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Investigation of Mechanical Properties of Train Brake Block Produced from Polypropylene-Matrix Composite

Eugenia Obiageli OBIDIEGWU1[1*], Henry Ekene MGBEMERE[2], Ayomikun Zainab OTEJU[3]

[1,2,3]*Metallurgical and Materials Engineering Department, University of Lagos, Akoka, Nigeria*
eobidiegwu@unilag.edu.ng / hmgbemere@unilag.edu.ng / ayomikunoteju@gmail

Corresponding Author: eobidiegwu@unilag.edu.ng, +2348035812874

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***Abstract**: Friction brakes in trains are very important aspect of railway transportation as they function based on friction between the braking elements and the wheels to perform speed control actions. Cast iron has been the conventional material for producing train brake blocks. The drawback with cast iron brake blocks is the noise generated during rolling of the wheels on the track as well as wear on the wheel tread surface. The wearing of wheel tread puts the safety of the passengers and goods being transported at risk. Thus, this work investigates the mechanical properties of train brake blocks produced from polypropylene (PP) blended with calcium carbide residue. The composite samples were produced using recycled (PP) as matrix, calcium carbide particulates at 150 and 300µm particle size as reinforcement and graphite varying the particles from 0 wt.% - 16 wt. %, step 4. The samples were subjected to mechanical tests conducted according to ASTM D3039(Tensile), ASTM D256 (Izod impact), ASTM E92-16 (Vickers hardness) and ASTM D3702-94 (Wear rate) standards. Results showed that the hardness value was found to increase from 77.7 to 88.1 Hv increase in calcium carbide level from 0 – 4 wt.%, but slightly reduced after 4wt. % of the reinforcement for both particle sizes. The same trend was observed for wear resistance and tensile test. This indicates that there was proper distribution and better bonding of the particles at 4 wt.% of reinforcement than at higher percentage compositions. Therefore, train brake block with required mechanical properties can be produced from polypropylene matrix composite reinforced with 4 wt.% of Calcium carbide residue.*

***Keywords:** Brake block, composite, mechanical properties, polypropylene and calcium carbide.*

1. INTRODUCTION

The braking system of a train is a complicate process, this significantly help to reduce the rate of trail derailment that can lead to loss of life of passengers [1]. Braking system plays a vital role in the train by either reducing the speed or stopping the train when the need arises. It helps the train to stop at a fixed point. This occurs by conversion of kinetic and potential energy of the train into mechanical work of braking force. The material used for braking is usually in form of a block or pad.

Recently, researches worldwide are concentrating on methods of using wastes form either industry or agriculture to enhance the properties of materials for brake block production.

Studies on the friction and wear properties of train brake blocks produced from clay blended with steel slag was carried out [2]. It was discovered that composite friction materials with improved tribological properties can be developed using steel slag as a reinforcement.

Investigation on the tribological and mechanical behaviour of different compositions of aluminium-clay composites for the production of automobile brake disc was carried out [3]. It was discovered that the wear behaviour of the composite developed depends on the sliding speed, load applied and clay particle's weight fraction.

Palm kernel shells (PKS) and some additives were successfully used in replacing asbestos in materials used brake pad production [4, 5, 6. The results revealed that palm kernel shells (PKS) which are readily available and cheap gave good friction for brake pads.

Brake pad based on coconut shell and epoxy resin, reinforced with iron chips was produced by [7]. It was observed that as the percentage content of coconut shell increased, there was decrease in the tensile, compressive and breaking strength as well as increase in hardness which leads to brittleness of the brake pad sample. This is in conformity with the opinion that impact and tensile strength of polymer composite blended with coconut shell decreased as the filler content increased.

Geological studies were carried out on kaolin clay from Ise-Orun-Emure local Government Area in Ekiti State, Nigeria [8]. Beneficiation and analyses of the clay was carried out to find its suitability for automotive friction lining applications. It was revealed that kaolin clay has good heat resistance property, hence, it can be used for automotive friction lining applications.

