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Effects of Crab Shell and Charcoal Reinforcements on the Mechanical Properties of Polyester Composites

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Abstract

In this work, the effect of particulate crab shell and charcoal reinforcements on the mechanical properties of polyester composites was investigated. Polyester composites with Crab Shell and Charcoal reinforcements of varying weight percents ranging from 5 percent to 25 percent with five percent weight intervals were prepared. These samples were subjected to tensile, impact, hardness and flexural tests. Mechanical tests revealed that there was a non - uniform increase with the Crab Shell and Charcoal reinforcement additions. The composites, nonetheless exhibited different maximum properties at specific percentages of reinforcement additions.

The polyester composites with 20 percent weight percent of Crab Shell and Charcoal reinforcements exhibited the maximum bending strength, and can be considered for applications where flexibility is a major consideration. Polyester composites reinforced with 20 percent and 25 percent of Crab Shell and Charcoal particles showed the highest impact strength. These composites can be used in applications where impact strength is a major concern. The composites with 20 percent and 25 percent of Crab Shell and Charcoal respectively gave the highest tensile values, while the 15 percent and 10 percent of Crab Shell and Charcoal reinforced composites were the hardest of all the samples and may be recommended for applications where hardness is a major consideration.

Keywords: *Mechanical properties, Polyester, Charcoal and Crab shell, Reinforcements*

1.0. INTRODUCTION

Polymer matrix composites are made of matrix materials such as polyester, epoxy, and vinyl ester and reinforcements such as fibres, particles and flakes. The matrix material (resin) transfers the applied load to the particles which improves the physical and mechanical properties of the resin.

In recent times, the engineering applications of composites have increased tremendously because of the continuous advancement in the quality of composites produced. Polymer matrix composites are the most common advanced composites. They provide great strength and stiffness along with resistance to corrosion.

Mechanical properties of a polymer can be controlled by the incorporation of well-defined modifier particles in the polymer matrix. Reinforcement of polymers with particulates plays an important role in the improvement of the mechanical properties of high-performance materials.

The negative environmental impact as a result of non-biodegradability of carbon/glass fibre reinforced polyester composites is creating pressure for the substitution of high energy consumption materials for natural and sustainable ones. Compared to synthetic fibers, natural fibers and particulates have shown advantages in aspects such as flexibility and toughness. So, there is a growing worldwide interest in the use of these fibers and particulates.

The use of agro-based materials/wastes in reinforcing polymers have recently attracted the attention of researchers because of their advantages over other established materials. Agro-based materials are environmentally friendly, fully biodegradable, abundantly available, renewable, cheap and have low density. Precisely, researches have been carried out on Polyester composites with several agro wastes as reinforcements.

Laly *et al*. (1997) evaluated the tensile, impact, flexural properties and aging behavior of short banana fiber reinforced polyester composites with special reference to the effect of fiber length and fiber content. The maximum tensile strength was recorded at 30 mm fiber length while the impact strength gave the maximum value for 40 mm fiber length. Incorporation of 40% untreated fibers gave a 20% increase in the tensile strength and a 341% increase in impact strength. On treatment with silane coupling agent, composites showed a 28% increase in tensile strength and a 13% increase in flexural strength. Aging studies showed a decrease in tensile strength of the composites. Water absorption studies showed an increase in water uptake with increase in fiber content.

Raghad *et al*. (2015) synthesized polyester composites reinforced with 3 - 9 wt % Arko shell (AS) particulate. There was considerable increase in tensile strength, young's modulus and hardness with increase in the filler content. The composites were found to have more impact strength when compared to unreinforced polyester.

Nwigbo (2013) produced a composite with a polyester matrix and chemically modified shells of castor seed (*Ricinus communis*) as reinforcement. The effect of the shell (filler) on the mechanical properties of the composite was experimentally quantified. The results of the mechanical tests revealed that the inclusion of the filler (shell) improved the strength of the base polyester matrix.

Durowaye *et al*. (2014) studied the mechanical behaviour of Coconut shell and Palm fruit particulate polyester composites. Particles of the reinforcement with different weight fractions (5-30wt. %) were added to 70-95g corresponding weight of polyester resin. An ultimate tensile strength of 70MPa was obtained for the coconut shell particulate polyester composite, while that of palm fruit particulate polyester composite was 62.5MPa. The highest impact strength value for coconut shell particulate polyester composite was 4.76J, while that of palm fruit particulate polyester composite was 4.60 J. The highest hardness value for coconut shell particulate polyester composite was 208 BHN while that of palm fruit particulate polyester composite was 182.30 BHN. It was noted that Coconut shell reinforced polyester has a relatively higher mechanical strength when compared to palm fruit reinforced polyester.

Meenambika (2014) worked on the chemical resistance and flexural properties of Bamboo/Glass reinforced polyester hybrid composites. It was observed that the flexural properties of the hybrid composites increase with glass fiber content. These properties found to be higher when alkali treated bamboo fibers were used in hybrid composites. The hybrid fiber composites showed better resistance to the acids. It was noted that the elimination of amorphous hemi-cellulose with alkali treatment leading to higher crystallinity of the bamboo fibers with alkali treatment may be responsible for these observations.

The toughness behavior of polyester matrix composites reinforced with up to 30% in volume of long, continuous and aligned Curaua fibers was investigated by Barcelos *et al.* (2014). The addition of the Curaua fibers resulted in a visible improvement in the energy absorption ability of the composites. Macroscopic observation of the post-impacted specimens and the SEM fracture analysis showed that longitudinal rupture through the curaua fiber interface with the polyester matrix is the main mechanism for the higher toughness attended by these composites.

