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Technical Research

PRODUCTION OF DUCTILE CAST IRON BY RECYCLING GRAY CAST IRON SCRAP WITH ADDING VARIOUS LOCAL MATERIALS

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Abstract: Ductile cast iron is also called spheroidal graphite cast iron or nodular cast iron. It contains graphite in the semblance of nodules. Automobile scrap (i.e., the engine block) made from gray cast iron was used in this study. In this paper, the recycling of gray cast iron to ductile iron, and its influence on the microstructure and mechanical characteristics be studied. Four kilograms of scrap were put in a crucible and then heated up to 1400°C in an oil-fired crucible furnace. For desulfurization, 4% burnt lime with 0.5% fluorspar was direct tapped into the melt at 1400°C. Then, the additions were 3.5% nickel, 0.75% ferro molybdenum, and 0.5% ferro manganese of the scrap weighing. Also, 3.75% nodularizing alloy and 1% inoculating alloy of scrap weight were to treat the molten at 1450°C. Samples analyses have been achieved to determine their composition, tensile strength, impact strength, Brinell hardness, and microstructural. The microstructures revealed that the scrap sample possesses flake graphite, and the produced sample includes nodule graphite. It is observed that the ultimate tensile stress, elongation and hardness of the scrap sample, which are 247.75 MPa, 6% and 400.3 HB, respectively, increased in the product sample to 416.23 MPa, 8% and 451 HB, respectively.

Keywords: *Scrap; recycling pearlite; nodular cast iron; microstructure; strength*

1. Introduction

The recycling of metal is one of the most recyclable products. The metals can be melted and then recycled into other products, which leads to a much longer life cycle for the material. Scrap recycling plays an important role in energy conservation due to that the recycling of scrap requires less energy than cast iron production from the ore of iron.

Also, the cast iron scrap consumption by recycling prevents the accumulation of the abandoned iron products in the environment and helps in conserving the world's resources and reducing the burden on the disposal facilities of landfills [1].

Production of nodular cast iron includes the choice of the ore of iron-based alloys and controlling the base iron composition, the spheroidizing treatment, inoculation treatment and pouring processes. Among these, the selection of the ore of iron materials and the control of base iron composition are of major importance. The elements in ductile iron can be divided into four groups: primary, spheroidizing, alloying, and trace elements.

Primary elements are iron, carbon, silicon, manganese, phosphorous and sulphur; spheroidizing elements are magnesium and rare earth elements such as cerium; alloying

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elements are typically copper, molybdenum and nickel; and trace elements are those whose contents are very low and unintentional; they normally originate from the charge materials and may or may not have an effect on the quality of the casting [2].

Spheroidal graphite cast iron is a type of iron featured via the finding of graphite in the form of nodules, which are scattered in the iron matrix fraction. It is a type of cast iron distinguished by containing graphite nodules dispersed in an iron matrix. The morphology of spheroid graphite confers a considerable enhancement in the mechanical characteristics of the spheroidal graphite cast iron, which is favored in the automobile industries over other types of iron due to its enhanced mechanical properties. Therefore, there is a requirement to attain the desired phase fraction that will be competent to yield sufficient strength. Rely upon the requirements of the applications, spheroidal graphite cast iron matrix includes ferritic, pearlitic, and martensitic or an amalgamation of pearlite and ferrite fraction, which can be done via the use of alloying addition and applying the heat treatment. Alloying has the feature of controlling the desirable steadiness of phases, and it is attainable to maintain the required microstructural (matrix structure). Nickel, manganese and molybdenum ($< 0.5\%$) affect the mechanical properties of the spheroidal graphite cast iron, which have the strength and the high hardness that could be achieved. However, the carbides present on the grain boundaries will weaken achieving characteristics in serviceable at greater loads. Ferrite and pearlite matrix affect the hardness, tensile strength and elongation of spheroidal graphite cast iron and show that the presence of a fraction of pearlite in a noticeable quantity in iron assists improve the mechanical characteristics.

