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Investigation of the Mechanical Properties of Ductile Iron Produced from Hybrid Inoculants Using Rotary Furnace

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ABSTRACT

The mechanical properties of ductile iron produced from hybrid inoculants using the rotary furnace were investigated. Four heats were carried out and powdered graphite with ferrosilicon mixed in ratio 1:1 (to produce the hybrid inoculants) were used as inoculants.680g of magnesium ferrosilicon was used as nodulizer to treat 40kg mass of molten metal in ladle by sandwich process and poured into sand mould where it was inoculated with 72g of powdered graphite, 72g of powdered ferrosilicon, 36g each of powdered graphite and ferrosilicon mixture and 18g each of powdered graphite and ferrosilicon mixture respectively to produce 30kg ductile iron casting. Standard test samples were prepared from the castings obtained for each inoculation process and analyzed to obtain the mechanical properties. Increase in graphite addition resulted in increase in tensile strength and hardness and reduction in fracture toughness was observed. However, increasing the amount of ferrosilicon in the hybrid inoculant resulted in increase in fracture toughness but reduction in tensile and hardness values.

Keywords: *Hybrid inoculants, Nodulizer, Rotary furnace, mechanical properties.*

1. INTRODUCTION

Cast iron is a useful engineering material, which has been known in some forms for several thousand years. It is primarily an alloy of iron and carbon [1]. Grey cast iron is comparatively brittle, it is not suitable for purposes where a sharp edge or flexibility is required but it is strong under compression, and not under tension.

The discovery of Ductile Iron in 1943 by Keith Mills gave a new lease of life to the cast iron family in view of this limitation. This was achieved by combining the castability of gray iron and the toughness of steel. While most varieties of cast iron are brittle, ductile iron is much more flexible and elastic, due to the presence of nodular graphite in the matrix. Ductile iron is also known as nodular cast iron, spheroidal graphite iron or spherulitic graphite cast iron [2].

Fifty years of research and development have led to developing this material whose properties can be tailored for applications requiring high toughness, corrosion resistance and high tensile strength [3]. Ductile iron is one of the most important engineering materials, in view of its excellent castability, significantly better mechanical properties and low cost [4]. It represents the fastest growing segment of the iron market [5]. The common defining characteristic of this group of materials is the morphological structure of the graphite. In ductile irons the graphite is in the form of spherical nodules rather than flakes (as in grey iron), thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name. The formation of nodules is achieved by addition of nodulizing elements, most commonly magnesium and less often, cerium, into the melt [6].

The first step of the production of ductile iron castings is the careful selection of the charge materials. Manganese and chromium have the most influence on all mechanical properties. For this reason, their concentration in metal is of particular importance [7]. Achieving the full potential of ductile iron requires superior metallurgical process control, as well as the highest levels of skill in melting, spheroidizing and inoculation in order to obtain the desired mechanical and microstructural properties**.** The magnesium or magnesium alloy is added to cast iron with the purpose of changing graphite shape from flake to spheroidal is an essential processing step for manufacturing ductile iron. The choice of the treatment method (open ladle, sandwich, tundish cover, in-mould, plunger, converter injection and others) for an individual foundry is based on the facilities present in the foundry [8]. Inoculation is a necessary step for the production of ductile iron castings. It may take place at different process in combination or separately. Inoculation is a procedure whereby microstructure and properties of cast iron are controlled by increasing the number of nucleating sites for eutectic solidification. Several variables influence the effectiveness of inoculation: charge materials, temperature of the melt, inoculant, time, casting method, section size, mode of inoculation, and others [9]. Besides the requirement that the graphite be manipulated into the spheroidal shape, the ferrite and pearlite ratios can be controlled through alloying, shakeout temperature control or post-casting heat treatment to vary the relative amounts pearlite and ferrite from 0% pearlite and 100% ferrite, to 100% pearlite and 0% ferrite. The control of the pearlite and ferrite ratio manipulates the tensile, yield and elongation characteristics of the ductile iron to produce numerous standard grades of material [10]. Matrix control, obtained in conventional Ductile Iron either "as-cast" through a combination of composition and process control, or through heat treatment, gives the designer the option of selecting the grade of Ductile Iron which provides the most suitable combination of properties [11]. Ferritic Ductile Iron, Ferritic Pearlitic Ductile Iron, Pearlitic Ductile Iron Martensitic Ductile Iron Bainitic Ductile Iron Austenitic Ductile Iron. The substantial advantage obtained from ductile iron is its high yield strength and ductility which makes it an economical choice for many applications [12].

