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Effect of Filler Particle Size on the Mechanical Properties of Waste Polypropylene/ Date Seed Particulate Composites

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ABSTRACT

This study was aimed at investigating the effects of filler particle size on mechanical properties of waste polypropylene (wPP) / date seed particles (DSP) composites. Filler particle size of 63, 125, 250, 500 and 750 µm were used at 20 % filler loading. The composites obtained were subjected to mechanical tests (tensile and flexural test, impact test and hardness HV) and the morphological analysis was done using scanning electron microscopy (SEM). The tensile, flexural and impact strength and elongation at break were observed to decrease with increase in filler particle size, while tensile modulus, flexural modulus and hardness (HV) increased with increase in filler particle size. The scanning electron microscopy (SEM) of the tensile fractured surfaces revealed a better particles distribution at 63 µm than 250 µm and 750 µm where agglomerations and interfacial gaps were observed.

Keywords: *Composites, waste polypropylene, date seed, filler particle size and mechanical properties*

INTRODUCTION

Government regulations and a growing environmental awareness throughout the world have triggered a paradigm shift towards designing materials that are compatible with the environment. The use of biofibres derived from renewable resources as reinforcing fibres in both thermoplastic and thermoset matrices provide positive environmental benefits with respect to ultimate disposability and raw material utilization [1]. Recent legislations associated with environmental impacts of post-consumer plastic wastes have driven substantial attention towards developing viable recycling techniques. The advantages of natural fibres over traditional reinforcing materials such as glass fibre, talc and mica are: acceptable specific strength properties, low cost, low density, high toughness, good thermal properties, reduced tool wear, reduced thermal and respiratory irritation, ease of separation, enhanced energy recovery and biodegradability [2]. Lignocellulosic-plastic composites have been reviewed by Kowell, *et al.*, [3]**.** The quest for an economically feasible light weight composite that will compete favourably with the conventional materials such as metals in terms of physico-mechanical properties for structural engineering and in building application led to the use of ligno-cellulosic materials as reinforcing fillers in the production of composites[4]. The date (*Phoenix dactylifera L.*) has been an important crop in arid and semiarid regions of the world. It has always played an important part in the economic and social lives of the people of these regions. The fruit of the date palm is well known as a staple food. Pits of date palm (seeds) are a waste product of many industries after technological transformation of the date fruits or their biological transformation. In some date-processing countries, such as Tunisia, date seeds are discarded or used as fodder for domestic farm animals [5].In Nigeria date palm is very popular among the people of Northern Nigeria. It is one of the major sources of income to farmers.

Despite the abundance of date seeds, their use as fillers in composites has not been widely reported. Using date seed as bio-filler can help add value to it instead of farm base animal's feed or disposal. Therefore the aim of this research was to produce waste polypropylene / date seed particulate composites (wPP / DSP) from the light fraction of municipal plastic wastes (post-consumer).

Materials and Methods

Materials

The matrix waste polypropylene (materials used as packaging from dump sites). The filler (date seeds) used in this study were collected from Zaria city market (y'an dabino) Kaduna State, Nigeria.

Methods

The matrix (waste polypropylene) collected were cleaned to remove impurities such as oil and soil dirt from the containers, air dried and then shred to smaller pieces (flakes form) and kept in the laboratory for future work.

Date seeds were cleaned to remove impurities such as soil dirt, sundried and then ground to particles using jaw crusher and ball mill machines (Retsch Masch. Nr 70992 GMbH & CO. and Kera b.v. Soeter berg Overveld 057748 Holland) respectively. The date seed particles were then sieved using Impact Lab. Seive ISO 3310-1:2000, bs 410-1:2000) to obtain particle sizes of 63, 125, 250, 500 and 750 µm. It was finally dried in an oven at 70^{o}C for 24hours.

