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OXIDATION RESISTANT AUSTENITIC DUCTILE NICKEL-CHROMIUM IRON

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10 Claims

ABSTRACT OF THE DISCLOSURE

Directed to alloyed ductile irons having in the as-cast condition high temperature oxidation resistance, and useful high temperature strength and dimensional stability during thermal cycling or long time holding at high temperatures, which contain about 1.6% to 2.4% carbon, about 0.5% to 1.5% manganese, about 5% to 6.5% silicon, about 34% to 40% nickel, about 1.5% to 2.5% chromium, an effective amount of a graphite spheroidizing agent and the balance iron.

Industry is demanding in many areas highly castable alloys having oxidation resistance, dimensional stability and useful strength at high temperatures. This is particularly true in the gas turbine industry where these properties are needed in applications such as shrouds and the like to maintain close tolerances and also to prevent possible seizures. At present, the use of relatively expensive materials of the nickel-base superalloy type are needed to provide the necessary properties. Such materials may be investment cast to provide parts of complex configurations, but this practice is expensive. This cost factor, while not limiting when the material is used in an expensive aircraft gas turbine engine, becomes extremely important and even limiting when the material is to be used for automotive gas turbines where the cost savings due to materials alone may be determinative in relation to the adoption of this type of automotive engine. These automotive gas turbines, which are still in the prototype stage, require relatively inexpensive materials of construction so as to meet the cost requirements existing in the industry. These material requirement and cost problems, which are rated among the most critical in the automotive gas turbine program, promoted the need for the alloy of this invention.

It would be desirable to employ castings made of ductile iron instead of more expensive alloys if the requisite properties could be developed in ductile iron. Presently available alloyed ductile iron castings do not have the required high temperature oxidation and growth resistance (dimensional stability) needed for such uses as turbine shrouds for automotive gas turbines.

I have now discovered alloy ductile irons capable of providing, in the as-cast condition, excellent high temperature oxidation and growth resistance.

It is an object of the present invention to provide alloyed ductile iron castings having excellent oxidation resistance and dimensional stability during thermal cycling or long time holding at high temperatures such as 1600° F.

It is a further object of the invention to provide an austenitic ductile iron having good castability coupled with retention of strength and ductility properties after repeated cycling to temperatures on the order of 1600° F.

Other objects and advantages of the invention will become apparent from the following description:

Generally speaking, the present invention is directed to alloyed ductile iron compositions containing about 1.6% to about 2.4% carbon, about 0.5% to about 1.5% manganese, about 5% to about 6.5% silicon, about 34% to about 40% nickel, about 1.5% to about 2.5% chromium, a small amount up to about 0.1% magnesium effective to

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control graphite in the cast iron to the spheroidal form and the balance essentially iron.

In carrying the invention into practice, a preferred compositional range for the alloyed ductile iron comprises about 1.8% to about 2.2% carbon, about 0.5% to about 1% manganese, about 5.5% to about 6.0% silicon, about 36% to about 38% nickel, about 1.8% to about 2.2% chromium, about 0.04% to about 0.09% magnesium and the balance essentially iron.

Nickel and silicon are highly important alloy constituents in the irons of the invention. Thus, nickel contents lower than about 34% decrease oxidation resistance, increase growth due to thermal cycling, and lower the yield strength after thermal cycling of the resulting casting. Increasing the nickel content above about 40% would unnecessarily increase the cost. It is found that reduction of the silicon content below about 5% results in irons in which the oxidation resistance decreases rapidly. High silicon levels outside the range of the invention, e.g., about 10.3% silicon, cause brittleness with the result that the alloy does not have the necessary toughness for normal handling.

