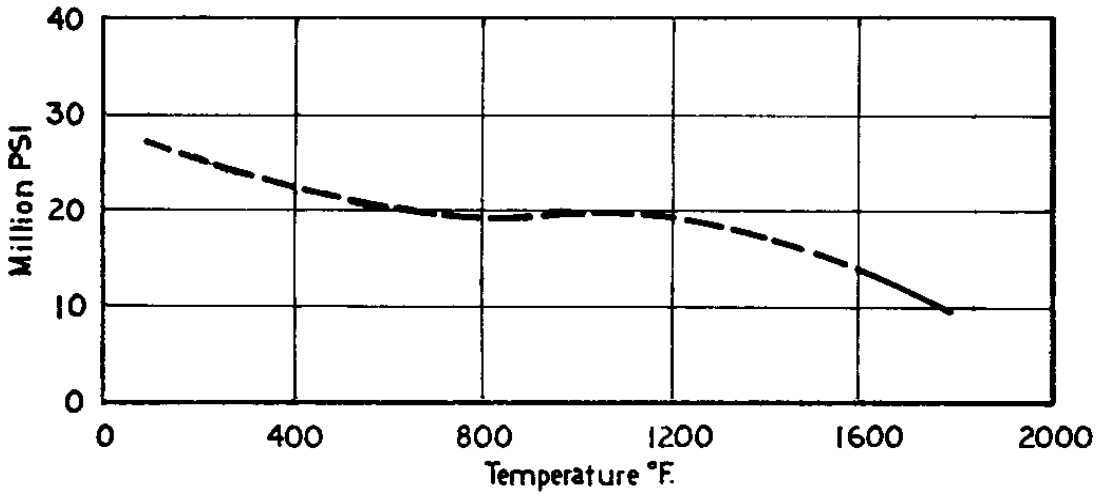


Fig. 2 Effect of temperature of tension test on approximate modulus of elasticity of Type HT alloy

