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Original article

Influence of Palm Kernel Shell Powder on the Mechanical Properties of Inoculated Gray Cast Iron

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ABSTRACT

The use of agricultural by-products and waste materials as fillers and additives to produce different mix designs with enhanced properties is one of the ways researchers are shifting focus to seek and develop materials that rely on renewable resources. The present research investigates the influence of Palm Kernel Shell Powder (PKSP) on the mechanical properties of inoculated Gray Cast Iron (GCI). Five specimens consisting of sample C0 (0.3%FeSi, 0%PKSP), Sample C3 (0.3%FeSi, 0.3%PKSP), sample C6 (0.3%FeSi, 0.6%PKSP), sample C9 (0.3%FeSi, 0.9%PKSP), and sample C12 (0.3%FeSi, 1.2%PKSP) were developed using sand mold casting method, the chemical analysis, and their mechanical properties (tensile, hardness, and microstructures) were evaluated. The chemical composition shows that the produced gray cast iron solidified within the hypereutectic cast iron range (Carbon Equivalent, CE > 4.5), while the microstructure reveals through the graphite flakes distribution that the produced gray cast iron consists of type A graphite. The highest tensile strength and hardness values were observed in sample C3 with tensile strength and hardness values of 155.97MPa and 156.74 BHN respectively. From the result obtained, an increase in both tensile and hardness values was observed up to 0.3% PKSP addition, beyond this amount, shows a decrease in both tensile strength and hardness values for the developed gray cast iron samples.

Keywords: *Cast Iron; Tensile Strength; Hardness; Microstructure; Palm Kernel Shell Powder*

1. INTRODUCTION

Gray cast iron is one of the most common types of cast iron. Good castability, simplicity in production, and a combination of good mechanical and physical properties make gray cast iron an excellent option for the production of many engineering materials [1]. Microscopically, all gray irons contain flake graphite dispersed in a silicon-iron matrix. How much graphite is present, the length of the flakes, and how they are distributed in the matrix directly influence the properties of the iron [2]. The basic hardness and strength of gray iron are provided by the matrix in which the graphite occurs. A typical chemical composition to obtain a graphitic microstructure is 2.5 to 4.0% carbon and 1 to 3% silicon by weight [3]. Ordinarily, graphite has little strength or hardness, hence, it decreases the overall strength of the metallic matrix of its cast iron. However, the presence of graphite provides several valuable characteristics to gray cast iron, and this includes good machinability, ability to produce sound casting in complex shapes, high vibration damping as in power transmission cases, and dimensional stability under differential heating such as in brake drums and disks.

Owing to the little strength and hardness possessed by gray cast iron, it is characterized by relatively high brittleness and thus may not be used in applications where strength is of utmost importance. However, alloy additions and heat treatment can be used to produce gray iron with very fine pearlite or with an acicular matrix structure to achieve a microstructure with relatively higher strength. In recent times, a lot of alloying elements and additives have been employed to enhance the mechanical properties of gray cast iron. The addition of a variable percentage of Molybdenum to gray cast iron has been observed to enhance the mechanical properties of the iron. By inducing precipitation and solution reinforcement, the inclusion of 120 grams of Molybdenum was functional in improving the ultimate tensile strength and hardness properties in gray cast iron [4]. Studies on the

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wear resistance of gray cast iron with different additions of copper show that copper addition changes the ferrite matrix into pearlite matrix with significant improvement in wear resistance and a slight increase in hardness [5]. Increasing the silicon content in gray cast iron has been found to reduce both the tensile strength and hardness values of the iron as a result of an increased volume of soft graphite flakes which increases grain size [6].

While the elemental additions of various alloying elements have been observed to modify the mechanical properties of gray cast iron, however, due to the growing concern of resource depletion and pollution, researchers are shifting focus to seek and develop materials that rely on renewable resources wherein these elements are inherent. This includes the use of agricultural by-products and waste materials as fillers and additives to produce different mix designs with enhanced properties. Some of the agricultural by-products that have been explored as additives in developing engineering materials include risk husk, groundnut shell, rice straw, cow bone, and palm kernel shell. Particularly, palm kernel shell which is a major agricultural by-product in Nigeria has been successfully used as an additive to enhance certain properties in composite mix designs. The effects of palm kernel shells on the microstructure and mechanical properties of recycled polyethylene/palm kernel shell particulate composites have been studied [7]. Palm kernel shell ash has also been characterized and reported to enhance the mechanical properties of as-cast Aluminum matrix composite [8]. Thus, this present research aims to investigate the influence of Palm Kernel Shell Powder (PKSP) on the mechanical properties of inoculated gray cast iron. Ultimately, the suitability of the various elemental components found in PKSP such as Silicon, Calcium, Molybdenum, etc., in enhancing the mechanical properties of gray cast iron may further open new frontiers of applications for the iron, as in high performance cast iron (HPCI), while also reducing the environmental impact of agricultural waste palm kernel shells, a major source of environmental solid waste concern in Nigeria.

