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Microstructure and Mechanical Properties of Sisal Particles Reinforced Polypropylene Composite

S. I. Durowaye*, **G. I. Lawal**, **O. I. Olagbaju**

Department of Metallurgical and Materials Engineering, University of Lagos, Akoka, Lagos, Nigeria

Abstract The mechanical properties of polypropylene composite reinforced with sisal particles were studied to assess the possibility of using it as a new material for engineering applications. The composite was produced by compounding and compressive moulding technique by using different weight fractions (0, 5, 10, 15, 20 and 25) % of reinforcement with particles size of 150 and 300μm. The results revealed that sisal particles improved the hardness property of the polypropylene matrix composite. A general increase was observed in the hardness trend of 300μm sisal particles reinforced polypropylene composites, showing a peak value of 3.83BHN at 25 %wt of sisal reinforcement. The toughness of the composites dropped as the concentration of sisal particles increased in the polypropylene matrix. This indicates that shock absorption reduces with increase in reinforcement. The microstructural analysis shows a good dispersion of the sisal particles in the matrix which is responsible for the increase in strength. The tensile strength increased up to a maximum value of 6.96MPa at 20 wt % of reinforcement using 150μm particle size. In terms of strength, 150μm particle size is better than the 300μm. Hence, this grade can be use for interior applications such as car seat, dash board, and car interior for decorative purposes or other interior parts of automobile where high strength is not considered a critical requirement. Hence, polypropylene matrix composite reinforced with sisal particles is a good material for engineering applications.

Keywords Mechanical properties, Polypropylene, Sisal plant, Composite, Microstructural analysis

1. Introduction

Global market pressure requires faster product development and reduced time to market [1]. Customer driven product customisation and continued demands for cost savings are forcing companies to look for new technologies and processes that can cope with high volume production in a quicker and cheaper manner [2]. Materials containing fiber or particle reinforcement belong to the class of materials known as composite. Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics and polymeric materials [3]. This is especially true for materials that are needed for aerospace, underwater and transportation applications. For example, aircraft engineers are increasingly searching for structural materials that have low densities, high strength, stiffness, high abrasion, impact and corrosion resistance. This is a rather formidable combination of properties. Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength. Material property combinations and ranges have been and are being extended by the development of composite materials [4].

Generally, composite are produced when two or more materials are joined together to give combination of properties that cannot be attained otherwise [5]. According to the principle of combined action, better property combinations are fashioned by the judicious combination of two or more distinct materials. Composites of sorts include multiphase metal alloys, ceramics and polymers. There are also a number of composites that occur in nature. For example, wood consists of strong and flexible cellulose fibers surrounded and held together by a stiffer material called lignin. Bone is a composite of the strong yet soft protein collagen and the hard, brittle mineral apatite. Also teeth and abalone shell. A composite is a multiphase material that is artificially made, as opposed to one that occurs or forms naturally [6]. In a composite, one phase is usually continuous and it is known as the matrix while the other phase is known as the reinforcement which is distributed within the matrix. It may be in the form of fibrous or particulate. In addition, the constituent phases must be chemically dissimilar and separated by a distinct interface. Thus, most metallic alloys and many ceramics do not fit this definition because their multiple phases are formed as a consequence of natural phenomena. Most composites have been created to improve combinations of mechanical characteristics such as strength, stiffness, toughness, ambient

* Corresponding author:
durosteve02@yahoo.com (S. I. Durowaye)
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and high-temperature [7].

Polymer-matrix composite (PMCs) consists of polymer resin (a high molecular weight reinforcing plastic) as the matrix with particulate as the reinforcement medium [8]. The primary functions of the matrix are to transfer stress between the reinforcing fibres or particulate, act as a glue to hold the fibers together and protect it from mechanical and environmental damage [3]. However, fibers and particulate (reinforcement) are hydrophilic in nature, so they take in water. These materials are used in producing greater composite and larger quantities in respect to their room temperature properties, cost and fabrication. Particulate composites produced have distinct properties like improved strength and contain large amounts of coarse particles that do not block slip effectively [9]). Sisal plant can also be used as particulate as well as fibre in order to improve the mechanical property of the material which includes stiffness, strength, corrosion resistance and hardness.

