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INFLUENCE OF SILICA SAND PARTICLES ON THE TENSILE PROPERTIES AND WATER ABSORPTION BEHAVIOUR OF HIGH DENSITY POLYETHYLENE MATRIX COMPOSITES

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ABSTRACT: The use of silica particles as reinforcement in polymers has gained much attention in recent years. It is expected that its addition in polymer will enhance the mechanical properties of such polymer. In this work, silica sand were locally sourced from Igbokoda, Nigeria and we repulverized by ball mill and sieved into <75 μm particle size which were used as reinforcement in High Density Polyethylene (HDPE) to produce composites. HDPE matrix composites with 2, 4, 6, 8, 10 wt.% of silica sand particles were developed using compression moulding technique. Tensile, flexural and water absorption properties were investigated. It was observed that as the silica sand particles content in HDPE increases up to 6 wt%, the tensile and flexural properties increases with an optimum value. At higher silica sand particles content in HDPE, the mechanical and water absorption properties depreciate dowing to particles agglomeration whichr esulted into poor interfacial bonding at the particulate (silica sand) – Matrix (HDPE) interface as shown on the SEM images.
Keywords: Silica sand particles; HDPE; Mechanical properties; Water absorption properties

1. INTRODUCTION

Particulate reinforced polymer composites are of great interest due to the advantage of low cost and ease of fabrication compared with fibrous and laminate composites [1-2]. Particulate chosen as reinforcement are usually harder and stiffer than the polymer matrix, which thus improves the mechanical properties of the polymer composite [3]. Particulate reinforced polymer composites have been explored for wide range of industrial applications such as production of pipes and fittings for the water and gas transportation under pressure [4].

Among the commonly used particulate reinforcement, silica particles reinforcement has gained much attention in recent years due to its availability, low cost and stiffness [3, 5]. Several attempts have been made by researchers to study the effect of silica particles in polymer matrix. Both thermoset and thermoplastic polymer reinforced with silica particles have been reported in the literature. In the previous work [6], Sol-gel process for the manufacturing of submicron silica particles from rice husk ash (RHA) was described and the influence of the silica particles on the mechanical properties of High Density Polyethylene was also presented. Energy dispersive x-ray spectrometer (EDX), as well as scanning electron microscopy (SEM), was used to determine the elemental composition and the morphology of the powder respectively. The EDX analysis confirmed the presence of silica in the composite to be 96.1%. The powder particle size was also verified by Horiba dynamic particle size analyzer. The average particle size was 0.5μm. The silica powder causes enhancement in the mechanical properties of HDPE up to 4 wt.%.

Jordan et al. [7] studied the effect of micron and nanosized silica particles inclusion in polyurethane matrix and observed that the presence of micron sized silica particles further increased the overall density of the composites as compared to the nanosized inclusions. Tahir and Othman [8] developed HDPE reinforced with silica nanoparticles. In their work, higher weight content of silica sand nanoparticles decreases the mechanical properties of the composite. Tahir et al. [9] studied the effect of silica sand nanoparticles on epoxy-based composites. They observed that 15 %wt. addition of silica sand nanoparticles improves the young modulus of the composites. A reduction of tensile strength was also observed due to improper mixing of the silica sand nanoparticles in the epoxy resin. The absence of any improvement in the tensile properties was due to particle clustering.

The aim of this work is to develop micron sized silica sand particle reinforced HDPE composite by compression moulding. In this study, micron size locally sourced silica sand particle was used as reinforcement in HDPE. The choice of HDPE as matrix is due to its advantage of low cost, high chemical resistance and stable mechanical properties [4]. The effect of silica sand particles on the mechanical and water absorption properties of silica sand particles reinforced HDPE composite was studied.

2. MATERIAL AND METHOD

The silica sand particles used as reinforcement in this work was sourced locally from Igbokoda, Nigeria. High-density polyethylene (HDPE) with melt flow index (MFI) of 8g/10min (XZ 89712-00 RD 10140182040), 168, 000g mol^{-1} molecular weight, 130°C melting point and 0.954gcm^{-3} density was supplied by DOW Chemicals, Republic South Africa.