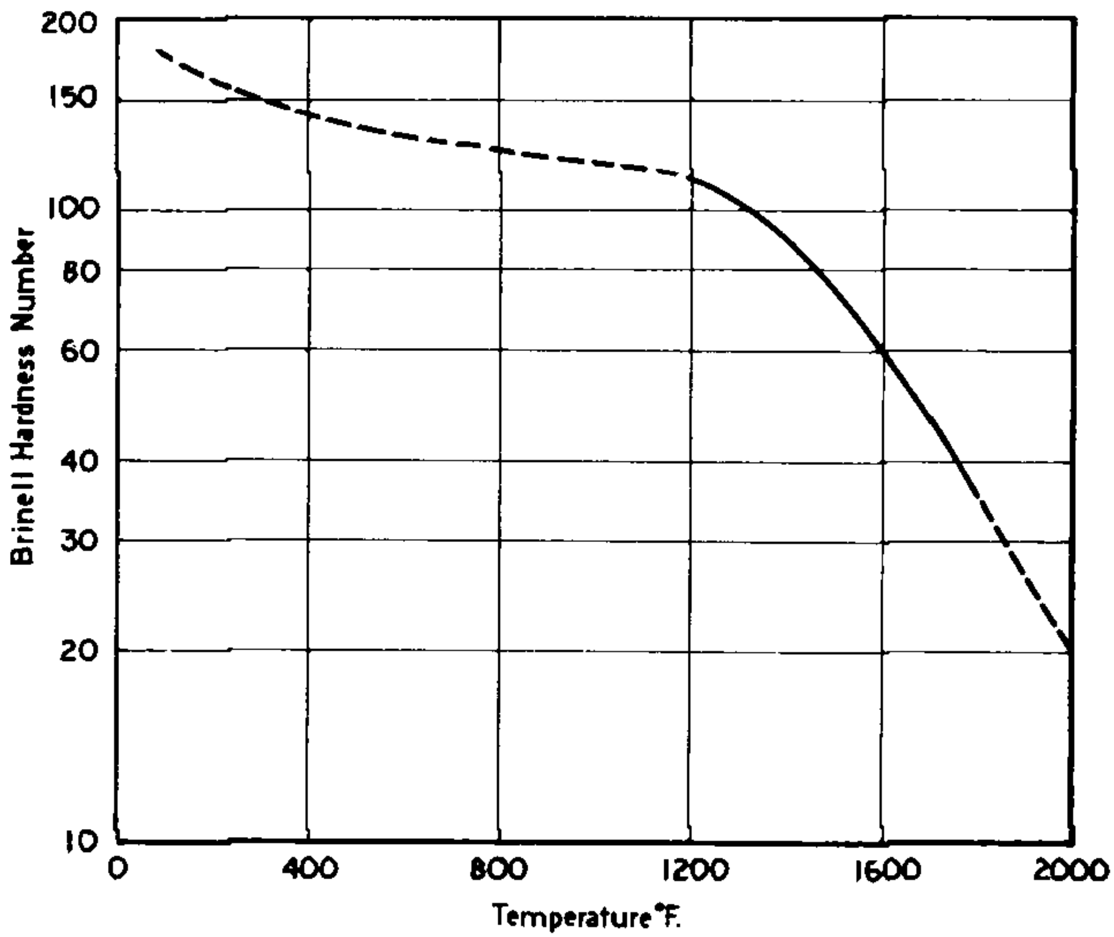


Fig. 3 Effect of temperature on hardness of Type HT alloy.

