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Study on the Properties of Coconut Shell Powder Reinforced High-Density Polyethylene Composite

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Abstract

The properties of a composite which consists of coconut shell powder and high density polyethylene (HDPE) were investigated. The reinforced composite was prepared by compacting High density polyethylene with coconut shell powder varying from 5 % - 25 % volume fraction. Tensile density, impact, hardness tests and microstructural analysis were carried out to determine the characteristics of the reinforced composite. Result shows that the hardness of the composite increased with increases in coconut shell powder content while the impact strength and ductility of the composite decreased with increases in coconut shell powder content. The density of the composites decreased as the percentage of coconut shell powder increased. The result also show that there was a fairly uniform distribution of the coconut shell powder in the micrographs of HDPE composites which is the major factor responsible for the observed improvement in the mechanical properties of the composites.

Keywords*:* Coconut shell powder, high density polyethylene, tensile strength, density, impact, hardness.

1.0 Introduction

Composites are increasingly used in place of metals in a wide range of structural applications in the aerospace, construction and automotive industries due to their lightweight and high specific stiffness and strength (Bledzki & Gassan, 1999). In addition to being lighter and stronger, composites offer better performance than metals at high temperatures and do not develop potentially dangerous weaknesses such as fractures and fatigue. The need for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced composite materials that not only decrease dead weight but also absorbs shock and vibration through tailored microstructures. The use of composite materials is evolving in the automotive industry. Composite materials offer great potential in reducing vehicle weight, thus, increasing fuel efficiency and thereby reducing CO_2 emissions. In addition to weight reduction, the number of components can be significantly reduced making the high-volume composite car concept cost effective (Sapuan & Harimi, 2003; Husseinsyah & Mostapha, 2011). Composites are also used extensively for rehabilitating/strengthening pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damages caused by seismic activity. Unlike conventional materials (e.g. steel), the properties of the composite material can be designed taking into consideration the structural properties and varying reinforcement matrix or filler content. The design of a structural component using composites involves both material and structural design. Composite properties such as stiffness and thermal expansion can be varied continuously over a broad range of values under the control of the designer (Aigbodion *et al*, 2013). Careful selection of reinforcement type enables finished product characteristics to be tailored to almost any specific engineering requirement. The use of composites is a clear choice where material selection will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience skills of the designer in utilizing the optimum potential of composites (Sarki *et al*, 2011).

The use of natural fillers to reinforce composite material has the following advantages; strong and rigid structure, light weight material, environmental friendly, economical, renewable and abundant resource in comparison with mineral fillers (Brahmakumar *et al*, 2005). Natural fillers such as coconut shell powder have outstanding potentials as reinforcement in plastics. (Roopa & Siddaramaiah, 2010). Sapuan & Harimi (2003) studied coconut shell filled composites prepared from epoxy polymer matrix, containing up to 30 % coconut shell fillers and reported that increasing the coconut shell content increased the tensile strength, Young's modulus and water absorption rate of the composites but decreased the elongation at break of the polyester composites. Andrzej & Abdullah, (2010) observed that incorporating coconut shell powder reduces the damping property of bio-composite with significant improvement in the tensile strength and tensile modulus. Coconut shell is an agricultural waste having no industrial applications. However, it is often used as fertilizer in other farm applications (Widowati & Utomo, 2014). There is need to develop new uses for agriculture wastes since this will benefit the agricultural industry and other industries. The development of polyethylene composite from coconut shell powder will find utilization for this agriculture waste and increase its value. The choice of high density polyethylene as a matrix for this study is because the resin is cheap, available with good mechanical properties and has applications in the transport, marine and sport industries (PPI, 1993). In the current study, coconut shell powder and high density polyethylene were used, exploring the potential of coconut shell as reinforcement for composite.

