

Cast Heat Resistant (Fe-Cr-Ni) Alloy HH ASTM A447 Grade HH-Type I and Type II ASTM A297 Grade HH

Ferrite-Austenite microstructure balance influences its performance in heat resistant end applications. Make an informed choice for optimal performance.

A wide range of cast-heat resistant high alloy steels has been developed to meet industrial needs. The compositions of these are covered as standard grades in ASTM A297, A351, A447 and A560 and alike equivalent international grades, fall in a range from 0-60% nickel with 8-32% chromium and the balance primarily iron plus up to 2.5% silicon and 2.0% manganese. ACME® and other manufacturers offer proprietary alloys that are highly alloyed. Single and multiple additions of elements aluminium, cobalt, molybdenum, titanium, tungsten, zirconium, niobium and the rare earth metals (REM)- Ce, La, Y are added to enhance specific properties such as high-temperature strength, carburization resistance, weldability, and resistance to thermal cycling.

There are four groups: Fe-Cr, Fe-Cr-Ni, Fe-Ni-Cr and Ni-Fe-Cr which comprise of cast resistant alloys. Alloys in Fe-Cr-Ni group contains 18-32% chromium and 8-22% nickel, with chromium always exceeding nickel and include the grades HE, HF, HH, HI, HK and HL. While these alloys are considered to be austenitic, the lower nickel compositions will contain some ferrite. Transformation of the ferrite to brittle sigma phase is a concern with this group, even in the higher nickel grades, particularly if their compositional balance leans to ferrite. The high temperature strength of this group is greater than that of the Fe-Cr alloys and their creep and rupture strength increases as nickel is raised.

ASTM A 297 Standard Specification for
Steel Castings, Iron-Chromium and Iron-Chromium-Nickel
Heat Resistant, for General Applications

Grades - HF, **HH**, HI, HK, HE, HT, HU, HW, HX, HC, HD, HL, HN, HP, HG10MN, CT15C

HH C 0.20-0.50, Ni 11-14, Cr 24-28, Mn 2.0 max, Si 2.00 max, S & P 0.04 max, Fe balance

ASTM A 447 Standard Specification for
Steel Castings, Chromium-Nickel-Iron Alloy (25-12 Class)
For High Temperature Service

Intended for structural elements, containers, and supports in electric furnaces, petroleum still tube supports, and for similar applications up to 1095°C (2000°F). The purchase should inform the manufacturer when the service temperatures are to exceed 980°C (1800°F).

Type-I Alloys characterized by relatively low limiting creep stress at temperatures between 815-1095°C (1500-2000°F), and relatively high ductility at ordinary temperatures after aging for short periods at temperatures between 705-815°C (1300-1500°F)

Type-II Alloys having relatively high limiting creep stress but which may develop low ductility at ordinary temperatures when ages for short periods at temperatures between 730-815°C (1350-1500°F)

C 0.20, Ni 10-14, Cr 23-28, N 0.20 max, Mn 2.50 max, Si 1.75 max, S & P 0.03 max, Fe Balance

Ferrite-Promoting versus Austenite-Promoting Elements

Ferrite Promoting Elements	Austenite Promoting Elements
Chromium	Nickel
Molybdenum	Manganese
Silicon	Carbon
Niobium /Columbium	Nitrogen
Titanium	Copper
Aluminium	Cobalt
Vanadium	
Tungsten	

Stainless steels are iron-based alloys containing from 12% to over 50% wt. alloying additions. Alloying elements affect the equilibrium phase relationships relative to the stability of the austenite, ferrite and martensite phases. Elements added to the stainless steels can be divided into those that promote, or stabilize, either the ferrite or the austenite phase. Martensite is a transformation product that forms from austenite upon rapid cooling from elevated temperature. If austenite does not form at high temperatures, martensite cannot form at low temperatures.

Austenitic stainless steels contain high levels of nickel and other austenite forming elements which promote the formation of austenite phase, so that it is stable at room temperature and below.

Ferritic stainless steels contain a balance of elements, such as high chromium contents such that ferrite is the predominant metallurgical phase present.

Martensitic stainless steels are austenitic at elevated temperature, but this phase is unstable and transforms upon cooling. By balancing austenite- and ferrite-promoting elements, the microstructure of the stainless steel and hence its performance in specific end application can be controlled. This balance has important implications with respect to room temperature and elevated temperature mechanical properties, heat and corrosion resistance, and weldability.