2.1 Materials and Methods

The charcoal and crab shell reinforcements used in preparing the composites were obtained from a local market in Mushin, Lagos, Nigeria. The polyester resin (unsaturated), catalyst and accelerator were bought from Ojota chemical market, Lagos. Fourier Transform Infrared Spectroscopy was used to confirm the identity of the Polyester resin, and the reinforcements.

Apparatus used in the preparation of the samples include: Wooden mould, masking tape, plastic containers, stirring rod, weighing balance and standard sieves.

2.2 Preparation of Crab Shell and Charcoal reinforced Polyester Composite samples

The crab shells and charcoal were washed and sun dried for some days before grinding. Both reinforcements were then sieved with a hand sieve of size 100BSS (149 microns).

The polyester and the particulates were mixed in different proportions while maintaining a total weight of 100g. Five composite mixtures with particulate compositions of 5%, 10%, 15%, 20%, and 25% were obtained. The fillers were added in the right proportions, drops of catalyst and accelerator were also added to the mixture and then stirred vigorously so as to achieve uniform distribution of filler and avoid air bubbles.

Each of the mixtures was then poured into a wooden mould lined with paper tape and PVA to serve as a releasing agent. Thereafter the samples were left to cure at room temperature. The dimensions and shapes of the cavities were tailored to the size and shape of the sample as per ASTM Standard D638-03 with clearance for shrinkage. The composites with amounts of Charcoal and Crab shell powder ranging from 5% to 25% weight fraction were fabricated.


Figure 1: Charcoal before grinding

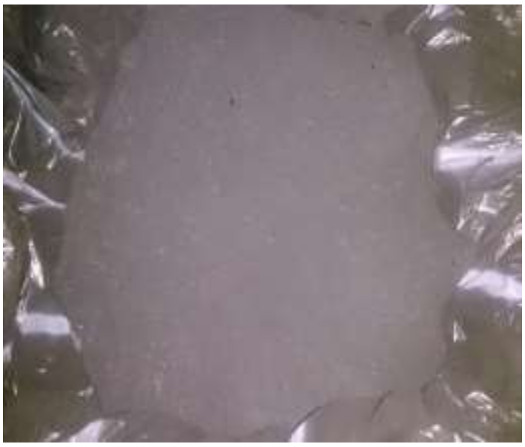
Figure 2: Charcoal after grinding


Figure 3: Crab Shell before grinding


Figure 4: Crab Shell after grinding

Figure 5: Mould used for preparation of composite samples

Figure 6: Some prepared composite samples

The polyester resin was weighed using an electronic weighing balance. A beaker was placed on the weighing machine, and the polyester resin was gradually stirred until the desired weight was achieved.

The crab shell and charcoal particulates were also weighed using an electronic weighing machine. A petri dish was also used for this purpose. This process was repeated for the five weight formulations used for this research.

The formulation used for the polyester resin was x/100 x 100g, where x is the percentage of resin. The formulation used for the reinforcement was y/100 x 100g, where y is the percentage of reinforcement. The basis used for the preparation of samples was 100g.

Table 1: The weight values of polyester resin and reinforcements (crab shell and charcoal)

Percentage filler %	Polyester resin (g)	Reinforcement (g)
5	95	5
10	90	10
15	85	15
20	80	20
25	75	25

After curing at room temperature, all the samples were removed from the mould.

2.2 Mechanical Tests

Tensile, Flexural, Hardness and Impact tests were carried out on the samples. The tensile testing was performed using a Testometric universal testing machine with serial number 25257 and capacity M500-25KN at Federal Institute of Industrial Research, Oshodi (FIIRO). This test was operated at a cross head speed of 30mm/min. The tensile test specimen preparation and testing procedures were conducted in accordance with the American Standard testing and measurement, method D412 (ASTM D412 1983), using dumbbell test piece. Each tensile specimen was positioned in the testometric universal tester and then subjected to tensile load, as the specimen stretches the computer generates graph as well as all the desired parameters until the specimen fractures. A graph of load versus extension is plotted automatically by the tester and various property of the specimen determined are; tensile strength, tensile strain, modulus, tensile strain at break.

Three-point flexural testing was conducted using Testometric Universal Testing Machine with serial number 25257 and capacity M500-25kN at Federal institute of Industrial Research, (FIIRO), Oshodi, Lagos, Nigeria. The flexural test was carried out according to ASTM D 7264 at a cross-head speed of 30mm/min, maintaining a span of 100mm. This test was conducted at room temperature. The flexural test specimens' dimensions were of 120 X 50 X 5 mm, and were conducted at room temperature.

The impact tests of the composite samples were carried out at the Obafemi Awolowo University, Ife. Impact test is a standard method of determining the impact resistance of materials. An arm held at a specific height (constant potential energy) is released. The arm hits the sample placed on the anvil and breaks it. The energy absorbed by the sample gives the impact energy. A notched sample is generally used to determine impact energy and notch sensitivity. A material's toughness is a factor of its ability to absorb energy during plastic deformation.

The hardness test was carried out in Obafemi Awolowo University, Ife. The Brinell hardness machine employed a 20mm ball indenter and a load 4000N. The hardness test was carried out on each of the composite samples. The sample for ascertaining the hardness of the composite was placed on the anvil and three to five indentations were made on each of the samples while the Brinell number was read and recorded for each indentation. The average of the Brinell numbers corresponding to each of the indentations was obtained.