The various advantages of natural fibers over man-made glass and carbon fibers are low cost, low density, competitive specific mechanical properties, reduced energy consumption and biodegradability [2]. The use of green plant (sisal plant) as reinforcing fillers for thermoplastics has received great attention from a number of researchers and manufactures in recent years. Polypropylene is quite an outstanding polymeric material with respect to its performance, in particular its wide property spectrum, easy processability, versatility of applications and attractive combination of favourable economics. The thermal, mechanical and morphological properties of polypropylene clay and wood flour nanocomposites have been studied. The compaction of all these fillers in the matrix improves the thermal stability. The tensile modulus and strength of most of the hybrids were highly increased with increased loading of clay [10]. Coconut fiber reinforced polypropylene composite was studied. The coconut fiber was varied based on weight composition and then mixed with polypropylene powder and a coupling agent. The water resistance and internal bond strength of the composite was influenced negatively by the increase in coconut fiber. The flexural strength, tensile strength and the hardness of the composite improved with increasing coconut fiber content [9]. Polypropylene composites filled with Hevea Brasilliensis (wood flour) at filler content up to 60wt% were prepared and examined in order to determine the effects of polymer melt flow rate, number of reprocessing times, filler size, and filler content on thermal and mechanical properties. The results reveal that the composites of polypropylene with higher melt flow rate (lower viscosity) provided greater values of flexural and tensile properties. The study exhibits the recyclability potential without losing mechanical properties. Both flexural and tensile modulus increased, while both flexural and tensile strength decreased with increasing wood flour contents. In addition, the average particle size of wood flour that was suitable for improving the mechanical properties was approximately 200-300μm. The modulus increased, while the strength decreased with increasing wood flour contents [11]. The use of rice husk ash to improve the property of high density polyethylene was also studied. When rice husk ash was blended with polymers without polar groups, it did not improve the properties of the polymer substantially. The properties improved when blended with polymers in the presence of a compatibiliser whose tensile strength is about 18% higher than that of a virgin high density polyethylene. The results proved that rice husk ash is a valuable reinforcing material for high density polyethylene [12].

To cope with the obvious limitations of polymers, for example, low stiffness and low strength, and to expand their applications in different engineering areas, different types of particulate fillers are often added to process polymer composites, which normally combine the advantages of their constituent phases. Reinforcement of polymers by particulates plays an important role in the improvement of the mechanical and physical properties of high performance materials. Mechanical properties of a polymer can be controlled by the incorporation of particles in the polymer matrix. In view of this background, this study is aimed at evaluating the mechanical properties of sisal particulate reinforcement in polymer (polypropylene) matrix composite in order to develop a material for novel configurations in engineering applications.

2. Experimental Procedure

2.1. Materials

The materials used for this study are sisal plants (leaves) and polypropylene.

2.2. Equipment

The equipment used for this study are: Plastic crusher machine, A Digital weighing scale, A compression mould, A dynamic hardness tester, A pair of scissors, An optical microscope, A charpy impact tester, A two-roll rheomixer (Haake Rheomix 600), An Instron Tensile Testing Machine, An Avery Denison Impact testing machine.

2.3. Drying and Grinding of Sisal Plant (Leaves)

Figure 1. Sieved sisal leaves

The sisal plant used for this study was obtained from Ikotun, Lagos. It was thoroughly washed with detergent and washed in distilled water in order to remove the dirt. It was then dried in the sun to remove residual moisture. It was torn to small pieces manually, ground into powder using a grinding machine and sieved to 150µm and 300µm sizes. The sieved sisal powder shown in Figure 1 was used as the reinforcement.

