A DUCTILE IRON AND METHOD OF MAKING IT

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Field of Search ..... 148/15, 35, 138, 139, 140, 148/141; 75/123 CB

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2,324,322 7/1943 Reese et al. ................. 148/35 X
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ABSTRACT
For a ductile iron of the type which has been heated, after casting, to its austenization temperature and austenitized and subsequently heat-treated isothermally by quenching in a hot bath to start a bainite reaction which is continued until a desired fraction of the austenite have formed into bainite, improved properties are achieved by adding as alloying elements molybdenum 0.10 – 0.26 % and manganese 0.3 – 1.4 % by weight and preferably also an additional alloying element which promotes the formation of a pearlite microstructure during casting and, consequently, accelerates the austenitization, said additional element consisting of nickel in an amount less than 2.5 % by weight, and tin and/or copper. Preferably said iron contains molybdenum 0.15 – 0.22 % by weight and less than 0.2 % by weight of tin and/or less than 1.0 % by weight of copper.

7 Claims, 3 Drawing Figures
The present invention relates to a ductile iron alloyed with molybdenum and manganese and which has, after an isothermal heat treatment, a bainitic microstructure with a considerable amount of retained austenite.

Ductile iron is generally used unalloyed or alloyed in various ways, and with, for example, a ferrite, ferritepearlite, pearlite, annealed martensite, or bainitic microstructure.

The most essential characteristic of the ductile iron according to the present invention is its bainitic microstructure in combination with a considerable amount of retained austenite.

Previously known is a process for bainitizing ductile iron or SG-iron; in this process the bainite reaction is obtained in a highly alloyed ductile iron in connection with cooling immediately after casting. Such a ductile iron is introduced in U.S. Pat. application Ser. No. 1,808,515. Figure 1 shows an example of such a ductile iron; the S-curves are indicated by solid lines and the curve which illustrates the cooling of the piece by a broken line in the time-temperature coordinate system. Under the influence of the alloying elements the S-curves have moved considerably to the right from where they would be in an unalloyed ductile iron and, thus, owing to the high degree of alloying, bainite is obtained in connection with the cooling. In addition to molybdenum, a great amount of nickel (3.2 – 7.0 %) is used as an alloying element. By this process, a bainitic micro-structure is obtained in pieces with even thick walls, but it has disadvantages in the high price caused by the alloying and, especially, in that the alloying ratios must be determined according to the wall thickness of each given piece to be cast.

Also known is a bainitizing process in which pieces manufactured from unalloyed ductile iron are heat-treated isothermally. In this heat-treatment, the cast piece is reheated to the austenitization temperature after the casting process and is then cooled rapidly in a hot bath at a constant temperature. The piece is kept in the bath and thereby at a constant temperature until the bainite reaction has taken place, thereafter the piece is cooled to room temperature. In Figure 2, the S-curves according to this process are indicated by solid lines and the curve illustrating the cooling of the piece by a broken line in a time-temperature coordinate system. By this process, a bainitic microstructure is obtained in a ductile iron which does not contain expensive elements. The rapid cooling required by this process is possible only with thin-walled castings. The greatest suitable thickness of material is about 20 mm.

SUMMARY OF THE INVENTION

The present invention provides a ductile iron of the character described, which comprises as alloying elements molybdenium 0.10 – 0.26 % by weight and manganese 0.3 – 1.4 % by weight and possibly also an alloying element which promotes the formation of a pearlitic micro-structure during the casting and thereby accelerates the austenitization and which consists of nickel in an amount of less than 2.5 % by weight and at least one of the elements tin and copper.

The ductile iron and its bainitization process according to the present invention can be applied to both thick and thin castings. In this process, the alloying ratios need not be changed according to the wall thickness of the casting.

This ductile iron is rather mildly alloyed so that the alloying elements do not raise its price very much. In addition, the retained austenite present in this ductile iron, in addition to bainite, gives it toughness and makes it capable of being hardened by machining. Hardening by machining creates a compression stress at the surface and thereby increases the fatigue strength. Its elongation at rupture is great.