3.0 RESULTS AND DISCUSSION

The results of the various mechanical tests (Tensile strength, Flexural strength, Hardness and Impact tests) carried out are discussed below. Each mechanical test was carried out on five different samples for each composite weight fraction. Based on the tabulated test results in tables 2 and 3, various bar charts and line graphs were plotted and presented for the average of the five composite samples for each weight fraction.

Table 2: Result of mechanical tests on the Crab Shell reinforced composite (Average of five samples)

Reinforcement	Bending modulus (MPa)	Impact strength (J)	Brinell Hardness (BHN)	Young's Modulus (MPa)
Crab Shell (5%)	301.59	4.76	112.29	209.91
Crab Shell (10%)	197.07	4.90	91.28	203.62
Crab Shell (15%)	264.81	5.30	107.56	336.30
Crab Shell (20%)	281.83	5.71	121.13	73.41
Crab Shell (25%)	373.72	4.90	80.00	94.16

Table 3: Result of mechanical tests on the Charcoal reinforced composite (Average of five samples)

Reinforcement	Bending modulus (MPa)	Impact strength (J)	Brinell Hardness (BHN)	Young's Modulus (MPa)
Charcoal (5%)	174.31	4.70	82.00	165.23
Charcoal (10%)	115.66	4.90	85.85	223.32
Charcoal (15%)	235.37	5.03	89.25	255.24
Charcoal (20%)	324.94	5.71	116.59	315.55
Charcoal (25%)	313.42	5.58	102.51	93.54

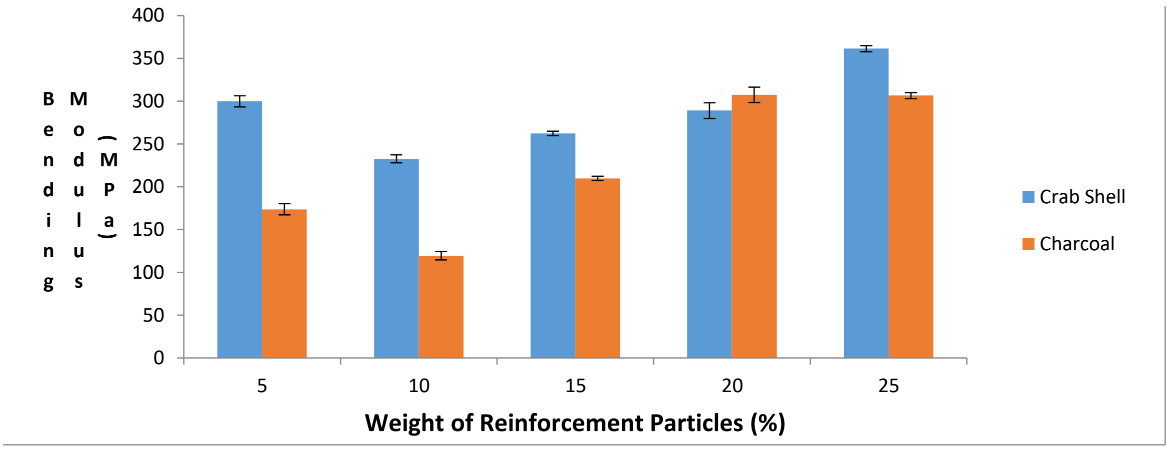

Figure 7: Bar Chart of Bending Modulus against Weight of Reinforcement Particles for Crab Shell and Charcoal Polyester composite samples.

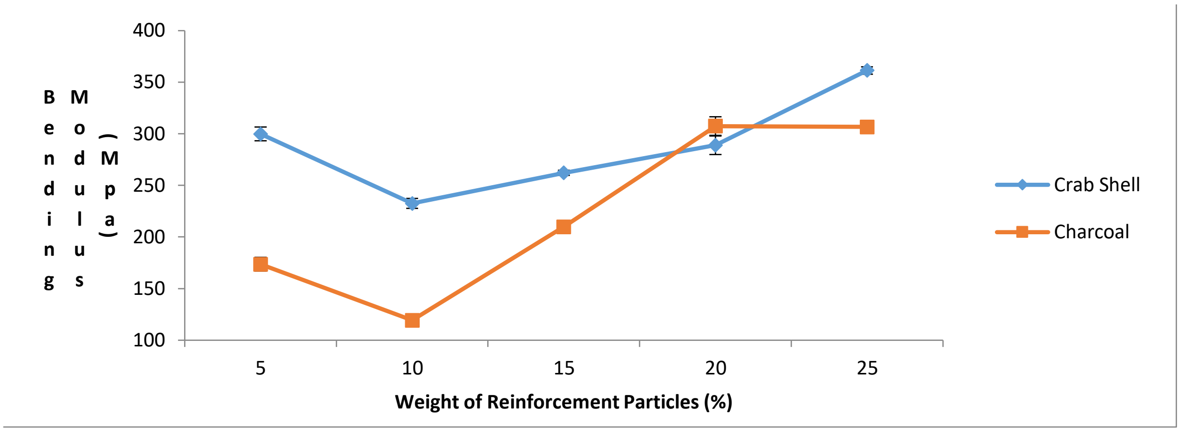

Figure 8: Line graph of Bending Modulus against Weight of Reinforcement Particles for Crab Shell and Charcoal Polyester composite samples.

From figure 8, it is observed that Crab Shell has higher bending modulus than Charcoal reinforced Polyester composites. This obvious in 5%, 10%, 15% and 25% weight percent reinforcements. The Crab Shell shows a decrease in flexural modulus from 5 to 10% weight percent, followed by an increase up till 25%.