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Researchers [9] developed brake pads using banana peels in order to replace asbestos with phenolic resin binder. They conducted some tests on mechanical, physical and morphological properties of the brake pads. It was observed from the result that hardness, compressive strength and specific gravity of the samples increased as the percentage composition of resin increased.

A study was carried out on the effect of guinea corn husk ash (GCHA) particulate on the wear and mechanical properties of epoxy matrix composites [10]. The results indicated that there was a noticeable improvement in the mechanical properties while wear properties of the GCHA reinforced epoxy matrix composites deteriorated.

Researchers [11] worked on maize husks (MH) based composite brake pad. In the work, epoxy resin binder was used with maize husks particulate as filler. The results obtained showed that decrease in filler addition increased thermal conductivity, wear rate, hardness, tensile and compressive strength, while increase in filler content increased the coefficient of friction.

Investigation was carried out on composite brake pad produced with pulverized cocoa beans shell [12]. The results revealed that as the percentage composition of filler decreased, hardness and coefficient of friction decreased. Also, as the binder content increased, from 50 to 55 wt.%, the hardness value decreased, but when the binder content increased from 55 wt.% to 60 wt.% the hardness value increased with corresponding brittleness. This can be attributed to close packing of particles and increase in bonding.

Investigation was carried out on the influence of delonix regia seed particulate on the tensile strength of reinforced polymeric composites [13]. The result shows that voids in the composite grains lowered the tensile property of the product, at a certain percentage of delonix regia seed particles and at a very low micrometers particle size addition, the tensile strength and the strain will increase to the maximum.

Research on the characterization of train brake-blocks composite produced with aluminium-dross as reinforcement was carried out [14]. The results of tribological, thermal and mechanical properties obtained indicated that, 5% aluminium dross can be used to produce brake block that with required property recommended by Rail Industry Safety and Standard Board (RISSB).

Influence of agents that will improve compatibility of rice-husk flour reinforced with polypropylene for composites production was investigated [15]. It was found that the tensile strength of the composite slightly reduced as reinforcement content increased and the impact strengths were lowered by the addition of rice-husk flour.

Composites were prepared using polypropylene and calcium carbonate with varying particle sizes [16]. It was discovered that the particle size had no influence on the thermal properties of the polypropylene sample, while there was significant enhancement on the impact resistance of the composite sample.

Most of the researchers used agro wastes, while some used industrial waste, but none has harnessed the use of calcium carbide residue as this can help to eradicate pollution of environment. Thus, this research used calcium carbide residue and polypropylene as the principal materials.

The aim of this research is to produce high quality, low- cost composite brake blocks friction materials from calcium carbide residue as an alternative to locally produce train brake systems in the country.

2. METHODOLOGY

2.1 Materials:

The materials used in this study are; Sample brake block (Rubber matrix composite brake block), Polypropylene (recycled), Calcium carbide residue and Graphite.

Chemical properties of Materials

2.1.1 Polypropylene Pellet

Polypropylene which serves as the matrix or binder, is a thermoplastic with density ranging from 0.895- 0.92 g/cm^3 and tensile strength 0.95 - 1.30 N/mm^2. It is tough, flexible and has a good resistance to fatigue and heat. It has good resistant to dilute acid and base. The polypropylene was sourced from Ojota market and is shown in Figure 1.

Figure 1: Polypropylene pellets used as Matrix material for the composite

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2.1.2. Calcium Carbide residue

Calcium Carbide

Calcium Carbide is a compound with chemical formula CaC_2. This is obtained from reaction

$$Ca + 2C \rightarrow CaC_2$$

Calcium Carbide is a non-volatile and non-soluble substance. Its density is 2.22g/cm$^{3.}$ Its melting point is 2160 ^oC, Boiling point is 2300^oC. It reacts with water to form acetylene gas and calcium hydroxide. (https://melscience.com/US-en/articles/chemical-characteristics-calcium-carbide-and-its-r/)

Calcium carbide residue is shown in Figure 2. It was sourced from a weld shop that uses oxy-acetylene welding. Calcium carbide is a chemical compound with the chemical formula of CaC_2. It serves as the reinforcement to improve the wear properties of the composite. It was obtained as by-product from oxy-acetylene welding from weld shop.