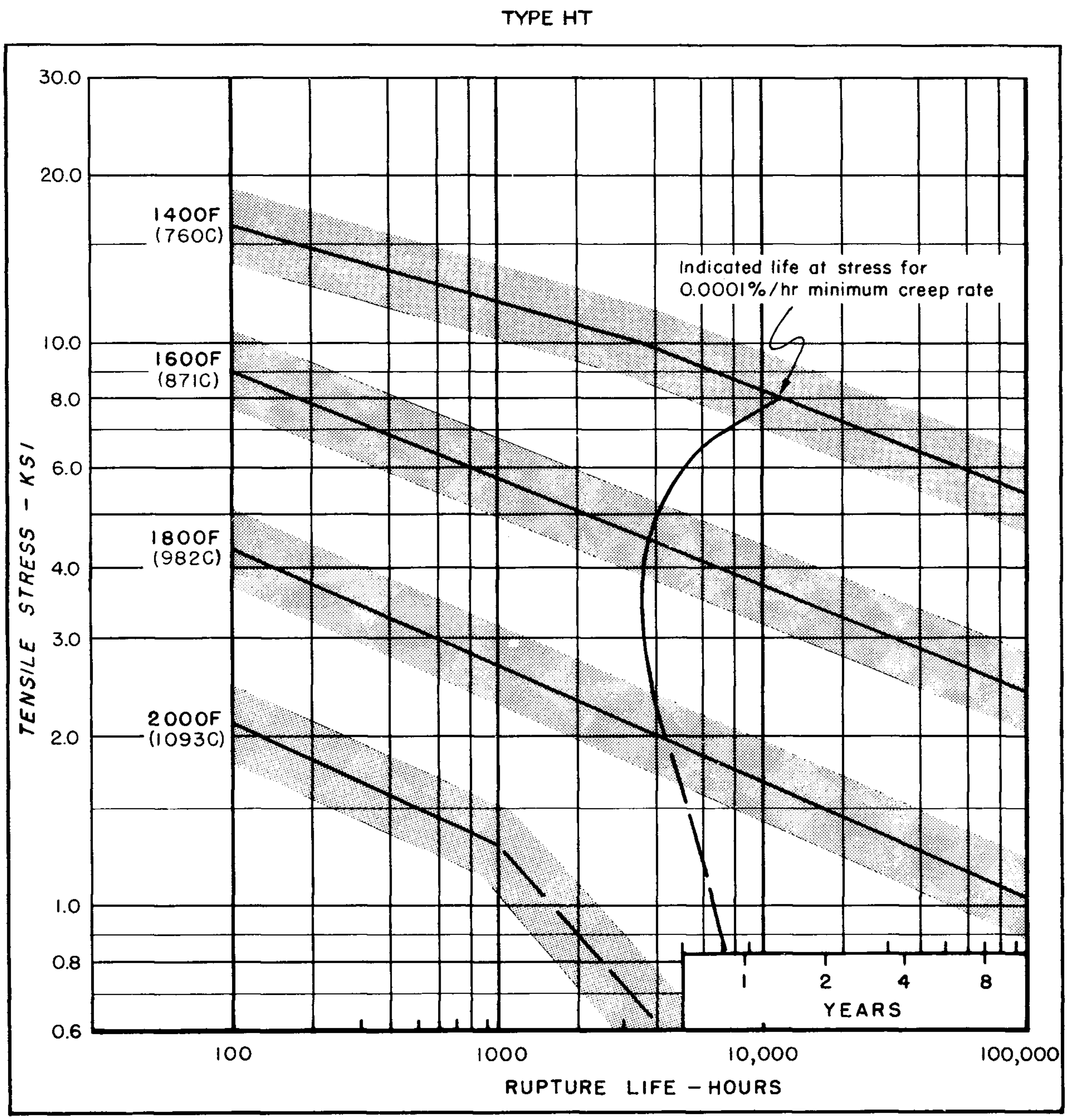


Fig. 4. Creep-rupture properties of Type HT alloy. The scatter bands shown are set arbitrarily at ±20% of the stress for the central tendency line. Such a range usually embraces test data for similar alloy compositions, but should not be considered statistically significant confidence limits.

Heat Resistant Type HU (UNS J95405)

Description

Type HU is an iron-chromium-nickel alloy similar to type HT, but its higher chromium and nickel contents give this grade greater resistance to corrosion by either oxidizing or reducing hot gases, particularly those containing appreciable amounts of sulfur. High temperature strength, resistance to thermal fatigue, and resistance to carburization of the alloy are essentially the same as shown by the HT type; hence, its improved corrosion resistance makes the HU type especially suited for severe service conditions involving high stress and rapid thermal cycling.

The as-cast and aged microstructures of type HU alloy, as well as its physical properties and fabricating characteristics are about the same as those of the HT grade.

Heat Treatment

Castings of type HU alloy are normally supplied in the as-cast condition. The alloy cannot be hardened by heat treatment, but for applications involving thermal fatigue from repeated rapid heating and cooling, improved performance may be obtained by heating castings at 1900°F (1038°C) for 12 hours followed by furnace cooling prior to placing in service.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HU alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Aluminum, Heat Treating, Steel.

Castings Articulated trays, burner tubes, carburizing retorts, conveyor

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.35						17	37	
max.	0.75	2.00	2.50	0.04	0.04	0.5[1]	21	41	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	27.0
Density, lb/in^3	0.290
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, µΩ.m, at 70 °F	1.05
Melting point, approximate °F	2450
Magnetic permeability	1.10 - 2.00

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion µ in./(in. °F)			
At 212 °F	7.0	70 - 200 °F	8.8	70 - 1800 °F	9.6
At 600 °F	8.9	70 - 400 °F	9.0	70 - 2000 °F	9.7
At 1000 °F	10.8	70 - 600 °F	9.2	1200 - 1800 °F	10.5
At 1200 °F	11.9	70 - 800 °F	9.4	1200 - 2000 °F	10.6
At 1400 °F	12.9				
At 1600 °F	14.0				
At 1800 °F	15.3[2]				
At 2000 °F	16.3[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Aged 24h at 1800 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	70.0	73.0	65.0
Yield strength, 0.2% offset, ksi	40.0	43.0	-
Elongation, in 2in., %	9	5	4
Brinell hardness (HBW)	170	190	-
Charpy keyhole ft.lbs	4	-	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	40.0	-	-
1600 °F	19.6	-	20
1800 °F	10.0	6.2	28

Creep rupture properties
Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	Stress to rupture in stress, ksi hours 100	1,000	10,000
1400 °F	8.5	15.0	-	-
1600 °F	5.0	8.0	5.2	3.3
1800 °F	2.2	4.5	2.9	1.8
2000 °F	0.6	-	-	-

[3] For constant temperature, for cyclic temperature lower values would apply

screws and chains, cyanide pots, dipping baskets, furnace rolls, lead pots, muffles, pouring spouts, radiant tubes, resistor guides.

