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EFFECTS OF SECTION SIZE ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF GREY CAST IRON

Oyetunji Akinlabi and Ediale Ameya Lucky

Department of Metallurgical and Materials Engineering,
Federal University of Technology, Akure, Ondo State, Nigeria
(akinlabioyetunji@yahoo.com)

ABSTRACT

The same chemical compositions all through were used to produce grey cast iron samples of various sizes (15 mm, 20 mm, 25 mm, 30 mm, and 35 mm). The charges (ferrosilicon, graphite and cast iron scraps) were heated in a rotary furnace at 1450 °C to produce melt and tapped into a preheated clay ladle at 1270 °C. Green moulding sand was used to produce the moulds. It was a plastic mixture of silica sand, clay (bentonite), additive (coal dust) with water. Hard wooden patterns machined with woodworking lathe machine into cylindrical shapes, 200 mm long and of different diameters were used for making the sand moulds. The moulds were prepared in moulding boxes. The prepared moulds were allowed to dry to eliminate moisture content before receiving the molten metal and the castings were subsequently obtained after 24 hours of solidification. A stainless wire brush was used to remove sand adhered to the castings after solidification. Abrasive wheel cutting machine was used to remove gates and risers associated with the castings. Then, the castings were machined into standard test samples using lathe machine, for mechanical tests. Optical metallurgical microscope was used to examine the microstructure of the produced grey cast iron samples. The results of the mechanical properties such as the hardness and the tensile strength were observed to decrease with increasing cast sample sizes. However, the impact toughness was observed to increase with increasing cast sample sizes. The graphite flakes in the microstructure were observed to be finer in thin section than those in thick sections.

Keywords: Section sizes, mechanical properties, microstructural properties, grey cast iron, graphite flakes, moulds.

1.0 INTRODUCTION

Grey cast iron is one of the family members of cast irons. It contains free graphite whose fresh fracture surface appears grey because a large portion of its carbon content is present in the free state (Ibhadode, 2001). A typical feature of grey cast iron which determines many of its unique properties is the graphite in the form of flakes embedded in the matrix (Klaus, 2010). In the service condition, the strength of grey cast iron depends on the strength of the matrix, and the size and character of graphite flakes present in the matrix (Ruff and Wallace, 2008).

The eutectic of iron and carbon is at about 4.3%C. The addition of each 1.0% Si increases the effective amount of carbon in the eutectic by 0.33%. Since carbon and silicon are the two principal elements in grey iron, the combined effect of these elements in the form of percentage carbon (plus 1/3 percent silicon) is termed carbon equivalent (CE) (Oyetunji, 2010).

Grey irons having a carbon equivalent value of less than 4.3% are designated hypo-eutectic iron, and those more than 4.3% carbon equivalent value are called hyper eutectic (Oyetunji, 2010).

Grey iron is the common variety most extensively used in industry because of its variety of unique properties and other reasons such as the high damping capacity and high compressive strength which make them suitable for applications in casting of base and bed structures of heavy machine frames and heavy equipment (Oyetunji, 2007).

Good wear resistance, good machinability and damping capacity make them suitable for applications like locomotive and internal combustion engines, cylinder blocks, cylinder heads, and piston rings. The good castability and low cost of production make them suitable for industrial furnace doors, fly wheels, motor frames, gear housings, and pump housings, steam turbine housings, and enclosures for electrical equipment(Hein *et al.*, 2007).

Microscopically, all grey irons contain graphite flakes dispersed in a matrix. The amount or quantity of graphite present, the length of the flakes and the way the graphite is distributed in the matrix directly influence the mechanical properties of the grey iron (Park and Verhoeven, 2008).

The basic strength and hardness of the iron is provided by the matrix in which the graphite occurs. The matrix can be entirely ferrite for maximum machinability but the iron will have reduced wear resistance and strength. An entirely pearlitic matrix is characteristic of high strength grey irons, and many castings are produced with a matrix microstructure of both ferrite and pearlite to obtain intermediate hardness and strength (Park and Verhoeven, 2008).

A typical chemical composition of a graphitic microstructures is 2.5 to 4.0% Carbon and 1.0 to 3.0% Silicon. Silicon is important in production of grey iron as opposed to white cast iron because silicon is a graphite stabilizing element in cast iron (Park and Verhoeven, 2008).

Another factor affecting graphitisation is the solidification rate. Section sizes are one of the factors that determine the solidification rate and this dictates the resulting mechanical and microstructural properties of grey cast iron. This prompted this research to investigate the effects of various cast section sizes on the mechanical and microstructural properties of grey cast iron.

