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(54) Simo ductile iron castings for gas turbine applications

(57) A cast article of a ductile iron wherein the ductile iron includes carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than 0.01 weight percent and nickel from about 0.0 to 1.3 weight percent, the remaining content being iron is provided. The cast article is suitable for a gas turbine casing. A method of manufacturing a cast article is also provided.

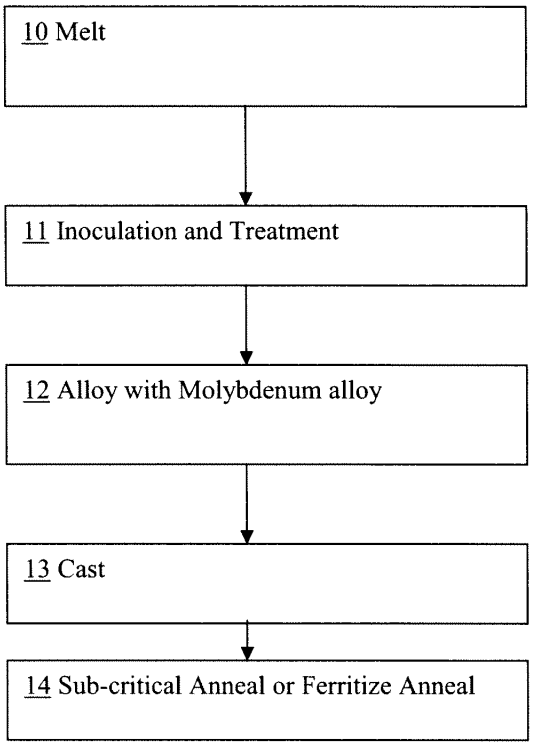


FIG. 1

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Description

BACKGROUND OF THE INVENTION

[0001] The invention relates to ductile iron for use in gas turbines that provides cost benefits and improved supplier choices.

[0002] Currently, gas turbine casings operating at elevated temperatures (greater than 370 °C) are restricted to alloy steel castings or fabrications. Gas turbines must endure unsteady operation to cover peak loads. This places thermal and mechanical stresses on the gas turbine components. Therefore, gas turbine casings must be able to withstand high temperature environments and repeated temperature cycling. The strength of the gas turbine casing material at high temperatures must be high. Presently, alloy steel castings for gas turbine casings meet these requirements; however, gas turbine casings of alloy steel are expensive to manufacture and there are a limited number of suppliers.

[0003] Traditional ferritic ductile irons are less costly than alloy steels but typically, have inadequate combination of properties, precluding their use in advanced gas turbine compressor discharge and turbine shell casings. Irons with higher silicon and molybdenum contents have found use in certain automotive applications, typically exhaust manifolds. These irons are referred to as SiMo irons. However, these irons are generally brittle at cold temperatures making them likely to crack. In addition, these materials do not possess the requisite toughness at elevated temperatures. Examples of such materials are found in US Pub. 2008/0092995, WO 2006/121826, US Patent 6,508,981 and EP 1724370 A1.

[0004] With increasing casing size it becomes more costly to manufacture gas turbine casings from steel castings. In addition, the current supply base to produce such large steel castings is small.

SUMMARY OF THE INVENTION

[0005] Embodiments of the invention include a ductile iron gas turbine casing wherein the ductile iron includes carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than about 0.01 weight percent and nickel from about 0.0 to 1.3 weight percent, the remaining content being iron.

[0006] Embodiments of the present invention also include a ductile iron gas turbine casing wherein the ductile iron includes carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than 0.01 weight percent, nickel from about 0.0 to 1.3 weight percent, phosphorous less than 0.05 weight percent, titanium less than 0.05 weight percent, vanadium less than about 0.05 weight percent, tin less than 0.05 weight percent, aluminum less than about 0.10 weight percent, copper less than about 0.10 weight percent, chromium less than about 0.10 weight percent and manganese at less than about 0.15 weight percent, the remaining content being iron.

