Production of Ductile Iron from Waste Sleeve Scraps for Automobile Applications

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Abstract- There is continuous demand for local production of quality automobile spare parts in the country nowadays. The current economic condition of the nation has placed more challenges on the indigenous foundry to improve on their technology to make automobile spare components accessible and affordable to the nation. This study examined the possibility of converting the indiscriminately dumped sleeve scraps from state of waste to ductile iron useful products thereby adding value to it. The mechanical properties of ductile iron produced from the sleeve scraps using local technology were determined and found comparable to that of international standard (ISO). Sleeve scraps were charged with graphite and FeSi into a rotary furnace and melted. Nodularization was achieved using MgFeSi as an indigenous technology of the production process. The hypotheses of the study were tested and compared with the ISO standard of the grade of ductile iron and the findings revealed that Ductile iron that corresponds with the standard was successfully produced from solid waste (automobile sleeves scraps).

It was recommended among others that the effort be made towards the conversion of sleeve scraps to ductile iron automobile components, in order to minimize the menace of environmental pollution which leads to numerous health hazards and mortality. Also, making automobile spare parts available to the end users and reduce its importation.

Keywords: Recycle, Solid waste, sleeve scrap, ductile iron, Rotary furnace, local technology and automobile application

1 INTRODUCTION

The request for local production of automobile spare parts continue to be on the increase just as the management of solid waste is increasingly becoming a source of concern globally, most especially, in the developing countries due to increase urbanization, changes in consumer pattern and industrialization that have direct impact on the solid and industrial waste generation which include metals, scraps, chips and grits from machine and automobiles (Kadafa et al, 2013; Oyetunji and Omole, 2011). Waste generation is an integral part of human activity influenced by social dynamics and economic development. However, the challenge of its adverse environmental effects on human being must be greatly minimised. Automobile scrap metals are among the most important and priced materials in municipal solid waste (MSW) that are of high value when recycled. The recycling as raw materials prevents air, water and soil pollution, saves energy and reduces greenhouse gas emissions.

In Nigeria, the bulk of raw materials for the development of foundry and automobile industries are designed to be supplied from Ajaokuta Steel Company which is yet to fully take off. Consequently, attention has now been focused on the use of scraps as major raw materials for the production of automobile spare parts. Hence, this study focused on the use of sleeve scraps recycling to produce ductile iron for automotive applications.

Scrap is a term commonly employed to describe used and recyclable materials left over from every manner of product such as parts of vehicles (metal, tyres, paper, nylon, computer parts and other numerous parts). Often confused as waste, scraps are in fact, have significant monetary value. They are articles that are not wanted but are of some value for the material they are made of and metal iron scraps are useful because of the iron they contain. Examples of metal scrap include automobile parts (where cast iron sleeves can be obtained), ship wrecks parts, industrial parts, building and household parts that metal can be extracted from. Many important metals being recovered and recycled include iron and steel, copper, brass, aluminum (Ohimain, 2013). Recycling of these metal scraps prevent air, water and land pollution which eventually save energy and raw materials; and reduce greenhouse gas emissions. Many used automobile component parts such as piston, engine block and connecting rods have been recycled to produce useful engineering materials. However, the use of sleeve scraps for the production of useful engineering materials of ductile iron of ISO standard and specification due to its low sulphur content has been confirmed in this work.

Ductile cast irons are engineering materials from the ferrous metal with carbon contents above 2.1 wt % (Rilwan, 2015). Based on the application and the inclusion of other relevant alloying elements especially, silicon in practice, cast iron contains 3-4.5wt% carbon. The castability makes them suitable for the manufacture of engineering automotive components (Bocus and Zaldarys, 2010). It is one of the most essential engineering materials, in view of its excellent castability. It possesses better mechanical properties at low cost. It belongs to a class of cast graphitic irons which have high strength, ductility and resistance to shock. It also denotes the fastest growing section of the iron market (Bockus and Dobrovolskis 2006).

In ductile iron, the addition of a few hundredths of 1% of magnesium or cerium causes the graphite to form in small spheroids rather than flakes. These create fewer discontinuities in the structure of the metal and produce a stronger, more ductile iron. Annealed cast ductile iron can be bent, twisted or deformed without fracturing. Its strength, toughness and ductility reproduce many grades of steel and far exceed those of standard gray irons. Thus, it has the advantages of design flexibility and low cost casting procedures similar to gray iron. The difference between ductile iron and gray iron is in the graphite formation. Ordinary gray iron is characterized by a random flake graphite pattern in the metal matrix.
Achieving full potential of ductile iron requires superior metallurgical process control as well as the highest levels of skill in melting the ductile iron base, spheroidizing and inoculation (Bockus and Dobrovolskis, 2006). It is this nodular graphite formation which accounts for the fact that ductile iron is also referred to as “nodular iron”.