Figure 2: Calcium carbide residue used as the reinforcement in the composite

2.1.3. Graphite

Graphite is a naturally-occurring form of crystalline carbon. It is non-flammable. It has a melting point of 1554.9^oC and boiling point of 2963^oC. It is a native element mineral found in metamorphic and igneous rocks. It serves as a dry lubricant. Dry lubricants or solid lubricants are materials that, despite being in the solid phase, are able to reduce friction between two surfaces sliding against each other without the need for a liquid or oil medium. They offer lubrication at temperatures higher than liquid and oil-based lubricants can operate. The graphite used is shown in Figure 3.

Figure 3: Ground graphite which served as a lubricant

2.2. Method: Calcium carbide residue was sun dried and secured in an air tight container to avoid air or moisture coming in contact with it. It was afterwards sieved using a standard sieve of mesh sizes 150μm and 300μm as shown in Figure 4.

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Figure 4: Standard sieving machine

The graphite was crushed, ground and secured in an air tight container and then sieved to particle sizes of 150 and 300 μm. All the materials were weighed according to the Formulation in Tables 1 and 2, kept in air tight containers and taken for production.

Table 1: The Formulation of the prepared samples for 150 μm particle size

Specimen	**Polypropylene (g)**	**Calcium Carbide (g)**	**Graphite (g)**
A	100	-	-
B	100	4	4.0
C	100	8	4.0
D	100	12	4.0
E	100	16	4.0

Table 2: The Weight Composition of the prepared samples for 300 μm particle size

Specimen	**Polypropylene (g)**	**Calcium Carbide (g)**	**Graphite (g)**
F	100	-	-
G	100	4	4.0
H	100	8	4.0
I	100	12	4.0
J	100	16	4.0

The method of production adopted was plastic compounding and compression, using a Two Rolling Mill and Hydraulic Compression mould. This was done at the polymer laboratory of Yaba College of Technology, Yaba, Lagos.

The polypropylene was fed into the two roll mill, through the hopper and allowed to melt at a temperature of 200 ^oC. Graphite was then introduced and allowed to mix with the molten polypropylene. The reinforcement, calcium carbide residue varying in 0 wt%, 4.0 wt%, 8.0 wt%, 12.0 wt% and 16.0 wt% respectively were then fed into the mix to strengthen it. After 30 minutes of proper mixing, the blend was poured into a mould and taken to the hydraulic compression mould, this was compressed at a temperature of 200 ^oC and a pressure of about 140-150 Pa for 7 minutes. This process was repeated for each specimen and the samples produced are as shown in Figure 5. Various mechanical tests were carried on the samples.

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Figure 5: Composite samples

2.3. Hardness Test

Hardness test was carried out by pressing a loaded object which is an indenter into the surface of the material, it is measured by the distance of indentation and recovery, hardness value measured in Vickers (HV). This was carried out in accordance with ASTM E92-16 using a REX Durometer, Model number OS-2H.

2.4. Wear Test

Wear test is done in accordance with ASTM D 3702 -94 with a DIN Abrasion Tester, Model No: FE05000 to predict the wear performance of a material or its resistance to the abrasion of the surface. The material was weighed before and after its subjection to an abrasive wear machine and the amount of material lost was recorded. This was compared to the loss of material from the conventional brake block exposed to the same conditions.
The test specifications are: Abrasion distance of specimen 40 m, Diameter of specimen 16 mm
Abrasion sheet P60, Number of revolution per minute 40 /min

Weight loss (g) = (Initial weight – Final weight)

Abrasion distance (m) = (Speed × Time)

Wear rate (g/min) = $\frac{\boldsymbol{Weight\ loss}\ (\boldsymbol{W})}{\boldsymbol{Time}\ (\boldsymbol{min})}$

2.5. Tensile Test

Tensile strength of the produced composite was measured using a Universal tensile testing machine, Instron model number: 3369 under 60 kg load according to ASTM D3039 standard.

