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In-situ Behaviour of Selected Local Sand Binders on Microstructure and Mechanical Properties of Grey Cast Iron

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Abstract
The need to develop local sand binder by manufacturing industries has become necessary for national development. In this paper, the suitability of selected local sand binders on microstructural and mechanical properties of sand cast-grey cast iron was examined. The bentonite, cassava starch, rubber latex is varied for 5w% - 11w% fritter added to 100% silica sand of 5w% water. The selected scrap was superheated to 1550^{o}C with 0.1% (Fe-Si) inoculant for proper dissolution. The microhardness and tensile properties were examined using Brinnel hardness (HBN) and Instron Tensiometer (1195) for tensile values (MPa) respectively. The microstructural properties of the produced cast were examined through Nikon metallurgical microscope. Results obtained from the grey cast revealed a pearlite matrix interface, massive carbide and graphite phases. Molds bonded with bentonite and cassava starch appears better with average hardness value of 437 and 385 (HBN) respectively. The microstructure was seen to be dominated by majorly pearlite matrix with little carbide which are favorable for the formation of gray cast iron which requires low chilling in the mould.

Keywords: Local sand binders; microstructure; mechanical properties; Grey cast iron.

1. Introduction

Nigeria is richly blessed with agricultural products and mineral resources. Unfortunately most of these resources are in their natural forms rather than usable forms in terms of quality and specification. However, the industrial development and self-reliance of a nation depends on her ability to start the development of her locally available materials, which will in turn improve it economy. It is a fact that most of the surviving industries and companies in the world all over today owe their origin and continue existence to the emergence of new products, improved manufacturing techniques and the use of available natural resources. The pace with which foundry technology is developing in Nigeria has call for the high demand for raw materials [1]. New materials continue to be developed to meet special requirements, which require special processing in order for their properties to be effectively utilized. The high cost of imported binders has generated great interest in characterizing the locally available materials, therefore necessitating the need to look into domestically available binders that will meet the criteria for manufacturing, i.e. reliability, cost, toxicity and availability [2].

Binders are added to base sand to bond the sand particles together (i.e. it is the glue that holds the mould together).They are added to moulding sand to impart sand with sufficient strength and cohesiveness. This enables it to remain the shape after the mould has been rammed and the pattern withdrawn. It also improves the thermal conductivity of the bulk materials as well as the surface finish. Bentonite is composed of plate-silicate minerals, and belongs to the group of minerals known as alumino-silicates. It present strong colloidal properties and increases its volume several times when coming into contact with water, creating a gelatinous and viscous substance. The unique properties of bentonite yield green sand moulds with good flow ability, compatibility and thermal stability for the production of high quality castings. Sand is the principal moulding material used for all types of castings, irrespective of whether the cast metal is ferrous or non-ferrous. This is because it possesses good properties such as refractoriness, mould ability, permeability, collapsibility, chemical resistivity, etc that are vital to foundry applications [3].

Grey cast iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance [4]. Among the various types of cast iron for engineering applications, grey cast iron is the most commonly used iron and the most widely used cast material base on weight [5]. Although, it has less tensile strength and shock resistance as compared to steel. Its relative cheapness and ease of melting with very good machinability makes it interesting. They also possess high damping capacity, good resistance to wear, good compressive strength and high fluidity which makes it easy to form into intricate shapes. They have melting point between 1147 and 1250℃, which is considerably lower than that of mild steel which gives derivable advantages that make it a preferred material of choice for a number of engineering applications including engine blocks, flywheels, cylinder heads, machine beds and brake drums [6, 7].

In the recent years, the importance of the relative versatility of this attractive engineering material (grey cast iron) as compared to the other types of cast iron has been widely applauded. Base on the previous work done, micro structural phases and mechanical properties has mostly been improve from melt treatment(carbon content), alloying element, solidification rate, heat treatment practice and cooling rate with mould binders relatively limited to mould strength and cohesiveness. Various works have been done on sand binders which have narrowed its effect to mould strength and cohesiveness without much consideration to structure and mechanical properties of the cast. To this end, effects of some selected sand binders including bentonite, cassava starch and rubber latex in varying quantity added to moulding sand on the microstructures and mechanical properties of grey cast iron will be investigated in this work.

2. Experimental details

2.1. Materials

The materials used were scrap (automobile part), silica sand, bentonite, cassava starch, rubber latex, ferrosilicon, spent graphite and calcium carbonate.