The alloying significantly affects the nodular iron structure. This demanded the usage of alloying to enhance the mechanical properties of nodular iron. Therefore, improving the pearlite fraction of volume is a basis of enhancing the properties of the mechanical of spheroidal graphite cast iron [3].

Numerous investigators have offered studies on recycled gray cast iron and the produce nodular iron, for instance. Omole et al. [3] investigated recycled gray cast iron and the produced pearlitic-ferritic nodular iron and also determined the importance of a combine the additions of alloying required to attain greatly enhanced physical characteristics in the spheroidal graphite cast iron. Oyetunji [4] studied the achievement of nodules from low purity scrap (i.e. gray cast iron) and using oil furnace rotary to produce spheroidal graphite cast iron. Mogni [5] studied the opportunity to reduce the import quantity of nodular iron yields by fabricating this class of nodular iron having specialized properties. Fatahalla et al. [6] investigated the produce nodular cast iron to attain the usage of nickel, silicon or carbon as elements for alloying.

The importance of the study hinges on the fact that the spheroidal graphite cast iron becomes necessary in the industrialized countries due to its multiple characteristics, among them: best castability, good elongation, the possibility of the manipulation of structural and cheapness of production. Realizing nodules from the scraps of low purity cast iron and using an oil-fired crucible furnace to intent the production of spheroidal graphite cast iron will help small and medium-sized establishments attain and maintain the evolution of industries. The investigation assesses the effect of the addition of alloying elements (molybdenum and nickel) on a matrix of structure, and how that influences the characteristics of mechanical nodular irons.

The outcome of this investigation benefits in defining the needed amalgamate of the alloying required to attain considerably enhanced mechanical characteristics in the spheroidal graphite cast iron.

The study limitations are the formation of spheroid graphite in a high sulphur content excess of 0.01. With this, the control of sulphur content may be difficult. This is because of the used waste motor oil in the melting furnace, which increases sulfur pick in the molten is a known common phenomenon. Scrap, fuel (waste motor oil), and the combustion output are liaising together in this systemic.

2. Experimental

2.1. Materials

In this research, the materials used are as follows:

- Engine block (i.e., grey cast iron scrap) from the automotive motor used as base metal,
- Calcium-carbide (CaC_2) used as desulphurizer,
- Burnt-lime (CaO) and fluorite (fluorspar) utilized as desulfurizer,
- Little weights of alloying (nickel, molybdenum and manganese) to the improve mechanical properties, and
- Spheroidizing alloy (FeSiMg) was utilized for the therapying of the molten iron to acquire graphite nodular, inoculate alloy (FeSi) to enhance the mechanical characteristics and spheroidizing.

2.2. Equipment

- Furnace (Oil-fired crucible) with a capacity of (10 kg) to melt the scrap,
- The temperature controller with thermocouple and monitor, as shown in Fig. 1,
- The optical emission spectrometer (OES) to analyze the chemical composition,
- A rotating disc grinder and polisher to prepare the metallographic samples,
- An optical microscope with a digital camera used to take the photomicrographs,
- Teflon round bar modal of 25 mm by 250 mm was utilized to preamble the mold created of quartz sand, and
- Sand mold was created by the addition of 5% bentonite as a link material and 5% water into quartz sand in accordance with [7]. The mould was prepared using sand around the model to create an inner hole. In which the melt was cast after the withdrawal of that model from the sand mold.

Figure 1. Thermocouple type S class 1 (Pt10%Rh-Pt) with temperature controller to monitor the temperature.

2.3. Methods

The following methods are utilized in the fulfilment of the research work:

2.3.1. Chemical analysis

A scrap of specimen (A) was examined utilizing optical light emission spectroscopy to determine the average chemical composition of the elements present. Two or three sparks were implemented per sampling at the two heads and the center points, and an average of the three readings was taken and recorded, as listed in Table 1. The chemical components of ferromolybdenum, ferromanganese, spheroidizing alloy, inoculation alloy and stainless-steel wire mesh were already given by certificate that accompanied the products from the manufacturer's, as shown in Tables 1 to

Table 3.