Environment Air, carburizing gases, combustion gases, flue gases oxidizing and reducing, molten cyanide, molten lead.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HU. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HU alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 5/16 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HU castings can be welded by metal-arc, inert gas-arc, and oxyacetylene gas methods. Electric arc processes are most widely used, but satisfactory welds are also made with the oxyacetylene flame. The optimum balance between weld soundness and ductility is obtained if the Si to C ratio in the weld deposit is about the same as in the cast alloy, i.e. about 2:1.

Neither preweld nor postweld heat treating is required.

Welding procedures utilizing SMAW, GMAW and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HT alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

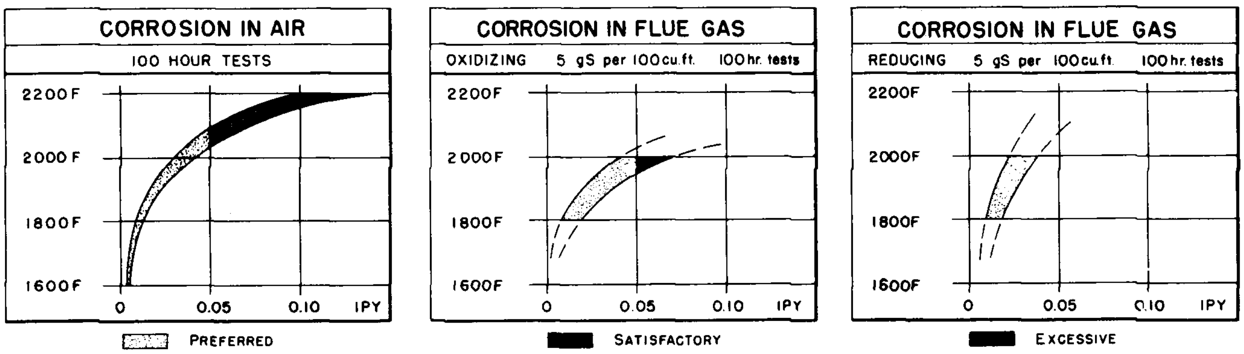
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

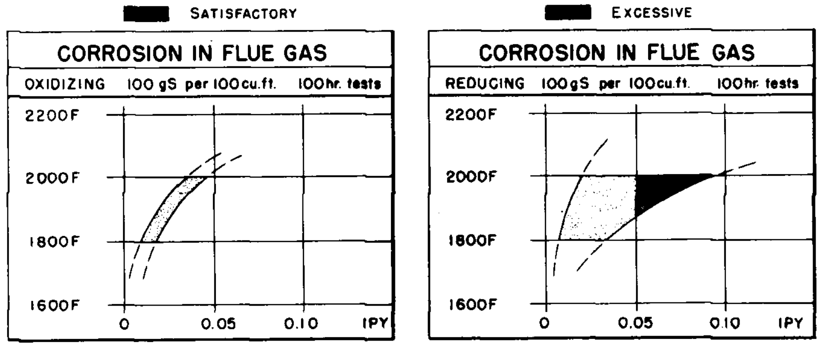
Cast ASTM: A297(HU), A608(HU50), SAE 70331

Wrought None



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering	GOOD	LEAD	GOOD	TYPE METAL	POOR
Neutral	FAIR with proper control	TIN	GOOD to 650F	SOFT SOLDER	POOR
		ZINC		BABBITT	POOR
Cyaniding	GOOD	ALUMINUM	Not Resistant	ANTIMONY	POOR
High Speed	Not Resistant	Magnesium	Not Resistant	CADMIUM	GOOD to 775F