2.2. Equipment

The equipment used includes Standard Testing Sieves, Mass Spectrometer Analyzer, for chemical analysis of the grey cast iron. Moulding box, rammer, vent wire, sledge hammer, weighing balance, sand mixer/miller, oil fired rotary furnace of 60 kg capacity. Brinnel hardness tester, Instron tensiometer (1195), Metallographic equipment: buhler grinding/polishing machine, backsaw blade, bench vice, and research metallurgical microscope. The chemical composition of the uninoculated grey cast iron is depicted in Table 1.

2.3. Methods

2.3.1. Pattern Making

A wooden pattern of 150 mm length and 20 mm thickness used for producing the experimental samples was machined to shape with wood lathe machine with contraction allowance of 1.5%

introduced. Nine experimental samples was produced which were later machined to the required shape for a universal tensile test samples.

Table 1: Spectrochemical Analysis of the Uninoculated Grey Cast Iron

C	Si	Mn	P	S
2.98	**1.03**	**0.382**	**0.071**	**0.178**
Cr	**Ni**	**Al**	**Cu**	**Mo**
0.008	**0.003**	**<0.0010**	**0.280**	**0.002**

Table 2: Spectrochemical Analysis of the 0.1% Inoculated Grey Cast Iron

C	Si	Mn	P	S
2.91	**1.46**	**0.346**	**0.067**	**0.169**
Cr	**Ni**	**Al**	**Cu**	**Mo**
0.008	**0.003**	**<0.0010**	**0.270**	**0.002**

Table 3: Chemical Composition of the Fe – Si inoculants used

Elements	Si	Ca	Al
% Composition	**74.20**	**2.32**	**1.28**

2.3.2. Mould Preparation

A 150 mm long, 20mm in diameter pattern made of wood was used to prepare the mould. Nine different molds were prepared using Silica sand as follows: Group (1) were made of three different binders (Bentonite, cassava starch and rubber latex) each at 5 % with 88 % Silica sand each and 5 % water were added respectively. In group (2), the same binders in (one) above at 8 % each with 85 % silica sand each and 5 % water were produced respectively, while group (3) the same binders in (one) above at 11 % each with 82 % silica sand each and 5 % water were produced respectively. The various sand mixtures were prepared using a sand muller. The moulds were then prepared using moulding boxes of dimension 25cm length, 20cm breadth and 4cm height. The moulds were air dried for 24 hours to remove the moisture**.**

2.3.3. Casting of the Grey Cast Iron

60 kg diesel field EMDI model watery furnace was used to remelt scrap cast from engine block [8]. 2kg spent graphite electrodes as carburizer was added to compensate for carbon loss during melting while limestone was added to aid easy removal of slag and ferro – silicon foundry additive (74.86% Si,1.26 % Al, 2.40% Ca, Fe balance) was added at 0.1% weight into the ladle before pouring. The furnace was heated to a temperature of 1300 ^{0}C the melting temperature of cast iron, but to ensure total melting of charge materials, 1490 ^{0}C temperature was maintained for 10 minutes, and afterwards tapped into preheated ladles at 1475 ^{0}C.

2.3.4. Compositional Analysis Test

Sample of the cast was taken for compositional analysis. The result of the spark spectrometric analysis of the sample was carried out with Hilger Analytical Direct Optical Light Emission Polyvac Spectrometer E980C.

2.3.5. Tensile Test

Nine tensile test specimens were machined to a standard specification. All the nine tensile test specimens were subjected to tensile loads until fracture using the Instron Tensometer machine at the Engineering Materials Development Institute (EMDI), Akure.

2.3.6. Hardness test

Samples of dimensions 20 mm length, 10 mm breadth and 6 mm thickness were cut and machined to standard hardness specimens, they were properly ground to ensure flat and stable surface using a hand grinder. Thereafter, hardness measurement was made using Brinnel Rockwell hardness testing machine with a hardened steel ball of diameter 10mm and load 3000kg.