Table 1. Composition of sample scrap (A) and wire mesh

Elements	Compositions % scrap (A)	Compositions % wire mesh
C	3.79	0.08
Si	1.82	1.0
Mn	0.63	2.0
P	0.12	0.045
S	0.037	0,03
Cr	-	16
Mo	-	2
Ni	-	11
Fe	Balance	Balance

Table 2. Composition of (FeMo) and (FeMn85)

Elements	Compositions % ferromolybdenum	Compositions % ferromanganese
Mo	65	-
Mn	-	85
C	0.1	0.1
Si	1.0	-
Cu	0.5	-
P	0.12	0.04
S	0.1	0.04
Fe	Balance	Balance

Table 3. Composition of FeSiMg and FeSi75

Elements	Compositions % spheroidizing alloy	Compositions % inoculation alloy
Si	45	75
Mg	7.5	-
Ca	3.0	-
Re	3.0	-
Al	1≥	1.5
P	-	0.03
S	-	0.02
Mn	-	0,04
Fe	Balance	Balance

2.3.2. Melting and casting

The scrap was prepared by cutting it into small pieces with a size of (5-10 cm) before putting it in the crucible. The scrap weighing four kilograms was charged in the crucible into the furnace, which works by waste motor oil. The scrap was then heated to the temperature of 1400°C and used temperature controller to observe the temperature with a thermocouple. For desulfurization, 4%CaO with 0.5% fluorspar was inserted into the melt at 1400°C. Then, a ladle usage to remove drossing on the surface of the melt resulting from the desulfurizer. Then, 3.5 % nickel (Ni), 0.75 % ferro-molybdenum and 0.5% ferro-manganese from the charge weighing were added. After that, 3.75% spheroidizing alloy (FeSiMg) and 1% inoculant alloy (FeSi75%) of the scrap weight were added. The melt into a crucible of 1450°C was treated directly by tapping the magnesium to it, followed directly with the inoculation alloy. Also, (6 g) of chromium were added by (52.4 g) wire mesh containing 16% chromium. Spheroidization and inoculation treatment were carried out using the plunging method in the crucible bottom by the wire mesh. As well, the chromium content increased in the casting produced. Instantly beyond finishing the treats at a temperature greater than 1350°C, the treated melt was cast into the designed mold to confirm the elimination of gassy bores. As shown in Fig. 2. Table 4 reveals the specifics of all added materials utilized in this research.

Figure 2. Production of specimens by sand casting in sand casting foundry

Table 4. Theoretical charge calculation of four kilograms scrap

Materials	% of scrap weight
CaO	4
Fluorspar	0.5
Ni	3.5
FeMo	0.75
FeMn	0.5
FeSiMg	3.75
FeSi75%	1.0
Chromium	0.2

2.3.3. Specimens preparation

Samples were equipped for mechanical inspection, chemical composition examination and optical microscope test. The mechanical examination was achieved to determine the values of the tensile, impact, and Brinell-hardness properties. Specimens were equipped with milling-lathing machines.

2.3.4. Tensile test

Tensile specimens were machined using a lathe machine to conform to the standard inspector specifications of 50.0 mm gauge length, which fit into the device. The tensile examination sample revealed in Fig. 3(a, b) is attached to the universal testing device in two jaws, one end is fixed, and the second is in motion. A device was then run at a constant-strain rate (cross-head speed of 2 mm/min), and the tensile testing was achieved according to the ASTM E8/E8M-13a standard [8].