2.6. Impact Test

The impact test was carried out using a Hounsfield Balanced Izod Impact Machine, with Serial No: 3915 in accordance with ASTM D256 standard. This is done to determine the impact toughness of a material.

3. RESULTS AND DISCUSSION

3.1. Chemical composition: The X-ray Fluorescence (XRF) result of the Chemical composition of a used brake block obtained from Nigerian Railway Corporation is shown in Figure 6. The major composition of the brake block is Carbon (56.54 %), Oxygen (15.08 %), Iron (13.27%), Barium (3.21), copper (3.09 %) and Calcium (1.76 %).

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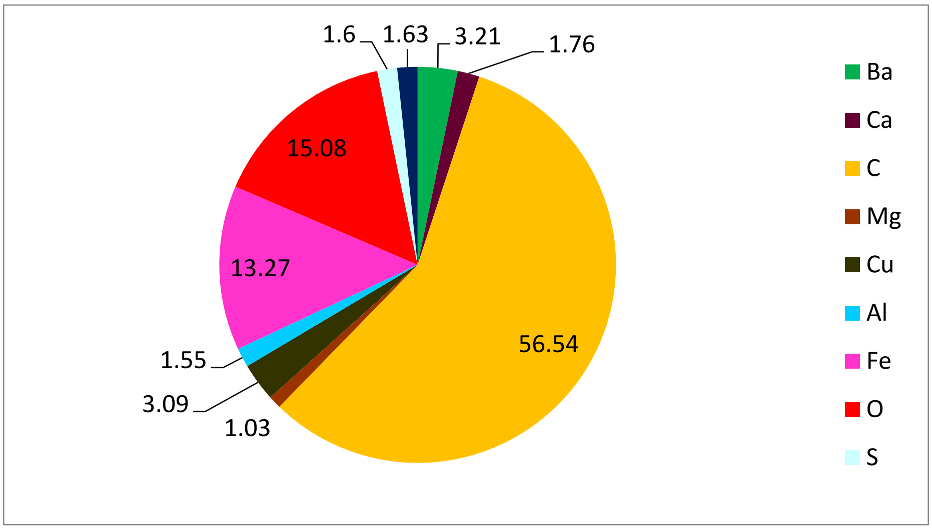

Figure 6: XRF Elemental composition of commercially used brake block

3.2 Mechanical Properties Characterization

3.2.1. Hardness Test

The variation in the hardness values for the polypropylene reinforced with calcium carbide residue of 150 and 300 μm particle size, at different loading rates is represented in Figure 7. As observed in the result, the hardness values of the composite increased from 77.7 to 88.1Hv as the calcium carbide reinforcement increases from 0 – 4 wt.% respectively. The hardness value decreased as the reinforcement increased to 8 wt.% but later increased from 88.6 to 92.6 HV at 12 – 16 wt.%. Tthe same trend was observed for 150 and 300 μm sizes respectively. This is in conformity with [6] This indicate that 4 wt.% calcium carbide can reinforce the propylene better than 8 wt. %. The decrease could be indication of saturation point of the mixture.