Heat Resistant Type HW

Description

Type HW is an iron-chromium-nickel alloy in which nickel is the predominant element. The high nickel content contributes toward the excellent resistance of the alloy to carburization and also makes this grade especially useful in applications where wide and rapid temperature fluctuations are encountered. In addition, the alloy is resistant at high temperature to oxidation and, although not as strong as the HT type, has good strength at heat treating temperatures. It performs satisfactorily up to about 2050°F (1121°C) in strongly oxidizing atmospheres and up to 1900°F (1038°C) in oxidizing or reducing products of combustion provided that sulfur is not present in the gas. The generally adherent nature of its oxide scale makes the HW type alloy suitable for enameling furnace service where even small flecks of dislodged scale could ruin the work in process. This grade is widely used for intricate heat treating fixtures that are quenched with the load, and for many other applications involving thermal shock and steep temperature gradients under highly stressed conditions.

The alloy has an austenitic structure containing varying amounts of carbides depending on the carbon content and thermal history. In the as-cast condition the microstructure consists of a continuous interdendritic network of massive and elongated eutectic carbides. After aging at service temperatures, the austenitic matrix becomes uniformly peppered with small carbide particles except in the immediate vicinity of the eutectic carbides. This change is structure is accompanied by an increase in room temperature strength without change in ductility. The alloy has good high temperature ductility that is not appreciably affected by increased carbon content resulting from carburizing service.

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.35						10	58	
max.	0.75	2.00	2.50	0.04	0.04	0.5[1]	14	62	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	25.0
Density, lb/in^3	0.294
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, μΩ.m, at 70 °F	1.12
Melting point, approximate °F	2350
Magnetic permeability	16.0

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	7.2	68 - 200 °F	7.00	68 - 1800 °F	8.47
At 600 °F	9.0	68 - 400 °F	7.22	68 - 2000 °F	8.74
At 1000 °F	11.1	68 - 600 °F	7.45	68 - 1800 °F	9.01
At 1200 °F	12.2	68 - 800 °F	7.70	68 - 2000 °F	9.28
At 1400 °F	13.3	68 - 1000 °F	7.95	1200 - 1600 °F	10.00
At 1600 °F	14.5	68 - 1200 °F	8.20	1200 - 1800 °F	10.33
At 1800 °F	15.7[2]				
At 2000 °F	17.0[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values As cast	Representative values Aged 24h at 1800 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	68.0	84.0	60.0
Yield strength, 0.2% offset, ksi	36.0	52.0	-
Elongation, in 2in., %	4	4	-
Brinell hardness (HBW)	185	205	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1400 °F	32.0	23.0	-
1600 °F	19.0	15.0	-
1800 °F	10.0	8.0	40

Creep rupture properties

Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	Stress to rupture in stress, ksi hours 10	100	1,000
1400 °F	6.0	16.0	10.0	7.8
1600 °F	3.0	8.2	6.0	4.5
1800 °F	1.4	4.3	3.6	2.6

[3] For constant temperature, for cyclic temperature lower values would apply

Castings of type HW alloy have good machining and welding properties if proper techniques are employed. Thermal expansion is about 20 percent greater than carbon steel or iron-chromium alloy types HC or HD, but about ten percent less than the iron-chromium-nickel alloy type HT. Electrical resistance is roughly seven times that of carbon steel and is characterized by a very low temperature coefficient of resistivity (0.000095 per °F, 70-212°F) (0.000171 per °C, 21-100°C) so that from room temperature to 1800°F (982°C) there is an increase of less than 10 percent in resistance. Thus, the alloy is useful for cast electric heating elements. At room temperature the HW type alloy is magnetic both as-cast and after aging at elevated temperature.

Heat Treatment

Castings of type HW alloy are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HW alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Heat Treating, Vitreous Enamel.

Castings Cyanide pots, electric heating elements, enameling tools, gas retorts, hardening fixtures, hearth plates, lead pots, muffles.

Environment Air, carburizing gases, combustion gases, flue gases, molten cyanide, molten lead.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HW. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HW alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 9/32 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HW castings can be welded by metal-arc, inert gas-arc, and oxyacetylene gas methods. Electric arc processes are most widely used, but satisfactory welds are also made with the oxyacetylene flame. Bare Inconel wire and stainless flux should be used for gas welding, and the flame should be adjusted to very rich in acetylene. Neither preweld nor postweld heating is required.