Figure 2. Polypropylene

2.4. Grinding of Polypropylene

Polypropylene (matrix) was procured at a local market in Ojota, Lagos. It was dried under the sun followed by grinding using a crusher machine.

2.5. Composite Preparation

The sisal powder and the ground polypropylene were blended together for about six minutes using a two-roll rheomixer at 165°C and a rotor speed of 60 rpm. The percentage of the sisal particles in the matrix was varied from 5% - 25% and five samples each were compacted using 150µm and 300µm sizes. Compression of the composites was carried out in a Wabash V200 hot press for 5 minutes under controlled pressure of 463MN/m^2 at 175°C. Each of the samples was cooled to room temperature under pressure before it was removed from the press. Prior to testing, all samples were conditioned for 72 hours at a temperature of 23°C ± 2°C and a relative humidity of 50% ± 5%. One sample represents the control sample that was not reinforced. 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. The hardness value of the samples was determined in line with the American society of testing materials (ASTM E10) standard using the Brinell hardness tester. Charpy impact test was conducted on notched samples using Avery Denson testing machine. Standard square impact test sample measuring 55 x 10 x 10mm with notched depth of 2mm and a notch tip radius of 0.02mm at an angle 45° was used. The Research microscope (CETI) 0703552 was used to identify the surface morphology of the samples with 100x magnification. The samples were thoroughly washed, cleaned, air dried and placed on the sample disc and the digitized images were recorded accordingly.

3. Results and Discussion

3.1. Tensile Strength

Table 1 shows the result of the tensile test of the polypropylene composites with sisal particle sizes 150 µm and 300µm. Figure 3 shows the variation of the tensile strengths of the composites with filler weight fraction. The 150µm sisal particles reinforced composite shows higher ultimate tensile strength (6.96MPa at 20 wt. %.) compared to 300µm. This is because of increase in the surface area. This may also account for the good distribution and dispersion of the sisal particles in the polypropylene matrix resulting in strong particles-matrix interaction. This good particles dispersion improves the particles-matrix interaction and consequently increases the ability of the particles to restrain gross deformation of the matrix. However, the tensile strength obtained in this study is good for car interiors [13, 14, 15].

3.2. Hardness

Table 2 shows the results of the hardness test of the polypropylene composites with sisal particle sizes 150µm and 300µm. In figure 4, the influence of the filler weight fraction on the hardness of the composite is shown. The 300µm particle size of sisal powder reinforced polypropylene shows progressive increase as the filler increases to a maximum of 3.83BHN at 25 wt. %. The peak hardness of 3.80BHN was attained at 10wt % for 150µm particle size of sisal powder reinforced polypropylene. These values are higher than the pure polypropylene (control sample) value of 3.43BHN at 0 % wt.

3.3. Impact Strength

Table 3 shows the results of the impact test. In Figure 5, the impact strength of the reinforced polypropylene shows that as the filler weight fraction increases, the impact strength decreases. An increase in concentration of filler reduces the ability of matrix to absorb energy and thereby reducing the toughness. Particle size of $300\mu m$ has highest impact strength of 4.5J at 10 wt. %.

Table 1. Ultimate Tensile Strength of the composites of particle sizes 150µm and 300µm

Sample number	% Filler	150µm particle size		300µm particle size	
		Tensile stress at maximum load (MPa)	Tensile strain at maximum load (mm/mm)	Tensile stress at maximum load (MPa)	Tensile strain at maximum load (mm/mm)
1	0	6.64	0.142	6.64	0.142
2	5	4.16	0.160	3.65	0.086
3	10	4.43	0.119	4.56	0.057
4	15	6.37	0.110	4.19	0.094
5	20	6.96	0.097	4.49	0.081
6	25	6.23	0.063	3.83	0.082