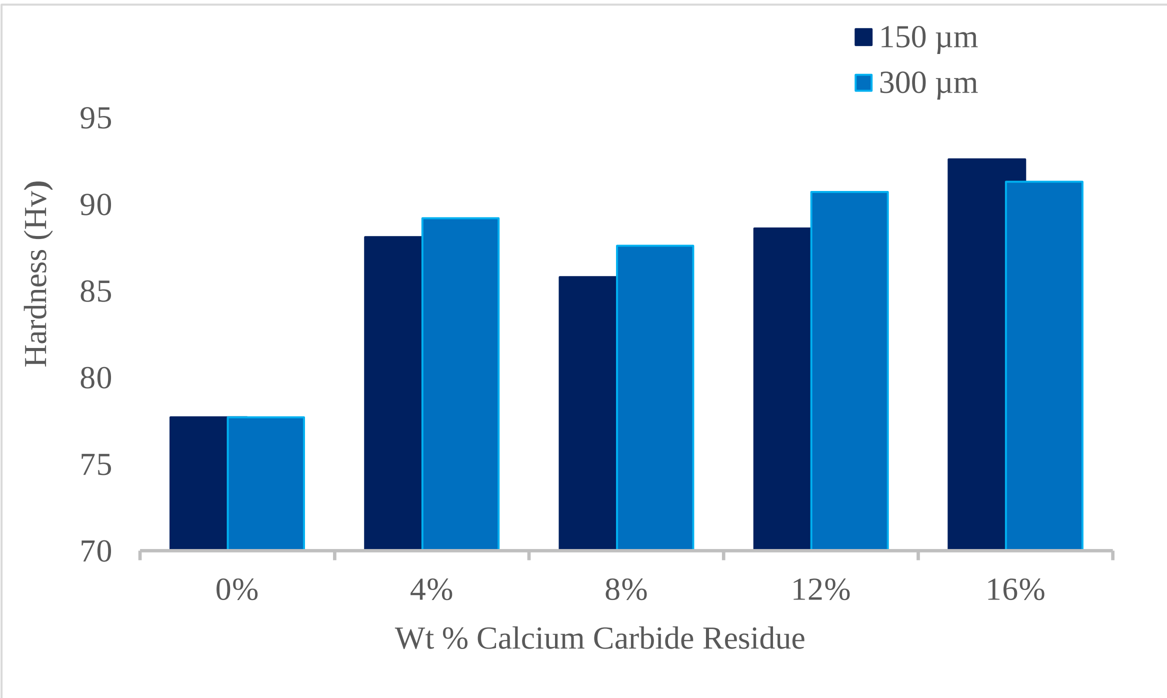

Figure 7: A graph of Hardness values as a function of reinforcement amount for composites produced using 150 μm and 300 μm particulate sizes.

3.2.2. Impact Test

The impact energy of the varying reinforcement loading is presented in Figure 13. The impact test was done to study the toughness of a material. It shows the ability of a material to absorb energy during plastic deformation. Observation

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from Figure 8 shows a reduction in the amount of energy absorbed by the composite above 4 wt.%. The energy absorbed increases from 9.93J to 11.29J at 0 – 4 wt.% of calcium carbide and decreases to 10.47 J at 16 wt.% for 150 µm reinforcement. Also, from 10.34J to 9.53J at 16wt.%, for 300 µm reinforcement.

It can therefore, be concluded that an increase in the concentration of the calcium carbide residue above 4 wt.%, decreases the ability of the composite to absorb more energy, thereby reducing the toughness.