2.0 Materials and Method

The coconut shell was dried in air for five days and fired in an electric furnace at temperature of 105^0 C. Emery paper was used to clean the outer shell. The cleaned coconut shells obtained were cut into pieces of dimensions 1 cm^2 using hammer mills and were put in stainless steel containers. The collected shell was ground to fine powder using a grinding machine to smaller particles after which it was pulverized in the pulverizing machine. The powder was sieved in accordance with BS 1377:1990 standard. The particle size used was 150 µm. The pelletized high density polyethylene (HDPE) was dried and shredded in a plastic crusher machine. The percentage of the coconut shell powder in the matrix was varied from 5% to 25% to produce five different compositions. The coconut shell powder size 150 µm was weighted in the mettle balance to different proportions of sample A=5%, sample B=10%, sample C=15%, sample D=20% and sample E=25% respectively and the high density polyethylene was weighted as follows sample A=95%, sample B=90%, sample C=85%, sample D=80% and sample E=85% respectively. Sample F contain 100% high density polyethylene was control. The samples shown in table 1 were compounded in a two roll mill at a temperature of 135^0 C to obtain homogenous mixture and poured into metal mould. Compression of the composites was carried out with a hydraulic pressing machine for 7 minutes under controlled pressure (30 tons) at 135^0 C. Each of the samples were cooled to room temperature under sustained pressure before it was removed from the hydraulic pressing machine. 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%.. A charpy impact machine was used to determine the impact strength of the samples and the micrographs of the composites was observed with an Accuscope microscope (Serial no 0524011, Maker: Princeton, US). Universal Testing Machine was used for the tensile test with strain speed of 10 mm/min. Each tensile specimen was positioned in the tester and then subjected to tensile load, as the specimen stretched the computer generated all the desired parameters until the specimen fractured. The hardness property of samples were determined using an Instron Tester 2000. The Brinell hardness (BHN) which is the pressure per unit surface area of the identification in kg per square meter is calculated from equation 1.

$$BHN = \frac{w}{(\frac{\pi D}{2})(D-\sqrt{D^2-d^2})} \quad (1)$$

where W is load on indenter, (kg), D is diameter of steel ball, (mm) and d is average measured diameter of indentation, (mm)

The densities of the composite samples of known weight were determined from equation 2

$$\rho = \frac{m}{v} \quad (2)$$

where ρ= density

m = mass,

v = volume of sample.

Table 1: Percentage weight proportion of the samples

Sample	Coconut	High Density Polyethylene
A	5 %	95 %
B	10 %	90 %
C	15 %	85 %
D	20 %	80 %
E	25 %	75 %
F	0 %	100 %

3.0 Results and Discussion

3.1. Density of HDPE Composites

Figure 1 shows the graph of measured densities of the composites against the percentage coconut shell powder in the composite. It was observed that as the percentages of coconut shell powders increase the density of the composites decrease. It is observed that as the coconut shell powder reinforcement percentages increase in the HDPE the density increase due to void percentage increase. The void content increase due to the increase in weight percentage of fiber. It was observed that the void fraction percentage of composites increased as the percentage of reinforcement increases still the void content is very less so it shows that the composite fabrication was done properly. It was observed that as the reinforcement percentages increased in the HDPE the density increases due to void percentage increases. The void content increases due to the weight percentage of coconut shell powder.

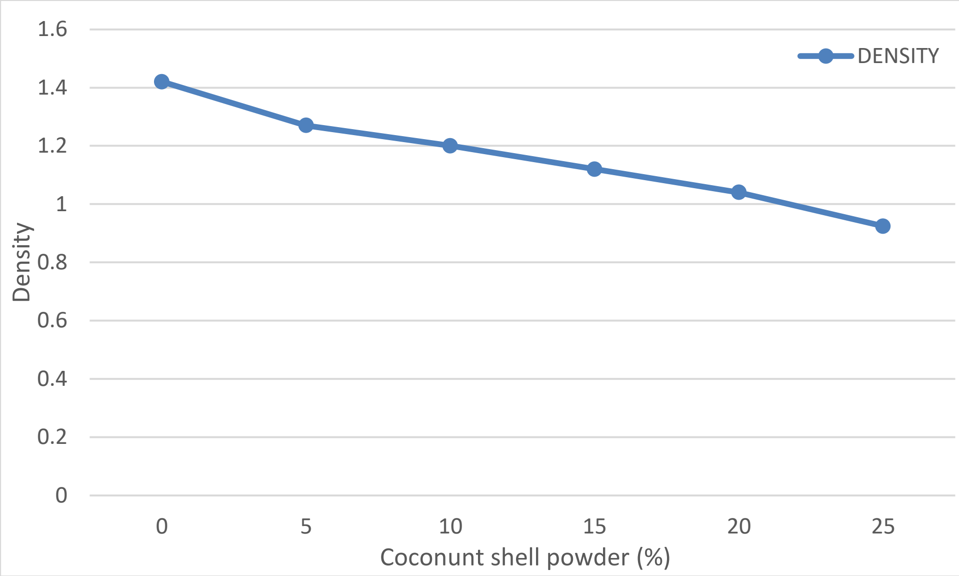

Fig.1: Effect of coconut shell powder on the density of coconut shell reinforced polyethylene composite.

