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Heat Resistant Castings-Iron Base Alloys

Castings are classified as heat resistant if they are capable of sustained operation while exposed, either continuously or intermittently to operating temperatures that result in metal temperature in excess of 650°C (1200°F). Alloys used in castings for such applications fall into four broad categories. A number of proprietary alloys viz. AiResist, Haynes, Inconel, Rene, Udimet, Hastelloy, MAR-M, RA-330, Nimonic and many other alloys developed by companies viz. Inco Alloys, Rolled Alloys, Carpenter Alloys, Krupp VDM, also fall within the four categories mentioned below: The discussion in this technical paper is restricted to iron-base alloys.

1. **Iron-base heat resistant alloys**
   - Straight Chromium alloys-**HA, HC, HD**
   - Iron-Chromium-Nickel (Fe-Cr-Ni) alloys-**HE, HF, HH-I, HH-II, HP-50WZ, HK, HK-30, HK-40, HK-50, HL**
   - Iron-Nickel-Chromium (Fe-Ni-Cr) alloys-**HN, HP, HT, HU, HW, HX**
2. **Nickel-base heat resistant alloys**
3. **Cobalt-base heat resistant alloys**
4. **Super alloys**
   - Iron base super alloys
   - Nickel base super alloys
   - Cobalt base super alloys

Table 1 shows the representative ASTM/ ACI compositions of iron-base heat resistant casting alloys. Other alloy standards DIN (Germany), BS (U.K.), ISO have their corresponding counterparts of heat resisting alloys designated to their respective standards but have inherently similar elemental chemical composition ranges. ASTM/ ACI standards are referred here, as they are the most popular and widely accepted materials & alloy standards across the world. Acme Alloys ™ manufactures its own proprietary alloys and proprietary alloys that are developed by companies, to meet a particular industry application or for superior performance in specific environments compared to generally available standard alloys.

Table 1: Composition of heat resisting iron base alloys

ACI Designation	ASTM Specifications	Carbon (C) %	Chromium (Cr) %	Nickel (Ni) %	Silicon (Si)%
Straight-Cr Alloys					
HA	A 217	0.20	8.0-10.0	-	1.00
HC	A 297, A 608	0.50	26.0-30.0	4.0	2.00
HD	A 297, A 608	0.50	26.0-30.0	4.0-7.0	2.00
Fe-Cr-Ni Alloys					
HE	A 297, A 608	0.20-0.50	26.0-30.0	8.0-11.0	2.00
HF	A 297, A 608	0.20-0.40	19.0-23.0	9.0-12.0	2.00
HH	A 297, A 608, A 447	0.20-0.50	24.0-28.0	11.0-14.0	2.00
HI	A 297, A 567, A 608	0.20-0.50	26.0-30.0	14.0-18.0	2.00
HK	A 297, A 351, A 567, A 608	0.20-0.60	24.0-38.0	18.0-22.0	2.00
HK-30	A 351	0.25-0.35	23.0-27.0	19.0-22.0	1.75
HK-40	A 351	0.35-0.45	23.0-27.0	19.0-22.0	1.75
HL	A 297, A 608	0.20-0.60	28.0-32.0	18.0-22.0	2.00
Fe-Ni-Cr Alloys					

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HN	A 297, A 608	0.20-0.50	19.0-23.0	23.0-27.0	2.00
HP	A 297	0.35-0.75	24.0-28.0	33.0-37.0	2.00
HP-50WZ		0.45-0.55	24.0-28.0	33.0-37.0	2.50
HT	A 297, A 351, A 567, A 608	0.35-0.75	13.0-17.0	33.0-37.0	2.50
HT-30	A 351	0.25-0.35	13.0-17.0	33.0-37.0	2.50
HU	A 297, A 608	0.35-0.75	17.0-21.0	37.0-41.0	2.50
HW	A 297, A 608	0.35-0.75	10.0-14.0	58.0-62.0	2.50
HX	A 297, A 608	0.35-0.75	15.0-19.0	64.0-68.0	2.50

§ American Society of Testing Materials (ASTM) specifications are the same as Alloy Casting Institute (ACI) specifications. Remainder is Fe in all alloy compositions. Mo, Al, Ti, W, V, Nb, Cb, B, and Ta are added intentionally, in appropriate proportions as trace elements for achieving enhanced physical properties and superior, stable grain microstructure.