With ductile iron, the safety and reliability of process equipment is improved. The as-cast ductile irons (ductile cast iron) have many advantages, which include energy-saving, equipment investment decreasing, production cycles shortening, reduction in production costs and promoting competitiveness, compared with heat treated ductile irons. Also, some defects from heat treatment, such as high temperature oxidation and deformation, can as well be avoided in the as-cast ductile irons. About 80% ductile iron casting components in automotive applications involved are manufactured in as-cast. Thus, the research and development in producing as-cast ductile irons for heavy duty applications are of great importance to metallurgical engineers. The mechanical properties are far above that of gray iron and this increases its resistance to breakage.

Locally in recent time, rotary melting furnace seems the most cost effective, flexible and universally designed equipment to recycle cast iron scraps. It is alternative melting equipment for small and medium size foundries using cupola furnaces or induction furnaces. This is because gray, nodular or malleable cast iron can be manufactured with high critical accuracy at a low personnel and investment cost (www.industrialmetalcastings.com, 2009). Hence, it provides an important missing links in the metal producing technology and building capacity in the foundry industries (Adewoye, 2005).

Sleeve scraps are waste cylindrical cast iron materials in the engine block of an automobile. They are available in large quantities in the mechanic workshop. Instead of leaving the sleeve scraps to litter the environment which will cause the environmental pollution; they can be converted into wealth to reduce the pollution that may be hazardous to the human’s health. This research was designed to employ the use of the solid waste that are disposed indiscriminately in our environment and convert to wealth by recycling in the metallurgical melting furnace to produce ductile iron that find useful engineering application through the use of indigenous technology of rotary furnace. This will reduce importation of parts that can be produced locally and hence, help to preserve the nation foreign exchange.

2 MATERIALS AND METHODS

2.1 Materials
The materials used in the research work include sleeve scraps as base metal, ferro-silicon alloy (FeSi), magnesium-ferro-silicon (MgFeSi), graphite, coal dust, bentonite and green moulding sand. The equipment used were 100 kg capacity diesel – fired rotary furnace, digital optical pyrometer, digital weighing balance, moulding box and its accessories, Instron universal tester of model type 3369, LECO Vickers Hardness tester of model LM700AT of 50mHV, Nikon Eclipse ME600 metallurgical microscope, spectrographic analyzer, grinding machine, polishing machine, portable hacksaw and lathe machine with its accessories.

2.2 Methodology
Standard procedures were used to prepare patterns and mould for producing the ductile iron in accordance to Alasoluyi et al (2013). Silica sand from Igbokoda, Ondo State-Nigeria was prepared, mixed with bentonite as binder and coal dust in order to enhance permeability. Adequate water was added to the mixture to ensure mouldability and flowability and the mixture was moulded in moulding boxes of size 500 mm by 350 mm by 250 mm to produce moulds for the ductile iron melts. The mould was thereafter left to dry and later fired to achieve casting of good quality and properties. The schematic diagram of the mould produced is shown in Fig 1.

The chemical analysis of the base metal (sleeve scraps) was carried out using spectrographic analyzer to determine the elemental composition and the result shown in Table 1. The composition of the graphite and ferro-alloys: FeSi and MgFeSi used are also presented in Tables 2, 3 and 4 respectively. The sleeve scraps were broken down into smaller sizes with hammer and cleaned to avoid contamination during melting. (Alasoluyi et al, 2013; Karsay, 1994). The charged materials were appropriately sized to facilitate easy charging and fast melting in the furnace. Other charged materials, the graphite and ferro-alloys were ground into smaller sizes before they were measured and charged into the furnace.
2.3 Charge Calculation for Melting with Rotary Furnace
To obtain in weight the quantity of the required metal scraps and alloying elements in order to carry out the melting process, equation 1 and 2 as proposed by Khanna, (2009) and Ziokowskia & Wrona (2007) was applied.

\[
\text{Weight of the element in kilogram} = \frac{\text{weight of the total charge or furnace capacity} \times \text{(fraction of element in the constituent)}}{(1)}
\]

\[
\text{Amount of Alloying Element to be added} = \frac{(\text{Required Amount}) - (\text{Amount in the base metal})}{(\text{Purity of the Alloying Element})} \times (\text{Total wt. of the Charge})
\]

10% of the ferro-alloy was added to make up for the furnace losses incurred during melting. Also 20% FeSiMg alloy addition was introduced to make up for the loss incurred in the 5% Mg in the low value magnesium alloy addition was introduced to make up for the loss incurred during melting. Also 20% FeSiMg alloy was added. The quantities of the materials charged into the furnace were contained in table 5.