3.2. Hardness of HDPE Composites

The coconut shell powder have significant effect on the hardness of the composite. Figure 2 shows the hardness of the composite samples. It was observed that the hardness increase as the percentage coconut shell powder increase in the HDPE matrix. This is due to increase in the percentage of the hard and brittle phase of the coconut shell powder in the polymer matrix. In comparison with the unreinforced HDPE matrix, the lowest hardness was observed in the reinforced polymer matrix. It was observed that as the reinforcement increase the hardness increase and the maximum value of 18.5 HRB was obtained for composite prepared with 25% coconut shell powder. 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 Olumuyiwa *et al*, (2012) who studied mechanical behaviour of coconut shell reinforced polymer matrix composite. They reported that the mechanical properties of the composites such as micro-hardness, tensile strength, flexural strength, impact strength of the composites are also greatly influenced by the coconut shell. This may be attributed to inherent properties such as high strength and high modulus.

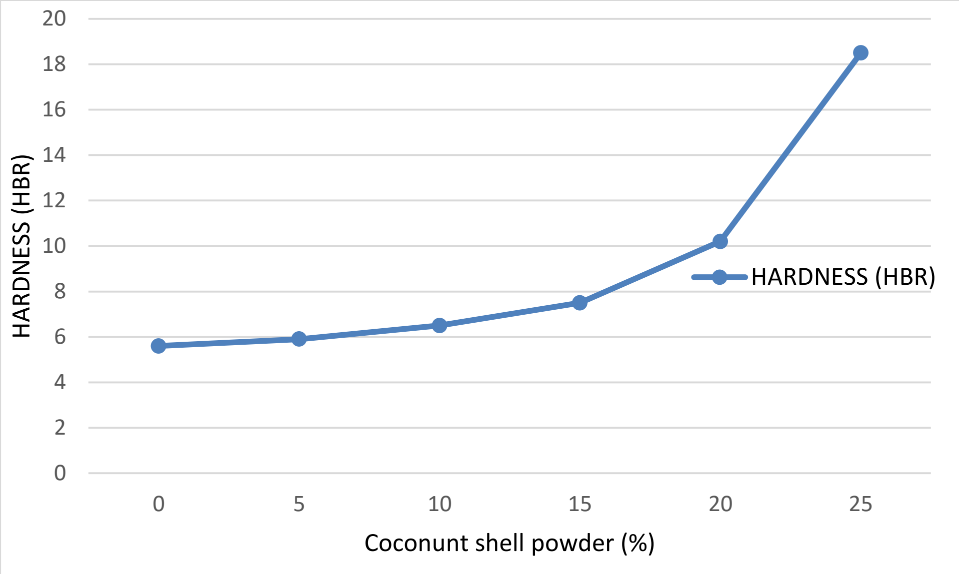

Fig. 2. Effect of coconut shell powder on the hardness of coconut shell reinforced polyethylene composite.

3.3 Impact Strength of HDPE Composites

Figure 3 illustrates the variation of impact strength with coconut shell powder on HDPE Composites. It is clear from the figure that the impact strength decrease with an increase in coconut shell powder content reinforced composite. This is mainly due to the reduction of elasticity of material due to powder addition and thereby reducing the deformability of matrix. An increase in concentration of coconut shell particles reduces the ability of matrix to absorb energy and thereby reducing the toughness, so impact strength decreases. The sample with 25% volume fraction coconut shell particles in the matrix has the lowest impact strength of 3.51 J.

The reduction in impact strength with increasing coconut shell powder loading might also be due to the decreased deformability of a rigid interface between the particles and HDPE matrix (Aigbodion, 2013). This could be the predictable result, because rigid body such as coconut shell powder acts as barriers against the mobility of dislocations. Therefore, by increasing the content of coconut shell powder, the rate of work hardening increases and this would lead to a decrease in toughness values.

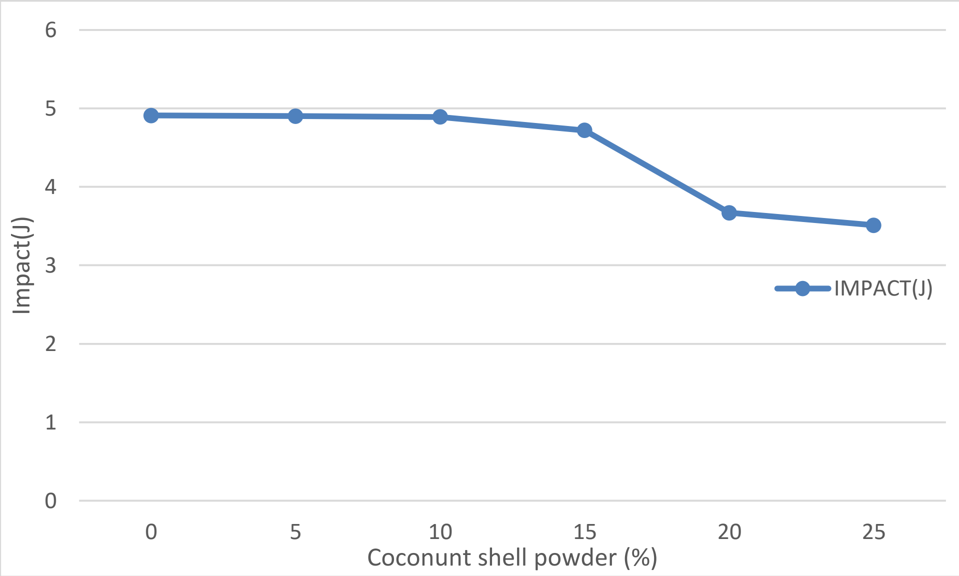

Fig. 3: Effect of coconut shell powder on the impact strength of coconut shell reinforced polyethylene composite.