2. EXPERIMENT AND METHOD

The materials used for this research work includes 80kg of grey cast iron scarp from an automobile engine block, 2kg of palm kernel shell powder, ferrosilicon inoculant, calcium silicate, and the equipment used include oil-fired lift out crucible furnace, ball mill machine, digital weighing balance, and muffle furnace. A tensile testing machine, Brinell hardness testing machine, optical microscope, and optical electron spectroscopy were also used in carrying out analysis on the five fabricated samples.

2.1 Material Preparation

The grey cast iron engine block scrap was broken into smaller pieces using a sledgehammer. The scrap was subsequently decreased by washing and sun drying for 5 days. The palm kernel shell used for this research work was first screened of dirt and unwanted materials, furnace roasted using a laboratory muffle furnace, and subsequently pulverized using a laboratory ball mill to obtain palm kernel shell powder. The powder was then screened to obtain a particle size of 300 microns. The PKSP was subjected to an XRF examination using an Epsilon 1, Spectris device to determine its elemental composition. Table 1 shows the elemental composition of the pulverized palm kernel shell powder.

2.2 Mold Preparation

The molds for casting were prepared using green sand, bentonite, and water. A pattern of dimension 16mm x 20mm was used in the wooden mold boxes to get the sample dimension for pouring.

2.3 Tensile Testing

Samples for tensile strength testing were machined to the specification of 25mm length x 4mm thickness. The tensile test was carried out using an Instron 3369 Universal Testing Machine, and samples were prepared according to the ASTM A48M standard for gray cast iron tensile strength testing. For each of the samples, three different tensile tests were conducted and the average of these three values was taken as the tensile strength of the sample. The Elastic Modulus of the 5 different samples was also measured and recorded

2.4 Hardness Testing

A hardness test was carried out on the 5 different compositions after the samples were machined to the specification of 30mm x 30mm for the test. The hardness test was carried out using a Standard Brinell Hardness Number (BHN) testing machine with an applied load of 700kg and ball diameter 5mm, the test was carried out according to the ASTM A48 standard for grey cast iron hardness testing.

Table 1 *Compositional Analysis of the PKSP*

Element	Al	Fe	Si	K	Ca	Sn	Sb	S	P	Ti
Intensity	1.290	9.749	3.161	1.986	2.942	1.693	1.497	0.655	0.308	0.132

2.5 Microstructural Examination

Samples for microstructural examination were cut out from the 0% PKSP control sample, likewise the 0.3%, 0.6%, 0.9%, 1.2% PKSP composition respectively. The microstructural examination was carried out according to the ASTM A247 standard for cast iron using an EXI-310 series Accu-Scope Inc. optical microscope. Emery papers were used for producing a shiny and scratch-free surface from the rough cut-out samples. The grit sizes used were 220, 320, 400, 600, 800, and 1200. After grinding, the samples were polished to produce a mirror-like scratch-free surface. After the grinding and polishing, samples were etched with 2% natal and viewed under an optical microscope at 100X, and 400X magnification respectively, unetched samples were also viewed at 100X and 400X magnifications under an optical microscope to determine their microstructural features.

3. Results and Discussion

3.1 Chemical Composition

Table 2 shows the elemental composition of the developed GCI. From the Carbon Equivalent Value (CEV) = C+((Si+P)/3) where C, Si, and P are the elemental compositions (wt%) of Carbon, Silicon, and Phosphorus in the GCI, it can be observed that the developed GCI solidified within the hypereutectic GCI range.