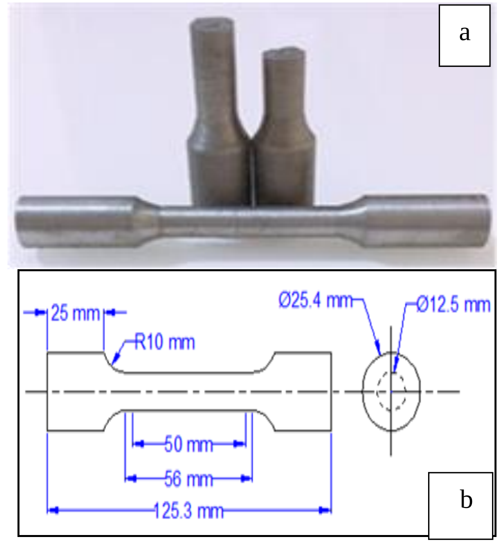

Figure 3. Standard tensile specimen: (a) tensile specimen before and after testing and (b) A schematic of standard tensile sample.

2.3.5. Impact test

Charpy impact test in the pendulum of 300 J maximum capacity was conducted with the notched specimen (10X10X55 mm) achieved by ASTM E23, accordance with the study of Nasir [10]. The impact tester sample is displayed in Fig. 4(a, b).

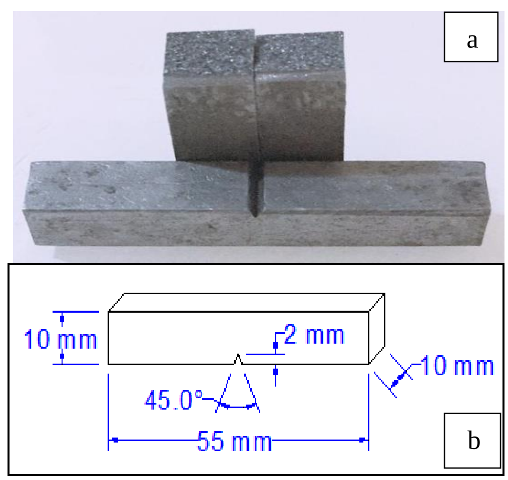

Figure 4. Standard Charpy impact specimen: (a) Charpy specimen before and after testing and (b) A schematic of standard Charpy impact

2.3.6. Hardness test

A Block having a dimension of (25 x 25 x 10 mm) was prepared according to the ASTM E10 standard that conforms to the standards, which fits a digital-hardness tester device. The test face of the sample was ground utilizing 250, 500 and 1000 Al_2O_3 emery-papers to create them luster and soft.

2.3.6. Metallographic examination

The preparation of the specimens for metallographic examination entailed grinding, polishing and etching. They were prepared by the following processes:

i. Grinding

Metallographic specimens of diameter 15 mm by 15 mm height were cut using a lathe machine. The surface of the cut metallographic samples was ground so that the light beam would have a focus from the microscope. A rotating disc grinder machine was used to perform the grinding of samples surface by different grits of grinding paper: 400, 600, 800, 1000, 2000 and 2500 grits to prepare the surface of the samples. During grinding, grits were changed from one to the next of emery paper at regular intervals, in which the specimen was rotated through 90°. The ground samples were finally washed with water to remove the particle product of the grinding.

ii. Polishing

After a successful grinding process, the ground samples were polished on a rotating disc polisher. All the rough surfaces left by final grinding were then removed using polishing cloth with a prepared suspension of alumina paste 3 microns. After that, the polishing process was completed using polishing cloth with a diamond paste suspension of 1 micron to obtain as a mirror semblance to the surfaces of all samples. Eventually, the all polished surfaces were cleaned with alcohol, and the microstructure images were taken by optical microscopy.

4. Outcomes and Discussion

The outcomes of the microscope were acquired, as depicted in Fig. 11 and Fig. 12 to sample scrap (A) and sample product (B), respectively. The tensile, elongate, impact and hardness values are revealed in Table 5 and Fig. 5 to Fig. 10. The outcome of the composition analyses of sample product (B) is presented in Table 6. A product (B) from smelting and sand casting, which was satisfactory good with defectless.

