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Development of High-Density Polyethylene /Orange Peels Particulate Bio-Composite

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ABSTRACT

Renewable resources such as natural fillers in the field of particles reinforced materials with their new range of applications represent an important basis in order to fulfill the ecological objective of creating environmental friendly materials. In views of enormous advantages a study on composites using orange peels particles as a reinforcing material and high-density polyethylene (HDPE) as a novel matrix has been made. The composite was first compounded to produce homogeneity of the particles in the matrix, and then it was compacted into flat plates. The composites were produced by varying the orange peels particles (uncarbonized and carbonized) from 5-25wt%. The properties of HDPE reinforced with orange peels have been studied using mechanical tests and microstructural analysis. The results shown that there was a fairly uniform distribution of the orange peels particles in the microstructure of HDPE composites which is the major factor responsible for the improvement in the mechanical properties. The obtained results of the developed composites have shown that the orange peels waste could be used as a biodegradable eco-friendly reinforcement.

Keywords: Polymer-matrix composites (PMCs), Mechanical properties, Microstructure and Compression moulding
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1. INTRODUCTION

Polymer composite materials are being used in a wide range of structural applications in the aerospace, construction and automotive industries due to their lightweight and high specific stiffness and strength[1]. A variety of materials are being used ranging from lower performance glass fibre/polyester, used in small sail boats and domestic products, to high performance carbon fibre epoxy systems used in military aircraft and spacecraft. One sector where the use of composite materials is still evolving is the automotive industry. Composite materials offer great potential in reducing vehicle weight, thus increasing fuel efficiency and reducing CO2 emissions. In addition to weight reduction, the number of individual parts can be significantly reduced making the high-volume composite car concept cost effective[2-3].

In its most basic form a composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the ‘matrix’), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix [4].

In recent years there is a perceived shortage of wood fibre for composite products due to competition for fibre by pulp mills, reduced harvesting and manufacturing and diminished log quality. Also, there is pressure from environmentalists to reduce forest use and regulatory legislation pending on disposal of agri-fibres[4-5]. For example, any potential to reduce

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[♠] Correspondingauthor, e-mail: aigbodionv@yahoo.com field burning is an environmental benefit and helps address the issue of restricted open burning. There are tremendous quantities of agricultural biomass available for non-agricultural uses such as paper and composite products.

There is a total of about 365,000,000 dry tonnes of all non-wood fibre produced in North America each year[6]. While it is estimated that only about 1/3 of the cereal straw produced annually is available for non-agricultural uses[6-8], the available agricultural residues could more than replace all of the wood based composites presently produced on the basis of volume only. There may be potential to sell agriculture residues based composite products as a premium product or alternatively to have additional marketing pluses based on environmental issues (formaldehyde free, sustainability of the product, green certification) and properties (moisture resistance, machining properties, low density). Based on the foregoing, this present study is looking into the possibility of using orange peels particle in the production of polymer bio-composite.

2. MATERIALS/EQUIPMENT

The orange peels used in this investigation where obtained from an orange fruit seller in Zaria, Nigeria and HDPE was purchased from a Chemical shop in Kaduna, Nigeria (see Figures 1-2).

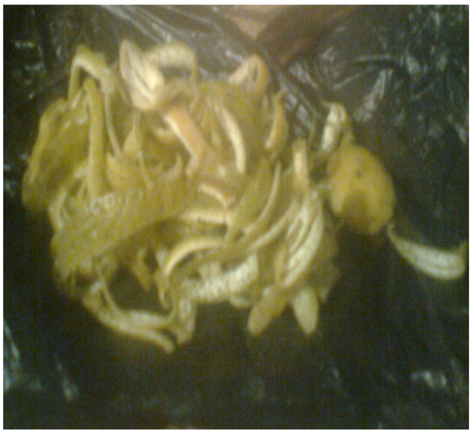


Figure 1. Fresh orange peels

Figure 2. Pellets of HDPE

Equipment used in this research are-, Metal mould, hydraulic press , Avery Denison impact tester, Rockwell hardness machine, Hounsfield tensometer machine, hacksaw and aluminium foil.

2.1 The Processing of The Orange Peels

The orange peels was dried and grind form uncarbonized orange peels particles(see Figure 3). The powder was then packed in a graphite crucible and fired in electric resistance furnace at temperature of 1200oC to form carbonized orange peels particles(see Figure 4). The particle size analysis of the orange peels particles was carried out in accordance with BS1377:1990. The particles was placed unto a set of sieves arranged in descending order of fineness and shaken for 15minutes which is the recommended time to achieve complete classification, the particle that was retained in the BS. 100µm was used in this research.

Figure 3. Uncarbonized orange peel powder

Figure 4. Carbonized orange peel ash

2.2. Sample Preparation

The fabrications of th composite materials were carried out through the compressive technique. HDPE was reinforced with orange peels particles uncarbonized(OPUp) and carbonized(OPCp). After drying in oven at 105oC, the orange peels particles and the HDPE were compounded in a two roll mill at a temperature of 130oC, to obtain homogenous mixture. The composites production was carried out with hydraulic press. The compounded mixtures were placed in a rectangular mould with a size of 350mm by 350mm. The composites were pressed to a thickness of 4mm. At the end of press cycle the composites was removed from the press for cooling. 5-25wt% of orange peels particles was used with interval of 5wt%. Five different types of composites was produced with two different orange peels particles (OPU and OPC).