Table 2 *Elemental composition of the developed GCI*

Sample	C	Si	Mn	S	P (Wt.%)	Cu	Ti	Fe	CEV
C_0	3.814	2.15	0.44	0.11	0.05	0.05	0.02	92.60	4.547
C_3	3.763	2.83	0.54	0.11	0.05	0.03	0.04	91.90	4.743
C_6	3.820	2.54	0.46	0.08	0.06	0.06	0.02	92.20	4.686
C_9	3.786	2.68	0.46	0.09	0.04	0.06	0.03	92.20	4.692
C_{12}	3.756	2.43	0.50	0.07	0.05	0.01	0.04	92.40	4.582

3.2 Tensile Strength

The tensile strength result is shown in Table 3 and Fig. 1. Sample C3 was observed to have the highest tensile strength value at 155.97MPa. This can be attributed to the smaller graphite flakes sizes observed in its microstructure which contributed to stress amplification reductions resulting in the observed maximum strength of the sample. A close comparison between the tensile strength of samples C3, C6, C9, and C12, a trend of decreasing tensile strength with increasing PKSP addition is observed. The decrease in tensile strength with increasing PKSP in these samples is likely caused by the increase in the supply of Fe compared to Si to the melt, which further facilitated the formation of cementite (Fe3C) as against graphite formation since the PKSP as analyzed in Table 1 contains more of Fe than Si. This result is consistent with the observation of Fesomade et al, which identified Palm Kernel Shell Ash (PKSA) to counteract silicon formation while enhancing carbon retention and caribe formation in white cast iron [9]. Consequently, the microstructural observation in samples C3 and C6 shows both nodular and flaky graphite whereas that of C9 and C12 is wholly graphite flakes. This observation can be corroborated by the observed superiority in the strength of samples C3 and C6 over samples C9 and C12, as nodular graphite acts as stress nullifiers in the cast iron matrix.

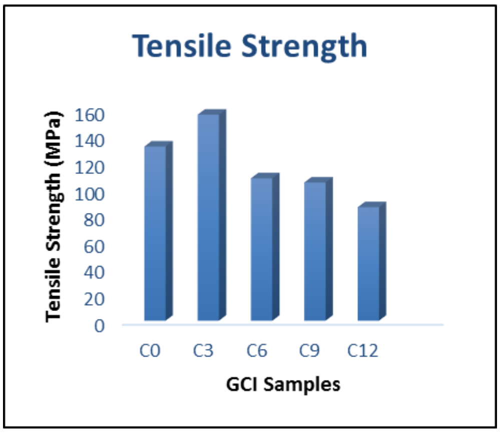

Fig. 1 *Variation of the Tensile Strength values of the Developed GCI*

3.3 Hardness

Table 4 and Fig. 2 show the hardness values of the developed GCI. Sample C_3 was observed to have the highest hardness value at 156.74 BHN. This can be linked to the manganese content in the sample, as the sample has the highest manganese content as shown in Table 2. Manganese has been identified to aid carbide formation [10]; hence the existence of carbide in the microstructure of the composition increased the hardness as observed. Generally, a decrease in hardness was observed beyond 0.3% PKSP addition as the hardness values of samples C6, C9, and C12 are 128.20 BHN, 131.59 BHN, and 143.89 BHN respectively.

Table 3 Tensile Strength Values of the Developed GCI

Sample ID	Composition of additive (%)	Tensile Strength (MPa)
C_0	0.3%FeSi + 0.0%PKSP	131.81
C_3	0.3%FeSi + 0.3%PKSP	155.97
C_6	0.3%FeSi + 0.6%PKSP	107.79
C_9	0.3%FeSi + 0.9%PKSP	104.57
C_{12}	0.3%FeSi + 1.2%PKSP	85.89

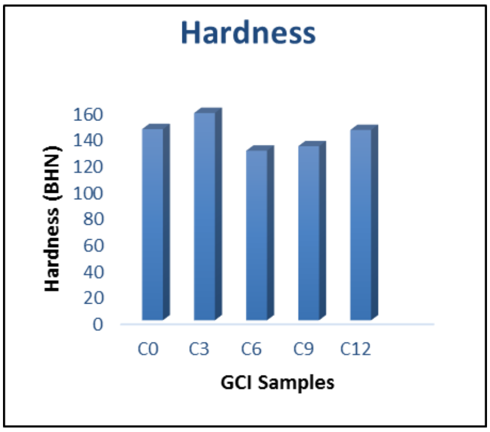

Fig. 2 *Variation of the Hardness values of the Developed GCI*

Table 4 Hardness Values of the Developed GCI

Sample ID	Composition of additive (%)	Hardness (BHN)
C_0	0.3%FeSi + 0.0%PKSP	144.50
C_3	0.3%FeSi + 0.3%PKSP	156.74
C_6	0.3%FeSi + 0.6%PKSP	128.20
C_9	0.3%FeSi + 0.9%PKSP	131.59
C_{12}	0.3%FeSi + 1.2%PKSP	143.89