Chromium- and Nickel-equivalency relationships for austenitic stainless steel

Author	Year	Chromium Equivalent Cr_e	Nickel Equivalent Ni_e
Schaeffler	1949	$Cr + Mo + 1.Si + 0.5Nb/Cb$	$Ni + 0.5Mn + 30C$
DeLong et al	1956	$Cr + Mo + 1.Si + 0.5Nb/Cb$	$Ni + 0.5Mn + 30C + 30N$
Hull	1973	$Cr + 1.21Mo + 0.48Si + 0.14Nb/Cb + 2.27V + 0.72W + 2.20Ti + 0.21Ta + 2.48Al$	$Ni + (0.11Mn - 0.0086Mn^2) + 25.4C + 14.2N + 0.41Co + 0.44Cu$
Hammer & Svennson	1979	$Cr + 1.37Mo + 1.55Si + 2Nb/Cb + 3Ti$	$Ni + 0.31Mn + 22C + 14.2N + Cu$
Siewert et al	1992	$Cr + Mo + 0.7Nb/Cb$	$Ni + 35C + 20N + 0.25Cu$

Estimation of Ferrite Content -Schoefer's Diagram

Estimation in the base metal of the casting by chemical composition in accordance with the Schoefer's Diagram shown below on this page.

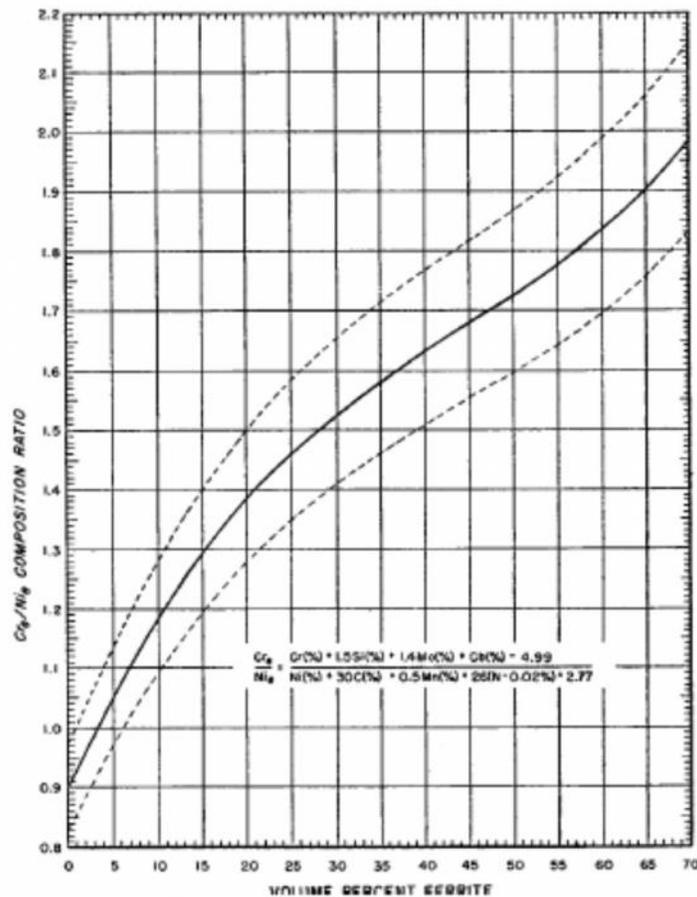
A chemical analysis of the heat from which the castings are poured shall include the following elements whether or not required by the chemical requirements of the product specifications: carbon, manganese, silicon, chromium, nickel, molybdenum, niobium/columbium and nitrogen.

The Schoefer's diagram is applicable to alloys containing elements (wt%) in the following ranges:

C	0.20 max	Cr	17.0-28.0	Nb or Cb	1.00 max
Mn	2.00 max	Ni	4.0-13.0	N	0.20 max
Si	2.00 max	Mo	4.00 max		

The ferrite content of the casting shall be estimated from the central line of the diagram at the composition ratio of Chromium Equivalent (Cr_e) to Nickel Equivalent (Ni_e) determined by the following formula:

$$\frac{[Cr(\%) + 1.5Si(\%) + 1.4Mo(\%) + Nb/Cb(\%) - 4.99]}{[Ni(\%) + 30C(\%) + 0.5Mn(\%) + 26(N - 0.02\%) + 2.77]} = (Cr_e)/(Ni_e)$$





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Alloy HH (26Cr-12Ni)

Alloy HH is prominently austenitic and consists of considerable carbon in solid solution, but carbides, ferrite (soft, ductile, and magnetic), and sigma phase (hard, brittle, and non-magnetic) may also be present in the alloy microstructure. The amounts of various structural constituent present depend on its composition and its thermal history. Two distinct grades of material can be obtained within the stated chemical composition (one mentioned on page #1) of the type alloy HH. These grades are defined as Type I (partially ferritic) and Type II (wholly austenitic) in ASTM A 447.

The partial ferritic (Type I) alloy HH is adapted to operating conditions that are subjected to changes in temperature level and applied stress. A plastic extension in the weaker, ductile, ferrite under varying load tends to occur more readily than in the stronger austenitic phase, thereby reducing unit stresses and stress concentrations and allowing rapid adjustment to suddenly applied overloads without cracking. Near 870°C (1600°F), the partially ferritic alloys tend to embrittle from development of sigma phase, while close to 760°C (1400°F), carbide precipitation may cause comparable loss in ductility. Such possible embrittlement suggests that 930°C to 1100°C (1700°F to 2000°F) is the best service temperature range, but this is not critical for steady temperature conditions in the absence of unusual thermal and mechanical stresses.