2.3. Microstructural Analysis

The scanning electron microscope (SEM) JEOL JSM-6480LV was used to identify the surface morphology of the composite samples. The surfaces of the specimens were examined directly by scanning electron microscope JEOL JSM-6480LV. The samples was washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV

2.4. Test Procedure

The composites test samples were cut for the mechanical test according to the recommended Standard for each test. Prior to the test all the samples was conditioned at a temperature of 23±2oC and relative humidity of 65% according to ATM D618-08[9]

2.4.1. Mechanical properties

Tensile test was carried out using an hounsefield tensometer machine, with maximum load of 3.0 KN and a strain rate of 0.002S-1. The standard tensile specimen was mounted by its ends into the holding grips of the testing apparatus. The machine is designed to elongate the specimen at a constant rate and simultaneously measure the instantaneous applied load and the resulting elongations obtained using an extensometer.

The four-point bending strength test (Instron machine) was measured according to DIN 51110. The test was carried out by two supports. The surface of the sample was sheer strained by bending die. It steadily down at speed of 10mm/min. The force was applied directly to the centre of the sample held on the support.

The hardness values of samples were determined according to the provisions in American Society of testing and materials(ASTM E18-79) using the Rockwell hardness tester on "B" scale (Frank Welltest Rockwell Hardness Tester, model 38506) with 1.56mm steel ball indenter, minor load of 10kg, major load of 100kg and hardness value of 101.2HRB as the standard block[9]. Before the test, the mating surface of the indenter, plunger rod and test samples were thoroughly cleaned by removing dirt, scratches and oil and calibration of the testing machine using the standard block. The samples were placed on anvils, which act as a support for the test samples. A minor load of 10kg was applied to the sample in a controlled manner without inducing impact or vibration and zero datum position was established, and then the major load of 100kg was then applied, the reading was taken when the large pointer came to rest or had slowed appreciably and dwelled for up to 2 seconds. The load was then removed by returning the crank handle to the latched position and the hardness value read directly from the semi automatic digital scale

The impact test of the composites sample was conducted using a fully instrumented Avery Denison test machine. Charpy impact tests were conducted on notched samples. Standard square impact test sample measuring 75 x 10 x 10 mm with notch depth of 2 mm and a notch tip radius of 0. 02 mm at angle of 45o was used[9]. The mechanical tests represent the average of four tested samples

3. RESULTS AND DISCUSSION

3.1. Visual Observation

The physical appearance of the composites after production revealed that as the weight fraction of orange peels particles increased in the HDPE matrix, there was a colour change from white to black for the composites reinforced with carbonized orange peels particles and white to brown colour for composites reinforced with uncarbonized orange peels particles (see Figure 5).

Macrostructural studies revealed a uniform distribution of orange peels particles. The distribution of orange peels particles is influenced by the compounding of the orange peels particle and the HDPE matrix which resulted to good interfacial bonding between orange peels particles and matrix material.

Figure 5. Photograph of the Developed composites

3.2. Morphological Properties

SEM is used to study the morphology of HDPE/orange peels composites. Figure 6 shows the SEM micrograph of the HDPE, while Figures 7-11 shows the SEM micrographs of the composites.Morphological analysis using SEM clearly show difference in the morphology of the HDPE and it composites (see Figures 6-11). The microstructure clearly shows that when the orange peels particle was added to the HDPE morphological change in the structure take place. The microstructure of the HDPE matrix reveals chain of lamellae and interlammeller amorphous structure with linear boundaries between adjacent spherulites boundaries(see Figure 6). From the EDS spectrum it can be clearly see that the functional group of the HDPE was revealed[10-12].

Morphological study showed that the orange peels as a reinforcement having smooth spherical surface having more surface area for interaction. There is a good dispersion of orange peels particle in the polymer matrix. Figures 7-10, clearly shows that there is proper intimate mixing of orange peels particles with the HDPE. Particles-matrix interface plays an important role in composite properties. A strong particles-matrix interface bond is critical for high mechanical properties of composites[13-15]. As the orange peels particle is increased to 25wt% there is some agglomeration of the particles (see Figure 11)