2.3.7. Microstructural characterization

Specimens for microscopy studies were prepared from the scrap (automobile part) and cast samples by machining to dimensions of 20 mm length, 10 mm breadth and 8 mm thickness; they were mounted on thermosetting material known as Bakelite in order to make them convenient for handling. Thereafter, the surfaces of the specimens were then flattened by filing and grinding using laboratory grinding and polishing machines with a set of emery papers of 240, 320, 400, 600, 1000 and 1200 microns. The grinding was done in order of coarseness of the papers. As each specimen was change from one emery papers to the other, it was turned through an angle of 90^{o} so as to remove the scratches sustained from the previous grinding. After grinding, the specimens were polished using rotary polishing machine, to give it mirror like surface, and in conformity with [8, 9] a polishing cloth was used to polish the surface of the specimens. However, during the course of grinding and polishing, water was added on the samples and papers to prevent heat build-up and wearing away of the grit on the papers. The microstructure was done using Nital solution (2% nitric acid and 98% alcohol). The microstructures were examined at a magnification of 100xx.

3. Results and discussion

3.1. Mechanical properties:

Figs. 1-6, show the effect of binder's compositional concentration on hardness properties and ultimate tensile strength of grey cast iron alloy. It was noted that as percentage bentonite addition increases from 5wt% up to 11wt% there was a marginal reduction in the hardness and tensile behaviour. This may be due to the fact that permeability decreases with increase in the percentage of bentonite. The hardness value of bentonite which is the most performed among binder at 5 wt% bentonite is 437HBN, 8 wt% is 385HBN, and at 11 wt% is 360 HBN respectively (see Figs. 1, 2 and 3).

A significant hardness and tensile strength values were also recorded when cassava starch is added to moulding sand even in varying proportions. The well performed among the cassava starch binder was found at 5 wt% with 385 HBN. The reduction compared to that of bentonite may be due to the rate at which the bonding forces involved in holding the starch and sand particles together easily gives way because of the coarse nature of cassava starch in moulding sand. Another fascinating observation were traceable to the molten metal permissibility of gases to pass out easily, thereby creating more pores in the mould and hence favoring increased cooling and solidification. It was noticeable that as percentage of cassava starch addition to the moulding sand increases, there was a marginal reduction in both the hardness and tensile properties of the cast. Although for ultimate tensile strength only slight depreciation was notice within the trend of reduction (see figs 3-6).

With rubber latex used as binder, the hardness and tensile strength of the cast were observed to possess low properties possibly due to the weaker binding strength of rubber latex. Although [10] reported that mould with lacks of sufficient rigidity, weakness in binder characteristics causes expansion of the casting during solidification which often results in unsoundness in the form of internal porosity. On the other hand, the rubber latex percentage addition to the moulding sand could also be seen to greatly influence the mechanical efficiency of the cast in such a way that the increases of rubber latex decrease systematically, the permeability of the mould decreases which resulted in a marginal reduction in the hardness and tensile strength values.

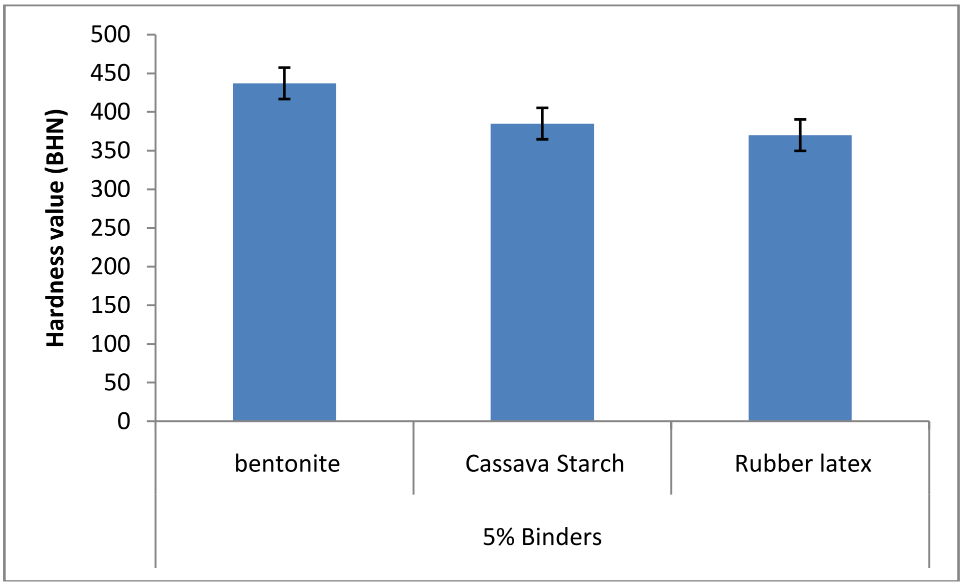

Figure 1: Effect of 5 % various binders on the hardness properties of grey cast iron.