[0007] Embodiments of the present invention also include a method of manufacturing a component. The method includes melting ductile iron that includes carbon, silicon, magnesium, sulfur and nickel, the remaining content being iron to form a melt. Inoculants and treatment alloys are added to the melt. Molybdenum is added to the melt. The melt is cast to form the component. The component includes carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than about 0.01 weight percent and nickel from about 0.0 to 1.3 weight percent, the remaining content being iron

[0008] The above described and other features are exemplified by the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] These and other features of this invention will be more readily understood from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings that depict various embodiments of the invention, in which:

FIG. 1 shows a block diagram of an illustrative method for implementing one embodiment of the invention.

DETAILED DESCRIPTION

[0010] High temperature strength, fatigue and creep behavior of ductile iron can be improved with large alloy additions of silicon and molybdenum. These irons are commonly classified as SiMo irons and have been used extensively in automotive applications such as turbocharger housings and exhaust manifolds.

[0011] Ductile irons typically fail to meet design requirements for high temperature gas turbine casing applications such as compressor discharge casings or turbine shells. Generally alloyed steels are used for gas turbine casings.

[0012] Ductile iron with improved high-temperature performance over conventional ferritic ductile iron by alloy additions of molybdenum and silicon is presented. The silicon and molybdenum additions are balanced to achieve adequate high temperature properties while retaining sufficient low temperature toughness.

[0013] Standard silicon levels in heavy-section ductile iron are typically between 2.0 and 2.2 weight percent. It has been found that increasing silicon content to between 2.8 and 3.5 weight percent substantially increases tensile strength between room temperature and about 400 °C. Isothermal creep performance for a 0.5 weight percent

molybdenum ductile iron is substantially better than conventional ductile iron. High temperature strength is an indication of creep resistance. Improvements in creep resistance performance is maximized as the Mo content is increased from 0.8 to 1.5 weight percent. By using Si and Mo in the weight percentages shown a ductile iron with properties suitable for gas turbine casings is provided.

[0014] The ductile iron used in embodiments of the present invention includes carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, nickel from about 0.0 to 1.3 weight percent, the remaining content being iron. These four components are critical to providing a ductile iron that meets the requirements for gas turbine casings. At elevated temperatures, tensile strength as well as low cycle fatigue (LCF) capability is determined by the occurrence of elevated temperature brittleness. Magnesium must be kept from 0.025 to 0.60 weight percent to provide a SiMo ductile iron with the proper characteristics with sulfur less than 0.01 weight percent. Magnesium loadings outside this range produce iron that generally has inadequate mechanical behavior. In addition to the components listed above, minor amounts of the following components are allowable. Phosphorous at less than 0.05 weight percent, titanium at less than 0.05 weight percent, vanadium at less than 0.05 weight percent, tin at less than 0.05 weight percent, aluminum at less than 0.10 weight percent, copper at less than 0.10 weight percent, chromium at less than 0.10 weight percent and manganese at less than less than 0.15 weight percent. In one embodiment, the tungsten content of the SiMo ductile iron is less than 0.05 weight percent.

[0015] Molybdenum-rich eutectic phases can lead to poor mechanical properties, specifically elongation and toughness. The strong partitioning of molybdenum to cell boundaries in the form of eutectic, intermetallic or metallic carbide phases is unavoidable. However, these phases can be reduced to acceptable levels by proper inoculation and chilling as well as implementing of other standard foundry practices.

[0016] A method of producing SiMo ductile iron is shown in FIG. 1. In step 10, the iron and other components are melted. Specified product chemistry is not identical to melt chemistry. As there are losses associated with the initial liquid melt, the final melt chemistry is different from the initial melt chemistry. In step 11, standard inoculants and treatment alloys are added to the melt. A molybdenum alloy is added to the melt in step 12. The melt is cast to form the part in step 13. Higher dross levels are associated with SiMo iron chemistry so these levels need to be accounted for in the foundry. Additionally, higher shrinkage and reduced feeding characteristics of the parts are typical. A heat treatment or ferritizing anneal in step 14 is generally required to improve toughness and prevent cracking during handling at the foundry.