It can be seen that there is a reduction in the bending strength of the snail shell from 5-10% after which an increase in bending strength sets in as the snail shell filler content increases. There is a decrease in the flexural modulus for the Charcoal from 5 to 10%, followed by an increase in modulus to 20%. However, there is a slight decrease in flexural modulus from 20 to 25%. This reduction in bending strength at peak of the charcoal reinforced composite sample can be attributed to controlled mobility of matrix by filler particles. As amount of reinforcement increases, there’s reduction in total surface area available for matrix-filler interaction.

Figures 9 and 10 shows the graphs of the impact values of the Crab Shell and Charcoal reinforcements against varying weight percent. Both the Crab Shell and Charcoal reinforced samples absorbed the highest amount of energy at 20%. The impact strength increased as the filler content increased from 5-20%, but a decrease in impact strength is observed at 25%. It seems that increase in the concentration of the filler material reduces the ability of matrix to absorb energy and thereby reduces the toughness. Generally, there is not much of a difference in the impact values between the Crab Shell and the Charcoal reinforced polyester composite samples

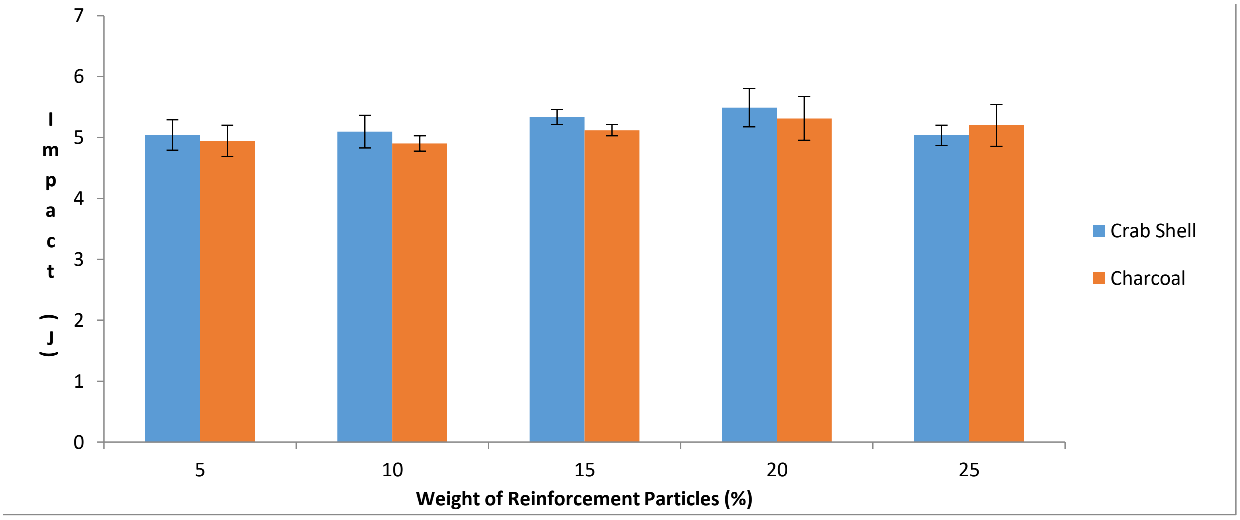

Figure 9: Bar Chart of Impact Strength against Weight of Reinforcement Particles for Crab Shell and Charcoal Polyester composite samples.

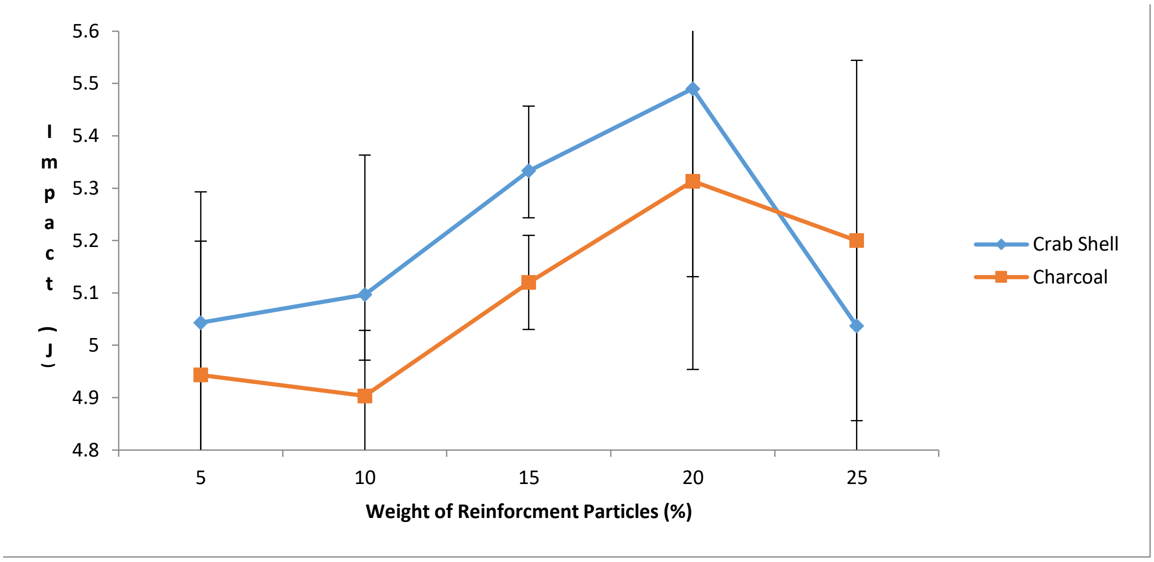

Figure 10: Line Graph of Impact Strength against Weight of Reinforcement Particles for Crab Shell and Charcoal Reinforced Polyester Composites samples.

