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Production of Austempered Ductile Iron with Optimum Sulphur Level for Effective Mechanical Properties

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ABSTRACT

This research work is on the production of austempered ductile iron with optimum sulphur level for effective mechanical properties. Austempered ductile iron is a new material obtained from ductile iron. It has attracted considerable interest because of its excellent properties such as good ductility, good wear resistance, and high strength to mention but a few. The main objective is to produce a ductile iron of various compositions and heat treating it to obtain the required austempered ductile iron (ADI). The raw materials used include the following: scraps of engine block made of grey cast iron, graphite, Ferro-silicon magnesium, Ferro-silicon manganese, and powdered graphite and Ferro-silicon. Rotary furnace was used to melt the materials. The molten metal was poured into the already prepared mould for casting. Five other castings were carried out following the same procedure but with varying amount of Ferro-silicon manganese in order to vary the sulphur content and the compositions. Thus the ductile iron was produced. This was later heat treated to produce the Austempered Ductile Iron (ADI).

KEYWORDS: *Austempered ductile iron, austenitisation, furnace, sulphur level, ductility, compositions.*

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I. INTRODUCTION

In recent years, Austempered Ductile Iron (ADI) has attracted considerable interest because of its excellent properties, such as resistance to fatigue (1-5) good wear resistance (3), high strength with good ductility (2) and rolling contact resistance (4). According to Olivera et al 2006(6), the manufacturing cost of ADI is also substantially lower than wrought or forged steel. Furthermore, the density of ADI is lower than steel (7). Thus, ADI has the advantage of higher specific strength than steel (8). Due to all the stated properties of ADI above, it is considered a very promising engineering material, and an economical substitute for wrought or forged steel in several structural applications in the automotive industry(6). The mechanical properties of ADI can be tailored to suit particular applications by adjusting Heat treatment parameters or material compositions (6). This can aid the proportion of the phases present in the microstructure.

The process involves the production of a ductile iron casting, austenitisation at (800-950^{0}C), salt bath with potassium chloride, sodium chloride and barium chloride and then quenching to a temperature (250 – 400^{0}c) in salt bath of potassium nitrate and sodium nitrate. (1,11).Rebasa, (1) pointed out that it is possible to produce both compacted graphite irons and ductile iron from the same base iron by using cored wire containing a high magnesium and ferrosilicon(1). In this work proper method of producing Austempered Ductile Iron (ADI) will be established and sulphur level will be varied in order to obtain optimum mechanical properties.

II. LITERATURE SURVEY

2.1 CAST IRON

Although the focus of the work in this research is to assess the effect of residual sulphur in austempered ductile iron, a brief introduction to cast iron is useful since ADI emerged as a new member of the family during the1960's (3,5,19). The list of cast irons is large and only the most important ones are described here. Cast iron can be sub-divided in to three main parts namely;

(i) Grey cast iron.
(ii) Malleable cast Iron and
(iii) White cast iron – no graphite's

2.1.1 GRAY CAST IRON

Gray cast iron is produced from the foundry pig, scrapped casting and coke which is melted in a cupola blast furnace. Grey cast iron derived its name from the grey color obtained when it is fractured. The carbons in gray cast iron are in graphite form, so its microstructure is full of graphite flakes but this is not always desirable. About 0.8% of the carbon is in the form of iron carbide Fe_3C, and the rest 2 to 4% are in the form of graphite. It is possible for gray cast iron to have all its carbon inform of graphite. Such gray cast iron will be soft and easy to machine.(A). This type of cast iron will have high damping capacity and high compressive strength. The tensile strength, ductility and impact strength are much lower than steel due to the weakening effect of the graphite flakes but it has a high resistance to corrosion [21,]. On the other hand, the gray cast iron having the carbon content in the form of carbide is usually very hard, brittle and not easily machined. There are two main factors that determine which type of gray cast iron will be formed. These are

(i) the chemical composition of the desired gray cast iron;
(ii) The cooling rate from the molten state.

Gray Cast Iron is used for cylinder blocks, Piston rings, Internal Combustion engine, Machine tool structures, Ingot moulds et al. [3, 21]

2.1.2WHITE CAST IRON

This iron derived its name from its color which is white and dull. The carbon content of this type of cast iron is in the form of free cementite. White cast iron is produced either by casting the gray cast iron but rapidly cooled it or by adjusting the carbon content in the composition and makes it low.White cast iron is very hard, but wear resistant and very brittle. White cast iron can be used for the production of malleable iron castings and manufacture of components requiring hard and abrasion resistant surface.[3]

2.1.3MALLEABLE CST IRON

Malleable cast iron is obtained from the white cast iron. To do this white cast iron is annealed. The white cast iron is heated slowly to 870^0C. It is then homogenized for 25 to 60 hours depending upon its size. It is then cooled slowly in the furnace. This process is called malleabilizing heat treatment.Malleable cast irons are tougher than gray cast iron and more resistant to bending and twisting. It is used for various automobile, tractor and plough parts, gear housing et al. [3]