Properties of Heat Resistant Alloys

In application of heat resistant alloys, paramount considerations include

- Resistance to corrosion at elevated temperatures
- Stability (resistance to warping, cracking or thermal fatigue)
- Creep strength (resistance to plastic flow)

Elevated-Temperature Tensile Properties

The short-term elevated-temperature test, in the standard tension test bar is heated to a designated uniform temperature and then strained to fracture at a standard rate, identifies the stress due to a short-term overload that will cause fracture in uni-axial loading.

Creep and Stress Rupture Properties

Creep is defined as the time-dependent strain that occurs under load at elevated temperature and is operative in most applications of heat-resistant high-alloy castings at the normal service temperatures. In time, creep may lead to excessive deformation and even fracture at stresses considerably below those determined in room temperature and elevated-temperature short-term tension tests.

When the rate or degree of deformation is the limiting factor, the design stress is based on the minimum creep rate and design life after allowing for initial transient creep. The stress that produces a specified minimum creep rate of an alloy or a specified amount of creep deformation in a given time (for example, 1% of total 100,000 h) is referred to as the limiting creep strength, or limiting stress.

Stress rupture testing is a valuable adjunct to creep testing and is used to select the section sizes necessary to prevent creep rupture of a component. It should be noted that the long-term creep and stress-rupture values (For example, 100,000 h) are often extrapolated from short-term tests. Whether these property values are extrapolated or determined directly often has little bearing on the operating life of high-temperature parts. The actual material behaviour is often difficult to predict accurately because of the complexity of the service stresses, different applications, relative to the idealized, uni-axial loading conditions in the standard tests, and because of the attenuating factors such as cyclic loading, temperature fluctuations, and metal loss from corrosion. The designer and the metallurgist should anticipate the synergistic effect of these variables.

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Table 2 shows typical room-temperature properties of as-cast heat-resisting casting alloys

Alloy	Tensile Strength MPa	Tensile Strength ksi	Yield Strength MPa	Yield Strength ksi	Elongation %	Hardness Brinell HB
HC	760	110	515	75	19	223
HD	585	85	330	48	16	90
HE	655	95	310	45	20	200
HF	635	92	310	45	38	165
HH 1	585	85	345	50	25	185
HH 2	550	80	275	40	15	180
HI	550	80	310	45	12	180
HK	515	75	345	50	17	170
HL	565	82	360	52	19	192
HN	470	68	260	38	13	160
HP	490	71	275	40	11	170
HT	485	70	275	40	10	180
HU	485	70	275	40	9	170
HW	470	68	250	36	4	185
HX	450	65	250	36	9	176

Thermal Fatigue

Thermal fatigue involves cracking caused by heating and cooling cycles. Very little experimental thermal fatigue information is available on which to base a comparison of the various alloys, and no standard test to date has been adopted. Field and industry experience indicates resistance to thermal fatigue is usually improved with an increase in nickel content. Niobium/Columbium-modified alloys have been employed successfully when a high degree of thermal fatigue resistance is desired, such as in glass forming and reformer outlet headers, where rapid heating and cooling takes place of the parts.

Thermal Shock Resistance

Thermal shock failure may occur as result of a single, rapid temperature or as result of rapid cyclic temperatures changes that induce stresses high enough to cause failure. Thermal shock resistance is influenced by the coefficient of thermal expansion and the thermal conductivity of materials. Increases in the thermal expansion coefficient or decreases in the thermal conductivity reduce the resistance against thermal shock.

Corrosion Resistance

Table 3 shows general corrosion characteristics of heat resisting cast steels and final typical limiting creep stress values at indicated temperatures.

Alloy	Corrosion characteristics	Creep test temperature °C	Creep test temperature °F	Limiting creep stress (0.0001%/ h) MPa	Limiting creep stress (0.0001%/ h) ksi
HA	Good oxidation resistance to 650°C (1200°F); widely used in oil refining industry	650	1200	21.5	3.1
HC	Good sulphur and oxidation	870	1600	5.15	0.75