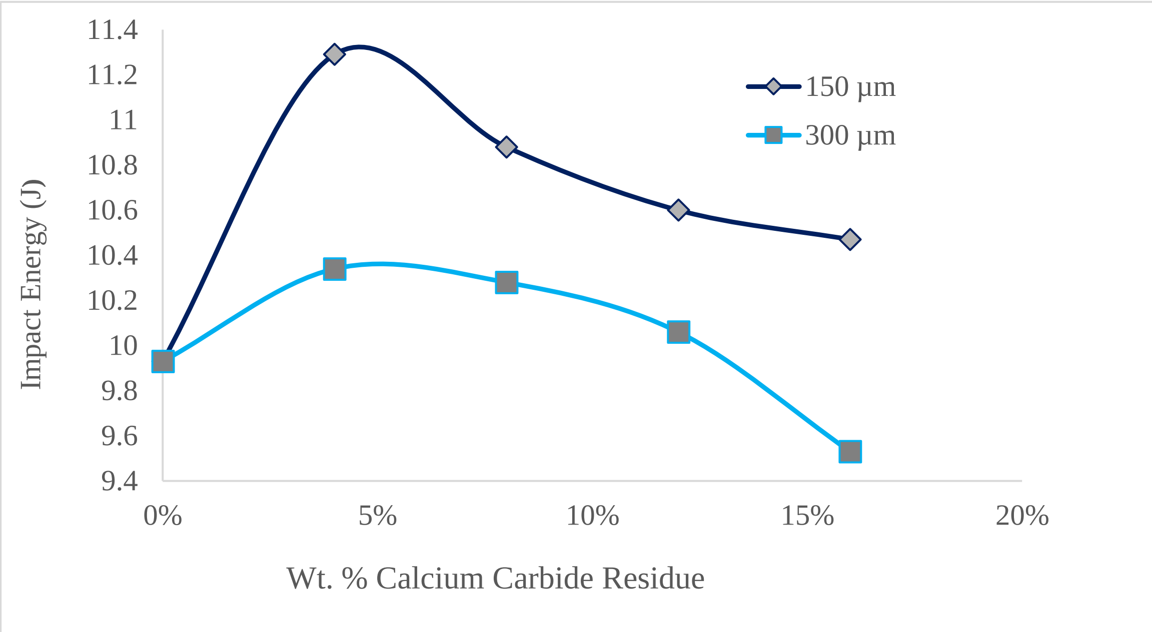

Figure 8: A plot of impact Energy of the composite as a function of difference in composition of calcium carbide with particle sizes of 150 µm and 300 µm

3.2.3. Tensile Test

Figure 9 shows that the tensile behaviour of calcium carbide residue reinforced polypropylene composite poses a corresponding decrease in tensile strength with percentage increase in weight composition above 4 wt.%. It is observed that the tensile strength sharply increases with increase in calcium carbide from 0% to 4% and then begins to decrease with increase in calcium carbide up to 16 wt.%, this implies that brittle fracture occurred in the composite as the weight percentage of the reinforcement increased above 4 wt.%, which can be due to over distribution and dispersion of reinforcements in the matrix, causing weak interfacial bonding.

At 4 wt.%, high tensile strength value indicates a better reinforcement distribution in the matrix leading to an enhanced tensile strength and resistance of the composite to plastic deformation.

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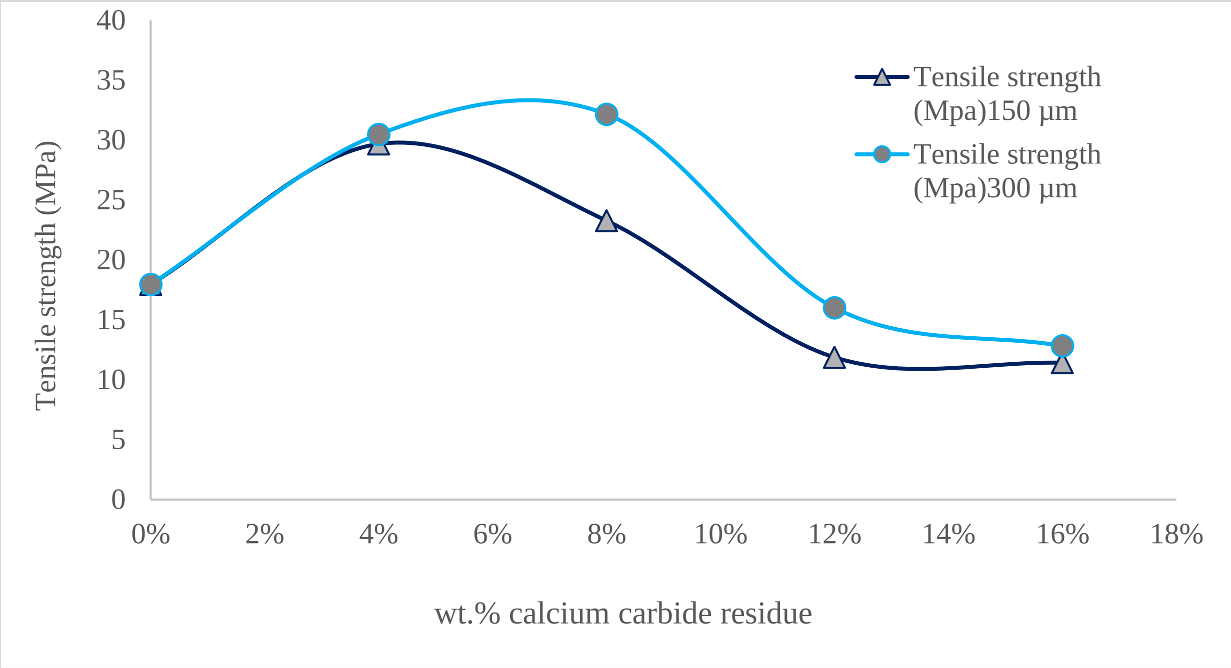