Thus the ductile iron according to the invention contains the conventional amounts of carbon, silicon, phosphorus, sulphur, and magnesium, and as actual alloying elements, molybdenum 0.10 – 0.26 %, preferably 0.15 – 0.22 %, and manganese 0.3 – 1.4 %. A ductile iron so alloyed is as such suitable for isothermal bainitization. If an amount of 0.03 – 0.2 % of tin, 0.3 – 1.0 % of copper, or 0.5 – 2.5 % of nickel is also added to the alloy, a pearlitic micro-structure is obtained in the piece in as cast condition, and when this structure is reheated to the austenitization temperature, it becomes austenitized considerably faster than a micro-structure which contains free ferrite, and thereby the heat-treatment period is shortened. Tin, copper and nickel have a similar effect on the pearlitic formation and therefore they can entirely or partly replace each other; for example, a one-third batch of each of the three additives can be used.

A ductile iron according to the invention, bainitized isothermally, is an excellent raw material for gears, especially when the teeth cannot be finished or are not worth finishing by grinding. An example of such a case is gears with inside teeth. It is also applicable to all kinds of machine elements exposed to fatigue stress loads. Examples of such machine elements are, in addition to gears, gear shafts, sprockets, support wheels or rolls which are to roll against a hard surface, cams, crankshafts, support rings, and various parts subject to wear and tear, such as friction plates.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows, in time-temperature diagram, some characteristic curves for a highly alloyed ductile iron belonging to the prior art; Figure 2 shows corresponding curves for a known unalloyed ductile iron; and Figure 3 shows corresponding curves for a ductile iron according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A ductile iron piece according to the invention is manufactured, for example, in the following manner: A disk-shaped blank with a diameter of 150 mm and a thickness of 50 mm is cast from a melt which contains as alloying elements carbon (C) 3.5 – 3.7 %, silicon (Si) 2.1 – 2.4 %, manganese (Mn) 0.50 – 0.55 %, molybdenum (Mo) 0.2 – 0.22 %, and copper (Cu) 0.7 – 0.8 %, and a conventional amount of magnesium. The blank is allowed to cool freely, or its treatment is continued while it is hot. The blank is transferred to a furnace with a temperature of 900°C. In the furnace, the micro-structure of the blank is transformed into austenite. After an austenitization of 2 hours, the blank is...
quenched into a salt bath at a temperature of 370°C. The quantity of the bath is 200 kg and it contains 1 part of sodium nitrate (NaNO₃) and 1 part of potassium nitrate (KNO₃). The bath has been provided with a agitation device and with a thermostat. The test piece is kept in the bath from 10 minutes to 4 hours, depending on the desired amount of bainite. The blank is removed from the bath and allowed to cool freely. Thereafter, the blank contains, for example, bainite about 50 % by vol., austenite about 40 % by vol., and graphite about 10 % by vol. A suitable amount of retained austenite is 20–50 % by vol. A ductile iron containing less austenite is not capable of being work hardened by machining and a ductile iron containing more austenite is not strong enough.

The isothermal heat-treatment of a ductile iron according to the invention is illustrated in FIG. 3 in a time-temperature coordinate system. The solid lines indicate the S-curves of the ductile iron. The broken line indicates the cooling curve of the piece.

An isothermally bainitized blank, cast from a ductile iron alloyed according to the invention, is of a very even quality and suitable for machining. It has been verified by tensile strength tests that its elongation, when a tensile strength of 110 kp/mm² is used, is about 10 %, which is high when compared to the respective value of a highly alloyed bainitic ductile iron or a quenched and tempered ductile iron of the same strength.