The fabrication of the composites was carried out by compounding and compression moulding techniques using two roll mill and compression moulding machines. The filler loading was 20/80 % filler/matrix at all the particle size investigated. A mould of dimension 150×120×5 mm made of steel was used. Control sample was produced using unfilled waste polypropylene. The matrix and filler were mixed for 5 min in a two roll mill for producing homogenous composites. The mixture was placed in a mould in which mould releasing agent was applied. The press cycle consist of three phases, i.e first phase involved the manual pressing to reduce the height, second phase involved in shifting the composite to the compression moulding machine and finally for cooling under pressure to facilitate the setting of thermoplastic resin. The maximum pressing temperature, pressure, time and cold pressing or pressure holding time were 160^{0}C, 5 N/mm^{2}, 15min and 5min respectively [6]. After cooling, the resultant composites were removed from the mould for further cooling at room temperature. The composites panels were then trimmed and put into an oven for conditioning at 70^{o}C for 48 hr before testing.

Tensile Test

The test was conducted according to ASTM D638 standard with a gauge length of 40mm. The samples were cut in dimension of 100 x 10 x 5mm and the test was carried out using YG026D. Multifunctional Electronic Fabric Strength Machine at a cross head speed of 10 mm/min. The test sample was mounted and proper gripping was observed. The tensile parameters were determined and recorded.

Flexural Test

Three point bending test was performed in accordance with ASTM D790M Test Method I, Procedure A to measure flexural properties of the composite samples. The samples measured approximately 100 x 20 x 5mm in length, width and thickness respectively. The span length was 80mm apart at 0.5mm / min strain rate

Impact Test

The impact strength of the composite samples was carried out according to ASTM E23 (Notched) using Norwood charpy impact tester (Model no. 6957, capacity of 15 joules). The specimen size was 100 x 10 x 5 mm. Each sample was placed on the vice and clamped firmly. The pendulum hammer was raised to the required height and then released and strike the sample at once. Then, the impact energy absorbed by the specimen was recorded.

Hardness Test

Indentation test for composite samples was carried out using Vickers hardness tester (HV) according to ISO 6507. Each sample was loaded on the machine while in the compressed moulds form of 30 x 10 x 5 mm and the indenter (steel ball indenter) brought down to make contact with each sample at three different places. The average of the three readings were calculated and recorded.

Morphological Studies

The Scanning Electron Microscopy (SEM) of the composites were studied using Scanning Electron Microscope (SEM) Joel JSM 7600F at an accelerating voltage of 5.0Kv and magnification of 500.

RESULTS AND DISCUSSION

Tensile Strength

Figure 1 shows the graph of tensile strength of the composites at different filler particle size 63, 125, 250, 500 and 750 µm of DSP. It is shown that increase in filler particle size from 63 to 750 µm led to a decrease in tensile strength. The highest tensile strength was seen with 63 µm at 23.15 MPa and the lowest was seen with 750 µm at 20.26 MPa. This decrease in tensile strength with increase in filler particle size was due to lower surface area provided by the larger particle size led to irregular distribution of the filler particles reducing efficient stress transfer from the polymer matrix to the filler particles. Similar trends were reported by [7,8,9,10].

Tensile Modulus

The results of tensile modulus are presented in Figure 2. It can be seen that there was an increase in tensile modulus with increase in filler particle

size. The highest tensile modulus was seen with 750 µm at 1.27 GPa and the lowest was seen with 63 µm at 1.12 GPa. This increase in tensile modulus with increase in filler particle size may be due to irregular distribution of filler particles within the matrix structure limiting or reducing polymer molecular chain mobility. This trend was also reported by Genevieve and Isaac [11].