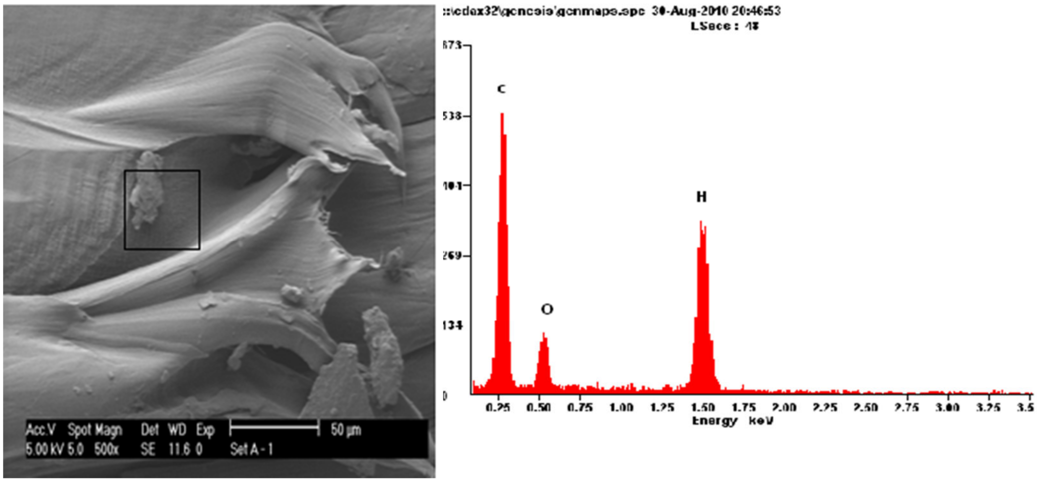


Figure 6. SEM/EDS microstructure of the HDPE x500

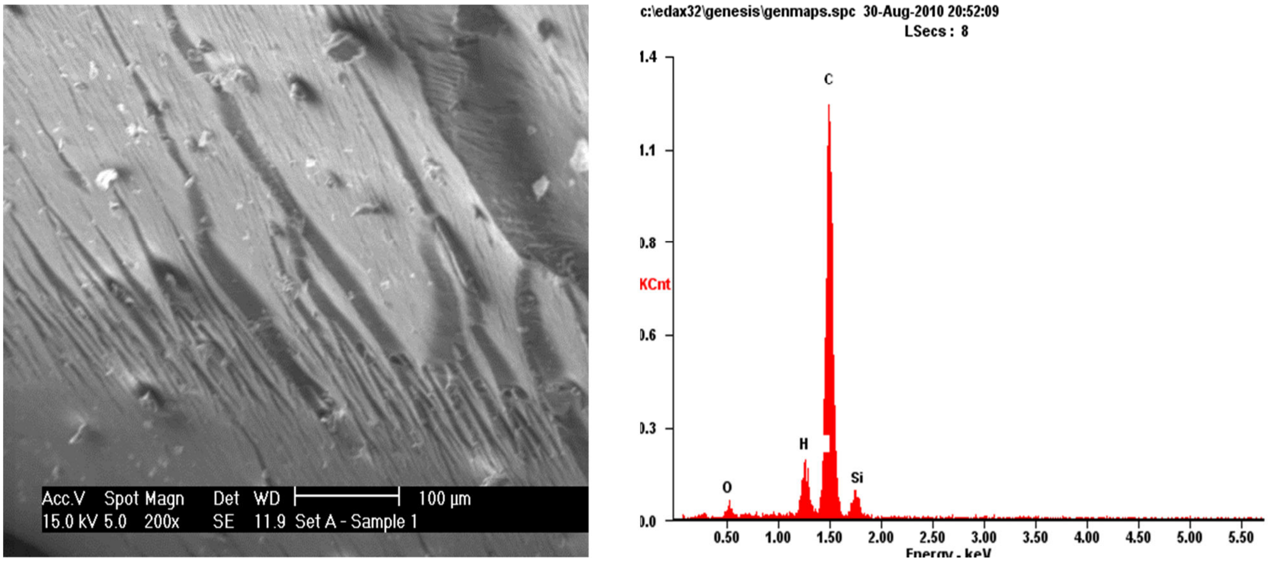


Figure 7. SEM/EDS microstructure of HDPE reinforced with 5wt%OPUp x200

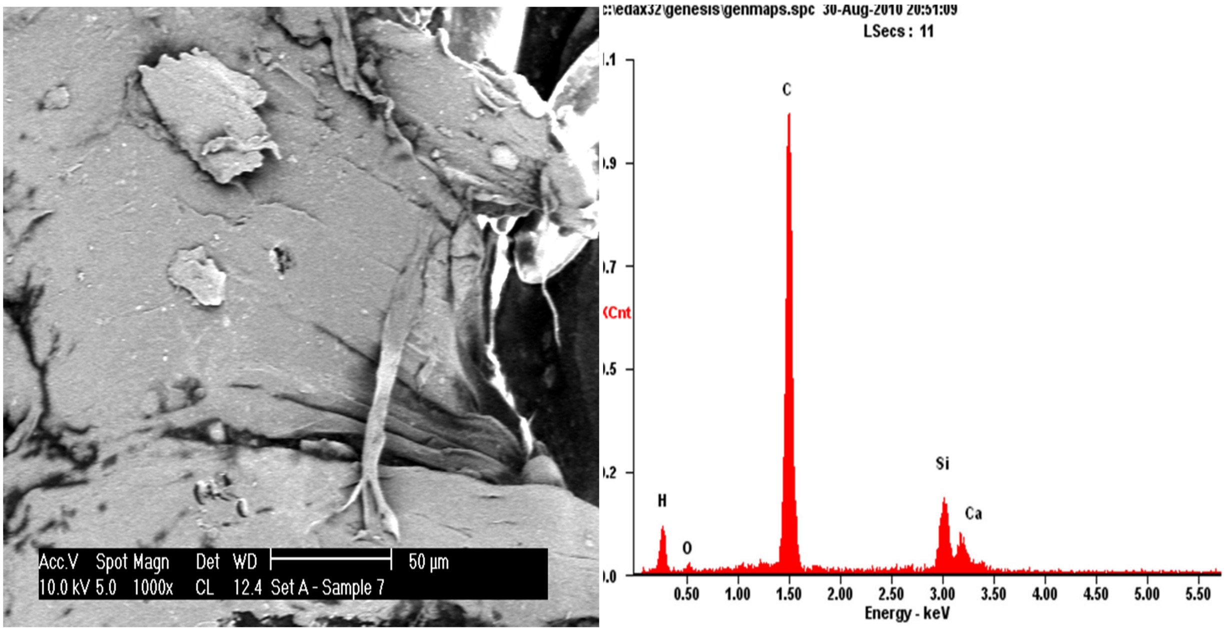