[0017] A typical heat treatment or ferritizing anneal process for the cast material is as follows. Hold cast part at 900 °C for at least 7 hours. Allow part cool to 720°C and hold for at least 2 hours. Allow part cool to 690 °C and hold for at least 8 hours.

[0018] Rather than a ferritizing anneal process, a stress relief anneal can be performed on cast parts. The stress relief anneal is from about 650 to 750 °C for 1 hour per inch thickness of the section with the greatest thickness.

[0019] Inoculation is required to promote the formation of graphite instead of metastable carbide. Inoculants provide heterogeneous nucleation sites (seeds) for graphite to form. The primary component of the inoculant is silicon. Foundry grade ferrosilicon (75 weight percent Si) is often used for inoculation. Typical commercial inoculants contain high levels of silicon plus various levels of calcium, germanium, strontium, and rare earth elements (cerium is most common due to other beneficial characteristics in heavy section iron). Inoculants are often added multiple times in the production of large ductile iron castings. Suitable inoculants are available from many sources.

[0020] Standard treatment alloys are added to the melt in step 11 of Fig. 1. Treatment (sometimes referred to as modification) is necessary to force the formation of graphite spheroids instead of flakes. Treatment can be in the form of nearly pure Mg in powder form (George Fischer converter) or most cases in the form of a Mg-bearing alloy (often with Nickel).

[0021] Shrinkage occurs during solidification. Chilling (strategic placement of large cast iron blocks to remove heat) is used to promote directional solidification to limit macroscopic shrinkage porosity in critical areas of the casting. The size, type, number and placement of these chills becomes more important in SiMo irons due to reduced feeding and shrinkage levels associated with these irons.

[0022] Risers (or feeders) are needed to supply molten metal to prevent large shrinkage porosity in critical locations. These risers are often placed in regions susceptible to shrinkage (hard to feed thick-to-thin geometry transitions, for example). General foundry practice requires the distance between risers to decrease as the castability decreases. Additionally, larger risers and riser necks are often used as the castability decreases. Adjustments in pouring temperature are also common as the castability of the alloy decreases.

[0023] The terms "first," "second," and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms "a" and "an" herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context, (e.g., includes the degree of error associated with measurement of the particular quantity). The suffix "(s)" as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including one or more of

that term (e.g., the metal(s) includes one or more metals). Ranges disclosed herein are inclusive and independently combinable (e.g., ranges of "up to about 25 weight percent, or, more specifically, about 5 weight percent to about 20 weight percent", are inclusive of the endpoints and all intermediate values of the ranges of "about 5 weight percent to about 25 weight percent," etc).

[0024] While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made by those skilled in the art, and are within the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A gas turbine casing comprising:

a cast ductile iron wherein the ductile iron comprises: carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than about 0.01 weight percent and nickel from about 0.0 to 1.3 weight percent, the remaining content being iron.

2. The gas turbine casing of claim 1, further comprising phosphorous, titanium, vanadium and tin each at weight percent of less than about 0.05.

3. The gas turbine casing of claim 1 or claim 2, further comprising aluminum, copper and chromium each at weight percent of less than about 0.1.

4. The gas turbine casing of any preceding claim, further comprising manganese at weight percent of less than about 0.15.

5. The gas turbine casing of any preceding claim, further comprising tungsten at a weight percent of less than about 0.05.

6. The gas turbine casing of claim 1, comprising:

a cast ductile iron wherein the ductile iron comprises: carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than 0.01 weight percent, nickel from about 0.0 to 1.3 weight percent, phosphorous less than about 0.05 weight percent, titanium less than about 0.05 weight percent, vanadium less than about 0.05 weight percent, tin less than about 0.05 weight percent, aluminum less than about 0.10 weight percent, copper less than about 0.10 weight percent, chromium less than about 0.10 weight percent, manganese less than about 0.15 weight percent, tungsten less than about 0.05 weight percent, the remaining content being iron.