Carbon in the range of about 1.6% to about 2.4% is essential in the iron to provide graphite, with the carbon content being maintained at a value of at least 1.6% to confer castability and not exceeding about 2.4% to avoid hypereutectic graphite flotation. Magnesium is present in the iron for the purpose of spheroidizing graphite and is present in amounts to provide a good spheroidal graphite structure, usually in amounts of about 0.03% to about 0.10%. Other known graphite spheroidizers such as cerium, lanthanum and other rare earth metals of the Lanthanide series may be employed by themselves or in conjunction with magnesium in amounts up to about 0.1% for this purpose. Chromium is also an important constituent of the iron since it improves oxidation resistance. Decreasing the chromium level below about 1.5% reduces the oxidation resistance markedly, whereas chromium levels above about 2.5% introduce the likelihood of causing poor ductility by creating excessive carbides. Manganese should be maintained in the range of about 0.5% to about 1.5% since greater amounts of manganese can lead to the formation of detrimental primary carbide networks, particularly in heavy sections, whereas lower amounts of manganese impair oxidation resistance. Cobalt, in an amount up to about 5%, may improve the oxidation resistance and dimensional stability of the alloy, but is not a substitute for nickel. The balance of the composition is iron, including small amounts of impurities. Impurities such as phosphorus up to about 0.02% or even 0.04% and sulfur in an amount up to about 0.01% can be tolerated. Calcium, which is present in the ferrosilicon as an impurity, can also be tolerated in trace amounts.

In order to give those skilled in the art a better understanding of the invention, the following examples are given:

EXAMPLE I

A heat (Alloy No. 1) was prepared by air induction melting of an initial charge of high grade (Sorel) pig iron, electrolytic nickel, ferrochromium and Armco ingot iron. Ferrosilicon and ferromanganese to provide the required silicon and manganese contents were added at a melt temperature of 2850° F. The melt was then cooled to 2750° F. and tapped onto an 85% nickel-15% magnesium alloy in a separate ladle. The melt was then reladled, inoculated with calcium-bearing ferrosilicon and cast into green sand keel block molds. In the region used for testing, the keel block dimensions were 16" x 2 3/4" x 3/4". Blanks were removed from the casting, machined

and tested as-cast. The melt contained 2.10% carbon, 0.55% manganese, 5.5% silicon, 36.4% nickel, 1.9% chromium 0.078% magnesium and the balance iron.

The following properties were obtained in the alloy:

Coefficient of thermal expansion: 9.45×10^{-6} in./in./° F.
 Weight change due to oxidation after 75 thermal cycles from room temperature to 1600° F. (total time at 1600° F. was 2000 hrs.) -2.21 mg./cm.².
 Length change due to 75 thermal cycles from room temperature to 1600° F. (total time at 1600° F. was 2000 hrs.) +0.04%.
 Tensile properties after 75 thermal cycles from room temperature to 1600° F.:
 (Total time at 1600° F. was 2000 hrs.)
 Yield strength at 0.2 offset, 32,200 p.s.i.
 Ultimate tensile strength, 74,400 p.s.i.
 Elongation in 1 inch, 23%.
 Reduction of area, 23.5%.

EXAMPLE II

Another heat (Alloy No. 2) was prepared using the same procedure as described for Example I with the melt containing 1.95% carbon, 0.65% manganese, 5.77% silicon, 36.7% nickel, 2.07% chromium, 0.085% magnesium and the balance iron.

The following properties were obtained in the alloy:

Coefficient of thermal expansion: 10.0×10^{-6} in./in./° F.
 Weight change due to oxidation after 43 thermal cycles from room temperature to 1600° F. (total time at 1600° F. was 1400 hrs.) +1.30 mg./cm.².
 Length change due to 43 thermal cycles from room temperature to 1600° F. (total time at 1600° F. was 1400 hrs.) +0.04%.

Alloy No. 2 was also tensile tested in the as-cast condition (without thermal cycling) with the following results:

Test temperature (°F.)	Yield strength at 0.2% offset (p.s.i.)	Ultimate tensile strength (p.s.i.)	Percent elongation in 1 inch	Percent reduction of area
Room temperature...	36,400	64,000	20.5	18.5
500.....	31,400	56,000	19.0	19.0
1,000.....	30,400	53,400	18.0	18.0
1,200.....	25,200	42,100	20.0	27.0
1,400.....	13,200	19,800	44.0	60.5
1,600.....	6,200	10,100	45.0	55.0

The above described examples were tested using the following procedures:

Coefficient of thermal expansion

The test specimen bars are 2¼ inches long with a ¼ inch diameter over 2 inches. There is a ⅛ inch extension at each end which is 0.075 inch diameter. The coefficient is calculated as the slope of the line joining the starting point (at room temperature) and the 1600° F. point on the temperature versus length-extension curve. A mechanical-type dilatometer was used to make the measurements.