From figures 11 and 12, it can be observed that as the weight percent of the Charcoal reinforced composite samples increased from 5 to 20 %, the hardness values also increased while the Crab shell reinforced polyester composite samples showed an undulating pattern. The undulating pattern of the Crab Shell reinforced polyester composite samples may be attributed to the poor interfacial bonding or surface adhesion of the fillers and polyester resin. It is also observed that the highest hardness values for both the Crab Shell and Charcoal reinforced polyester composite samples was 20%. Also, up to a weight percent of 20%, the Crab Shell Polyester composites have higher hardness values than the Charcoal reinforced polyester composites, while the Charcoal reinforced composite samples had a higher hardness value at 25%.

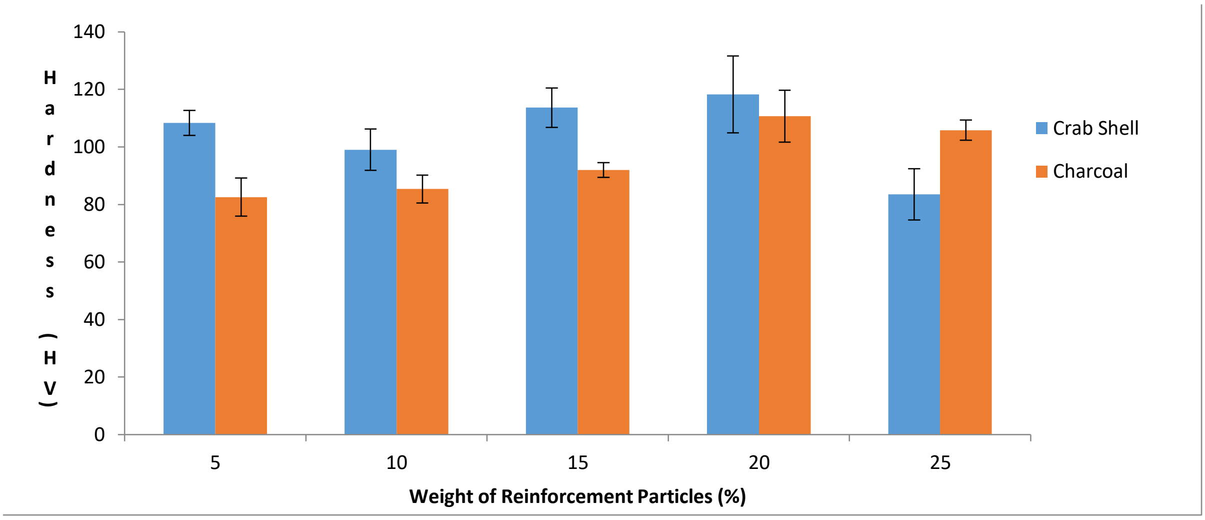

Figure 11: Bar Chart of Hardness Values against Weight of Reinforcement Particles for Crab Shell and Charcoal Polyester composite samples.

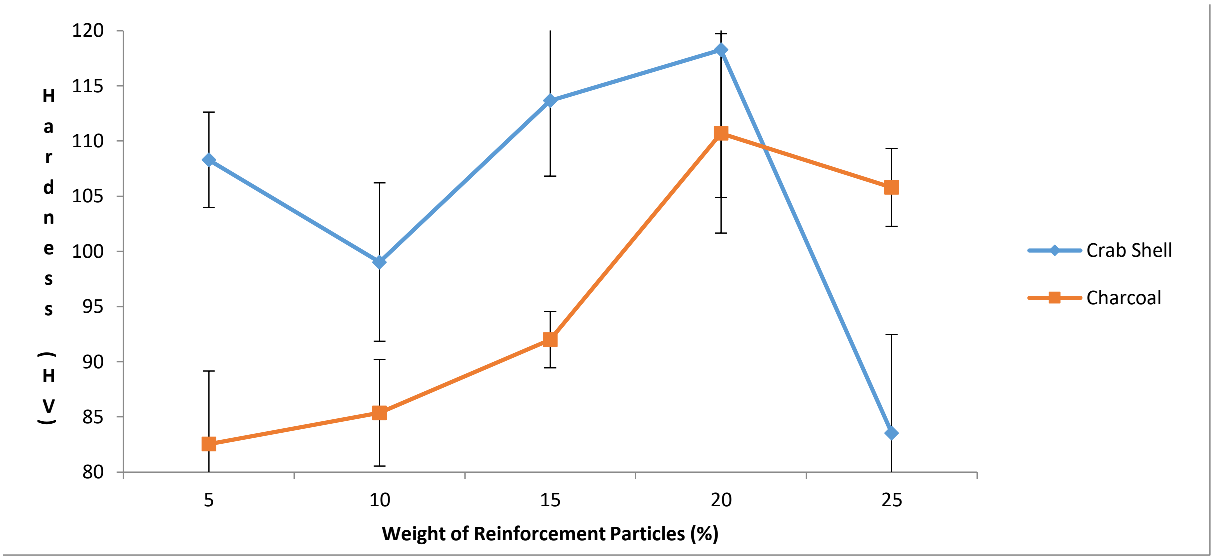

Figure 12: Line Graph of Hardness Values against Weight of Reinforcement Particles for Crab Shell and Charcoal Reinforced Polyester Composites samples.