Preparation of silica sand particles

The silica sand collected was first screened to remove unwanted particles and was thereafter ball milled to fine particle sizes. The particles were separated into various particle sizes with the aid of sieve shaker. Silica particles that passes through the 75 μm mesh was used as reinforcement in this work.

Preparation of composites

Silica sand were mixed with HDPE in a proportion of 2 wt.%, 4 wt.%, 6 wt.%, 8 wt.% and 10 wt.% weight fraction. The resultant mixture was moulded into dog bone shape tensile bar with a compression moulding machine at 150°C. Flexural test samples were also prepared according to ASTM D790-03 by compression moulding machine. Three test samples each were prepared for both tensile and flexural test. After melting, the composites were allowed to cool at room temperature before carrying out further analysis on them.

Mechanical testing

Tensile tests were performed on INSTRON 1195 at a fixed Crosshead speed of 10 mm min-1. Samples were prepared according to ASTM D412 [10] standard test methods for polymer composite properties in tension. Flexural test was carried out by ASTM D 790 [11] Standard test method for flexural properties for polymer composites. The flexural test was performed at the speed of 100 mm/min. Three samples were tested for each representative samples from where the average values for the test samples were used as the illustrative value.

Water absorption test

Water absorption tests were carried out following the recommendations specified in ASTM D5229M-12 [12]. Samples were immersed in water at room temperature for 24 hrs. Thereafter, samples were removed from the water, cleaned using a dry cloth and weighed. The weight measurements were taken periodically at time intervals of 24hrs for up to 96 hrs as soon as water saturation in all the composite samples had been noticed. The amount of water absorbed by the composites (in percentage) was calculated using the equation:

$$(W\%) = \frac{W_t - W_0}{W_0} \times 100 \tag{1}$$

Where W is percent water absorption, W_o and W_t are the dry weight, and the weight of the specimen after time t, respectively.

Scanning electron microscopy (SEM) observation

The surface morphology of the samples was studied using an AURIGA Scanning Electron Microscopy (SEM) (Carl Zeiss, Germany) with an accelerating voltage of 15 kV. The compression-moulded samples were first cryogenically fractured in liquid nitrogen and the cryo-fractured surfaces were mounted on aluminium stubs and were sputter coated with gold using EMITECH K950X sputter coater before being subjected to SEM analysis.

3. RESULTS
Tensile Test

Tensile strength at yield of a material is the stress the material can withstand without permanent deformation. In Figure 1, it was observed that as the silica particles reinforcement in the neat HDPE increases, the tensile strength at yield of the composite samples increases upto 6 %wt. The optimum value of tensile strength at yield was 16.10MPa at 6 wt% silica sand content. It was also observed that further increment from 6% to 10% silica sand reinforcement in the neat HDPE resulted to tensile strength at yield reduction in the composite samples. The reason could be that high silica particles in neat HDPE had stick together and form agglomerate due to poor interfacial bonding between the silica particles and HDPE.

Tensile modulus is the ratio of stress to strain in the linear region of the stress- strain curve. The tensile modulus for HDPE/SiO2 composite samples were shown in Figure 2. From the graph, it was observed that the tensile modulus for silica/HDPE composite samples increases as the silica content increases. Optimum value of tensile modulus was 395 MPa at 10 wt% silica. It was established that high silica sand particles in HDPE enhanced the tensile modulus of the composite, as oppose to result obtained for tensile strength at yield.
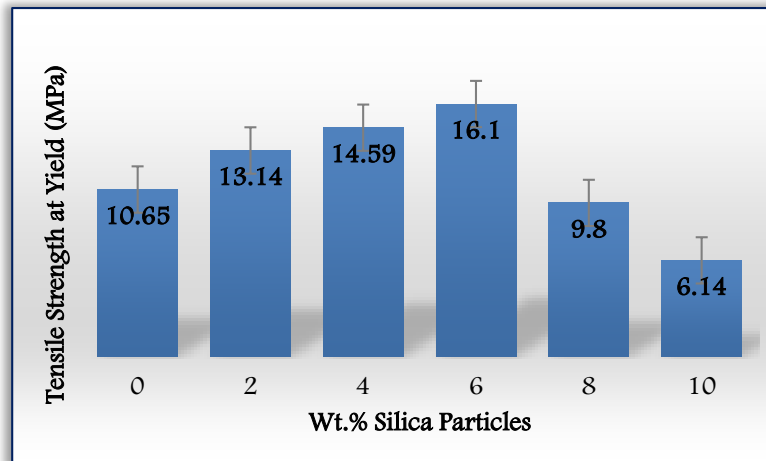