2.0 MATERIALS AND EQUIPMENT

White silica sand (SiO_2) obtained from Igbokoda Ondo State, Nigeria, bentonite (clay), coal dust and small proportion of water were used to prepare the mould. The charge materials include graphite, cast iron scraps, and ferro-silicon.

The equipment used for the experimental work includes; rotary furnace which was used to melt the charges, OHAUS-CS200 electronic weighing scale used to measure the mass of the charges, Dong Jin heavy hydraulic power hack saw used to cut the scraps into smaller pieces, SBT Model 900 grinder, Metaserv 2000 Polishing machine to obtain flat and stable surface of the cast samples, Woodworking lathe machine model MCF3020 used to machine the patterns into cylindrical shapes, AR 4 30 metal analyser used to analyse the chemical composition, LECO Micro hardness tester LM700AT used to measure the hardness of the test samples, Instron Universal testing machine Model 3369 used to determine the tensile strength of the test samples, Avery Denison impact testing machine that measured the impact toughness of the test samples, Optical Metallurgical microscope model AXIA 1m used to observe the microstructure, of the test samples, Stainless wire brush using to remove sand that adhere to the castings, Vernier caliper to measure the diameter of the samples, Abrasive wheel cutting machine used for fettlings, and ladle used to pour the melt into the prepared moulds.

3.0 METHODOLOGY

Pattern Making and Mould Preparation

A woodworking lathe machine model MCF3020 was used to machine the wooden pattern materials obtained from hard wood to produce the pattern, sprue and risers with adequate taper. The patterns were dimensioned 300 mm long and of different diameters; 15 mm, 20 mm, 25 mm, 30 mm and 35 mm. The patterns were made 2% oversize than the specified dimensions to compensate for metal contraction during solidification. The down sprue of diameter 50mm, tapered to diameter 40mm, and was 30mm in length

White silica sand (80%) was mixed with 10% bentonite as binding agent to give the moulding sand its strength and plasticity, 2% coal dust as carbonaceous material to enhance permeability and 8% water to activate the clay and to enhance mouldability and flowability of the sand. The mixture was moulded in moulding boxes of 500mm length by 350mm breadth by 250mm height as shown in Fig. 1 to produce moulds for the grey iron melts. The moulds were subsequently allowed to dry in air to remove moisture (Oyetunji, 2010).

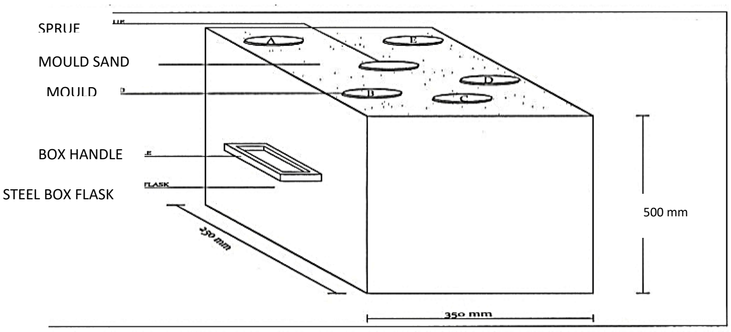

Fig. 1: Diagram of Steel Moulding Box

Casting and Machining

1000 kg capacity rotary furnace was used to melt the cast iron scraps, graphite and ferrosilicon that were charged and heated to1450 ^{0}C temperature. The rotary furnace was tilted to allow the melt flow out through the outlet into the ladle and the melt was then poured into the already prepared mould of various diameters where it was allowed to cool freely in air and solidify. The solidified castings were subsequently shaken out of the mould 24 hours after cooling (Oyetunji, 2010). Stainless wire brush was used to remove sand that adhered to the castings and fettling was done by abrasive wheel-cutting machine to remove gates and risers (Oyetunji, 2010).

Mechanical Tests

Subsequently, Dong Jin heavy hydraulic power hacksaw was used to cut the cast samples and universal lathe machine Type C80 was used to machine the cast samples into standard test samples for mechanical and microstructural analysis

Hardness Measurement

LECO Micro hardness tester LM700AT at Engineering Materials Development Institute, Akure was used to determine the hardness of the test samples. The surfaces of the test samples were dimensioned 10 mm length and 8mm thickness as shown in Fig.2, and were properly ground to give it flat and stable surfaces using a grinding machine. Test load 490.3MN and dwell time 10 seconds were applied on the test samples before taking the readings. The results are presented in Fig. 5

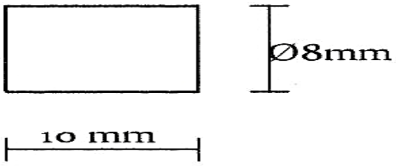

Fig. 2: Hardness Test Sample

Tensile Strength Testing

Instron universal testing machine model 3369 at a speed of 0.02 ms^{-1} was used to carry out the tensile test. The samples were machined with Universal Lathe Machine TYPE C80 to produce standard test samples as shown in Fig. 3 (Oyetunji, 2010). The test results are shown in Fig. 6.