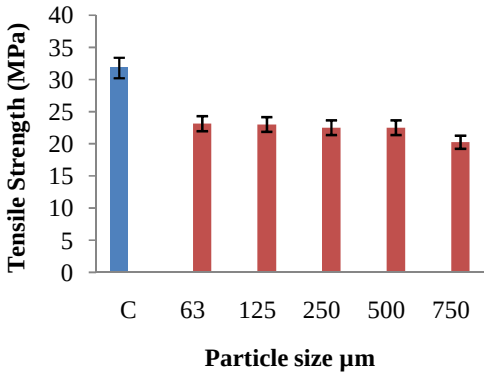

Figure 1: Effect of particle size (µm) on Tensile Strength of wPP / DSP composites

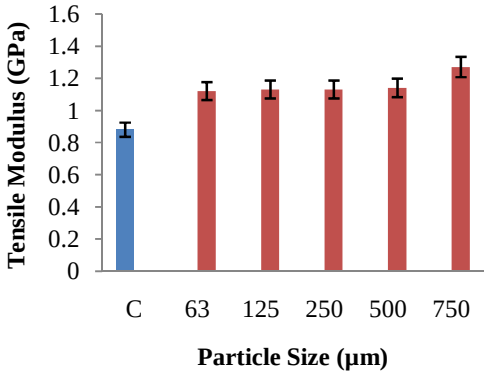

Figure 2: Effect of particle size (µm) on Tensile Modulus of wPP / DSP composites

Elongation at Break

Elongation at break results in Figure 3 can be seen to decrease with increase in filler particle size. Highest elongation at break was seen with 63 µm at 139.62 (%) while lowest was seen with 750 µm at 73.0 (%). This could be attributed to the fact that lower particle size has larger surface area enabling the particles to orient themselves in a form of layer absorbed and share the transmitted stress with the matrix. Also, it could be due to weak matrix / filler interfacial adhesion as a result of lower surface area provided by larger particles compared with smaller particle size. Genevive *et al.*,[11] reported that the elongation at break of snail shell powder filled polypropylene composites decreased with increases in the filler particle size. According to Mehdi *et al.*,[12], the particle size of filler greatly affect the elongation at break of the resultant composites by decreasing with increase in particle size from 3 to 48 µm. This may be due to the increased porosity, discontinuity in the microstructure and less formability.

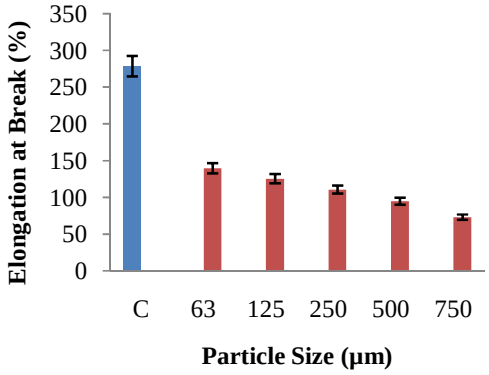

Figure 3: Effect of particle size (µm) on Elongation at break of wPP / DSP composites

Flexural Strength

Flexural strength results in Figure 4 showed a decline with increase in filler particle size. The highest flexural strength was obtained with 63 µm at 100.0 MPa while lowest was seen with 750 µm at 38.0 MPa. This is attributed to the difficulties in achieving homogeneous dispersion associated with larger particles led to inefficient stress transfer from matrix to the filler particles. This difficulty in achieving homogeneous dispersion caused irregular distribution of filler particles within the polymer matrix structure resulted in the formation of agglomeration as can be seen in the SEM images. These agglomerated particles could be stress concentrator points and could affect the final performance of the composites, counterparts were also observed in other studies [13, 14].

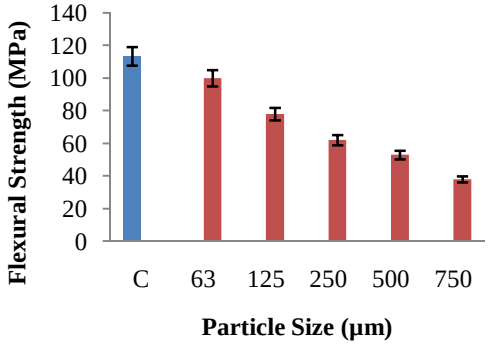

Figure 4: Effect of particle size (µm) on Flexural Strength of wPP / DSP composites