From figures 13 and 14, it can be observed that the Crab Shell reinforced composite sample showed the highest elastic modulus at 15% reinforcement, while Charcoal reinforced composite sample had the highest modulus at 20%. The variation in the elastic modulus for the Crab Shell and Charcoal reinforced polyester composite samples from 5% to 20% was in an undulating pattern. The high elastic modulus of the polyester with 15% of Crab shell and 20 % Charcoal reinforcements could be as a result of better interfacial bond and the absence of voids or porosity in the sample. The polyester composite samples with 10% Crab Shell and 25% Charcoal reinforcements have the lowest elastic modulus. This could be attributed to the poor stress transfer between the particle matrix interface.

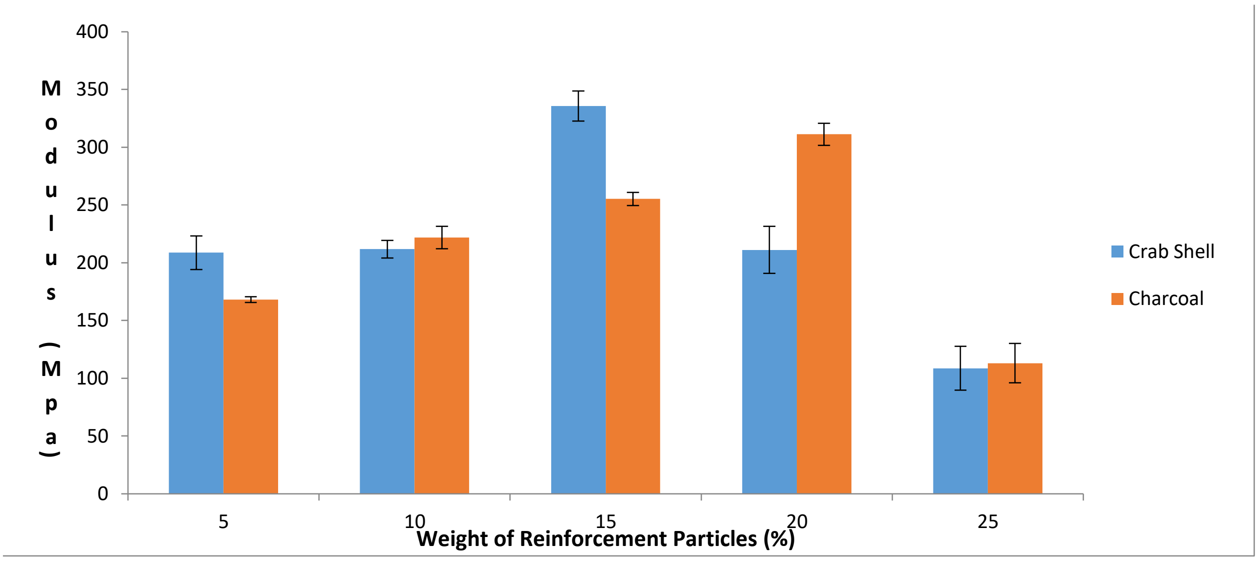

Figure 13: Bar Chart of Youngs Modulus against Weight of Reinforcement Particles for Crab Shell and Charcoal Polyester composite samples.

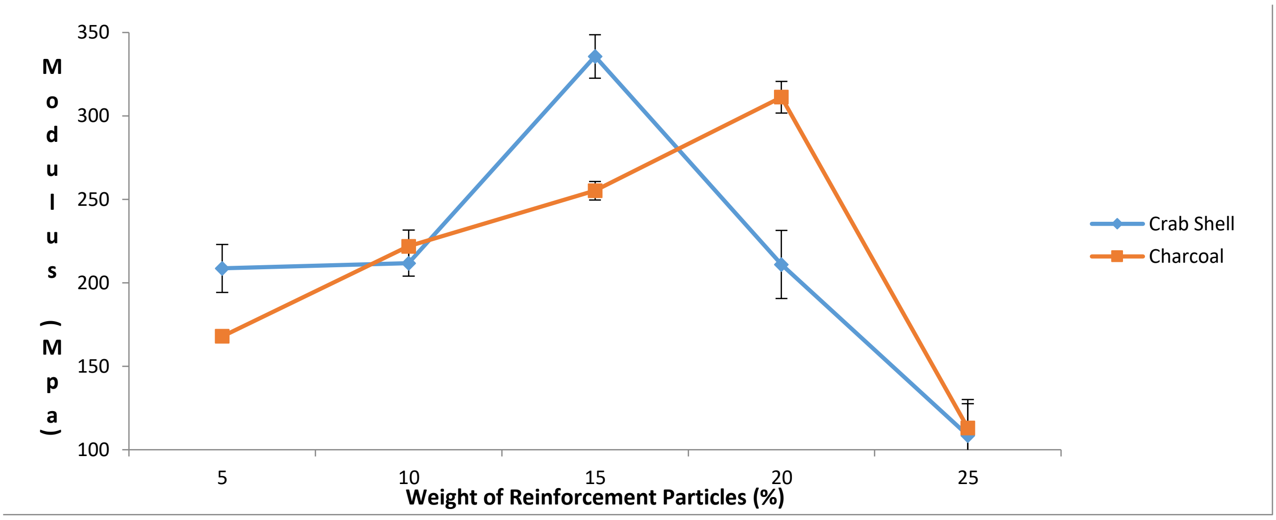

Figure 14: Line Graph of Hardness Values against Weight of Reinforcement Particles for Crab Shell and Charcoal Reinforced Polyester Composites samples.