Nevertheless, to achieve maximum strength at elevated temperatures, the alloy HH must be wholly austenitic i.e. of Type II, where load and temperature conditions are comparatively constant and hence, Type II HH alloy provides the highest creep strength and permits use of maximum design stress. Type II HH is also a preferred choice for cyclic temperature service conditions that might induce sigma phase formation in the Type I HH alloy.

When alloy HH is heated to between 650°C and 870°C (1200°F and 1600°F), a loss in ductility may be produced as a result by either of two changes within the alloy: precipitation of carbides or transformation of ferrite to sigma phase. When the composition is balanced so that the alloy microstructure is fully austenitic, only carbide precipitation normally occurs. In partly ferritic alloys, both carbides and sigma phase may form.

The wholly austenitic Type II alloy HH is used widely in high-temperature applications because of its combination of relatively high strength and oxidation resistance at temperatures up to 1100°C (2000°F). However, HH alloy (Type I or Type II) are seldom used for carburization applications because of embrittlement from carbon absorption. High silicon content (above 1.5%) will mitigate its carburization under mild conditions, but will promote ferrite formation and possible sigma phase embrittlement. For wholly austenitic Type II alloy HH, compositional balance is critical in achieving desired austenitic microstructure. An imbalance of higher levels of ferrite promoting elements compared to austenite promoting elements may result in substantial amounts of ferrite, which improves ductility but decreases strength at elevated temperatures. If a balance is maintained between ferrite promoting elements (such as chromium and silicon) and austenite promoting elements (such as nickel, carbon and nitrogen), the desired austenitic microstructure can be obtained. In commercial alloy HH castings with the usual carbon, nitrogen, manganese and silicon contents, the ratio of chromium to nickel necessary for a stable austenitic structure is expressed as

$$\%Cr - 16(\%C) / \%Ni \leq 1.7$$

Silicon and molybdenum have definite effects on the formation of sigma phase. A silicon content higher than 1% is equal to chromium content three times great, and any molybdenum content is equivalent to a chromium content four times as great.



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Before alloy HH is selected as a heat resistant casting material, it is suggested to consider the relationship between chemical composition and operating temperature range. For castings that are intended to be exposed to temperatures appreciably above 870°C (1600°F), there is less prominent danger of severe embrittlement either from carbide precipitation or from the formation sigma phase, and composition should be 0.50% C (maximum) [0.35-0.45% C preferred], 10-12% Ni, and 24-27% Cr.

On the other hand, castings to be used at temperatures from 650°C to 870°C (1200°F to 1600°F), should have compositions of 0.40% C (maximum), 11-14% Ni, and 23-27% Cr. For applications involving either of these temperatures ranges that is 650°C to 870°C (1200°F to 1600°F) or appreciably above 870°C (1600°F), composition should be balanced to ensure complete austenitic structure. For service from 650°C to 870°C (1200°F to 1600°F), for example, a combination of 11% Ni and 27% Cr is likely to produce sigma phase and its associated embrittlement which occurs most rapidly around 870°C (1600°F). It is preferable, therefore, to avoid using the maximum chromium content with minimum nickel content. Often the mistake observed in failure analysis.

Short-time tensile testing of fully austenitic alloy HH shows the tensile strength and elongation depend on carbon and nitrogen contents. For maximum creep strength, alloy HH must have complete austenitic structure. In the design of load-carrying castings, data concerning creep stresses should be used with caution and understanding of the limitations of such data. An extrapolated limiting creep stress for 1% elongation (obtained from Larson-Miller Plot) in 10,000 hours cannot necessarily be sustained for that length of time without structure damage. Stress-rupture testing is a valuable adjunct to creep testing and a useful aid in selecting section sizes to obtain appropriate levels of design stress.

It is plausible to measure the ferrite content since fully austenitic alloy microstructure ensures greater strength at elevated temperature compared to partly ferritic alloys of similar compositions. Although the ratio calculated from earlier said equation that is less than 1.7 indicates wholly austenitic material, ratios greater than 1.7 do not constitute quantitative indications of ferrite content. It is possible, however, to measure ferrite content by magnetic analysis after quenching from about 1100°C (2000°F) and also by microscopic structure evaluation techniques suggested in ASTM A 800. The magnetic permeability of alloy HH increases with ferrite content. This measurement of magnetic permeability, preferably after holding 24 hours at 1100°C (2000°F) and then quenching in water, can be related to creep strength, which also depends on the structure. In accordance with A 447, the magnetic material shall conform to the following requirements:

Alloy	Magnetic Permeability
Type I	1.70 max
Type II	1.05 max

Alloys HH are often evaluated by measuring percentage elongation in room-temperature tensile testing of specimens that have been held 24 hours at 760°C (1400°F). Such a test maybe misleading because there is natural tendency for engineers to favour compositions after this particular heat treatment. High ductility values are often measured for alloys that have low creep resistance, but conversely, low ductility values do not necessarily connote high creep resistance. Do make an informed choice of alloy in heat resistance application to achieve optimal performance.

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