7. A method of manufacturing a component, the method comprising:

melting ductile iron comprising carbon, magnesium, sulfur and nickel, the remaining content being iron to form a melt;
adding inoculants and treatment alloys to the melt;
adding molybdenum to the melt; and
casting the melt to form the component wherein the component comprises carbon from about 2.8 to 3.7 weight percent, silicon from about 3.0 to 3.5 weight percent, molybdenum from about 0.8 to 1.5 weight percent, magnesium from about 0.025 to 0.60 weight percent, sulfur less than 0.01 weight percent and nickel from about 0.0 to 1.3 weight percent, the remaining content being iron.

8. The method of claim 7 further comprising:

annealing the component after casting the melt.

9. The method of claim 8, wherein the annealing comprises:

holding the component at 900 °C for at least 7 hours;
cooling the component to 720°C and holding for at least 2 hours;
cooling the component to 690 °C and holding for at least 8 hours.

10. The method of any one of claims 7 to 9, wherein the component comprises a gas turbine casing.

11. The method of any one of claims 7 to 10, wherein the component comprises phosphorous, titanium, vanadium, and tin each at weight percent of less than about 0.05, and/or aluminum, copper and chromium each at weight percent of less than about 0.1; and/or manganese at weight percent of less than about 0.15; and/or tungsten at a weight percent of less than about 0.05.

12. The method of any one of claims 7 to 11, wherein the inoculants comprise ferrosilicon.

13. The method of claim 12, wherein the inoculants further comprise calcium, germanium, strontium and rare earth elements.

14. The method of any one of claims 7 to 13, wherein the treatment alloys comprises magnesium and nickel.

15. The method of any one of claims 7 to 14, further comprising;
stress relief annealing at about 650 to 750 °C for 1 hour per inch thickness of the component.

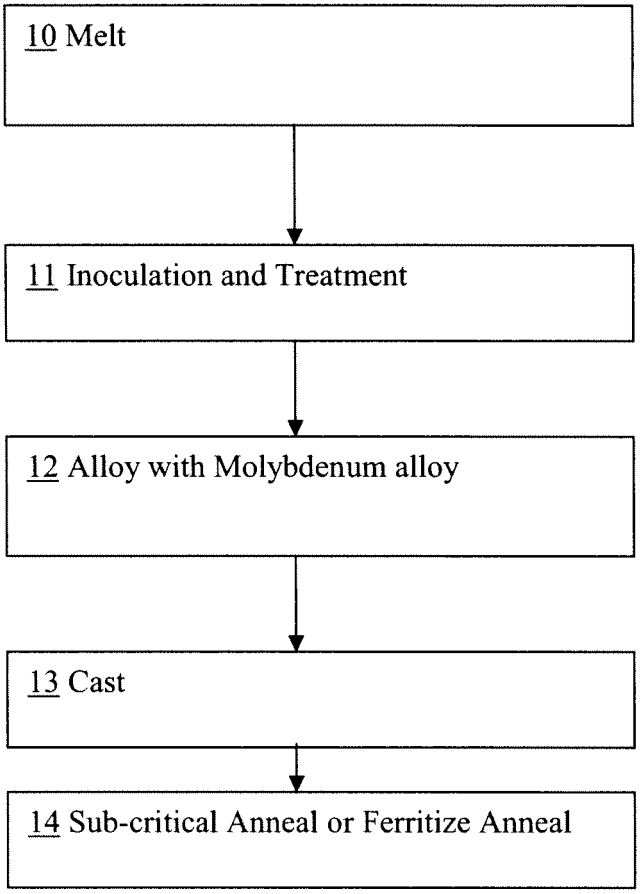

10 Melt
11 Inoculation and Treatment
12 Alloy with Molybdenum alloy
13 Cast
14 Sub-critical Anneal or Ferritize Anneal

FIG. 1

REFERENCES CITED IN THE DESCRIPTION

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