Figure 8. SEM/EDS microstructure of HDPE reinforced with 15wt%OPUp x1000

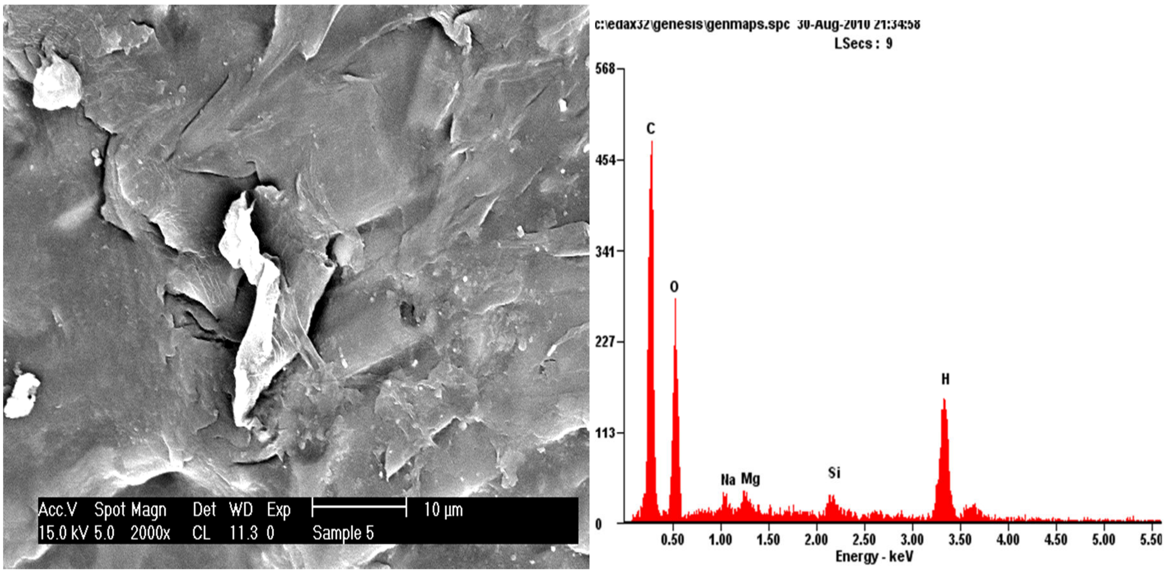


Figure 9. SEM/EDS microstructure of HDPE reinforced with 5wt%OPCp x2000

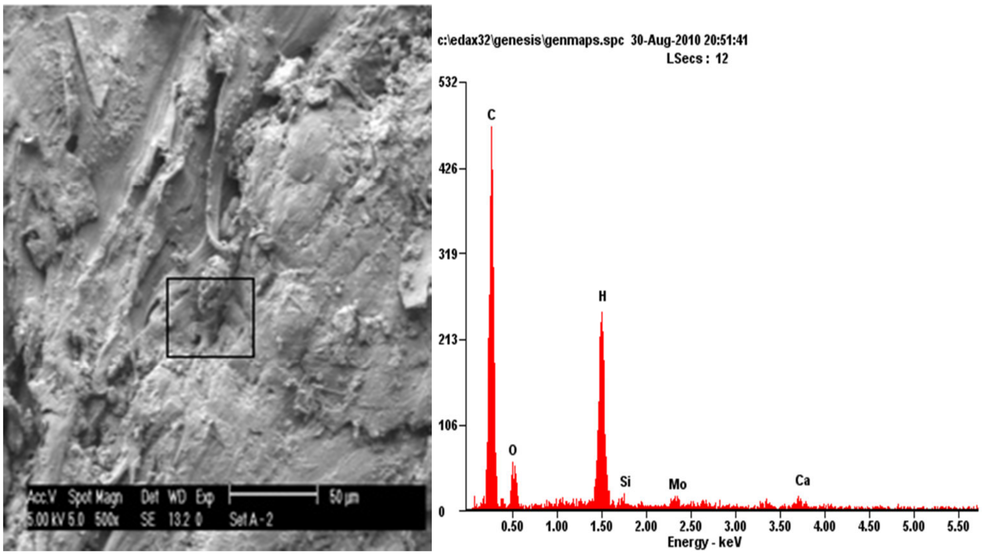
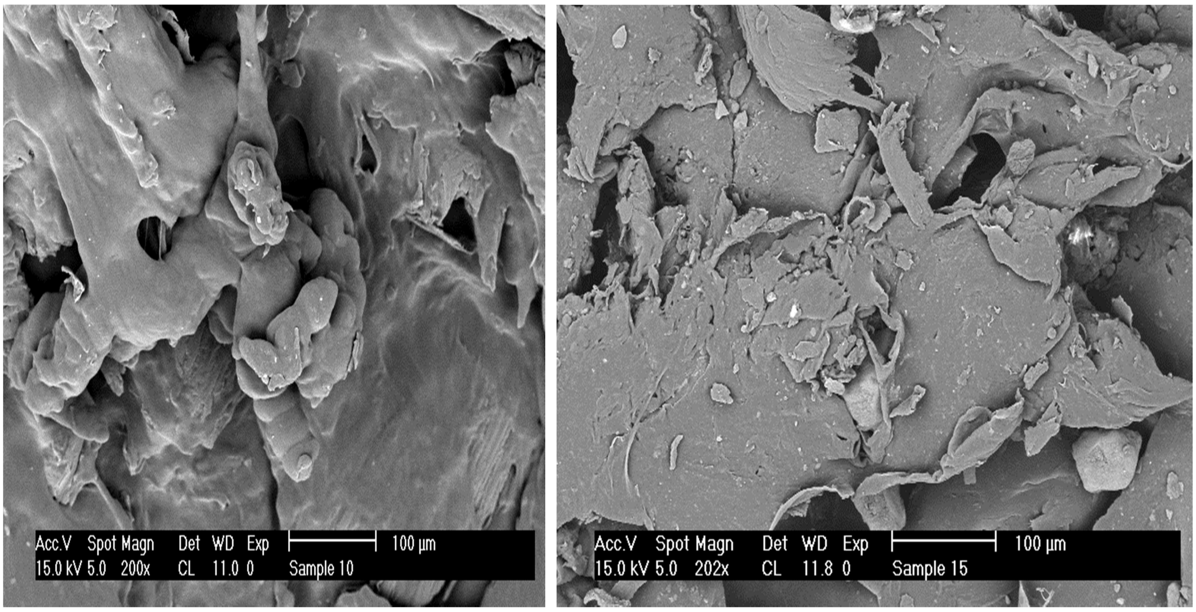