Majority of ductile irons produced today are melted in cupolas and induction melting furnaces [13]. However, good quality ductile iron have been produced from a rotary furnace, that was designed and developed via indigenous technology at Engineering Materials Development Institute, Akure, Nigeria [14]. From this product, Austempered ductile irons of international standard were produced from the rotary furnace recently [15]. This innovation is targeted towards providing the important missing link in the metal producing technology and also a way of building capacity in the foundry industries [16].

2. MATERIALS AND METHOD

A wooden pattern of diameter 60mm by 250mm length was turned using the wood lathe. The down sprue of diameter 40mm, tapered to diameter 30mm and length 200mm and overflow of diameter 80mm by 250mm was also produced to enhance easy withdrawal from mould. Contraction allowance of 1.5% was used to produce the pattern materials to avoid severe shrinkage on the castings. White silica sand obtained from Igbokoda, Ondo State was mixed with bentonite as the binder, coal dust was added as a carbonaceous material to enhance permeability and water was reasonably added to ensure mouldability and flowability of the sand. The mixed sand was moulded in moulding boxes of size 500mm by 350mm by 250mm to produce moulds for the ductile iron melts. The moulds were subsequently dried to remove moisture that can affect the final casting quality and properties.Graphite recarburizer of 66%C grade of 2Kg was weighed with 60Kg gray cast scraps for melting. Table 1 shows the composition of graphite used in this investigation.

Table 1: Composition of the Graphite used

Carbon %	Ash %	Volatiles %	Sulphur %	Moisture %
66.00	30.20	3.10	0.570	0.10

The scraps used were carefully selected and cleaned to avoid melt contamination during melting and treatment in ladle. The sizing of the scraps was adequately carried out to facilitate easy charging as well as fast melting in the furnace. The composition of scraps used in this work is presented in Table 2.

Magnesium ferrosilicon (analysis shown in Table 3) and Ferrosilicon 75% Si grade were used as nodulizer and inoculant for the gray cast iron treatment in the ladle and in-mould respectively.

Table: 2 Composition of cast iron scraps used for the production of the ductile iron (wt. %)

C	3.24	Al	0.004	As	0.013
Si	2.22	Cu	0.005	Fe	93.83
Mn	0.25	Co	0.007	Ni	0.065
P	0.099	V	0.02	Mo	0.049
S	0.03	W	0.008	Sn	0.001
Cr	0.21	Pb	0.005	Zn	0.002

Table: 3 Analysis of the nodulizer, MgFeSi used for treating cast iron melt in the ladle

CODE	CHEMICAL COMPOSITION (%)						
	Si	Mg	Ca	RE	Sb	Al	Fe
ZFSB-5	42-44	4.8-5.2	Moderate	0.8-1.2	Moderate	<1.0	Bal

A ladle with 2mm mild steel sheet of capacity 40kg was lined with white silica sand bonded with sodium silicate, pocket of dimension 100 mm diameter by 50mm depth was incorporated at the centre to accommodate the noduliser during treatment. The sandwich process of ladle treatment was adopted for the nodulization process.

Inoculation can be safely carried out in the range 0.2% to 0.75% for heavy ductile iron castings, [17]; to this end 0.24% inoculant was used as benchmark for inoculation in mould in this investigation.

The charge materials is summarised in Table 4 below were then heated in a rotary furnace. The temperature of the molten metal obtained was measured using the optical pyrometer. The tapping temperature of the melts is within 1550^0C to 1530^0C while the pouring temperature obtained ranges from 1490^0C to1470^0C. The castings were allowed to cool to room temperature before been knocked out of mould boxes.

Table 4: Summary of charged materials

MASS OF CHARGED MATERIALS	QUANTITY (kg)
Cast iron scraps	60
Graphite charged	2
Nodulizer (MgFeSi)	0.760
FeSi used as inoculant (in-mould)	0.072
Graphite used as inoculant (in-mould).	0.072
FeSi/Graphite used as inoculant (in-mould).	0.036/0.036
FeSi/Graphite used as inoculant (in-mould).	0.018/0.018
Total Charge	**63.336**

Standard test samples were then prepared for mechanical test, Instron universal testing machine was used to carry out the tensile test, Avery Denison impact testing machine for the charpy impact test and the LECO Vickers microhardness tester LM700AT was used to measure the hardness of the cast samples.