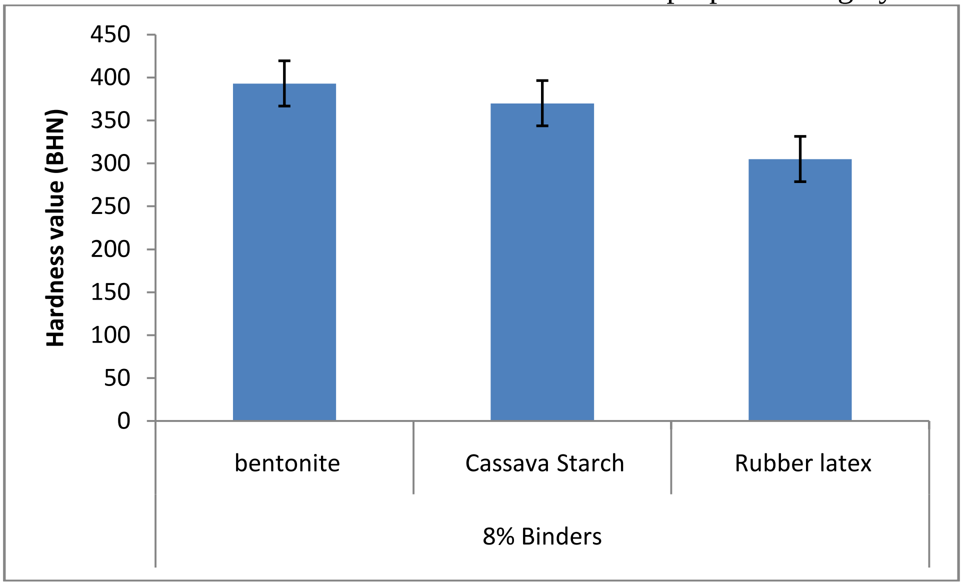

Figure 2: Effect of 8 % various binders on the hardness properties of grey cast iron.

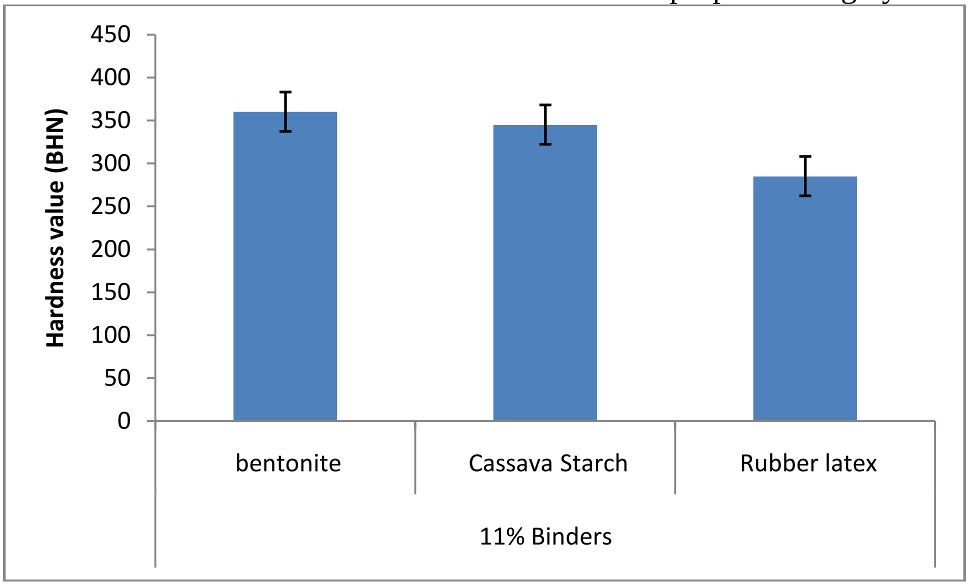

Figure 3: Effect of 11 % various binders on the hardness properties of grey cast iron.