Flexural Modulus

The results of flexural modulus are presented in Figure 5, similar to the tensile modulus results, showed an increase with increase in filler particle size. The highest flexural modulus was seen with 750 µm at 1.52GPa and the lowest is seen with 63 µm at 1.22GPa. The increase in flexural modulus could be attributed to lower contact area provided by larger particle size filler that led to uneven distribution of filler particles which eventually leads to restrain or limiting polymer chain mobility thereby increasing its stiffness. These results also correspond with previously reported work by Zaini *et al.*,[15].It was reported that flexural modulus increased with increase in particle size for composites made with 230 to 60 mesh oil palm wood flour / polypropylene composites. These results also correspond with previously reported work by Stark and Berger [16].

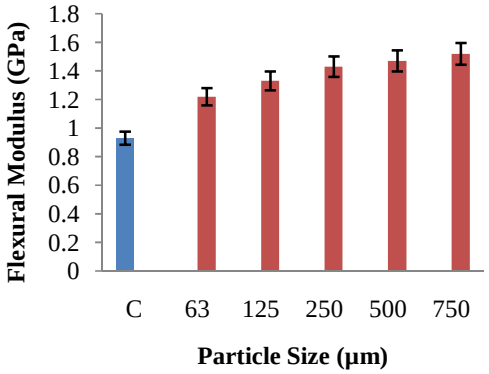

Figure 5: Effect of particle size (µm) on Flexural Modulus of wPP / DSP composites

Impact Strength

The impact strength results shown in Figure 6 indicate a decrease with increase in filler particle size. 63 µm had an impact strength value of 0.7 J/m^2 while 750 µm had impact strength of 0.42 J/m^2. 63 µm with higher impact strength value was as a result of lower particle's ability to orient themselves in a form of layer within the polymer matrix structure due to their high contact and surface area. This could also be attributed to better matrix / filler interaction when lower particle size filler was used. Larger particle size fillers having lower impact strength value indicated their incapability to support stress transfer from matrix to the filler. Gajender and Narula [17] made an observation where impact strength was observed to be dependent on the particle size, and the decrease was higher in the presence of macro filler as compared to micro filler.

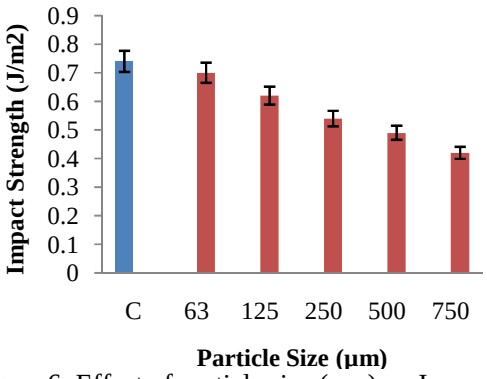

Figure 6: Effect of particle size (µm) on Impact strength of wPP / DSP composites

Hardness

The hardness test result is presented in Figure 7. As shown lower hardness value with 63 µm at 10.8vickers (HV) Hardness, while higher hardness value was observed with 500µm at 25.4vickers (HV) Hardness. This increase could be due to presence of more filler particles at the surface of the composites than in the core, thereby generating greater resistance to indentation and consequently resulting in high hardness values of the composites. Decrease in hardness value was observed at 750 µm with 16.0 vickers (HV) Hardness which may be attributed to void formation during processing. This observation is in agreement with the finding made by [18, 19]. The increase in hardness of the materials with increase in filler particle size may be as a result of irregular distribution that caused the formation of agglomeration seen in SEM micrographs.