2.2 DUCTILE CAST IRON

The ductile cast iron is another type of iron that can be obtained from grey cast iron. This is obtained by the addition of magnesium to the melt of grey cast iron. This will result in the production of nodules in the microstructure of the ductile cast iron and therefore called Nodular Cast Iron Ductile iron contains 3.2 – 4.2%C, 1.1 – 3.5%Si, 0.3 -0.8%Mn, 0.08%P and 0.02% - 0.05%S[3,8,20].Ductile cast iron possesses a good ductility. It has good machinability, wear resistance and very good castability [3]

2.3 AUSTEMPERED DUCTILE IRON

Austempered ductile iron is obtained by heat treating the ductile iron in salt bath of sodium chloride, potassium chloride and barium chloride at the temperature of 830^0C. It was austempered at 350 - 420^oC and later salt bath using sodium nitrate and potassium nitrate.

2.3.1 Typical chemical composition of Austempered Ductile Iron (ADI)

ADI nominally has the chemical composition Fe, 3.6 C, 2.50 Si, 0.5 Mn, 0.032 Mg, 0.05S, 0.114 P wt. %, but a variety of other additions may be made [3]. It is common to see additions of elements such as Mo, Ni and Cu. One reason for alloying is to suppress the pearlite reaction so that the austenite can transform into bainite. Other elements such as Chromium and Vanadium may be added also to improve hardenability [12] however; this is not common since these elements are strong carbide forming elements.Manganese is a strong promoter of hardenability; its addition is useful to prevent pearlite formation in thick cast – sections. However, since manganese segregates in the intercellular areas between the nodules of graphite, causing the precipitation of carbides [10], it is therefore advisable to keep its average concentration in the range of 0.25 to 0.5 wt% [20].Apart from carbon, molybdenum is the most potent hardenability enhancer in ADI (about 1.6 times more than Mn) [10]. However, like manganese, it segregates at cell boundaries during solidification to form carbides [6], so its concentration is usually limited to less than 0.3 wt % ([15].

Nickel and copper do not segregate as much as Manganese and Molybdenum, and in any case, they partition preferentially into the solid phase [14]. They do not significantly affect the hardenability, but when combined with manganese or molybdenum, there is a useful increase in the maximum section size that can be austempered successfully [13]. Additions of nickel may vary from 0.5 to 3.5 wt% whereas Copper (Cu) varies from 0.5 to 1.0 wt%.

There are three important points to consider when selecting the chemical composition of ADI;

1. The iron should be sufficiently alloyed to avoid transformation to pearlites, but not Over- alloyed to avoid the retardation of the bainite transformation.
2. The microstructure should be free from intercellular carbides and phosphates.
3. The tendency for chemical segregation should be minimized for the sake of uniformity in the constituents.

It has been claimed [20] that small additions of multiple alloying elements are more effective in promoting hardenability than large amounts of individual alloying element.

III. METHODOLOGY

3.3.1 RAW MATERIALS AND EQUIPMENT

(a(The selection of the material to be used for the casting was done. Two cast irons were available; the first is an engine block and the other industrial cast iron. Samples of the two materials were prepared and their compositions analyzed as shown in Tables 1&2 below:

The two metals are hypoeutectic cast iron (with carbon up to 4.20 percentages). The engine block was selected because it has carbon content within the realm of ductile Iron. In addition, the manganese and sulphur content in the engine block may compensate each other to give ductile iron of interest.

(i)Table 1: Compositions Analysis of Engine block.

Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co	Ti	Nb
%	4.32	2.20	0.79	0.077	0.199	0.326	0.44	0.011	<0.001	0.121	0.013	0.013	<0.001
Elements	V	W	Pb	Mg	B	Sn	Zn	As	Bi	Ce	Zr	La	Fe
%	0.0098	<0.010	0.0089	0.0039	<0.0025	0.040	0.0088	<0.0018	<0.0015	<0.0030	<0.0015	0.0028	91.8

(ii)Table2: Compositions analysis of industrial cast Iron[3].

Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co	Ti	Nb
%	4.72	2.16	0.55	0.231	0.166	0.032	0.024	<0.0020	<0.0010	0.057	0.013	0.087	<0.025
Elements	V	W	Pb	Mg	B	Sn	Zn	As	Bi	Ce	Zr	La	Fe
%	0.050	<0.010	0.012	0.0041	<0.0005	0.0060	0.0096	<0.024	<0.0015	<0.0030	<0.0015	0.0036	91.8

3.2 MELTING

The following raw materials were used in the production of the ductile cast iron:

i. Scraps of engine block which was made of grey cast iron, was broken in to pieces and 55kg was measured and charged in to the furnace.
ii. Graphite, 4kg of graphite was measured and charged in to the furnace
iii. Ferrosilicon Magnesium (700g)
iv. Ferrosilicon manganese (ranges between 47g to 326sg).
v. 18gm of powdered graphite and the same amount of powdered Ferro-silicon were added as inoculants.