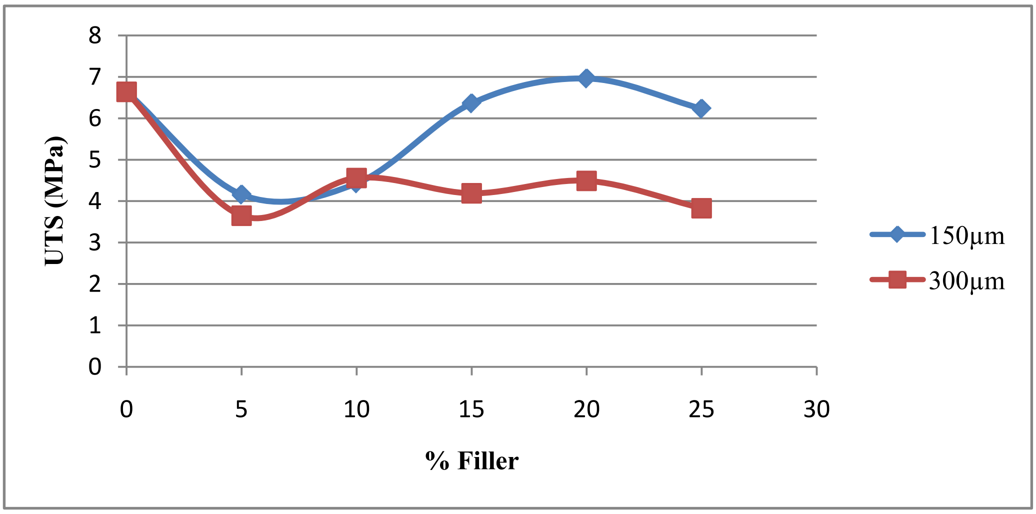

Figure 3. Variation of ultimate tensile strength of particulate reinforced polypropylene composites

Table 2. Hardness of the composites of particle sizes 150µm and 300µm

Sample number	% Filler	150µm particle size	300µm particle size
		Hardness (BHN)	Hardness (BHN)
1	0	3.43	3.43
2	5	3.47	3.21
3	10	3.80	3.28
4	15	3.56	3.10
5	20	2.90	3.40
6	25	3.76	3.83

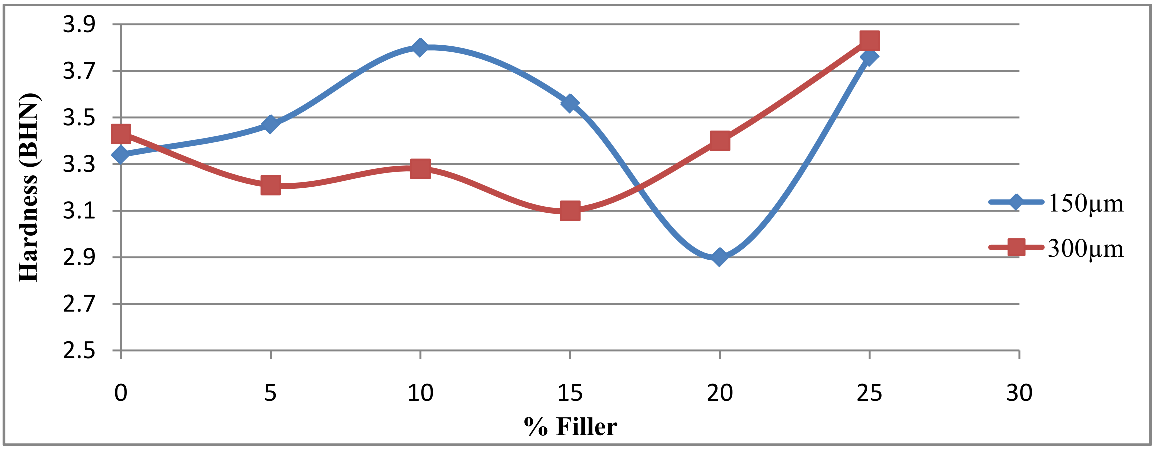

Figure 4. Hardness responses of particulate reinforced polypropylene composites

Table 3. Impact strength of the composites of particle sizes 150µm and 300µm

Sample number	% Filler	150µm particle size	300µm particle size
		Impact strength (J)	Impact strength (J)
1	0	4.28	4.28
2	5	3.96	4.00
3	10	3.50	4.50
4	15	3.17	3.70
5	20	2.93	2.00
6	25	1.20	1.90