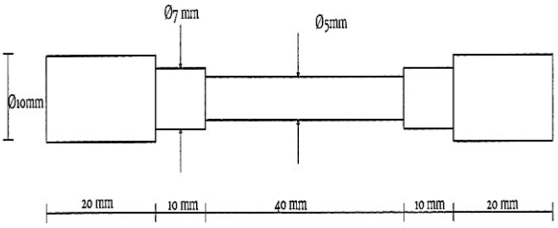

Fig. 3: Tensile Test Sample

Impact Testing

The test samples for the impact toughness were machined to 90 mm long and 8 mm thickness as shown in Fig. 4. Notches were made to depth of 8 mm at 45^0 at 10 mm from one end of each of the test specimens. Avery Denison impact testing machine was used to measure the impact toughness. The specimens were tested and values of the energy absorbed in fracturing the test samples were measured (Oyetunji and Omole, 2011) and the results are shown in Fig. 7.

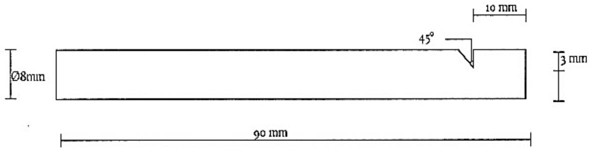

Fig. 4: Impact Test Sample

Metallographic Examination

The test samples for metallographic examination were mounted in plastic materials (Bakelite) for convenience of handling. The SBT Model 900 and Metaserv 2000 grinder/polisher were used with emery paper grit 60, 120, 240, 320, 400 and 800 to produce the test samples for metallographic examination (Oyetunji *et al*., 2013) (Inverseparadox, 2014)..

The prepared samples were etched with 2% nitric acid to 98% alcohol (Nital) and the etching time was 10 seconds. Optical Metallurgical microscope model AXIA 1m, was used to carry out the micro structural analysis and the microstructures obtained were observed and uploaded (Inverseparadox, 2014) (Oyetunji, 2010).

4.0 RESULTS

All the mechanical and microstructural analyses were carried out at room temperature and the following results were obtained. The spark analysis of the produced grey cast iron was carried out with the aid of a spectrometer analyser and the results are shown in Table 1 (Oyetunji *et al*, 2013).

Table 1: Chemical Compositions of Produced Grey Cast Iron

%C	%Si	%S	%Mn	%Ni
2.92988	2.75136	0.06393	0.17010	0.11110

%Cr	%Mo	%V	%Ca	%W	%Ti
0.15761	0.02061	0.01128	0.15175	0.00027	0.00824

%Sn	%Co	%Al	%Nb	%Mg	%Fe
0.02151	0.00857	0.00317	0.00001	0.00266	93.4092

The results of the hardness test, tensile strength, and impact toughness are all shown in Figs. 5, 6, and 7.

The various bar charts obtained from the mechanical tests and the microstructures of the test samples are shown in Figs. 5 to 7 and in Plates 1 to 5.