Figure 10. SEM/EDS microstructure of HDPE reinforced with 15wt%OPCp x500



Uncarbonized b) Carbonized

Figure 11. SEM/EDS microstructure of HDPE reinforced with 255wt% x200

3.3. Tensile Properties

The result of the tensile strength with weight percentage of orange peels particles is shown in Figure 12.

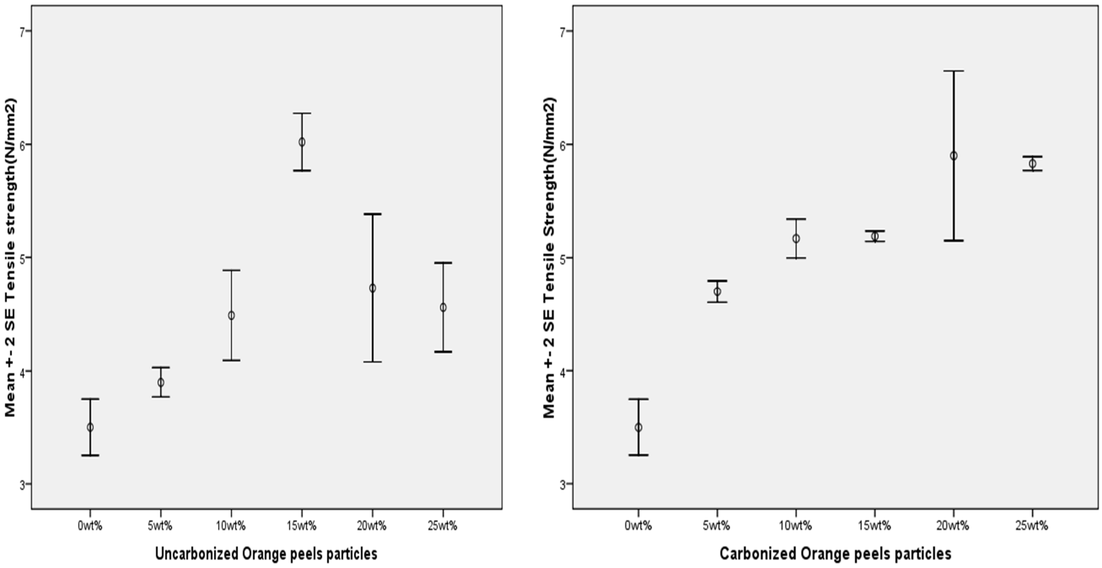


Figure 12. Variation of tensile strenght with %weight of orange peels. The error bars show the sample standard deviation

From the Figure 12, tensile strength increases with weight fraction of orange peel particles in the matrix. It clearly indicates that addition of orange peel particles improves the load bearing capacity of the composites. Similar observations have been reported by[5] for other fiber reinforced polymer composites. It can be seen that tensile strength of the composites increase with an increase of the orange peels particles content. The increment in tensile strength is due to the better-increased surface area of particles in the matrix(see Figures 7-10). As the orange peels particles loading increased, thereby increasing the interfacial area, there was fairly good interfacial bonding between the hydrophilic particles and hydrophobic matrix polymer, which leads to increased in the tensile strength[4]. The increase in tensile strength with increasing orange peels particles loading is expected since the addition of particles increases the stiffness of the composites, which in turn decreases the elongation at break. The presence of polar group in the matrix (HDPE groups) may contribute to electrostatic adsorption between HDPE and orange peels particles [4, 14]. This phenomenon is driven by different charges acting on matrix or fillers surfaces; which depend on filler's type, pH value or inter-medium [15]. This mechanism will strengthen the polymer-ceramic interface. It will hold them together and increase their resistance to deformation. This helps in increment of the composites tensile strength. The fairly uniform of fillers distribution has efficiently hinders the chains movement during deformation. This mechanism will increase the stiffness of the composites as well as tensile strength[13].