3. CALCULATIONS

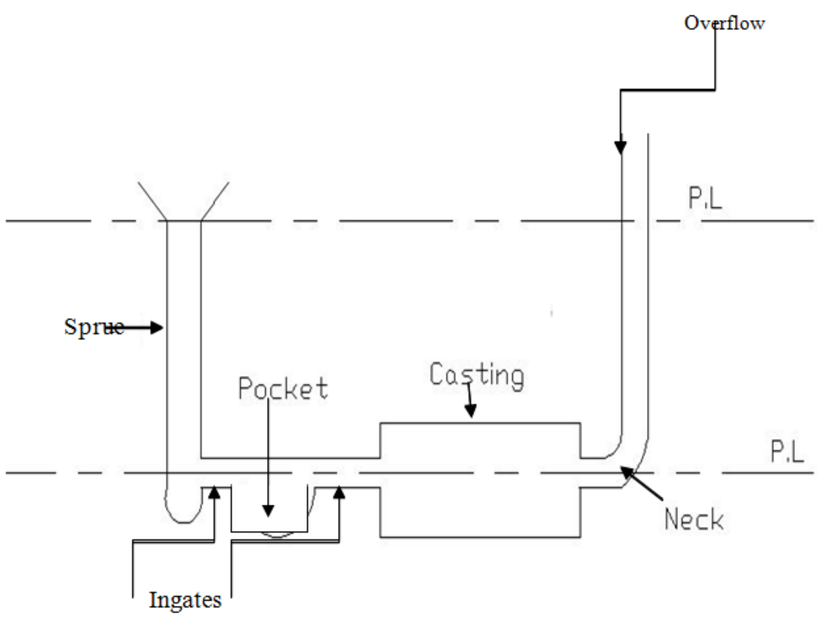

Figure 1: Schematic diagram of mould produced

Dimension of the Mould Sections

Density of Molten Ductile Iron =6.98×10^{-6}kg/mm^3

Sprue dimension = 500mm x Ø50mm

Ingate dimension = 25mm x 32mm x 47mm (2 locations)

Pocket dimension = 77mm x 45mm x 45mm

Casting dimension = 300mm x Ø60mm

Riser dimension= 500mm x Ø76mm

The volume of the mould sections was estimated by adding the volume of the sprue, the ingates, pocket, casting and riser which gave a total of 4,329,333mm$^{3.}$

Poured weight= Density x Total volume of cast

= $(6.98 \times 10^{-6}) \times (4,329,333)$
= 30kg

Cast weight= Density x $V_{(Casting),}$ where $V_{(casting)}$ is the volume of casting

= $(6.98 \times 10^{-6}) \times (848,230)$
= 6kg

$$\text{Yield} = \frac{6 \text{ X } 100\%}{30}$$

= 20%

4. RESULTS AND DISCUSSIONS

The microstructures of ductile irons produced from samples A, B, C and D are presented in Figures 2a - 2d, while the plots of tensile strength and percentage elongation of test samples against inoculant addition as well as of hardness and impact energy against Inoculants addition, are presented in Figures 3 and 4 respectively. It is observed that sample A had nodules entirely in pearlitic matrix with nearly no ferrite as seen in Figure 2a. This is a likely factor for the high strength of 611MPa, as a result the inoculant used as presented in Figure3, for sample A. It was also observed in this investigation that the strength increased inversely to the fracture toughness for the samples examined as shown in Figure4. When ferrosilicon was increased in the inoculant the tensile strength reduces while the fracture toughness increases this could be due to the presence of ferrite in the matrix. Decrease in strength occurred in ductile iron at higher silicon content as a result of increase in ferrite content/ nodule count in the ductile iron [18].