Table 5. Tensile analyses, Charpy impact and Brinell hardness values of sample scrap (A) and sample product (B)

Mixtures	(A)	(B)
UTS (MPa)	247.75	416.23
%El	6	8
BHN	400.3	451
Impact (J)	5.66	7.59

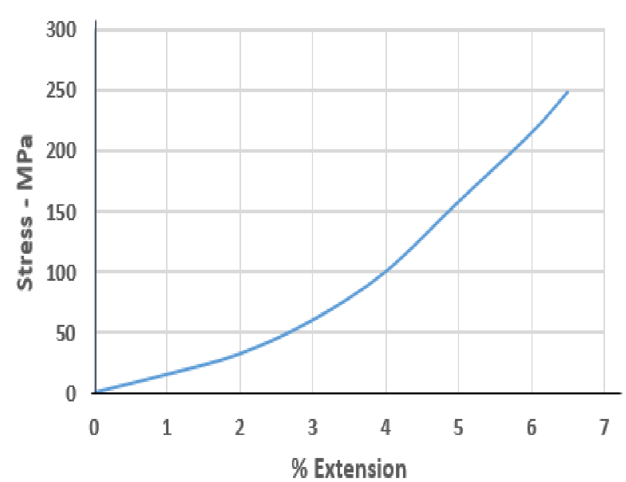

Figure 5. Stress – Extension curves of the sample A.

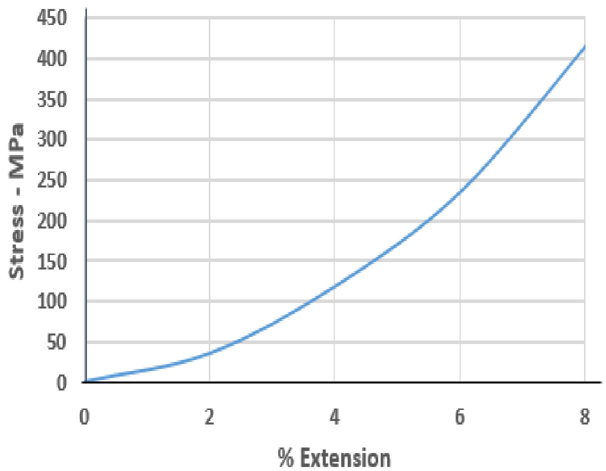

Figure 6. Stress – Extension curves of the sample B.