Welding procedure utilizing SMAW technique is described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HW alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

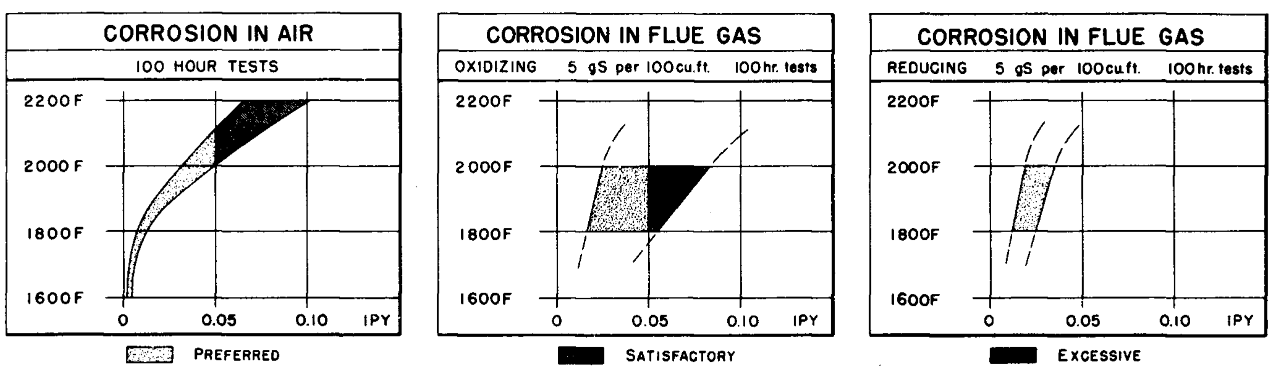
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

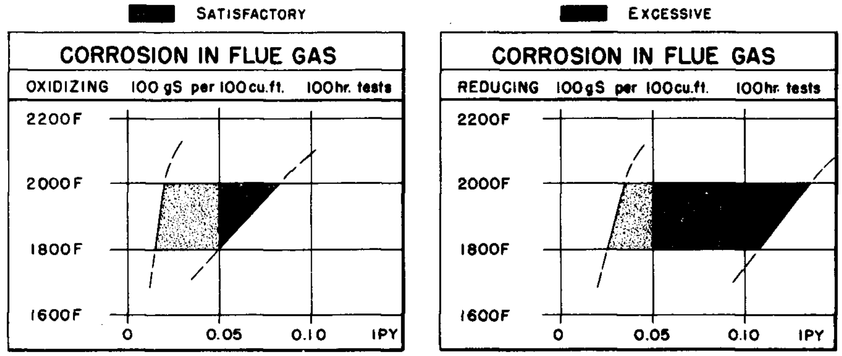
Casting designations, specifications, and corresponding wrought alloy

Cast ASTM: A297(HW), A608(HW50), SAE 70334

Wrought None



RESISTANCE TO CORROSION BY SALTS		MOLTEN METALS			
Tempering	Excellent	LEAD	Excellent	TYPE METAL	POOR
Neutral	FAIR with proper control	TIN	GOOD to 650F	SOFT SOLDER	POOR
		ZINC		BABBITT	POOR
Cyaniding	Excellent	ALUMINUM	Not Resistant	ANTIMONY	POOR
High Speed	Not Resistant	Magnesium	Not Resistant	CADMIUM	GOOD to 775F



Heat Resistant Type HX

Description

Type HX is an iron-chromium-nickel alloy similar to type HW, but containing more nickel and chromium. The increased chromium content confers substantially improved resistance to hot gas corrosion, even in the presence of some sulfur, which permits this grade to be employed for severe service applications at temperatures up to 2100°F (1149°C). High temperature strength, resistance to thermal fatigue, and resistance to carburization of the alloy are essentially the same as shown by the HW type; hence, it is suitable for the same general applications in situations where corrosion must be minimized.

The as-cast and aged microstructures of type HX alloy, as well as it physical properties and fabricating characteristics are about the same as those of the HW grade. A minor differences that the HX type is only slightly magnetic.