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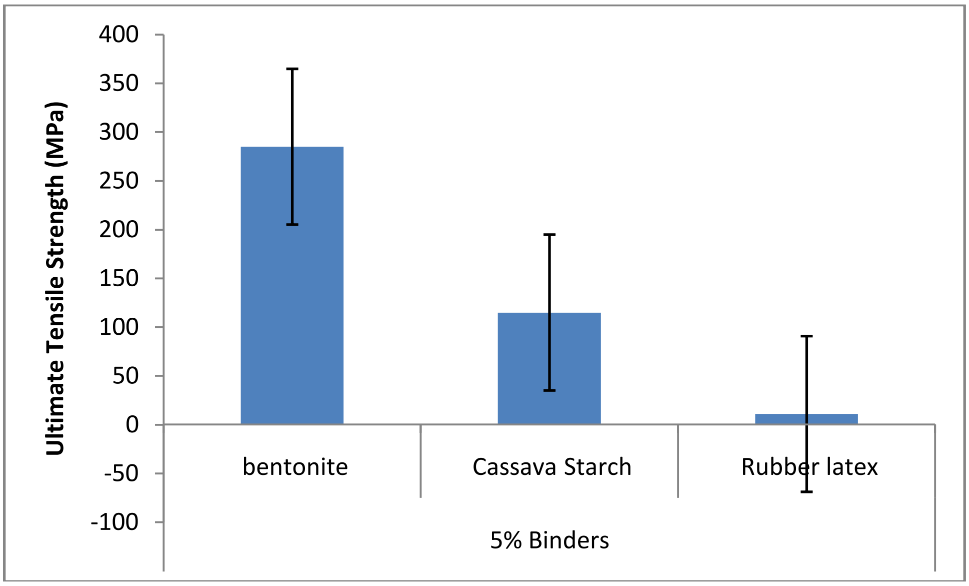


Figure 4: Effect of 5 % various binders on the Ultimate Tensile Strength properties of grey cast iron

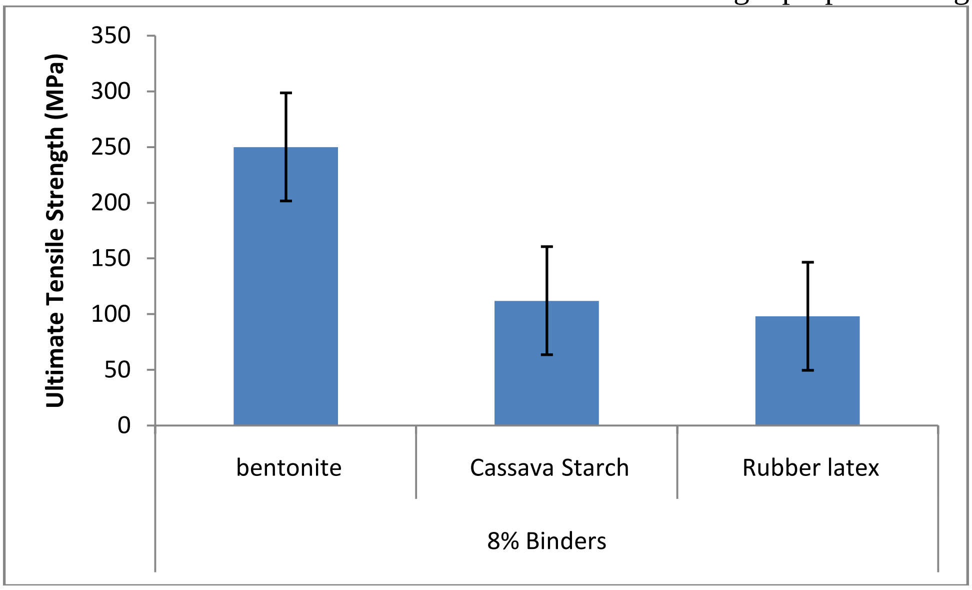


Figure 5: Effect of 8 % various binders on the Ultimate Tensile Strength properties of grey cast iron