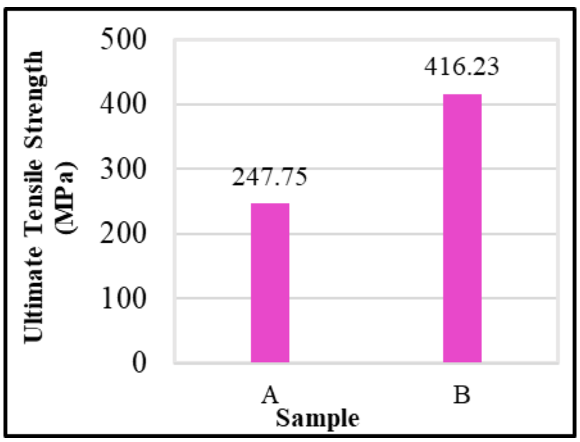

Figure 7. Variation of the Ultimate Tensile Strength of samples

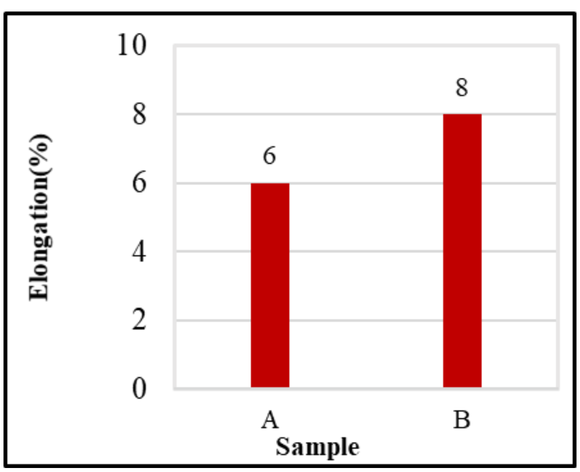

Figure 8. Change of the percentage elongation of samples

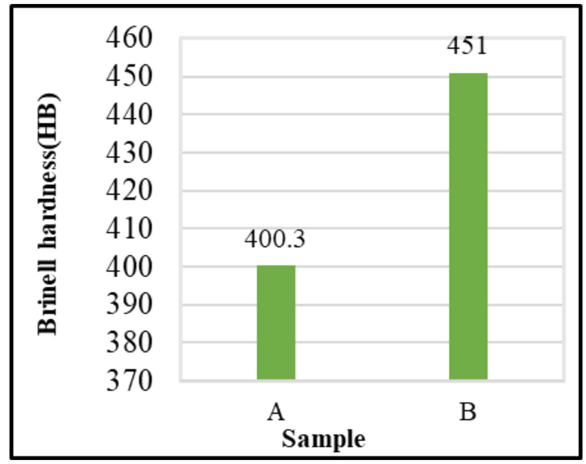

Figure 9. Change of the Brinell hardness of samples

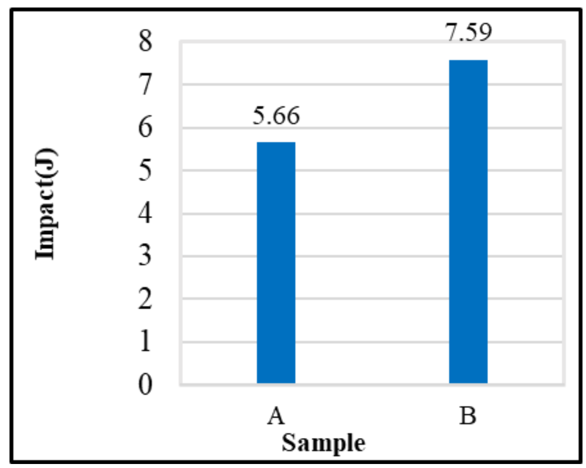

Figure 10. Change of the Charpy impact of samples

4.1. Composition Analyses and Desulfurization

The outcome acquired from the composition of the usage scrap given in Table 1 revealed that the carbon per cent of 3.79% oxidized to 3.38% C in sample B, representing a total carbon loss of 12.13%. That oxidation was caused by the nature of the operation manner of oil-fired crucible furnaces, in that the fuel, charge materials and the outputs of burn are all connected with each other. And, the loss of carbon content was caused by treating the melt with a desulfurizer in which the carbon reacts with the oxygen to release carbon monoxide.

It can be observed from Table 1 that the sulphur is 0.037 in scrap A. Great sulphur content up to 0.026% has yet to exist in as-cast B despite desulphurization. That is because of the inferior purity of the usage scraps and the melting technique in the crucible furnace. That is contrary to some literature indicating that sulphur must be a reduction to about 0.01% before the spheroidization treatment. However, the sulphur content of 0.026 did not prevent the formation of spheroids in casting B. That is a result of a sufficient residual magnesium content to sustain the spheroids in the as-cast. Sample B has the residual magnesium of 0.028% with the presence of sulphur content of 0.026%, so the retention of spheroids was achieved in B, as shown in Table 6.

Table 6. The composition analyses of product B

Elements	Compositions %
Carbon	3.38
Silicon	3.4
Manganese	0.47
Phosphor	0.039
Sulphur	0.026
Nickle	3.50
Molybdenum	0.44
Magnesium	0.028
Chromium	0.23
Ferrous	Balance

4.2. Microstructures

The microstructure of Fig. 11 and Fig. 12 manifest the as-cast structure of samples A and B at X100 magnification in both as polished. The microstructure obtained in sample B revealed the presence of spheroids that indicate the production of ductile iron. Also, a structure of B comprises graphite nodules in the envelopes of free ferrite (bull's-eye structure), in a matrix of pearlite, according to ASM Metals Handbook [11]. The scrap sample A contains no spheroids but flake graphite in an un-etched state and pearlite and ferrite in an etched condition, which indicates the grey cast iron, according to the micrograph's atlas of industrial alloys [11].