3.4 Elastic Modulus

Table 5 and Fig. 3 show the elastic modulus values of the developed GCI. Sample C_3 was observed to have the highest elastic modulus value at 10 GPa. This shows that there is an increase in elastic modulus value up to 0.3% PKSP addition, after which the elastic modulus decreases with an increase in PKSP addition. As seen in Fig.3, sample C_3 has a higher elastic modulus compared to samples C_6, C_9, and C_{12}.

3.5 Microstructural Analysis

The result of the metallographic analysis carried out on the developed GCI is shown in Fig. 4. (400X, unetched sample) and Fig. 5. (400X, etched sample). The microstructure clearly shows graphite flakes formation in both the control and PKSP added samples. Pearlite and ferrite phases are seen in all the developed samples. However, nodular graphite formation was observed in samples C_3 and C_6 respectively as shown in Fig. 4. This may be attributed to the increase in CEV of these samples as shown in Table 2, which consequently resulted in the separation of eutectic graphite from molten iron to form nodular graphite during solidification.

The ferrite phase in the matrix of grey iron is the softest structure and enhances good ductility in the iron, while the pearlite phase is stronger and thus enhances good strength in the iron while reducing ductility. For samples C_0, C_3, and C_6 there is clearly a predominantly pearlite phase in these samples as shown in Fig. 5, which consequently resulted in the higher strength observed in these samples since pearlite phases induce strength. However, for sample C_9 and C_{12}, graphite flakes dispersed in a predominantly ferrite matrix is observed. This can as well be attributed to the relatively lower strength obtained in these samples when compared to the earlier mentioned samples since high ferrite phases reduce strength.

Table 5 Elastic Modulus Values of the Developed GCI

Sample ID	Composition of additive (%)	Hardness (BHN)
C_0	0.3%FeSi + 0.0%PKSP	8.10
C_3	0.3%FeSi + 0.3%PKSP	10.0
C_6	0.3%FeSi + 0.6%PKSP	7.40
C_9	0.3%FeSi + 0.9%PKSP	7.70
C_{12}	0.3%FeSi + 1.2%PKSP	6.80

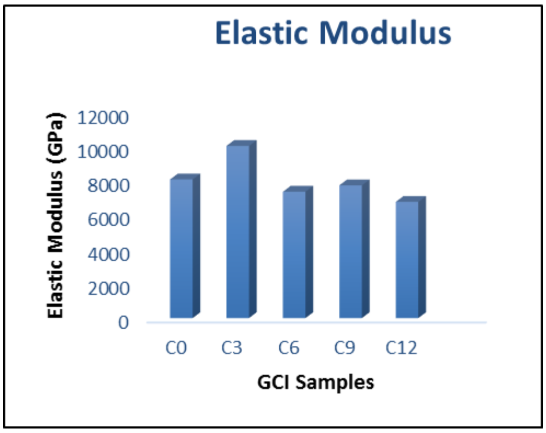

Fig. 3 *Variation in Elastic Modulus of the Developed GCI*

4. CONCLUSION

In this research work, grey cast iron was produced with varying additions of Palm Kernel Shell Powder (PKSP) using an oil-fired lift-out crucible furnace. Based on the result of this research, it can be concluded that PKSP addition is capable of modifying the mechanical properties of gray cast iron such as tensile and hardness. The increase in PKSP addition from 0% up to 0.3% increases strength and hardness values of the GCI, while beyond this amount, a decrease in both hardness and strength values is observed with increasing PKSP addition. This consequently implies that palm kernel shell, a readily available, agricultural by-product, can find potential application in improving the mechanical properties (tensile, hardness) of gray cast iron at an optimum amount of 0.3% addition of its powder (PKSP) during casting.