The tensile strength and elongation of some bainitized ductile irons having an alloy ratio according to the present invention are as follows:

<table>
<thead>
<tr>
<th>No.</th>
<th>Mo %</th>
<th>Mn %</th>
<th>Ni %</th>
<th>Cu %</th>
<th>Sn %</th>
<th>Tensile strength kp/mm²</th>
<th>Elongation at rupture %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.10</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>104</td>
<td>8.7</td>
</tr>
<tr>
<td>2</td>
<td>0.18</td>
<td>0.8</td>
<td>0</td>
<td>0.7</td>
<td>0</td>
<td>110</td>
<td>9.6</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
<td>1.4</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
<td>107</td>
<td>7.0</td>
</tr>
</tbody>
</table>

If less than 0.10 % of molybdenum is present bainitization will not take place in thick bodies, and if it is present in an amount exceeding 0.26 % the formation of carbides increases and so does the price.

If the manganese content exceeds 1.4 % the risk of carbide formation increases and the austenitization time gets longer.

If the nickel content exceeds 2.5 %, the price of the iron is uselessly high.

The retained austenite in a ductile iron according to the invention makes it capable of being hardened by machining and thereby capable of enduring a very fatigue load. A bending fatigue test with a turned and polished test bar of 12 mm gives a value of 50 kp/mm², which is high compared to the respective values of other ductile iron. A bending fatigue test with a notch bar of 12 mm into which there has been turned a groove with an angle of 60° and with a bottom rounding radius of 1.0 mm gives a value of 40 kp/mm², which is high even when compared to steels. The ratio of the values obtained from fatigue tests with the same SG-iron, i.e., the ratio of the smooth bar value 50 kp/mm² to the value 40 kp/mm² of the notched bar, namely, 1.25, called the notch effect, is very low.

Rolling fatigue tests with a ductile iron according to the invention gave the following values. The composition of the SG-iron used in the test was: C = 3.66 %, Si = 2.24 %, Mn = 0.54 %, Mo = 0.22 %, Cu = 0.78 %, P = 0.02 %, and S = 0.008 %. It was heat-treated so that the micro-structure contained bainite about 53 % by vol., austenite about 37 % by vol., and graphite about 10 % by vol. The Hertzian contact stress was determined in a rotary fatigue test and was comparable to the values given in DIN 3990 Bl 9. The test gears were machined, their module = 3.5, tooth number = 33, slant angle = 15°, and width = 45 mm. The counter gear was case-hardened steel (DIN 1720, 15CrNi6) with surface hardeners 58–68 HRC. The tooth number of the counter wheel = 65. Values 132, 138, and 150 kp/mm² were obtained with the test wheels. These values are more than double the respective values given for the strongest ductile iron in DIN 3990 Bl 9. The test results indicate how well the ductile iron according to the invention is applicable to rotary fatigue, i.e., it can be loaded with a considerable surface pressure without pitting damage.

What is claimed is:

1. A ductile iron especially applicable to machine elements exposed to fatigue stresses containing as alloying elements molybdenum 0.10–0.26 per cent by weight and manganese 0.3–1.4 per cent by weight and having a microstructure of isothermal bainite and 20 to 50 % by volume of retained austenite enabling work hardening of the ductile iron in use when exposed to said fatigue stresses or by machining.

2. A ductile iron as in claim 1 wherein the molybdenum content is 0.15–0.22 % by weight.

3. A ductile iron as in claim 1 containing tin up to 0.2 % by weight.

4. A ductile iron as in claim 1 containing copper up to 1.0 % by weight.

5. A method of producing an austenitic-bainitic ductile iron, comprising austenitizing a ductile iron containing as alloying elements molybdenum 0.10–0.26 per cent by weight and manganese 0.3–1.4 per cent by weight by heating it to the austenitization temperature and austenitizing it, then quenching it in a hot bath to form isothermal bainite, and cooling it further when the bainitic ductile iron so transformed still contains 20 to 50 % by volume of retained austenite.

6. A method as in claim 5 including machining the ductile iron before quenching it.

7. A machine element constructed of the ductile iron of claim 1.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION


Inventor(s) Jouko VUORINEN; Yrjo INGMAN; Matti JOHANSSON; and Martti KURKINEN

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the front page format, please correct the spelling of --Jouko Vuorinen-- each occurrence.

Signed and sealed this 10th day of June 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

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