Figure 9: Plot of tensile strength against wt. % calcium carbide residue for composites produced using 150 and 300 µm particle sizes

3.2.4. Wear Test

The Amount of weight loss during abrasion test indicate the measure of the wear resistance of the composite material, the lower the weight loss the better the wear resistance of the composite. The wear rate of the composite is represented in Figure 10, it is observed that the wear rate decreases with increase in calcium carbide residue particles between 2 to 6 wt%. It then increases with increase in addition of calcium carbide from 8 to 12 wt.%. This is trend shows that the optimum properties can be obtained with 4 wt.% calcium carbide reinforcement. Generally, an increase in the hardness value of a material leads to a decrease in its wear rate.

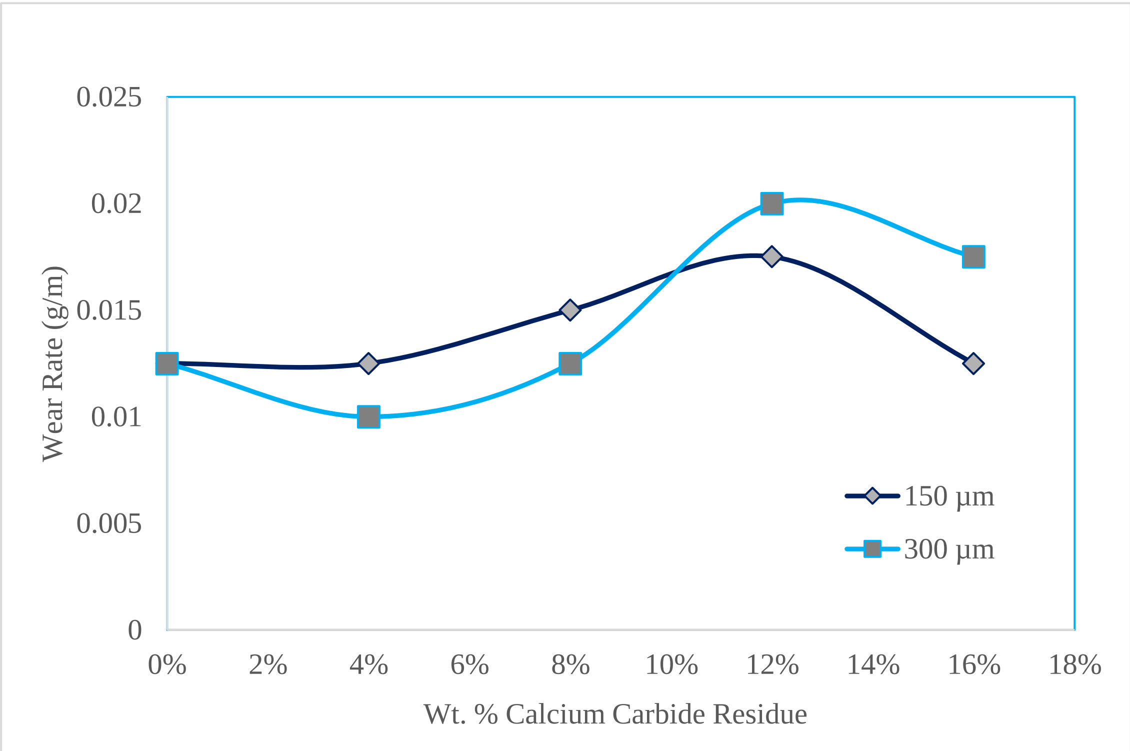

Figure 10: Plot of wear rate against wt. % calcium carbide residue for composites produced with 150 and 300 µm particle sizes

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3.3. Micro Structural Analysis

The morphology of the composite samples prepared with 0 wt.%, 4 wt.% and 16 wt.% of calcium carbide residues were determined using a Scanning Electron Microscope (SEM). The results are shown in Figures 11a - c. It was observed from the micrographs in Figure 16 a-c that the sample with 0 wt.% calcium carbide has a more uniform structure than the samples that contains 4wt.% and 16 wt.% calcium carbide. This can be attributed to the fact that addition of reinforcement brought about phase transformation which enhanced the mechanical properties of the composite earlier discussed.