The highest tensile strenght for HDPE reinforced with uncarbonized orange peels particles occurs at 15wt% which is 6.02N/mm2, while that of composite reinforced with carbonized orange peel particles has the highest tensile strenght at 20wt% with a values of 5.90N/mm2. (see Figure 12). The slightly decreased in tensile strength beyond the optimum point may be attributed to decreasing the interfacial area as the particles content increased, which resulted in worsening the interfacial bonding between the particles(hydrophilic) and matrix polymer(hydrophobic) (see Figure 11). Also the reduction in tensile strength may be due to agglomeration of the filler particles in the HDPE matrix which form a domain that look like a foreign body in the matrix or simply the result of physical contact between adjacent aggregates, these agglomerates act as obstacles to chains movement and initiate failure under stress. Agglomerates will become stress concentrator and building up stresses in composites quicker than usual and caused earlier rupture if compared to unfilled samples[15].

3.4. Hardness Values of The Composites

The result of the hardness values with weight percentage of orange peels particles is shown in Figure 13.

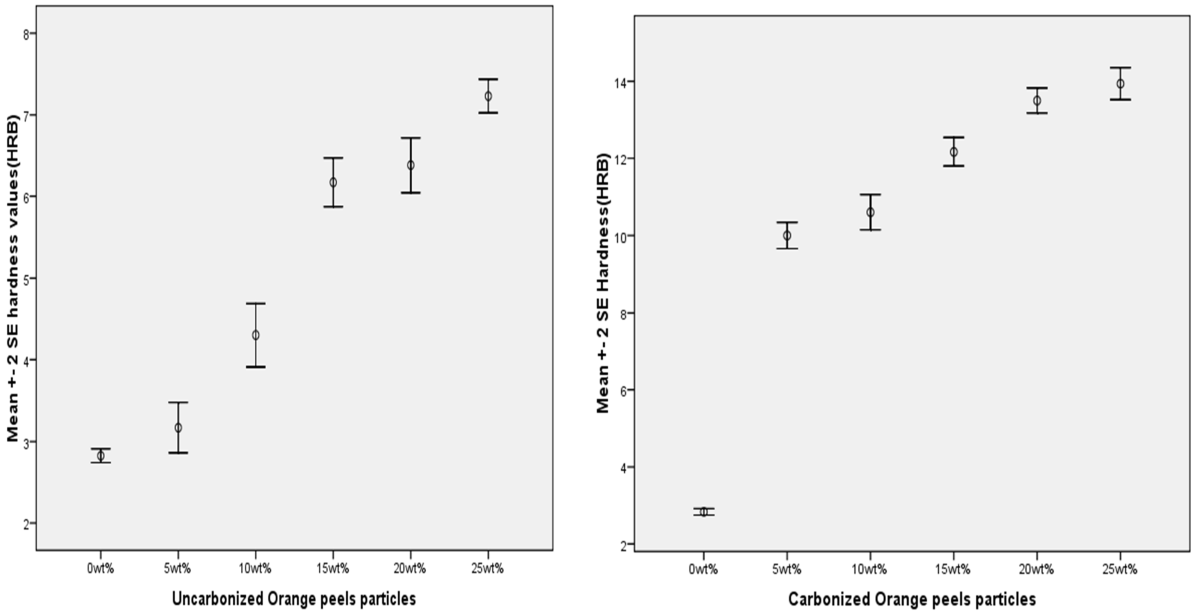


Figure 13. Variation of hardness with %weight of orange peels. The error bars show the sample standard deviation

The hardness values of the composite samples increases as the percentage orange peels particles addition increases in the HDPE matrix. This is due to increase in the percentage of the hard and brittle phase of the ceramics body in the polymer matrix e.g a hardness values of 2.83HRB, 7.23HRB and 13.93HRB (see Figure 13) were obtained for the matrix, 25wt% uncarboinzed orange peels, 25wt% carbonized orange peels respectivly. In comparison with the unreinforced HDPE matrix, a substantial improvement in hardness values was obtained in the reinforced polymer matrix. This is in line with the earlier researches of[4-6].

From the Figure 13, it is seen that the hardness values of the composite reinforced with carbonized orange peels is greater than that reinforced with uncarbonized orange peels particles. This may be attributed that carbonized orange peels particles may contains more carbon, has given off all combined moisture and therefore increase in the hardness of the composite.

3.5. Bending Strength of the composites

The result of the bending strength with weight percentage of orange peels particles is shown in Figure 14.