Heat Treatment

Castings of type HX alloy are normally supplied in the as-cast condition.

Applications

The following lists of consuming industries, cast parts, and corrosive environments are useful as examples of typical applications where type HX alloy has been employed successfully; they are not comprehensive, nor are they intended as guides to alloy selection for specific end uses.

Industries Heat Treating, Steel, Vitreous Enamel.

Castings Autoclaves, brazing furnace rails and doors, calciner tubes, carburizing boxes, cyanide pots, enameling tools, heating elements, hearth plates, heat treating trays and

Chemical composition - %

	C	Mn	Si	P	S	Mo	Cr	Ni	Fe
min.	0.35						15	64	
max.	0.75	2.00	2.50	0.04	0.04	0.5[1]	19	68	bal

[1] Mo not intentionally added.

Physical properties

Modulus of elasticity, psi x 10^6	25.0
Density, lb/in^3	0.294
Sp. Heat, Btu/lb.°F, at 70 °F	0.11
Electrical resistivity, μΩ.m, at 70 °F	1.16
Melting point, approximate °F	2350
Magnetic permeability	2.0

Thermal conductivity Btu/(ft.h. °F)		Mean coefficient of Linear thermal expansion μ in./(in. °F)			
At 212 °F	7.2[2]	70 - 200 °F	7.8	70 - 1800 °F	9.2
At 600 °F	9.0[2]	70 - 400 °F	8.1	70 - 2000 °F	9.5
At 1000 °F	11.1[2]	70 - 600 °F	8.5	1200 - 1600 °F	10.7
At 1200 °F	12.2[2]	70 - 800 °F	8.8	1200 - 1800 °F	11.3
At 1400 °F	13.3[2]				
At 1600 °F	14.5[2]				
At 1800 °F	15.7[2]				
At 2000 °F	17.0[2]				

[2] Estimated

Mechanical properties at room temperature

	Representative values: As cast	Representative values: Aged 24h at 1800 °F Furnace cooled	Minimum tensile requirements ASTM A297
Tensile strength, ksi	65.0	73.0	60.0
Yield strength, 0.2% offset, ksi	36.0	44.0	-
Elongation, in 2in., %	9	9	-
Brinell hardness (HBW)	176	185	-

At elevated temperatures

Representative values - short time	Tensile ksi	Yield ksi	Elongation in 2 in. %
1200 °F	45.0	20.0	8
1600 °F	20.5	17.5	48
1800 °F	10.7	8.0	40

Creep rupture properties
Representative values[3] - long time

	Limiting stress, ksi, creep rate 0.0001%/h	Stress to rupture in stress, ksi hours 10	100	1,000
1400 °F	6.4	18.0	13.0	-
1600 °F	3.2	10.0	6.7	4.0
1800 °F	1.6	5.4	3.5	2.2
2000 °F	0.6	2.5	-	0.9

[3] For constant temperature, for cyclic temperature lower values would apply

fixtures, lead pots, muffles, retorts, roller hearths, salt bath electrodes, salt pots, shaker hearths.

Environment Air, carburizing gases, combustion gases, flue gases, hydrogen, molten cyanide, molten lead, molten neutral salts.

NOTE: Proper selection of an alloy for a specific high temperature service involves consideration of some or all of the following factors: 1) required life of the part, 2) range frequency and speed of temperature cycling, 3) atmosphere and contaminants therein, 4) complexity of casting design, and 5) further fabrication of the casting. The criteria that should be used as the bases of alloy comparison will depend on the factors enumerated, and the designer will be aided in his choice by providing the foundry with as much pertinent information as possible on intended operating conditions before reaching a definite decision to use this alloy.

The mechanical property and physical property data presented here in tabular and graphical form are representative for alloy HX. These data are neither average nor minimum values and should not be used for either specification or design purposes. Information on specification and/or design can be obtained from an appropriate technical association such as: ASTM, ASME, API, SAE and NACE.