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	resistance up to 1095°C (2000°F); minimal mechanical properties; used in application where strength is not a consideration or for moderate load bearing				
HD	Excellent oxidation and sulphur resistance plus weld ability	980	1800	6.2	0.9
HE	Higher temperature and sulphur resistant capabilities than HD	980	1800	9.5	1.4
HF	Excellent general corrosion resistance to 815°C (1500°F) with moderate mechanical properties	870	1600	27	3.9
HH	Higher strength; oxidation resistance to 1090°C (2000°F); most widely used	980	1800	7.5 (type I) 14.5 (type II)	1.1 (type I) 2.1 (type II)
HI	Improved oxidation resistance compared to HH	980	1800	13	1.9
HK	Because of its high temperature strength, widely used for stressed parts in structural applications up to 1150°C (2100°F); offers good resistance to hot gases, including sulphur bearing gases in both oxidizing and reducing conditions (although HC, HE and HI are more resistant in gases); used in air, ammonia, hydrogen, and molten salts; widely used for tubes and furnace parts.	1040	1900	9.5	1.4
HL	Improved sulphur resistance compared to HK; especially useful where excessive scaling must be avoided	980	1800	15	2.2
HN	Very high strength at elevated temperatures; resistant to oxidizing and reducing flue gases	1040	1900	11	1.6
HP	Resistant to both oxidizing and carburizing atmospheres at high temperatures	980	1800	19	2.8
HP-50WZ	Improved creep rupture strength at 1090°C (2000°F) and above compared to HP	1090	2000	4.8	0.7
HT	Widely used in thermal shock applications; corrosion resistant in air, oxidizing and reducing flue gases, carburizing gases, salts, and molten metals; performs satisfactorily up to 1150°C (2100°F) in oxidizing atmospheres and up to 1095°C (2100°F) in reducing atmospheres, provided that limiting creep stress values are not exceeded	980	1800	14	2.0
HU	Higher hot strength than HT and often selected for its superior corrosion resistance	980	1800	15	2.2
HW	High hot strength and electrical resistivity; performs satisfactorily to 1120°C (2050°C) in strongly	980	1800	9.5	1.4

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	oxidizing atmospheres and up to 1040°C (1900°F) in oxidizing or reducing products of combustion that do not contain sulphur; resistant to some salts and molten metals				
HX	Resistant to hot-gas corrosion under cycling conditions without cracking or warping; corrosion resistant in air, carburizing gases, combustion gases, flue gases, hydrogen, molten cyanide, molten lead, and molten neutral salts at temperatures up to 1150°C (2100°F)	980	1800	11	1.6

Applications

In terms of usage, the most important use of heat-resistant castings is in metallurgical and other industrial furnaces. Iron-base alloys are most often used for this service, although significant amounts of nickel-base and cobalt-base alloys are also used. Other major applications of heat-resistant castings include turbochargers, gas turbines, power-plant equipment, and equipment used in the manufacture of glass, cement, synthetic rubber, chemicals and petrochemical products.

Alloy Selection

Heat-resistant alloys are selected on basis of structural integrity in a specific application. Strength, creep resistance and corrosion resistance are prime factors influencing alloy selection. Next in importance is cast ability, though it is difficult to obtain a quantitative evaluation of this factor. The part-geometry, and dimensions of the part to be cast and the alloy in which part is to be made are eventually critical factors. Our technical literature "**Conceptual Framework for Casting Design**" and " **Alloy Characteristics Affect Casting Design**", discusses the casting-ability of a part in a particular alloy to in a lucid manner and to sufficient depth.

Proper selection of an alloy for elevated temperature service involves consideration of some or all of the following factors:

1. **Required life of the part**
2. **Range of temperature cycling (heating and cooling)**
3. **Steepness of temperature gradient (rise or fall of temperature with respect to time)**
4. **Heat-treating atmosphere (oxidizing, reducing, or carburizing)**
5. **Contaminants and its percentage in the elevated temperature atmosphere (For example, the presence of sulphur gas)**
6. **Complexity of-Casting design, gating design, runner and riser feeding systems, directional solidification, poly, columnar or single- crystal solidification**
7. **Effect of heat-treatment on an alloy before put into use**

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8. **Further fabrication of the casting**

9. **Cost and availability of the alloy**

When the total manufacturing cost and the projected service life of a cast article have been determined it then possible to do a value analysis, and determine the unit operation cost. Cost per hour of service life is the ultimate criterion in selection of a heat-resistant alloy. On such basis, an alloy that is more expensive in initial cost provides lower cost per hour of service than a less-expensive type of an alloy. The higher alloy in the heat-resistant series, having higher cost, have lower life cycle cost than the lower series alloy, which are cheaper but eventually turn out to be more costlier, as they have shorter service life-cycle.

Example 1: Use of Cast Heat Resistant Alloy Bushings in a Glass Fiber Plant

The service life of cast heat resistant alloy bushings widely used in equipment for forming glass fibers indicate that at 1000 °C (1830°F) ASTM ACI HF (20Cr-10Ni) is 50 days and that of ASTM ACI HK (25Cr-20Ni) is 60-75 days. Higher life was achieved by using HH (26Cr-12Ni) alloy with higher nickel content to withstand operations at temperature up to 1100°C (2000°F). In this application, cast bushings are mounted in the fore-hearth of a glass-melting tank. Molten glass is fed by gravity to each bushing, flows through forming tips at bottom of the bushings and is mechanically drawn into elongated fibers. The diameter of each glass fiber is determined by the size of the hole in the bushing tip, the speed of pull, and the temperature and type of glass used. The bushing must be kept hot, so it is resistance heated by means of water-cooled clamps attached to terminals at each end.