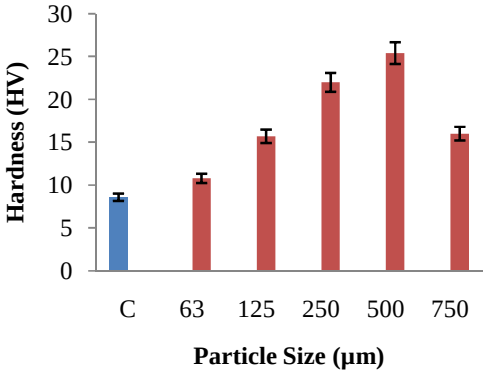

Figure 7: Effect of particle size (µm) on Hardness of wPP / DSP composites

Morphological Studies

The scanning electron microscopy (SEM) results as seen in Figure 8, 9 and 10 shows the fractured surface of the 63 µm (a) shows a better dispersion

of filler particles within the matrix with no clusters seen compared to 250 µm(b) and 750 µm(c). There are agglomerated fillers seen in the 250 µm(b), this is due to in homogeneity in the compounded materials and can account for some of the lower values in the results of tensile, elongation at break, flexural and impact test results.

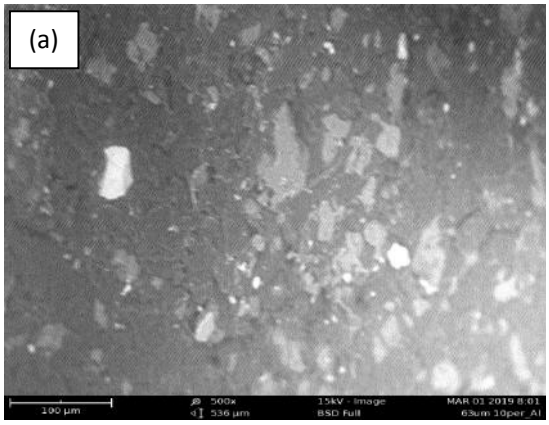

Figure 8: SEM micrograph of fracture surface of tensile strength specimen at 63 µm

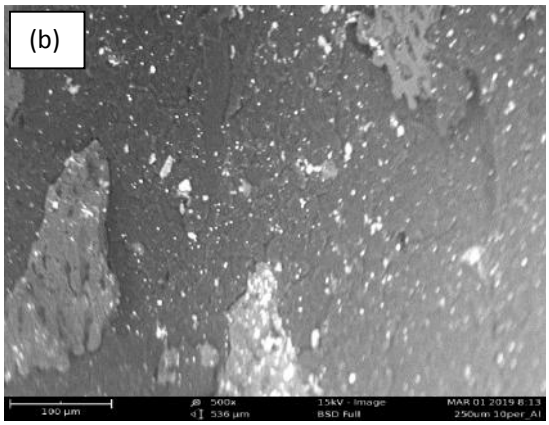

Figure 9: SEM micrograph of fracture surface of tensile strength specimen at 250 µm

Figure 10: SEM micrograph of fracture surface of tensile strength specimen at 750 µm

Similarly in 750 µm(c) agglomerations were observed, this can be the reason for the low mechanical properties such as tensile, elongation at break, flexural and impact compared to 63 µm (a). These agglomerated filler could be a stress concentrator point and can account for the reduction in tensile strength, elongation at break, flexural and impact strength. Dina *et al.,* [20] reported that there are a lot of fillers agglomerations and dispersions in the 50% recyclates and can account for some of the lower values in the results of tensile, flexural and impact test result. Similar report was made by [21].

CONCLUSION

It can be concluded that tensile strength, elongation at break, flexural and impact strength on wPP / DSP composites decreased with increase in filler particle size.63 µm with higher tensile strength, elongation at break, flexural and impact strength at 23.15 (MPa), 139.62 (%), 100.0 (MPa) and 0.7 (J / m^2) than 750 µm at 20.26 (MPa), 73 (%), 38.0 (MPa), and 0.42 (J/m^2) respectively.750 µm had the highest tensile and flexural modulus at 1.27 and 1.52 (GPa) than 63 µm at 1.12 and 1.22 (GPa) respectively. While 500 µm had the highest hardness values at 25.4 than 63 µm at 10.8 vickers (HV) hardness.

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