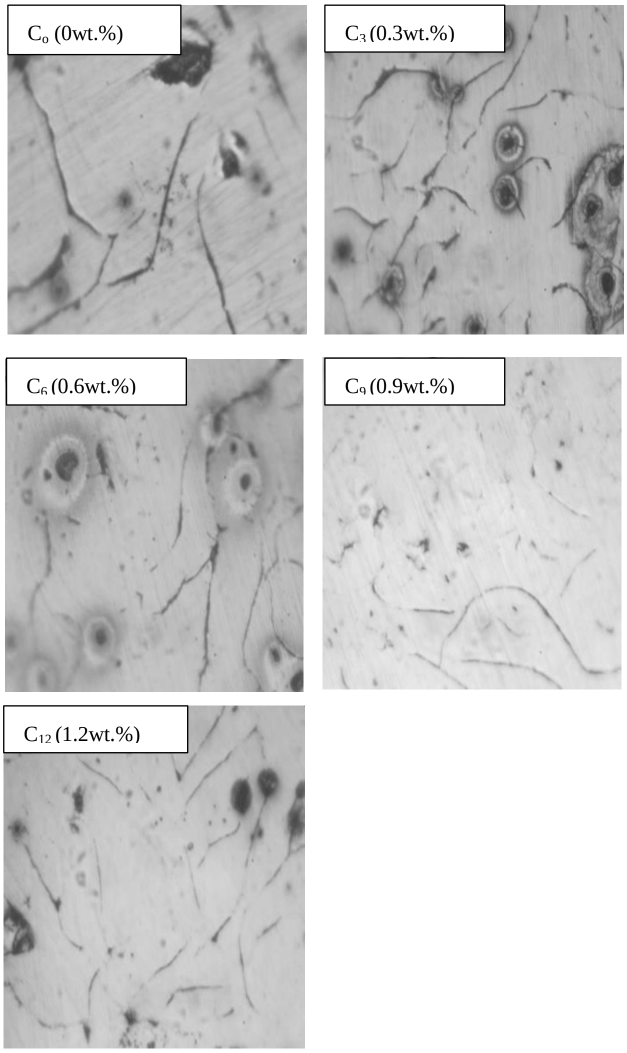

Fig. 4 *Effect of PKSP Addition on the Microstructure of Gray Cast Iron, 400X unetched*

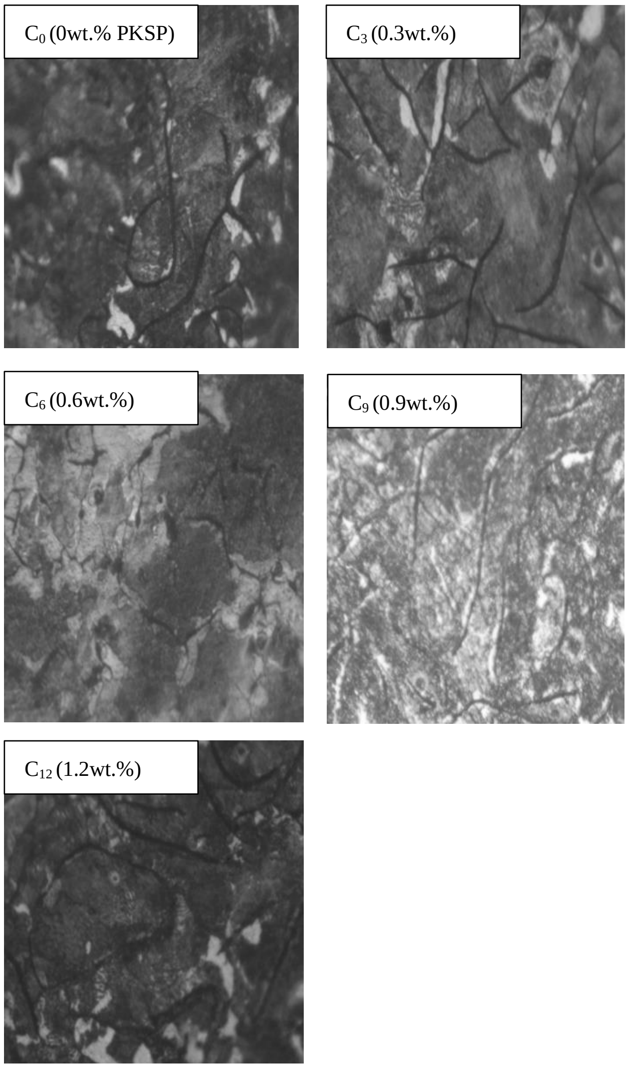

Fig. 5 *Effect of PKSP Addition on the Microstructure of Gray Cast Iron, 400X etched*

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