Since the unreinforced HDPE, the composite with 5 % and 10 % weight coconut shell powders have higher impact strength, indicating the greater toughness values of all the investigated samples, the increase in hardness is related with the increasing amount of hard coconut shell powder particles in the HDPE matrix. On the other hand, as can be suggested from the impact test, the elastic behaviour of the matrix proportionately varies with the addition of the coconut shell powders particles. As the loading of coconut shell powder 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 (Murali and Mohana, 2007).

3.4 Tensile Strength of HDPE Composites.

From the results below, sample D with 20 % coconut shell powders displayed the maximum tensile stress at 4.77510Mpa with the least tensile strain at 0.03778 mm/mm. Sample E having the highest HDPE percentage at 75% displayed the least tensile stress at 0.78645Mpa. Sample A has tensile stress at 3.23305Mpa while its maximum tensile strain was 0.178 mm/mm. It was observed that the level of HDPE present affected the strain values of the composites.

Table 2. Tensile strength of the composites

Sample	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
A	45.00000	6.00000	13.65000	3.23305
B	45.00000	6.00000	13.65000	4.33007
C	45.00000	6.00000	13.65000	3.10177
D	45.00000	6.00000	13.65000	4.77510
E	45.00000	6.00000	13.65000	0.78645

Table 3. Tensile extension of the composites

Sample	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
A	264.78681	0.12148	5.46675	1.00981	0.48963
B	354.63260	0.07482	3.36669	0.70443	1.02917
C	254.03458	0.02519	1.13337	0.13835	0.77739
D	391.08074	0.02074	0.93337	0.13289	0.48370
E	64.41029	0.02963	1.33337	0.04464	0.26379

Table 3: Tensile extension at break of the composites

Sample	Load at break (Standard) (N)	Tensile strain at break (Standard) (mm/mm)	Tensile extension at break (Standard) (mm)	Energy at break (Standard) (J)	Tensile stress at yield (Zero Slope) (MPa)
A	40.10048	0.17333	7.79994	1.23037	3.23305
B	84.28921	0.12444	5.59994	1.02307	4.33007
C	63.66832	0.07185	3.23337	0.33838	-----
D	39.61524	0.03778	1.70000	0.17467	-----
E	21.60430	0.06272	2.82262	0.09199	-----

The tensile strength increased with increased coconut shell powder content up to 20% and decreased with further increase in volume of coconut shell powder content due to the aggregation in the composites. The Tensile extension at Maximum Tensile (% of elongation) decrease as the coconut shell powder content increase.

3.5 Microstructural Analysis

Figure 4 and 5 show micrographs of the composites. The micrograph clearly show the coconut shells powder in the HDPE. There is a good dispersion of coconut shell powder in the HDPE. Micrographs clearly show that no de-bonding and crack formation was found and good adhesion between HDPE and coconut shell powder are seen. Bonding is strong between the HDPE and coconut shell powder reinforcement. Micrographs also showed that the coconut shell powder as a reinforcement have smooth spherical surface having more surface area for interaction.

Fig. 4: Microstructure of HDPE reinforced with 5 % coconut shell powder

Fig. 5: Microstructure of HDPE reinforced with 25 % coconut shell powder

4.0 Conclusion

In this present work, hardness, tensile strength, impact strength and microstructural studies have been carried out on the HDPE/coconut shell powder composite. From the results and discussion presented, the following conclusion are made: The hardness value of the composite increases with increase of the shell powder while the impact strength reduced with increase in coconut shell powder. It was observed that the 25 % coconut shell powder content recorded the highest result in hardness in comparison to others. The impact strength decreased with increase in the percentage of coconut shell powder in the reinforced composite samples. This indicates a good bonding between coconut shell powder and the HDPE matrix. In the tensile test, sample with 20 % of coconut shell powder recorded the best result and then a decrease was recorded with further increase in coconut shell powder volume of 25%. It was also observed that the introduction of coconut shell powder varied the tensile strength and affect percentage of elongation. As the percentage of the coconut shell powder increased, there was a corresponding decrease in density. The micrographs revealed that coconut shell powder had a uniform bond with the HDPE.

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