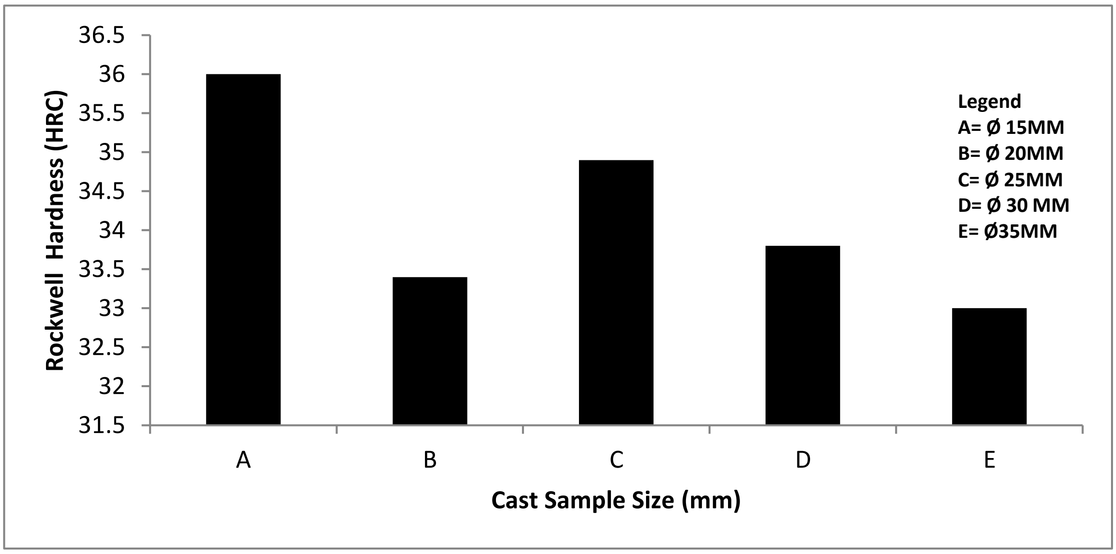

Fig.5: Variation of Rockwell Hardness (HRC) with Cast Sample Sizes (mm)