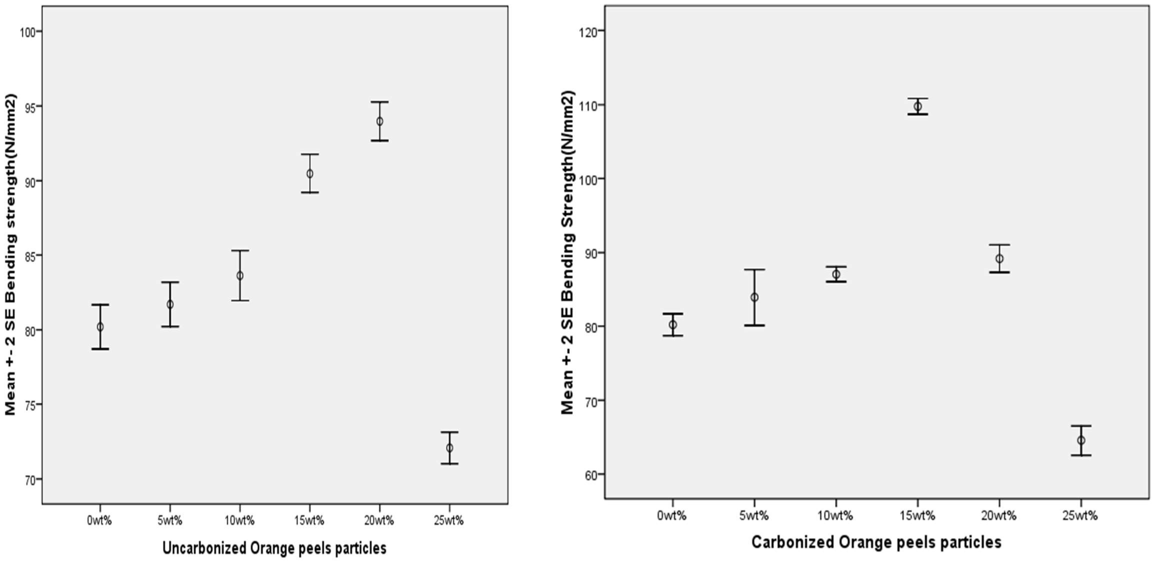


Figure 14.: Variation of bending strenght with %weight of orange peels. The error bars show the sample standard deviation

From Figure 14, the bending strength increases with weight fraction of orange peels particles in the matrix. It clearly indicates that addition of orange peels particles improves the load bearing capacity of the composites under bending. From Figure 14, the bending strenght of the composite reinforced with uncarbonized orange peels is highest at 15wt%, while the bending strenght of the composite reinforced with carbonized orange peels is highest at 20%wt. Composites with uncarbonized orange peels particles show higher value of bending strength.

The increment in bending strength of the composites is due to the better increased surface area of particles in the matrix (see Figures 7-10). It is worth pointing out that the total area for deformation stress also has an important role to play.

3.6. Impact Strength of The Composites

The result of the impact strength and strain at failure with weight percentage of orange peels particles is shown in Figures 15-16.

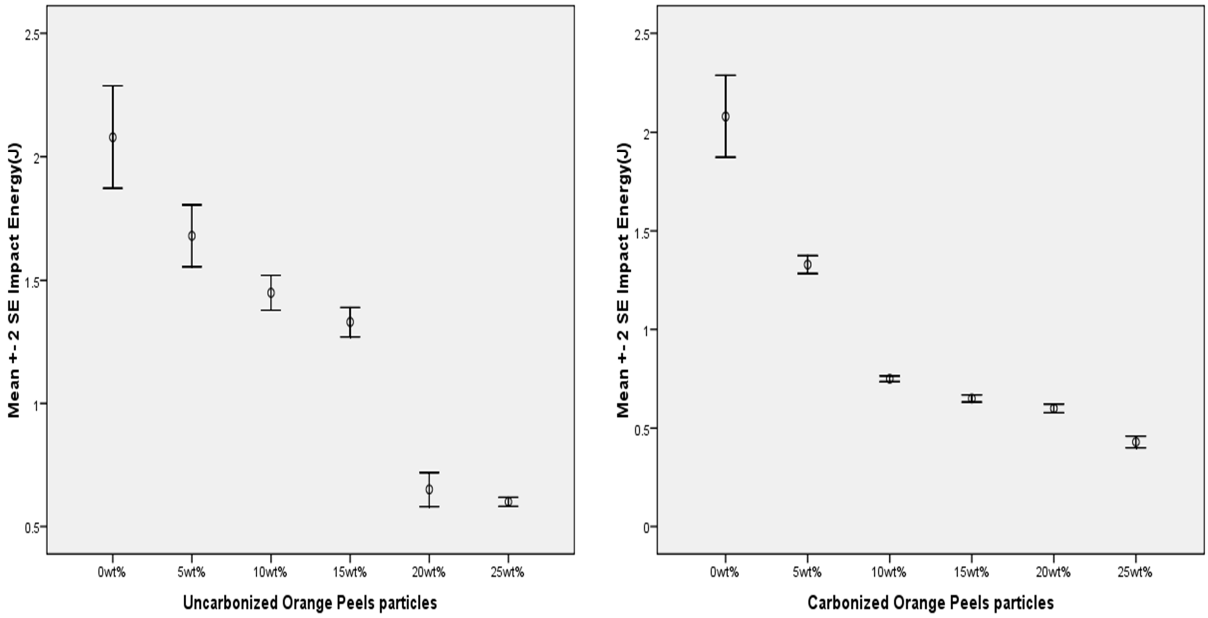


Figure 15. Variation of impact Energy with %weight of orange peels. The error bars show the sample standard deviation