Microstructural Analysis

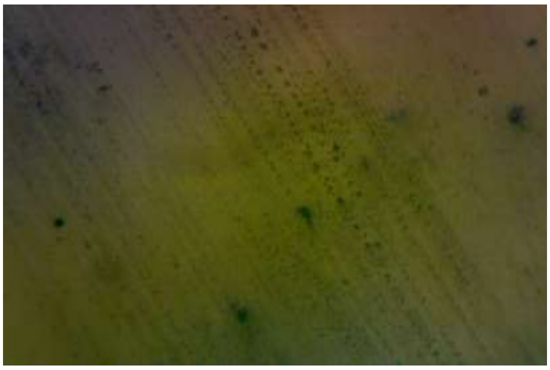

Figure 15: Micrograph of pure polyester Resin

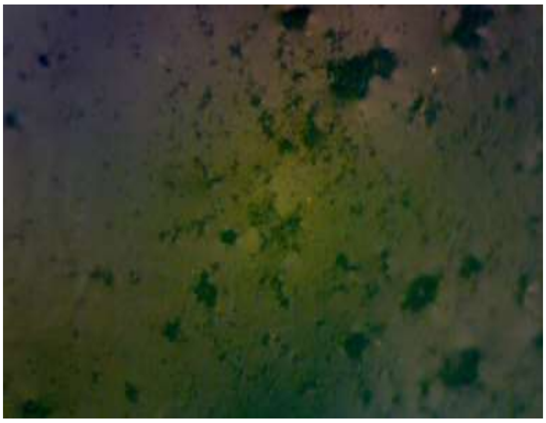

Figure 16(a): Micrograph of 5% Charcoal Reinforced polyester resin

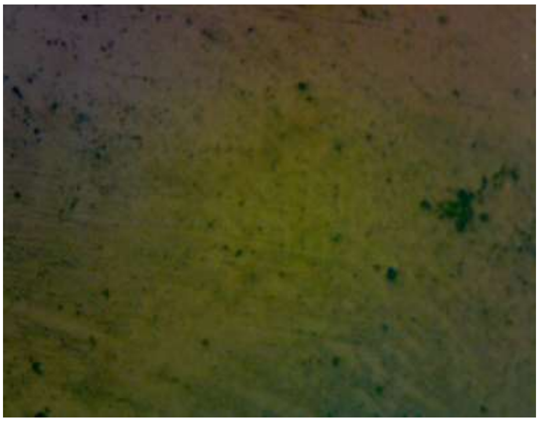

Figure 16(b): Micrograph of 5% Crab Shell reinforced polyester resin

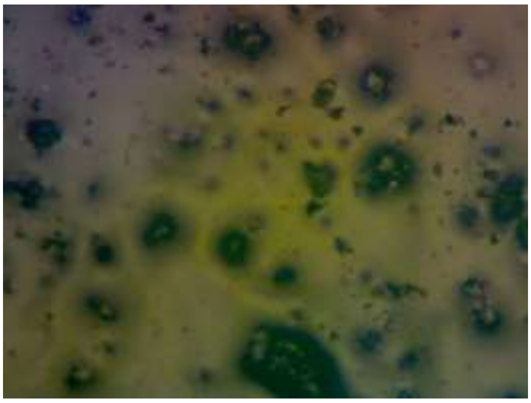

Figure 17(a): Micrograph of 10% Charcoal Reinforced polyester resin

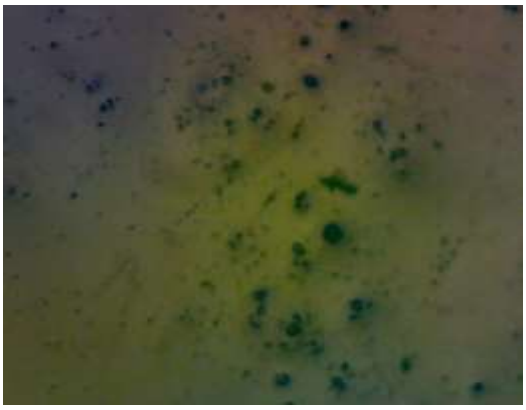

Figure 17(b): Micrograph of 10% Crab Shell reinforced polyester resin

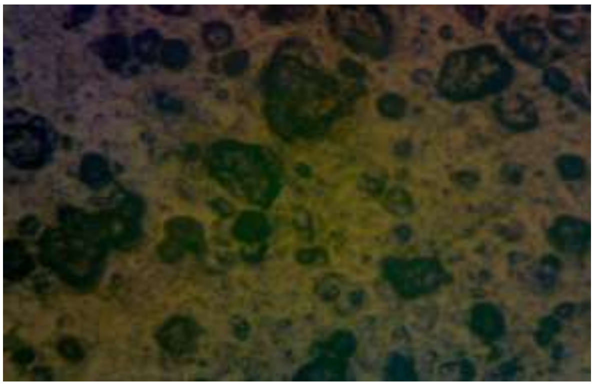

Figure 18(a): Micrograph of 15% Charcoal Reinforced polyester resin

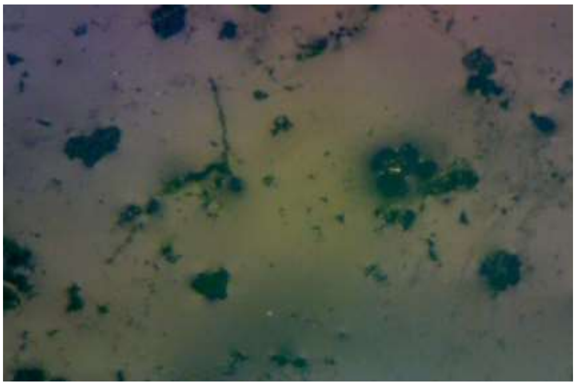

Figure 18(b): Micrograph of 15% Crab Shell reinforced polyester resin

Figure 19(a): Micrograph of 20% Charcoal Reinforced polyester resin

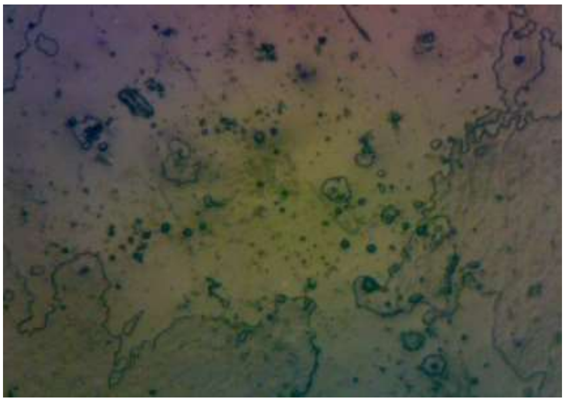

Figure 19(b): Micrograph of 20% Crab Shell reinforced polyester resin

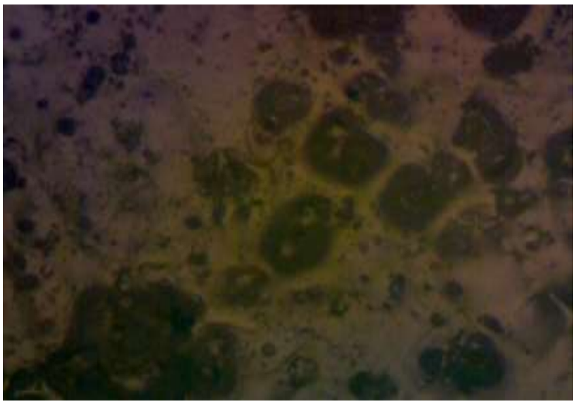

Figure 20(a): Micrograph of 25% Charcoal Reinforced polyester resin

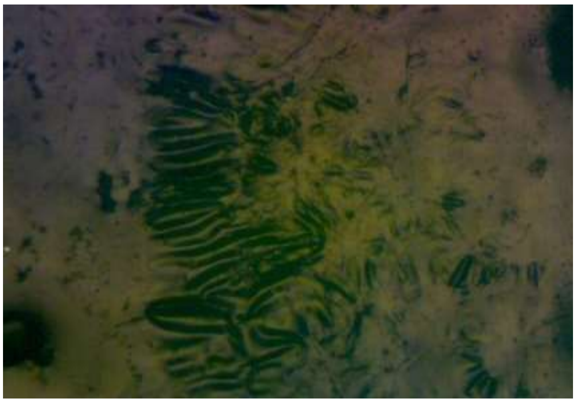

Figure 20(b): Micrograph of 25% Crab Shell reinforced polyester resin

From figure 15 above, it was observed that there are some traces of impurities appearing as dark particles on the unreinforced composite (i.e. 0% weight of particles). These traces are assumed to be insignificant amount of impurities, and they are not expected to have any effect on the properties of the subsequent fabricated composite.

Figures 17a and 17b (5% weight of particles) of both Crab Shell and Charcoal show some dark particles. These dark particles can be attributed to the Crab Shell and Charcoal reinforcements. The micrographs show that the reinforcements were evenly dispersed over the sample. It could be assumed that there was bonding between the reinforcement particle surface and the polyester resin.