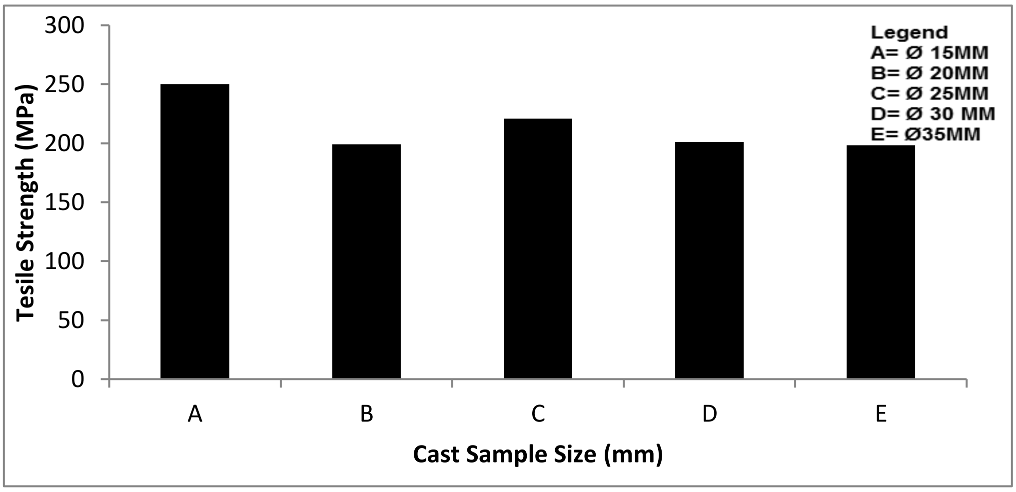

Fig.6: Variation of Tensile Strength (MPa) wi

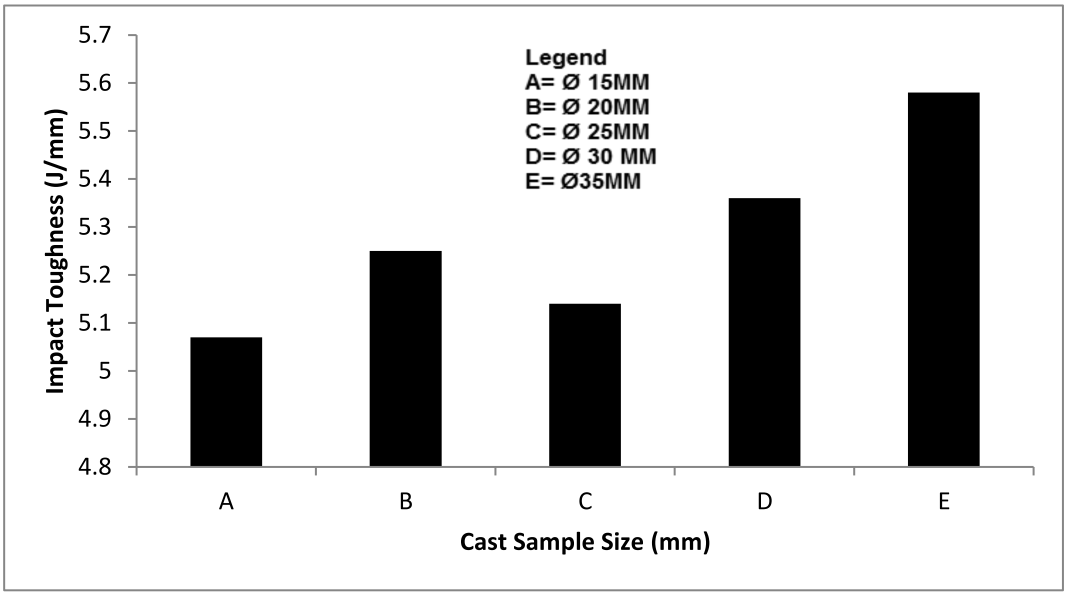

Fig.7 Variation of Impact Toughness (J/mm) with Cast Sample Sizes (mm).

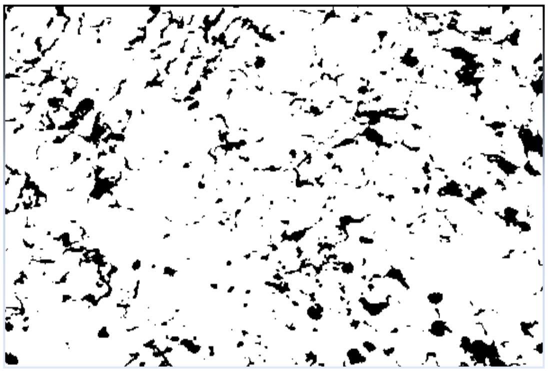

Plate 1: Microstructure of Sand Cast Grey Iron of Diameter 15 mm showing Fine Graphite Flakes in Pearlite Matrix Type B flakes (x100). Etching time 10 seconds.

Plate 3: Microstructure of Sand Cast Grey Iron of Diameter 25 mm showing Graphite Flakes breaking the continuity of the Ferrite Matrix Type A flakes (x100).Etching time 10 seconds.

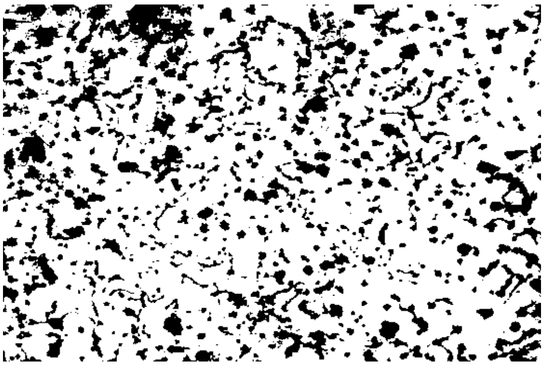

Plate 2: Microstructure of Sand Cast Grey Iron of Diameter 20 mm showing Graphite Flakes inclusion in Ferrite Matrix Type E flakes (x100).Etching time 10 seconds.

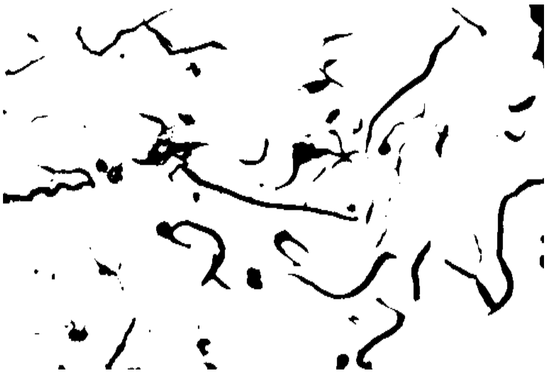

Plate 4: Microstructure of Sand Cast Grey Iron of Diameter 30 mm showing Graphite Flakes extension in Pearlite Matrix Type C flakes (x100). Etching time 10 seconds.

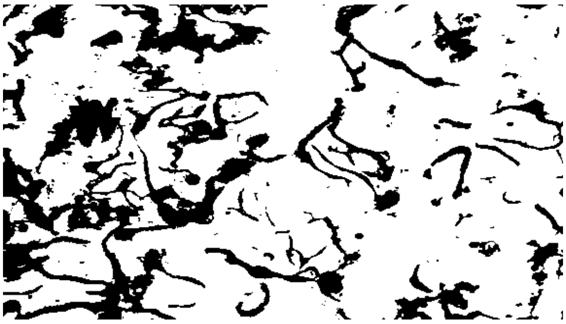

Plate 5: Microstructure of Sand Cast Grey Iron of Diameter 35 mm showing Graphite Flakes Network in Ferrite-Pearlite Matrix Type C flakes(x100). Etching time 10 seconds.