Table 1: Composition of Cast Iron Sleeve Scraps Used for the Production of the Ductile Iron (wt. %)

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (%)</td>
<td>93.7</td>
<td>3.092</td>
<td>1.522</td>
<td>0.749</td>
</tr>
</tbody>
</table>

Table 4: Composition of the Nodularizer (MgFeSi) - Code ZFSB-5 Used for Treating Cast Iron Melt

<table>
<thead>
<tr>
<th>Element</th>
<th>Si</th>
<th>Mg</th>
<th>Ca</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (%)</td>
<td>42 – 44</td>
<td>4.8 – 5.2</td>
<td>Moderate</td>
<td>0.8 – 1.2</td>
</tr>
</tbody>
</table>

2.4 Casting Method
100 kg capacity rotary furnace was pre-heated for 1 hour to a temperature of 1500oC. The charge prepared, that is, 60 kg of broken cast iron sleeve scraps, 2 kg graphite and 0.40 kg silicon alloy (lump) were charged, heated to a melting temperature of about 1450oC and superheated to 1550oC before tapping into an already pre-heated ladle of capacity 40 kg already lined with white silica sand bonded with sodium silicate. The ladle contained the already pre-heated 0.7 kg of FeSiMg (nodulariser) in its centre pocket of dimension 100 mm diameter by 50mm depth which was covered with a thin steel sheet to delay the reaction and avoid fading. (Alasoluyi et al, 2013). Hence, a sandwich process of ladle treatment was adopted for the nodularization process. The temperature of the melting process was measured using CHINO Portable Radiation thermometer IR-CH model. The melt was tapped at 1550oC to 1500oC while the pouring temperature ranged from 1490oC to1450oC. A violent reaction of nodularizer with the melt was observed for about 20 seconds. The dross on the surface of the ladle was removed before being poured into the mould containing the powdered inoculant in its reaction chamber for graphitization. 0.24 % inoculant was used as benchmark for inoculation in mould in this work (Alasoluyi et al, 2013).

The casting was knocked out of mould boxes after cooling. The turbulent reaction of the nodulariser during the Mg treatment in the ladle was both desulphurizing and deoxidising reactions. The removal of sulphur below 0.018% was done by the reaction of magnesium with the dissolved sulphur and oxygen in the melt formed sulphide and oxide which were then removed as slag (equations 3 to 6). The removal of the dissolved oxygen present in the base irons was to achieve a successful spheroidization of the graphite phase and avoid dross effect that can impair the casting quality while the spheroidization of graphite was promoted by the residual magnesium. The magnesium sulphide formed readily floats to the surface where it was removed. In order to avoid fading effect of magnesium, the Mg treatment in the ladle was done for 10 seconds only. The chemical analysis of the cast produced is contained in table 6.

\[
\text{Mg + S > MgS (s)}
\]
Mg + 1/2O2 = MgO (s) \hspace{1cm} (4)
Mg + Si + 3/2O2 >MgSiO3 (s) \hspace{1cm} (5)
2Mg + Si + 2O2 = Mg2SiO4 (s) \hspace{1cm} (6)

Table 6: Composition of As-Cast Ductile Iron Produced

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (%)</td>
<td>3.465</td>
<td>2.156</td>
<td>0.1721</td>
<td>0.031</td>
<td>0.0735</td>
</tr>
</tbody>
</table>

The carbon equivalent (Ceq) of the ductile iron produced based on the composition obtained is thus calculated by using equation 7 (Oyetunji and Omole, 2011):

\[
C_{eq} = \%C + \frac{\%Si + \%P}{3}
\]  

(7)

When \(C_{eq} < 4.33\) it is hypo-eutectic, if \(C_{eq} = 4.33\) it is eutectic and hyper-eutectic if \(C_{eq} > 4.33\). The produced ductile iron \(C_{eq} = 4.208\), hence, hypo-eutectic.

2.5 Microstructural Examination

The microstructural examination procedures include grinding, polishing, etching, microscopic viewing and capturing. Samples sizes (20 x 20) mm were machined from the cast and the surface ground using emery papers of grit sizes 120, 200, 400 and 600 in successive order to ensure smooth and flat surfaces. This was followed by polishing on a Buehler metaserv2000 polishing machine with 800, 1000 and 1200 grits sizes before final polishing on a cloth of 3 micros with diamond suspension paste to obtain mirror-image surfaces of samples. Both grinding and polishing were done in accordance with Zipperian (2009), and Oyetunji and Omole (2011). The samples were thereafter etched one after the other with 4% Nital and rinsed with distilled water before examined in the Nikon Eclipse ME600 metallurgical optical microscope of 50 and 100 magnifications (Oyetunji and Omole, 2011). The micrographs for the samples are as shown in Plates 1-4.