Design Considerations

Section thicknesses from 3/16 inch up can be cast satisfactorily in HX alloy. Somewhat lighter sections are also feasible depending on casting design and pattern equipment. Good castability of this alloy permits designs involving intricate shapes. Drastic changes in section should be avoided, however, and uniform thickness should be maintained as far as possible. This applies to the casting *as cast*; i.e., including finish allowance of 1/8 inch or more on surfaces to be machined. Normally used patternmakers' shrinkage allow for this alloy is 9/32 inch per foot.

Fabricating Considerations

Dimensional tolerances for rough castings are influenced by the quality of pattern equipment provided. In general, overall dimensions and locations of cored holes can be held to 1/16 inch per foot.

Welding Type HX castings can be welded by metal-arc, inert gas-arc, and oxyacetylene gas methods. Electric arc processes are most widely used, but satisfactory welds are also made with the oxyacetylene flame. Bare Inconel wire and stainless flux should be used for gas welding, and the flame should be adjusted to very rich in acetylene. Neither preweld nor postweld heating is required.

Welding procedures utilizing SMAW, and GTAW techniques are described in this section.

Machining Most machining operations can be performed satisfactorily on castings of HW alloy. It is important in all cases that the tool be kept continually entering into the metal to avoid work-hardening the surface. Slow feeds, deep cuts and powerful rigid machines are necessary for best results. Work should be firmly mounted and supported, and tool mountings should provide maximum stiffness. Both high speed steel and carbide tools may be used successfully. Chips are tough and stringy; chip curlers and breaker tools are recommended.

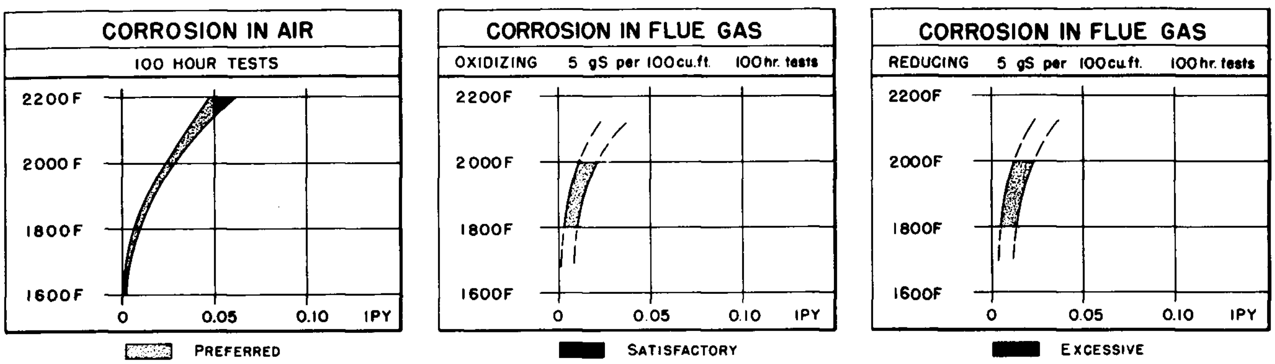
Good lubrication and cooling are essential. The low thermal conductivity of the alloy makes it most important to have the cutting fluid flood both the tool and the work. Sulfo-chlorinated petroleum oil containing active sulfur and about 8 to 10 percent fatty oil is suggested for use with high speed steel tools. Water-soluble cutting fluids are primarily coolants and are most useful for high speed operation with carbide tools.

Information on the procedures for specific machining operations is contained in SFSA Steel Casings Handbook, 6th Edition, Chapter 26.

Casting designations, specifications, and corresponding wrought alloy

Cast ASTM: A297(HX), A608(HX50), SAE 70335

Wrought None



RESISTANCE TO CORROSION BY

SALTS		MOLTEN METALS			
Tempering	Excellent	LEAD	Excellent	TYPE METAL	
Neutral	FAIR with proper control	TIN	GOOD to 650F	SOFT SOLDER	
		ZINC		BABBITT	
Cyaniding	Excellent	ALUMINUM	Not Resistant	ANTIMONY	
High Speed	Not Resistant	Magnesium	Not Resistant	CADMIUM	GOOD to 775F