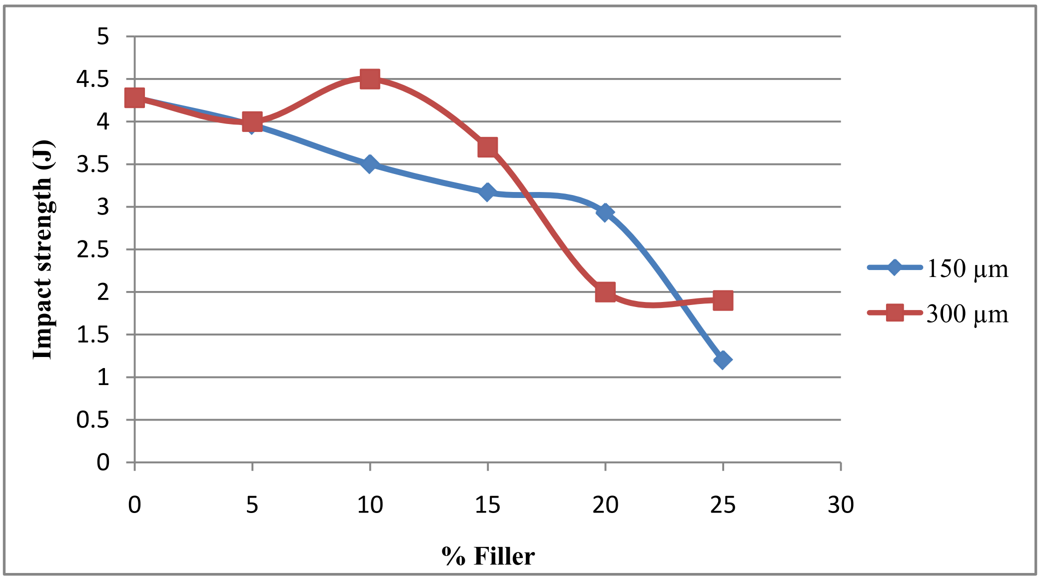

Figure 5. Impact strength of particulate reinforced polypropylene composites

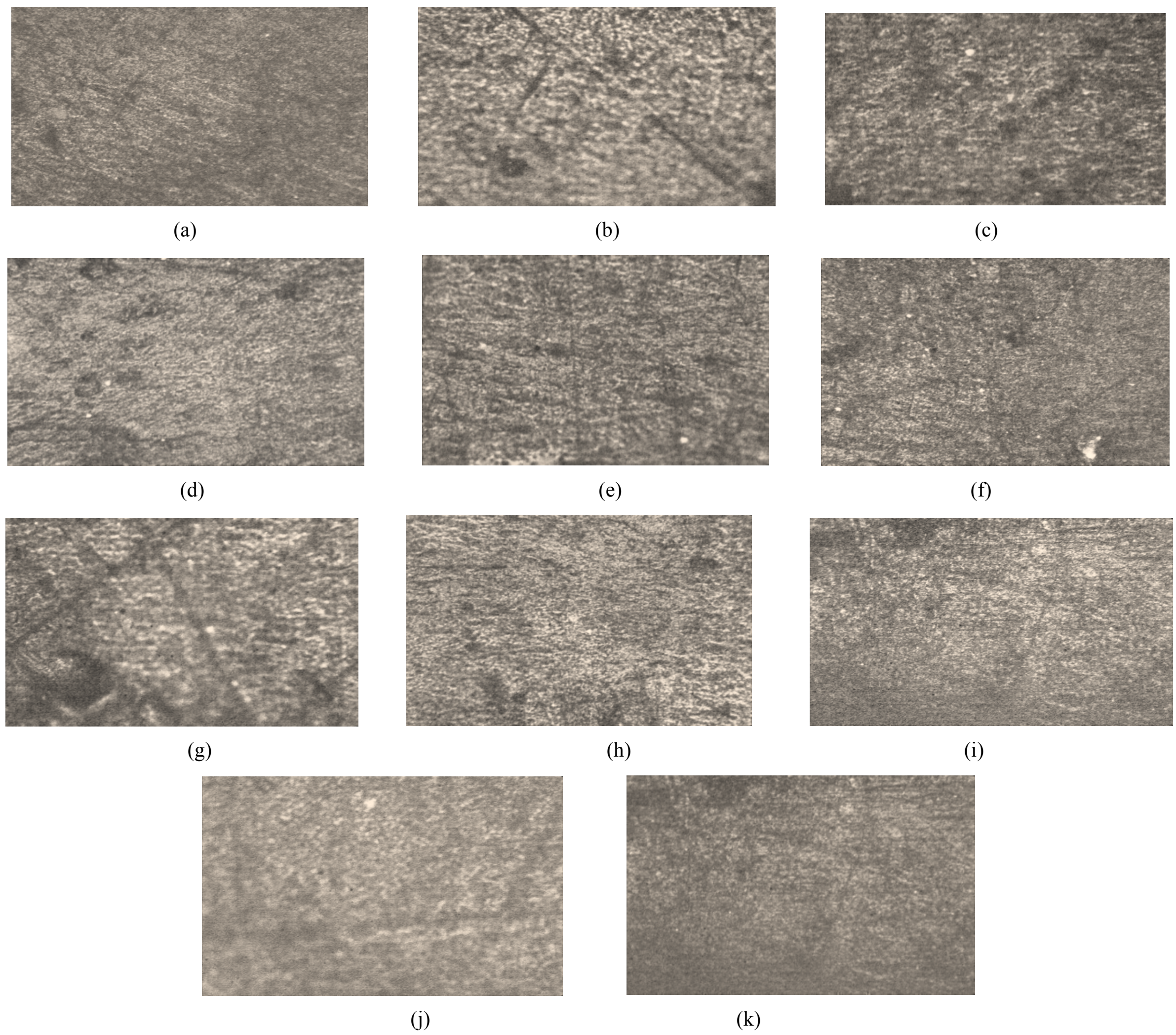

Figure 6. Microstructure of (a) virgin polypropylene; (b-c) 25 wt. %; (d-e) 20 wt. %; (f-g) 15 wt. %; (h-i) 10 wt. % and; (j-k) 5 wt. % 150µm and 300µm respectively

3.4. Microstructural Analysis

In Figure 6 (b-j), it is observed that there is homogeneity in the sisal powder reinforced polypropylene composite. There is a good interfacial bonding between the matrix and the reinforcement which is responsible for the increase in strength of the composite.

4. Conclusions

Sisal particles improved the hardness property of the polypropylene matrix composite**.** A general increase is observed in the hardness trend of the 300μm particles reinforced polypropylene composites, showing a peak value 3.83J at 25 %wt of sisal reinforcement. The toughness of the composites dropped as the concentration of sisal particles increased in the polymer matrix. This indicates that shock absorption reduces with increasing reinforcement. The microstructural analysis shows a good dispersion of the sisal particles in the polypropylene matrix which is responsible for the increase in strength. The tensile strength increased up to a maximum value of 6.96MPa at 20 wt % of reinforcement using 150μm particle size. In terms of strength, the 150μm particles size reinforced composite is better than the 300μm. This grade can be use for interior applications such as car seat, dash board, and car interior for decorative purposes or other interior parts of automobile where high strength is not considered a critical requirement. Hence, polypropylene matrix composite reinforced with sisal particles is a good material for engineering applications.

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