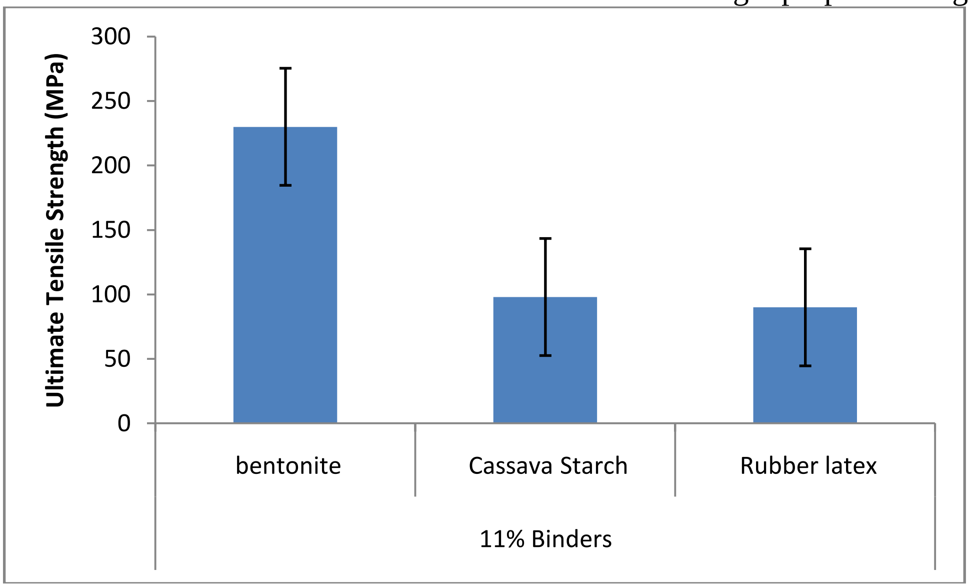


Figure 6: Effect of 11 % various binders on the Ultimate Tensile Strength properties of grey cast iron

3.2. Microstructural analysis

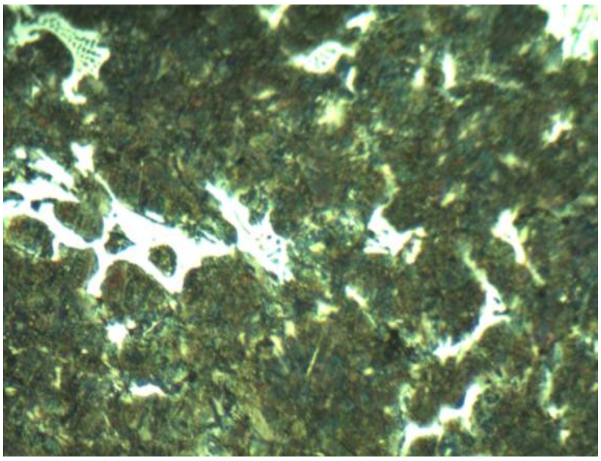
Microstructures of the grey cast alloys at different varying binder fractions were examined by the use of metallurgical microscope. The microstructure was observed to contain primarily Fe, silicon and eutectic pearlite phase as shown in Micrographs 1–9. In the microstructure of the bentonite additions, pearlite phase was seen apparently in the eutectic regions**.**

The microstructure of the grey bentonite samples reveals reasonably uniform distribution and precipitation of perlite phase in the alloy after casting (see Micrographs, 1, 4, 7). These structures are in agreement with the co-continuous interlaced phases studied by other researchers [11, 12]. But with the percentage of addition beyond 5% there are small discontinuities and uneven distribution alloy although that is expected.

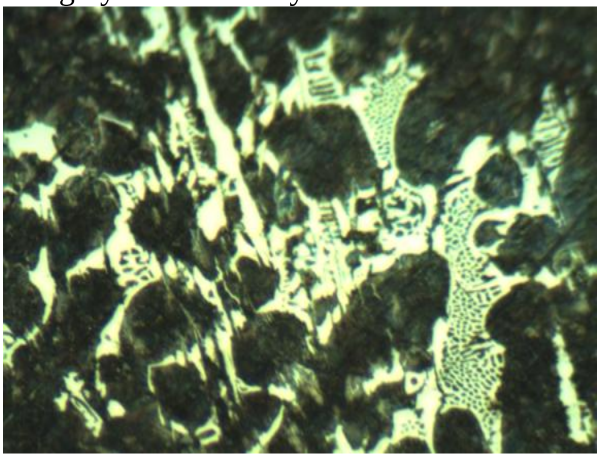
The obtained micro-structures show low distorted graphite phase, high pearlite matrix and massive carbides as expected. According to [13], low graphite flakes aids high tensile strength and high hardness values as recorded in this work while excess graphite flakes in morphology encourages low tensile strength and low hardness (maximum machinability).