5.0 DISCUSSION

Effects of Cast Section Sizes on Hardness

The Rockwell Hardness of the test samples A to B were observed to decrease from 36.0 to 33.40 HRC with increase in cast samples size as depicted in Fig. 5. This suggests that grey iron that is cast into section that is too thin will solidify very rapidly with fine graphite flakes formation in pearlite matrix in Plate 1 and will possess high hardness, but effective increase in section thickness possibly favours ferrite matrix in Plate 2 which reduces the hardness of the matrix. The thicker the metal in the casting, the slower the liquid metal will solidify and cool in the mould. A slower cooling of the casting will produce a lower hardness. A casting with separate sections that are appreciably different in thickness will have differences in graphite size and matrix hardness between the thick and thin sections even though the entire casting was poured with the same iron. The differences in structure produce differences in hardness properties (Atlas Foundry Company, 2010). The microstructure of both pearlite and ferrite matrix in Plate 3 of cast sample C was observed to have intermediate hardness. The graphite flakes' break the continuity of the ferrite matrix in the microstructure and thus increase hardness of the matrix (Singh, 2010). The graphite flakes extension through the pearlite matrix in Plate 4 of sample D reduces the hardness. Additionally, the network of graphite flakes in Plate 5 of sample E caused more reduction of the hardness of the matrix in accordance with Vijendra (2010).

Effects of Cast Section Sizes on Tensile Strength

The tensile strength was found to decrease from 242.0 MPa to 199.20 MPa with increasing cast sample thickness as shown in Fig. 6. This showed that the tensile strength of grey cast iron is section sensitive. It was also found that fine graphite flakes in Plate 1 of sample A appeared to be more crowded in specified areas with less (little) inter- flakes spacing and with random orientation and possessed high tensile strength. However, the formation of ferrite matrix in Plate 2 of sample B reduces the strength of the matrix. Similarly Roymech (2011) reported that thin sections can have high tensile strength which is not maintained as the section thickness is increased. The observation was also concurrent with that of Boomee and Stefanescu (2013) that increasing casting size considerably decreases the tensile strength of compacted graphite in the iron. It was also observed that the graphite flakes sizes in the matrix were directly influenced by effective increase of section thickness which in turn influenced the strength of the matrix. The flakes in thin section were found to be finer with higher tensile strength. However, larger flakes were observed in thick section in Plates 4 and 5 breaking the continuity of the matrix to greater extent, and lowering the tensile strength of the castings. This finding also implies that the smaller the diameter the higher the strength and the larger the diameter the lower the strength. In addition, Collini (2008) reported that as the cast section size increases, the solidification rate decreases with an accompanying increase in grain size and subsequent decrease in tensile strength.

Effects of Cast Section Sizes on Impact Toughness

Impact toughness (energy) increased from 5.07 to 5.58 J/mm with increasing cast sample thickness as depicted in Fig 7. This implies that grey iron cast into thick section as shown in Plate 5 of sample E requires higher impact energy to fracture than those cast into thin section in Plate 1 of sample A. The finding also implies that the thick section is associated with slow solidification that encourages formation of graphite flakes in ferrite or ferrite-pearlite matrix which in turn directly increases impact toughness and lowers both hardness and tensile strength of the matrix. Vijendra (2010) explained that graphite flakes in pearlite matrix cause brittleness and grey iron fractures at low stress. Related finding reported by Oyetunji (2010) also shows that mechanical properties such as impact toughness of grey cast irons are known to depend on the size of the test specimen among other factors.

6.0 CONCLUSIONS

The mechanical properties of any material are as important as service life of the material in which the microstructure analysis plays a tremendous role. From the experiments, it was observed that the properties of the produced cast samples were determined by the matrix structure, size of the castings and the characteristics of the flakes present in the matrix. The following conclusions were drawn:

i. Increase in section thickness decreases mechanical properties such as hardness and tensile strength of the grey cast iron and increases impact toughness (energy) of the grey cast iron;

ii. Thin section favours fine graphite flakes formation in pearlite matrix with high hardness and tensile strength but low impact toughness. Increase in section thickness enhances slower solidification (cooling rate), favours ferrite matrix and is accompanied with reduction in hardness and tensile strength (impact toughness exceptional);

iii. Increase in section thickness increases the length of graphite flakes in the ferrite and pearlite matrix with accompanying increase in impact toughness.

vi. Increase in section thickness is accompanied with slower solidification and subsequently favours graphite flakes network in the ferrite-pearlite matrix with low hardness and tensile strength properties but improved impact toughness.

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