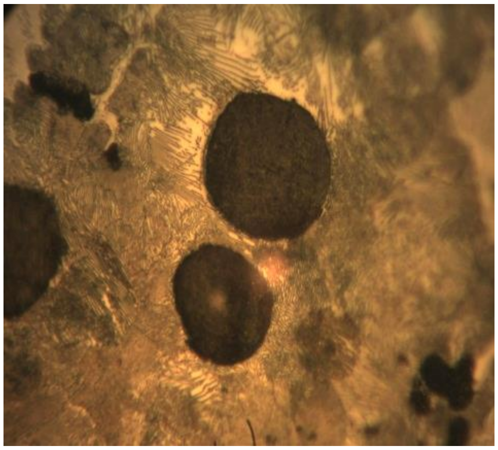

Figure 2a: Micrograph of as cast ductile iron inoculated with 72g powdered graphite showing nodules in pearlite matrix (X800)

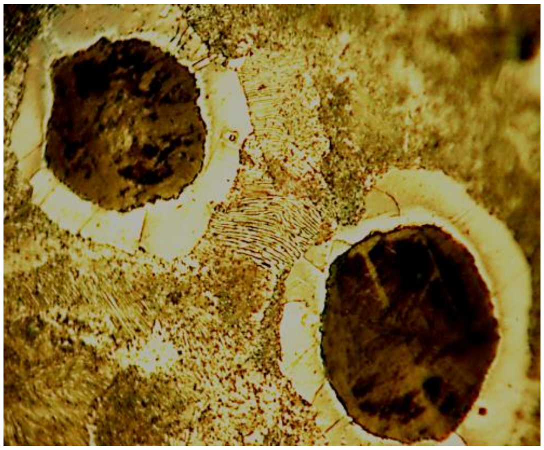

Figure 2b: Micrograph of as cast ductile iron inoculated with 36g powdered ferrosilicon mixed with 36g graphite showing ferrite ring around the nodules in pearlite matrix (X800)

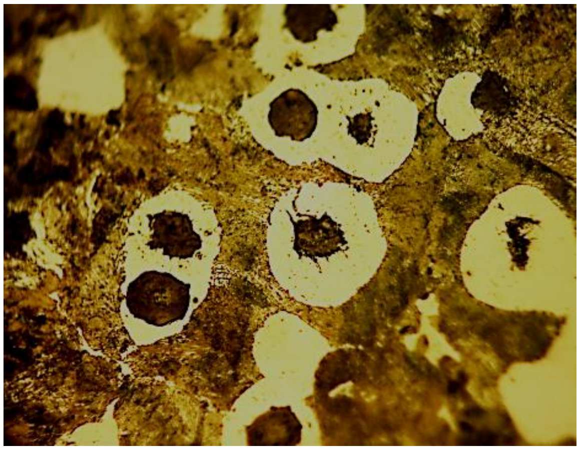

Figure 2c: Micrograph of as cast ductile Iron inoculated with 18g powdered graphite and 18g powdered ferrosilicon showing more ferrite around the nodules (bull's eye) in pearlite matrix (X800).=

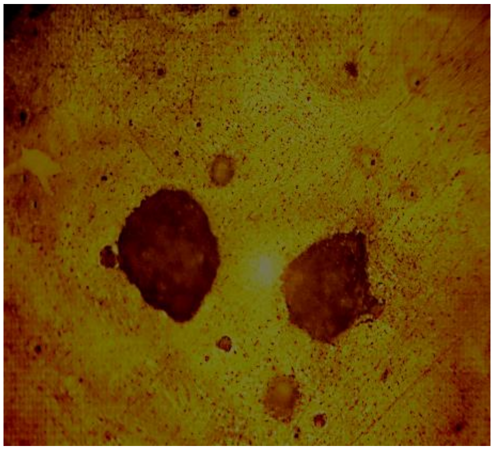

Figure 2d: Micrograph of as cast ductile iron inoculated with 72g powdered ferrosilicon showing nodules in entirely ferrite matrix (X800)