Oxidation resistance

The specimens, which are bars 1 inch long and 0.3 inch diameter and surface ground to a 15 microinch finish, were stood on end in holes in a fixture and placed in a furnace at 1600° F. for 22 hours per daily cycle. The fixture was removed from the furnace for 2 hours each day for weighing and examining of the specimen. A weight increase indicated an adhering scale whereas a weight loss indicated that the material had scaled and

spalled from the surface of the specimen. Daily cycles were extended to longer times over weekends and holidays to shorten the total time required for testing.

Dimensional stability (growth)

Growth tests were performed using test specimen bars 5 inches long and ½ inch diameter. The ⅛ inch diameter holes were drilled radially through the bar at a centerline to centerline length of 4.00 ± 0.01 inches. Heating and cooling of the specimens were performed using a procedure similar to that described for the oxidation tests. The percentage growth was calculated by measuring, on a machinist's optical comparator, the change in length between the holes.

The special ductile iron provided by the invention may be melted in the cupola or in the electric furnace using standard practices known to produce acceptable spheroidal graphite structures in sound, porosity-free castings. Castings may be subjected before use to a heat treatment comprising one to three cycles from room temperature to the intended use temperature, with five to twenty hours at the use temperature in each cycle. This heat treatment tends to stabilize the microstructure with regard to carbide precipitation. No phase transformation or significant hardening will be produced by these treatments.

The ductile irons of the present invention are particularly applicable for turbine applications, e.g., power turbine shroud castings, housings, etc., although they can be used, of course, wherever the above described combination of properties is deemed beneficial. They can be produced in the usual cast forms because of the high castability properties of the alloy. It might be specifically mentioned that the compositions contemplated herein are particularly beneficial in the production of cast articles of thin complex sections generally.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. An austenitic ductile iron characterized in the as-cast condition by high temperature oxidation resistance, moderate high temperature strength and dimensional stability during thermal cycling or long time holding at high temperatures consisting essentially of about 1.6% to about 2.4% carbon, about 0.5% to about 1.5% manganese, about 5% to about 6.5% silicon, about 34% to about 40% nickel, about 1.5% to about 2.5% chromium, a small amount up to about 0.1% of a metal agent effective to spheroidize graphite and the balance essentially iron.

2. An austenitic ductile iron in accordance with claim 1 wherein the graphite spheroidizing agent is magnesium.

3. An austenitic ductile iron in accordance with claim 1 wherein the graphite spheroidizing agent is selected from the group consisting of magnesium and a metal of the Lanthanide Series.

4. An austenitic ductile iron characterized in the as-cast condition by high temperature oxidation resistance, moderate high temperature strength and dimensional stability during thermal cycling or long time holding at high temperatures consisting essentially of about 1.8% to about 2.2% carbon, about 0.5% to about 1.0% manganese, about 5.5% to about 6.0% silicon, about 36% to about 38% nickel, about 1.8% to about 2.2% chromium, a small amount up to about 0.1% of a metal agent effective to spheroidize graphite and the balance essentially iron.

5. An austenitic ductile iron in accordance with claim 4 wherein the graphite spheroidizing agent is magnesium,

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6. An austenitic ductile iron in accordance with claim 4 wherein the graphite spheroidizing agent is selected from the group consisting of magnesium and a metal of the Lanthanide Series.

7. A cast power turbine shroud produced from a ductile iron having a composition as set forth in claim 1.

8. A cast power turbine shroud produced from a ductile iron having a composition as set forth in claim 4.

9. A cast article having thin complex sections produced from a ductile iron having a composition as set forth in claim 1.

10. A cast article having thin complex sections produced from a ductile iron having a composition as set forth in claim 4.

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