Figures 18 (a and b) and 19 (a and b) also show an increasing amount of Crab Shell and Charcoal reinforcements in the Polyester composite from 10% to 15%. As with the 5% weight composites, the reinforcements were evenly dispersed over the sample

Micrographs of Figure 20(a and b) and Figure 21(a and b) show that at 20% and 25% weight of particles respectively, in addition to more dark patches which indicated an increase in the reinforcements, there were also some agglomeration of the reinforcements. This may be as a result of the poor interface that exist between the particles and the polyester. This could lead to the restriction of polyester chain movement with a fairly good distribution of the particle due to the increase in particle concentration.

4.0 **CONCLUSION**

It was seen that the mechanical properties of polyester composites can be improved by the agro waste reinforcements of Crab Shell and Charcoal. From the flexural test, it can be seen that both the Crab Shell and Charcoal reinforced polyester composites at 25% and 20% weight reinforcements showed the highest resistance before shattering relative to other samples. This implies that the Crab Shell and Charcoal reinforcement of 25% and 20% can be used in place of the pure polyester for applications where flexibility is critical.

Both the Crab Shell and Charcoal reinforced Polyester composite samples with 20% reinforcement absorbed the highest amount of energy before shattering relative to other samples. Therefore, both composites can be used in place of pure polyester in applications where impact strength is a major concern.

From the hardness test, it can be seen that the Crab Shell and Charcoal reinforced Polyester composite samples with 20% reinforcement showed the highest hardness compared to all other samples. This implies that the Crab Shell and Charcoal reinforcement of 20% can be used in place of the pure polyester for applications where hardness is a priority.

The micrographs reveal an even dispersion of the reinforcements within the samples.

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