From micrograph (2, 5, 8) when the percentage of cassava starch addition increases from 5 % - 11 % high pearlite content were formed with carbide and distorted graphite phases, which might be responsible for the moderate hardness and tensile values recorded with 8 % and11 % binder addition as against the recorded high values with 5 % binder addition with massive carbide are predominant.

In micrograph (3, 6, 9) it was observed that as the percentage of rubber latex addition increases from 5 % to 11 %, the microstructure shows high pearlite content with moderate carbide and low graphite formation which might be responsible for the reduction in hardness and tensile values recorded. This assertion is in line with the results attained by [14].



Micrograph 1: Microstructure of grey cast iron alloy with 5 % Bentonite addition (×100).



Micrograph 2: Microstructure of grey cast iron alloy with 5 % Cassava Starch addition (×100).

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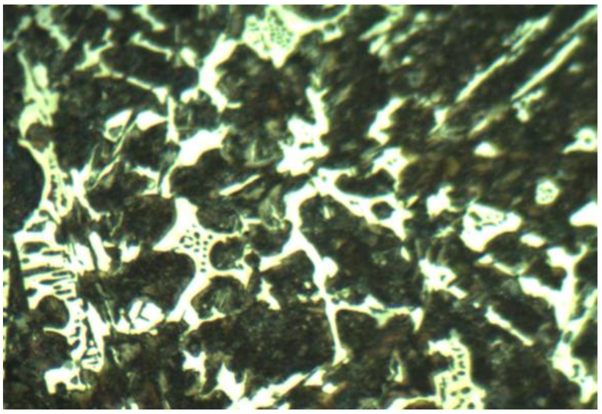
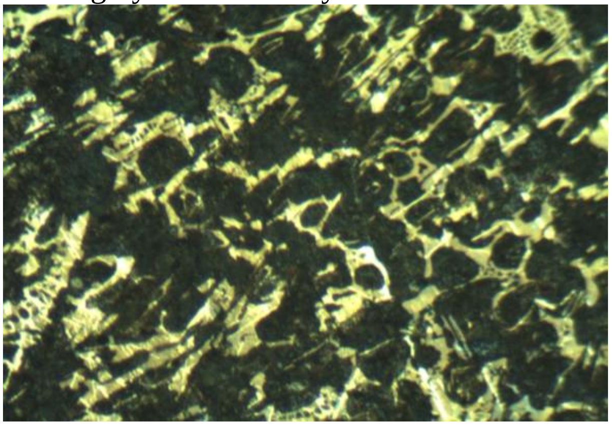
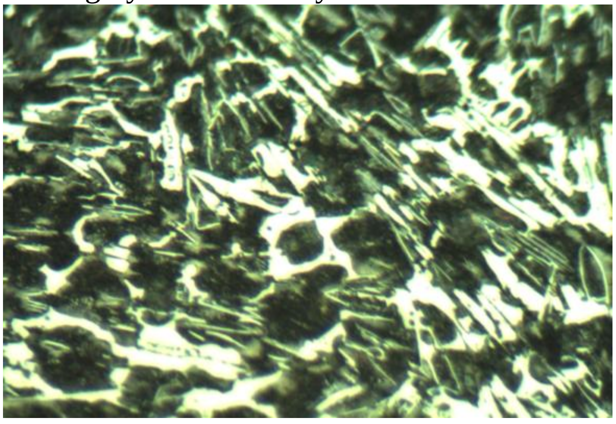


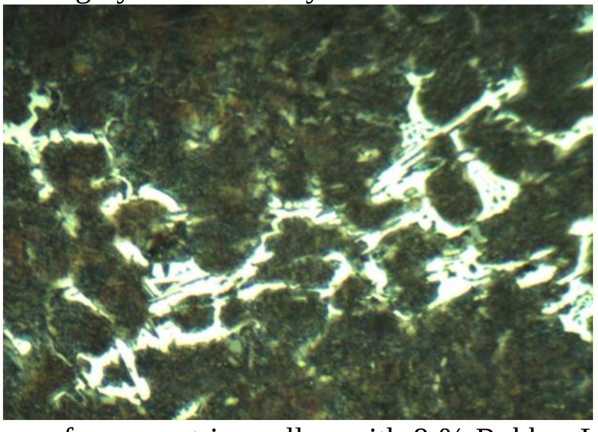
Micrograph 3: Microstructure of grey cast iron alloy with 5 % Rubber Latex addition (×100).