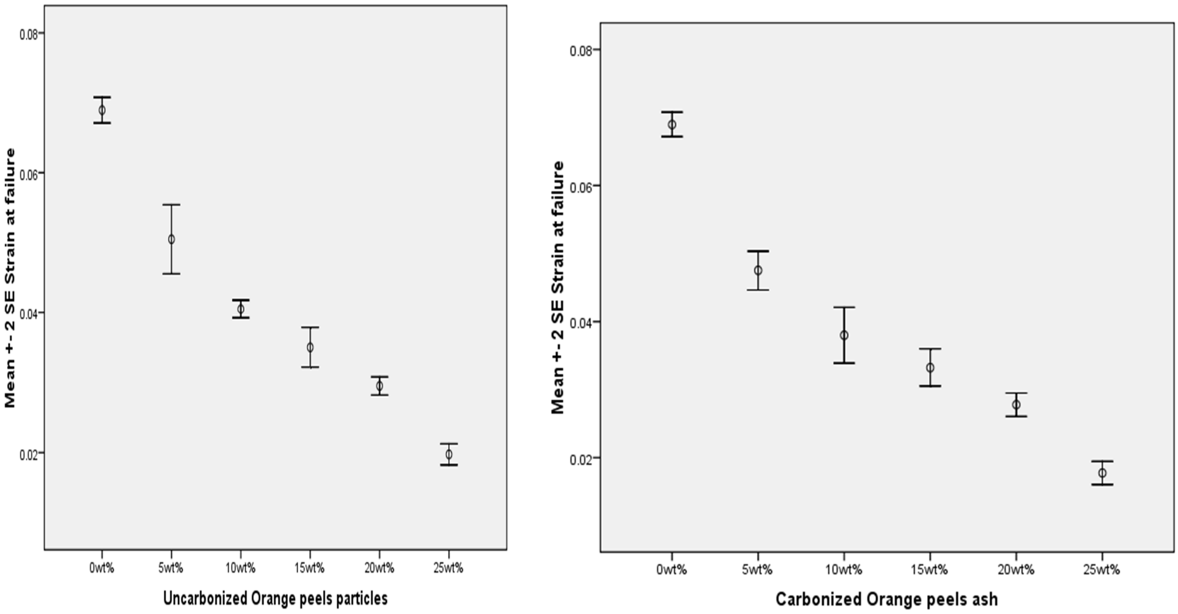


Figure 16. Variation of Strain at failure with %weight of orange peels

Figures 15-16, illustrates the variation of impact strength and strain at failure with orange particles loading. It is clear from the figure that the impact strength and strain at failure decreases with orange peels particles addition. This is mainly due to the reduction of elasticity of material due to particles addition and there by reducing the deformability of matrix. An increase in concentration of orange peels particles reduces the ability of matrix to absorb energy and there by reducing the toughness, so impact strength decreases.

From Figures 15-16, it is shown that the ability to resist impact force is higher in the composite reinforced with uncarbonized orange peels than than that of reinforced with carbonized orange peels this is because the presence of the high carbon content in the carbonized orange peels has introduced some brittleness as increase in hardness leads to a decrease in impact strenght. The reduction in impact energy and strain at failure with increasing orange peels loading might also be due to the decreased deformability of a rigid interface between the particles and HDPE matrix. At similar loading, composites with carbonized orange peels indicate lower impact energy than composites of uncarbonized orange peels.

From Figure 16, it is evident that the developed composites may has lower area under the stress-strain curves and therefore poor toughness. This could be the predictable result, because rigid ceramics body such as orange peels act as barriers against the mobility of dislocations. Therefore, by increasing the content of orange peels, the rate of work hardening increases and this would lead to a decrease in toughness values. Since the HDPE matrix and the composite with 5wt%orange peels have the highest impact energy, indicating the greater toughness values of all the investigated samples The tensile properties are in agreement with the results obtained from the analysis of the hardness and impact strength. The increase in hardness is related with the increasing amount of hard orange peels particles in the HDPE matrix . On the other hand, as can be suggested from the impact test, the elastic behavior of the matrix proportionately varies with the addition of the orange peels particles. As the loading of orange peels increases, the ability of the composites to absorb impact energy decreases since there is less ratio of the HDPE matrix to particles. However the results obtained are within the standard level for biocomposites [15].

4. CONCLUSIONS

In this present work, some mechanical and microstructural studies have been carried out on the HDPE /orange peels particles composite. From the results and discussion presented, the following conclusions can be made-:

Orange peels particles reinforced with HDPE was successfully produced by compressive moulding.

The tensile and bending strengths of the composite increase with increasing percentage of the orange peels particles.

Hardness values obtained when reinforcing HDPE with orange peels as particles increases as the weight of the particles increased in the HDPE matrix

The impact force required was lower in the composites reinforced with carbonized orange peels particles than that reinforced with carbonized orange peels and it reduced with increase in orange peels particles.

The obtained results of the developed composites have shown that the orange peels waste could be used as a biodegradable eco-friendly reinforcement.

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