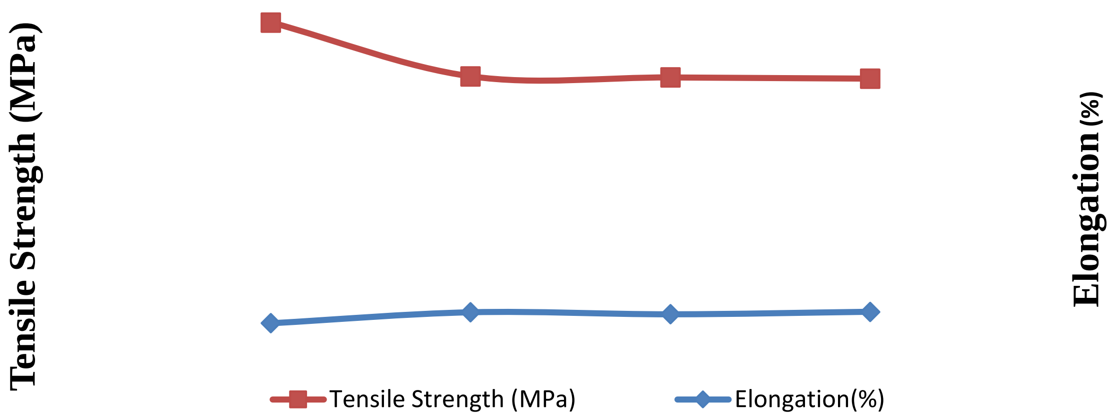

Figure 3: Plot of Tensile strength and Percentage Elongation of test samples against Inoculant addition

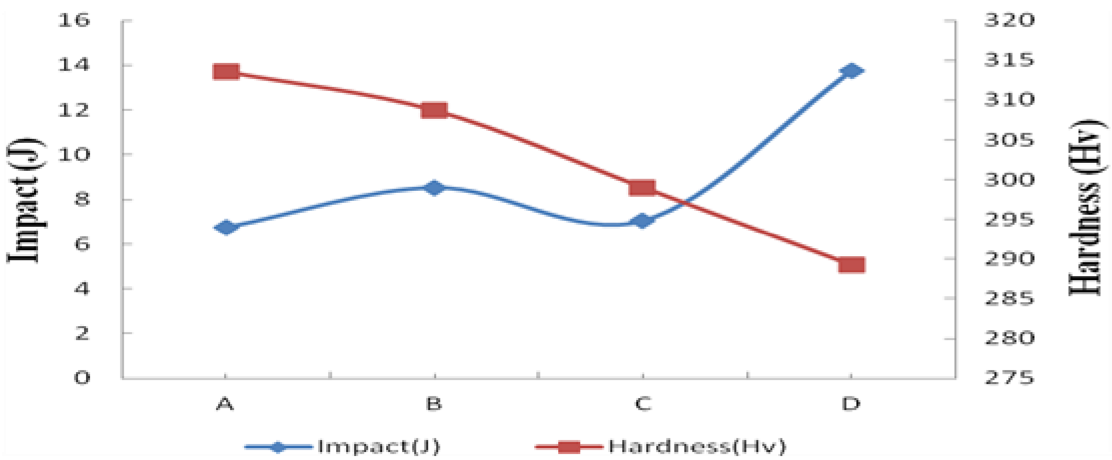

Figure4: Plot of Hardness and Impact energy against Inoculants addition

Percentage elongation and percentage reduction are properties that measure the ductility parameters of engineering materials. It is observed here that with increase in the addition of graphite there is decrease in the ductility due to the presence of pearlite that is more in volume than the ferrite in the matrix [19]. The increase in the silicon in the ductile iron resulted in increase in the ductility, (Figure 4) and ferrite in the matrix, (Figures 2b, 2c and 2d).

Increase in fracture toughness with increase in ferrosilicon addition in the inoculant which has resulted in ferrite formation. Ferrite matrix provides highly ductile cast iron while pearlite provides highly strong cast iron. The toughness of ductile iron also depends on the ferrite/pearlite ratio of the matrix [20]. It is also interesting to note that adding silicon above 3% in ductile iron results in increase in yield strength but lower toughness and elongation therefore; such material can be brittle at room temperature and can improve resistance to scaling at high temperature [21].

The hardness value was observed to increase with increase in graphite addition in the inoculant, Figure 4. This is so because with increase in the addition of graphite more pearlite is formed that can result in high hardness value since it is known to be harder than ferrite

5. CONCLUSION

This investigation has shown that graphite and ferrosilicon used individually and hybrid as inoculants, have notable influence on the mechanical properties of ductile irons produced. An increase in the amount of graphite used in the inoculation of ductile iron is a factor considered to be responsible for the pearlite matrix of the microstructure and also increased strength and hardness properties but reduction in ductility. However, increase in silicon in the inoculation of the ductile iron gave rise to increase in ductility but reduction in the strength properties.

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