The equipment used is Rotary furnace; which is located at Engineering Materials Development Institute,(EMDI),Akure, and was used to melt the charged materials.

(b) Diesel was mixed with used engine oil (SAE) to fire the furnace with the help of a blower.

3.3 PRODUCTION OF THE AUSTEMPERED DUCTILE IRON.

3.3.1 HEAT TREATMENT

Austempered Ductile Iron (ADI) was produced by an Isothermal heat treatment called austempering. This process is referred to as austenitising and occurred as follows:

1 The ductile iron was placed in a molten salt of potassium chloride (KCl), sodium chloride (NaCl) and barium chloride ($BaCl_2$) and in the ratio of ($KCl:NaCl:BaCl_2$) =(3:2:1) respectively. These samples were placed in the furnace and heated to 830^0C in two hours and soaked at this temperature for an extra hour. Hence the total time for the operation is three hours.

2. In order to austempered the Ductile Iron, equal amount of 500g of Sodium Nitrate ($NaNO_3$) and Potassium Nitrate (KNO_3) salts were mixed together and melted. The samples were removed from the austenitized bath of (1) above and quenched in the salt bath. The salts and the materials were then heated to a temperature of 450^0C.The metals were removed from the salt bath and allowed to cool to room temperature. The temperature was monitored to make sure ferrite and austenite transformation were obtained. The various results are discussed in the next chapter.

A multimeter tester AVD890C (thermocouple) was used to ascertain constant salt bath temperature of 450^0C.

IV. RESULTS AND DISCUSSION

INTRODUCTION

An attempt was made to produce ADI of varying sulphur level. The various temperatures during melting of the materials in the furnace were taken. The samples charged were ensured molten before tapping in to the ladle.

4.1 FURNACE TEMPERATURE RECORDED DURING MELTING OF THE CHARGED

Melt 1 contained no Ferro-silicon, magnesium and manganese. While 326,233,140,93 and 47 grams of fero-manganese were added to Melts 2,3,4,5and 6 respectively. Also 700grams of Ferro – magnesium was added to each melts 2-6. 18grams of powdered graphite and the same amount of powdered ferro-silicon were added as inoculants to all the melts except melt 1.

It is assumed that melting had occurred between 40 and 50 minutes of heating. The materials were completely melted at 40 minutes but super heat was imposed. Visual observation showed that it had melted.

4.2 MAINTENANCE OF DIFFERENT SULPHUR LEVELS.

The anticipation of varying sulphur level as calculated actually differs from the observed values even though it followed similar trend. Table 4 shows the calculated and actual values of sulphur obtained.

Table 3: The initial and the final values of Sulphur obtained.

MELT	Amount of Sulphur (%) Present in the cast iron	Amount of manganese Added (g)	Actual values of Sulphur obtained (%)
1	0.199	0	0.088
2	0.199	326	0.086
3	0.199	233	0.030
4	0.199	140	0.030
5	0.199	93	0.028
6	0.199	47	0.027

Table 4 above shows the results of the amount of sulphur present in the composition of the austempered ductile iron (ADI) produced. Before the casting was carried out, a certain amount of sulphur was presumed and used. This amount was used to calculate the value of manganese to be added to the charge. After casting and austempered, the chemical composition analysis of the ADI was carried out to obtain the actual amount it contained. These are also shown in table 3 above. These actual values were generally smaller than the assumed values. From the results obtained, the sulphur was reduced greatly by the addition of Ferro-manganese which must have combined with the sulphur present to form manganese sulphide. The manganese sulphide gets distributed in the surface of the molten metal because of its low density and formed slag.

With the following reactions:

$Mn + S \rightarrow MnS$ (manganese sulphide)

$Fe + S \rightarrow FeS$ (Iron (II) Sulphide

$O_2 + S \rightarrow SO_2$ (sulphurdioxide)

ssAustempered ductile cast iron (ADI)' 59th Japan Ductile Cast Iron. Association Conference, Tokyo, Japan, 1978 pp 138-150.

V. CONCLUSIONS

[1] **Duc**tile Iron was produced. The ductile iron was later heat treated to obtain Austempered Ductile Iron .These were the two products obtained from the casting carried out.

[2] The method for producing austempered ductile iron was fully established. It must be noted that the inoculants has to be added at the appropriate time which is when the molten metal is about to be poured into the ladle.

[3] Also, the sulphur level was varied to obtain the best product of the casting. Various temperature of the casting was obtained.

[4] In preparing ductile iron, the materials were completely melted in 40 minutes super heat was imposed for 10minutes.

[5] The composition of austempered ductile iron obtained is 3.41-4.10% C, 1.85-2.95%Si, 0.419-0.510 %Mn, 0.027-0.088 %S, 0.083-0.137 %P, 0.0042-0.035%Mg.Iron gave the balance.The composition obtained conformed to the general standard stated in the literature i.e. (3.2- 4.2%C, 1.1-3.5%Si, 0.3-0.8%Mn, 0.02-0.05%S, 0.08%P)(3)

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