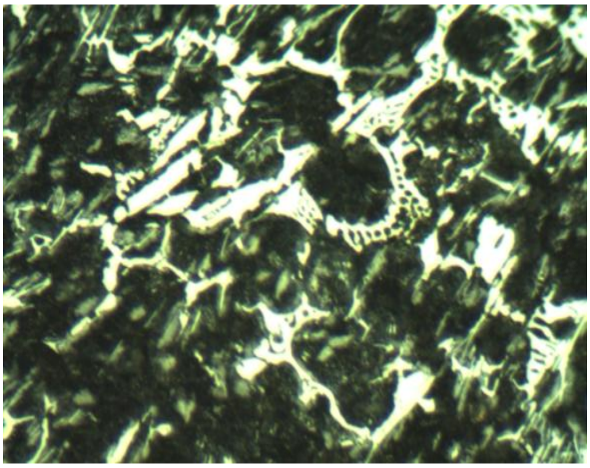
Micrograph 4: Microstructure of grey cast iron alloy with 8 % Bentonite addition (×100).



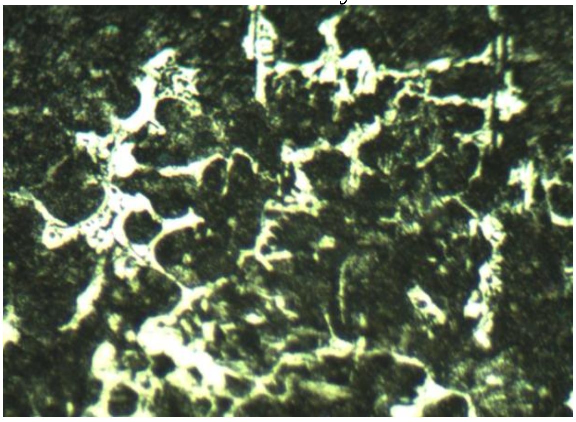
Micrograph 5: Microstructure of grey cast iron alloy with 8 % Cassava Starch addition (×100).



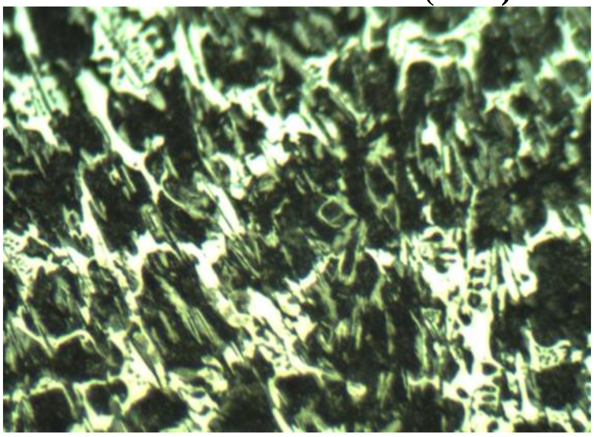
Micrograph 6: Microstructure of grey cast iron alloy with 8 % Rubber Latex addition. The structure reveals the dissolution of eutectic crystal black interface containing FeSi phase distribution (×100).



Micrograph 7: Microstructure of as-cast Al–Si–Fe alloy with 11 % Bentonite addition (×100).



Micrograph 8: Microstructure of grey cast iron alloy with 11 % Cassava Starch addition. The structure reveals the dissolution of starch within the interface (×100**).**



Micrograph 9: Microstructure of grey cast iron alloy with 11 % Rubber Latex addition. The structure reveals the dissolution of eutectic silicon phase (×100).

Conclusion

After successful selection of binder and cast performance, the following deduction were made:

- The moulds with bentonite binder were observed to possess the highest hardness value, followed by cassava starch, with rubber latex having the least average hardness value.
- Moulds bonded with cassava starch and bentonite were favorable for the formation of grey cast iron which requires low chilling in the mould as compared to when rubber latex binders were added to the moulding sand. More so there were expansions of the casting during solidification, resulting in unsoundness and internal porosity in the cast.

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- From the strength and cohesiveness of different moulds produced, which invariably tells more of the formed properties, bentonite is the best, cassava starch is better and rubber latex is good because it moulds lacks sufficient rigidity, which leads to expansion of the casting during solidification.
- Increasing the binder content caused marginal reduction in the hardness and tensile values for all the binders as permeability decreases with increase in the percentage of any of the binders used

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