Figure 11. Gray cast iron flake graphite in matrix of fine pearlite with less than 10% free ferrite [11]

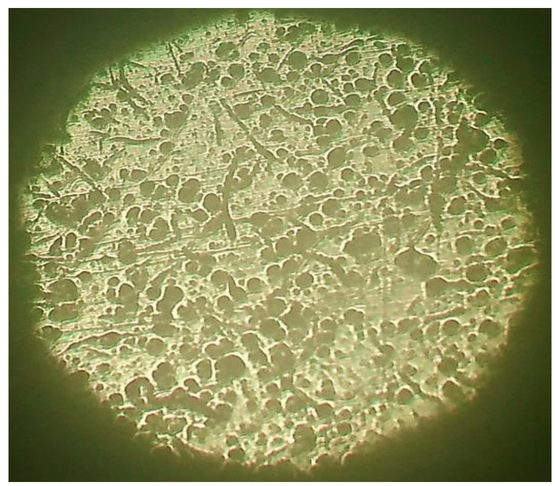

Figure 12. Pearlitic ductile iron as-cast. Graphite nodules (spherulites) in the envelopes of free ferrite (bull's-eye structure), in a matrix of pearlite [11]

4.3. Elongation and tensile strength

The results obtained in Fig. 6 and Fig. 8 from the tensile analysis evinced the high percentage elongation for casting (8% for sample B). This is the result of graphite spheroids achieved in the final as-cast B. These spheroids are fewer created in the matrix as-cast, thus producing more ductile cast material with its strength. The ultimate tensile strength obtained for sample B is 416.23 MPa as presented in Fig. 6 and Fig. 7, while for sample A is 247.75 MPa, which is significantly satisfactory, as shown in Fig. 5 and Fig. 7, according to the research by Olawale et al. [12].

4.4. Brinell hardness

The average hardness obtained in samples A and B was 400.3 HB and 451 HB, respectively, as shown in Table 5 and Fig. 9. This is beyond the minimum hardness limit (223 HB) for ferritic - pearlitic ductile iron, according to the British Cast Iron Research Association (BCIRA) [10]. As a result of the addition of nickel in specimen B, the increase in hardness was 451 HB because of the increased pearlite phase, according to Konca et al. [13].

5. Conclusions

1. The sulfur content was reduced from 0.037% to 0.026% when adding desulphurizer, 4% CaO with 0.5 fluorspar.
2. It is possible to obtain spheroid graphite at sulfur content 0.026%.
3. The spheroid graphite was obtained after the addition of 3.75 wt.% FeSiMg alloy.
4. The metallographic examination and the tensile test revealed that the produced pearlitic- ferritic ductile cast iron has properties that agree with the application of the required characterization according to the ASTM A536- grade 60/42/10, and according to the British Cast Iron Research Association (BCIRA) [14].
5. It is possible to produce a pearlitic-ferritic ductile iron with mechanical properties more than the gray cast iron from the recycling gray cast iron as scrap, with the alloying addition of molybdenum, manganese, chromium and nickel to the base metal.
6. The pearlite phase fraction in specimen B is more than that in specimen A. This is due to the content of elements (0.47% manganese, 3.50% nickel and 0.44% molybdenum), which are pearlite promoter. Where, the use of these elements in an appropriate amount does not form carbide. As well, the inoculation with FeSi75% alloy facilitates the suppression of the formation of carbides.
7. Values of the ultimate tensile strength and hardness of the spheroidal graphite cast iron increased significantly in specimen B because of 0.23% chromium content than that other. This is because of the effect of chromium, which does not only help in prompting pearlite in matrix structure but also strengthen the as-cast. A small amount of chromium enhances the hardness and tensile strength and also stabilizes the pearlite components.

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Conflict of interest

The authors confirm that there is no conflict of interest in publishing this article.

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