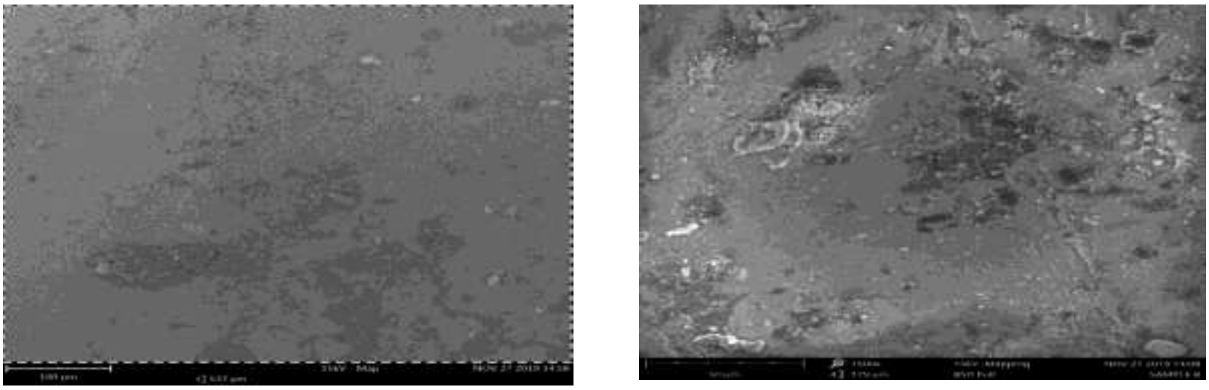

Figure 11 (a): SEM for 0 wt.% Calcium carbide residue (b): SEM for 4wt.% calcium carbide

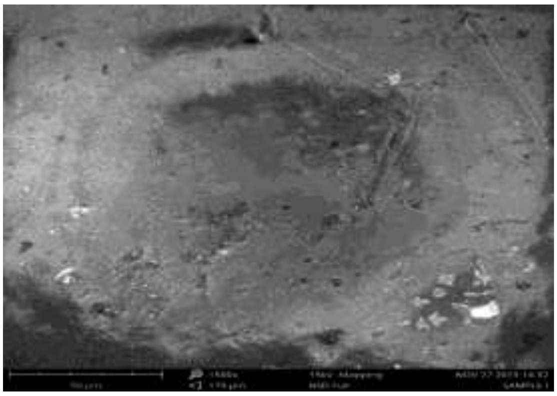

Figure 11c: SEM for sample with 16 wt.% calcium carbide

4. CONCLUSION

This The study on mechanical characterization of the recycled polypropylene reinforced with calcium carbide residue particulate composite has been carried out. The hardness value was found to increase from 77.7 Hv to 88.1 Hv with increase in calcium carbide addition from 0 - 4wt.%. The sample with 4 wt.% of reinforcement has the optimum required value, for both 150µm and 300µm particle size reinforcement. It was observed that the wear rate decreases with increase in calcium carbide residue particles between 2 to 6 wt%. At 4 wt.% there is a high tensile strength which indicate a better reinforcement distribution in the matrix leading to an enhanced tensile strength. The result of the impact energy shows that the energy absorbed increases from 9.93J to 11.29J at 0 – 4 wt.% of calcium carbide and decreases to 10.47J at 16wt.% for 150 reinforcement. Also, from 10.34J to 9.53J at 16wt.%, for 300 µm reinforcement. Therefore, a composite train brake block with enhanced mechanical property can be produced with 4 wt.% of calcium carbide residues as reinforcement.

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