The cast bushings are subjected to corrosion and erosion resulting from passage of molten glass at high temperature and from the oxidizing effects of surrounding air. At 1000°C (1830°F), HF alloy with low chromium and nickel contents had an average life of only about 45 days. When it was replaced by HK alloy, it was found that the average life of bushing life to 77 days. This improvement was effected with only a moderate increase in alloy content suggested by us. When the equipment was used at 1010°C (1850°F), however it was necessary to use bushings made of an alloy rich in nickel, i.e. HT, HU, HW and HX. The average life of these bushings improved to about 230 days.

Example 2: Use of Cast Heat Resistant Alloys in a Cement Plant

The cast-heat resistant alloys that are used for various components of burning layout in a cement mill are given in the table below. Significantly, more than one alloy can be used successfully in most of the twenty types of components listed. Environmental conditions that provide the basis for selection are also mentioned for each component.

Table 4: Use of Heat-Resistant Castings in a Cement Plant

Maximum Operating Temperature °C	Maximum Operating Temperature °F	Part Name	Environmental Conditions	Alloys Used §	Service Life in Years
650	1200	Conveyor parts	Severe abrasion and oxidation	HF, HH	Indefinite
650	1200	Cooler discharge chute	Severe abrasion and oxidation	HH, HK	3 to 5
650	1200	Clinker drag	Severe abrasion and oxidation	HH	5 to 10
760	1400	Feed-end seal ring	Some abrasion and oxidation	HH	Indefinite
815	1500	Brick anchors	Even temperature	HK	Indefinite

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815	1500	Burner barrel	Slight abrasion and oxidation	HK, HH	5 to 10
815	1500	Hood, anchor firing end	Even temperature, oxidation	HH	Indefinite
815	1500	Clinker chute	Severe abrasion, impact, oxidation	HH, HK	Indefinite
815	1500	Air-quench gates	Severe abrasion and oxidation	HK, HN, HT	3 to 7
925	1700	Anchors	Even temperature	HH	Indefinite
980	1800	Feed pipe	Moderate abrasion inside feed and dust particles outside, thermal shock, oxidation and sulphur gases	HC, HF, HK	2 to 7
980	1800	Feed-end tail ring	Abrasive dust particles, thermal shock and oxidation	HH, HK	10 to 15
980	1800	Feed lifters	Some abrasion, thermal shock, oxidation and sulphur gases	HH	5 to 10
980	1800	Chain support segments	Intermittent temperature surges, light abrasion, sulphur gases	HF, HH	Indefinite
980	1800	Cooler end plates	Severe abrasion and oxidation	HH, HN, HT	1 to 5
980	1800	Cooler grates	Severe abrasion and oxidation	HH, HK, HN, HT	1 to 5
980	1800	Cooler side plate	Severe abrasion and oxidation	HH	1 to 5
1100	2000	Nose seal ring	Some abrasion, oxidation and sulphur gases	HH	3 to 10
1100	2000	Burner nozzle	Some abrasion, oxidation and sulphur gases	HH, HT	1 to 3
1200	2200	Nose ring	Extreme abrasion, oxidation and sulphur gases	HF, HH, HK	3 to 5

§ Higher alloys in the series can also be used. When a lower grade alloy, from the series is used instead of the specified alloy for a particular application, it will result in part's - failure, poor performance and shorter operative life cycle.

Example 3: Recommended Materials (Iron, Nickel and Cobalt Base alloys) for Furnace Parts and Fixtures, used in Heat Treating

When more than one alloy is recommended, each has proved adequate, although service life varies in different installations because of the differences in exposure conditions.