2.6 Hardness Test

In accordance with ASTM E384 (Standard test method for micro-hardness of materials) the hardness test for the cast samples was conducted using LECO Vickers Micro-hardness Tester of model LM700AT of 50mHv on hardness test piece shown in figure 3. The micro-hardness values for the two as-cast samples were shown in Table 7.

2.7 Tensile Test

The tensile test was carried out to determine the Ultimate Tensile Strength of the produced ductile iron samples. The samples were prepared by machining to specification according to ASTM E8 standard as shown in Figure 3. Instron universal testing machine of 50 KN capacity was used to carry out the tensile test. The test specimen was mounted on the machine at the jaws-one end stationary and the other movable. The machine was operated, which pulled at constant rate of extension. The test was performed in accordance with ASTM E8-09/E8M-09 standards and work done by Hassan et al (2010). The result is as shown in Table 8.

3 RESULTS AND DISCUSSION

3.1 Results

The results of the micro-structural studies are presented plates 1 – 4, while the mechanical tests are shown in tables 7 and 8 as well as Figure 4.
3.2 Discussion of Results

3.2.1 Microstructure Examination

Plates 1, 2, 3 and 4 showed the micrographs of the as-cast ductile iron produced at x50 and x100 magnifications for both samples A and B. The micro-structure showed mainly pearlite network around the ferrite ring with graphite nodules embedded inside the ring. The amount of nodules observed in sample A seems more than that of sample B despite being of the same material and composition. This might have been due to the solidification gradient and defect in the material during casting. These variations in nodule count and graphite area fraction can be attributed to the fact that the carbon atoms get diffused into different matrices like ferrite and pearlite, especially when heat treatment is carried out (Bishnu, 2014).

The addition of ferrosilicon as inoculant enhanced the fluidity and graphitization of the molten metal. It was also responsible for the formation of the ferrite rings around the graphite nodules, giving rise to BULLS EYE structure.

Graphite addition functions as recarburizer which accounted for the carbon equivalent of the produced ductile iron. The introduction of the magnesium-ferro-silicon (MgFeSi) served as the nodulizer which was responsible for the transformation of the morphology of the graphite into spheroids (nodules), impacting a combined property of ductility and strength to the cast iron. The chemical analysis revealed that there was a residual magnesium Mg of 0.0545 in the ductile iron produced as shown in table 6 which indicated that enough Mg was available for the desulphurization process.

3.2.2 Mechanical Properties of the As-Cast Ductile Iron

The mechanical tests of the as-cast ductile iron namely-hardness and tensile tests were shown in Tables 7 and 8 respectively. The average hardness value of the as-cast ductile iron was 352.96 BHV or 35.85 HRC. The average tensile test result obtained for the as-cast ductile iron is 343.466 MPa which corresponds with the ISO standard tensile strength characterization of 350 N/mm² for as-cast ductile iron, that is, ISO 1083-2004. The percentage elongation of the as-cast specimen of 14.6% also correlates with the ISO 1083-2004 value according to Bishnu, 2014 and tensile strength is the common basis for the material designation or characterization. The mechanical tests and spectrographic analysis results in tables 6, 7 and 8 showed that the ductile iron produced is of good quality with a well homogenous structure. The carbon equivalent of 4.208 as obtained from equation 7 was recorded which enhanced the strength. However, the carbon content was high due to the excess quantity of the graphite and silicon charged (that is, in excess of the calculated amount) to cater for their loss to oxidation in the process due to the direct contact of the charge with the burning flame. The reason for the variation in the casting samples mechanical properties might have been due to casting defects in the material.
4 CONCLUSIONS
The following conclusions were drawn from the study:

a) Ductile Iron that corresponds with ISO standard, ISO 1083-2004, was successfully produced from automobile sleeves scraps (solid waste).

b) The production of as-cast ductile irons components brings about energy-saving, equipment investment decreasing, production cycles shortening, production costs reducing in conjunction with the versatile mechanical properties, most especially, the superiority of its strength and ductility, this can be locally adopted in casting components of automobile such as wheels, knuckles, brake calipers, gears in automobiles cars.

c) It will further assist in building the nation’s local technology and also reduce dependency of foreign importation of parts which have adverse effect on the nation’s economy.

d) Therefore, from the results obtained, the aim of the research was achieved.

5 REFERENCES