Carburizing and carbo-nitriding furnaces

Operating Temperature Range °C	Operating Temperature Range °F	Parts	Wrought Alloy	Cast Alloy
815 - 1010	1500 - 1850	Retorts, muffles, radiant tubes, structural parts	RA 330, 800H / 800HT, HR-120, RA85H, 600, 601, 617, 602CA, X, 214, 556, 230	HK, HT, HU, HX
815 - 1010	1500 - 1850	Pier caps, rails	RA 330, 800H / 800 HT, HR-120, 600, 601	HT
815 - 1010	1500 - 1850	Trays, baskets, fixtures	RA85H, RA 330, 800H / 800 HT, HR-120, 600, 601, 617, 602CA, X, 556, 214, 230	HT, HT(Nb), HU, HU(Nb), HX

Hardening, annealing, normalizing, brazing, and stress relieving furnaces

Operating Temperature Range °C	Operating Temperature Range °F	Parts	Wrought Alloy	Cast Alloy
595 - 675	1100 - 1250	Retorts, muffles, radiant tubes	430, 304	HF
		Mesh belts	430, 304	
		Chain link	430, 304	HF
		Sprockets, rolls, guides, and trays	430, 304	HF

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675 – 760	1250 - 1400	Retorts, muffles, radiant tubes	304, 347, 309	HF, HH
		Mesh belts	309	
		Chain link	309	HF, HH
		Sprockets, rolls, guides, and trays	304, 316, 309	HF, HH
760 - 925	1400 - 1700	Retorts, muffles, radiant tubes	309, 310, 253 MA, RA 330, 800 H / 800 HT, HR-120, 600, 601	HH, HK, HT, HL, HW
		Mesh belts	309, 314, 253 MA, RA 330, 601	
		Chain link	314, RA 330 HC, 800H/ 800HT HR-120	HH, HL, HT
		Sprockets, rolls, guides, and trays	253 MA, 310, RA 330, 800H/ 800HT, HR-120	HH, HK, HL, HT
925 - 1010	1700 - 1850	Retorts, muffles, radiant tubes	RA 330, 800H/ 800 HT, HR-120, 600, 601, 617, X, 214, 556, 230	HK, HL, HW, HX
		Mesh belts	314, RA 330, 600, 601, 214	
		Chain link	314, RA 330 HC, 802, 601, 617, X, 556, 230	HL, HT, HX
		Sprockets, rolls, guides, and trays	310, RA 330, 601, 617, X, 556, 230	HL, HT, HX
1010 - 1095	1850 - 2000	Retorts, muffles, radiant tubes	601, 617, X, 556, 230	HK, HL, HW, HX, NA22H
		Mesh belts	80-20, 600, 601, 214	
		Chain link	80-20, 617, X, 556, 230	HL, HT, HX
		Sprockets, rolls, guides, and trays	601, 617, X, 214, 556, 230	HL, HX
1095 - 1205	2000 - 2200	Retorts, muffles, radiant tubes	602 CA, 601, 617, 230	HL, HU, HX
		Mesh belts	602 CA, 601, 617, 230	
		Chain link	602 CA, 601, 617, 230	HX
		Sprockets, rolls, guides, and trays	602 CA, 601, 617, 230	HI, HX

Heat-resistant alloy designations

Names in tables	Common Designation
214	Cobot 214
230	Haynes No. 230
253 MA	253 MA
304	AISI type 304
309	AISI type 309
310	AISI type 310
314	AISI type 314
316	AISI type 316
347	AISI type 347
430	AISI type 430
556	Haynes No. 556
600	Inconel alloy 600
601	Inconel alloy 601
602 CA	Nicrofer 6025 HT
617	Inconel alloy 617
80-20	Nimonic alloy 75
800 H	Incoloy alloy 800 H
800 HT	Incoloy alloy 800HT
802	Incoloy alloy 802
HF	ASTM/ ACI HF
HH	ASTM/ ACI HH
HK	ASTM/ACI HK
HL	ASTM/ ACI HL
HR-120	Haynes alloy HR-120
HT	ASTM/ ACI HT

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HT(Nb)	ASTM/ ACI HT(Nb)
HU	ASTM/ ACI HU
HW	ASTM/ ACI HW
HX	ASTM/ ACI HX
NA22H	Ni-Cr-W-Fe casting alloy
RA 330	RA 330
RA 330 HC	High carbon RA 330
RA85H	RA85H
X	Hastelloy alloy X

Registered trademarks include CABOT, HAYNES, and HASTELLOY (Haynes International Inc.); 253 MA (Avesta Sheffiled Inc.), INCONEL, INCOLOY, and NIMONIC (the Inco Alloys International group of companies), NICROFER (Krupp VDM GmbH), and RA 330 and RA85H (Rolled Alloys Inc.) AISE is the American Iron and Steel Engineer of AISI the American Iron and Steel Institute. ASTM is the American Society of Testing Materials, ASM is the American Society of Metals International, ACI is the Alloy Casting Institute. ASTM designations are the same as ACI designations.

For selecting the right alloy and developing solutions, for your specific heat resistance applications, contact **Vishal Kumar** at **vishal@acmealloys.com**