Figure 1: Variation of tensile strength at yield of neat HDPE and composite samples

Figure 2: Variation of Tensile Modulus of neat HDPE/composite samples

Flexural Test

Flexural strength at yield of neat HDPE and silica/HDPE composites is shown in figure 3. From the graph, it was observed that silica sand particles reinforcement enhanced the flexural strength at yield of the neat HDPE. The flexural strength at yield increased upto 6 wt.% of silica sand particles in HDPE as shown in Figure 3. The increasing trend of the flexural strength at yield indicates that interfacial bond between the silica sand particles and HDPE is good. The optimum value for flexural strength at peak was 116.99 MPa at 6 % silica content. The obvious reduction in flexural strength at yield was noticed at 8-10 % silica

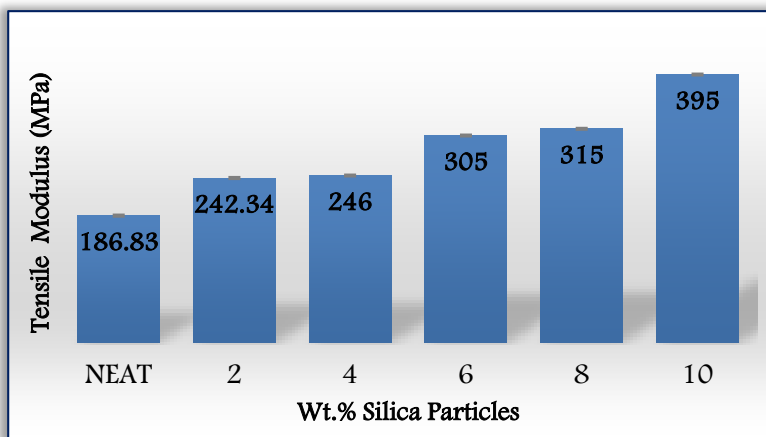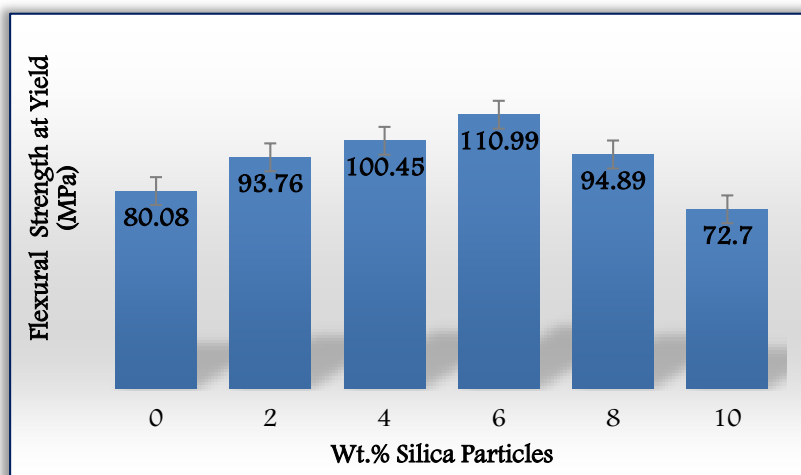Figure 3: Variation of Flexural Strength at Yield of neat HDPE and composite samples

content. This shows that high silica sand particles in HDPE affects the flexural strength at peak negatively due to particles agglomeration.

Flexural modulus of neat HDPE and silica/HDPE composite samples is shown in figure 4.

From the graph, it was observed that optimum value of flexural modulus was displayed at 6 %wt silica sand which was about 2018.75 MPa. Similar trend was noticed in fig 3, where further increase in silica sand particles resulted in properties reduction. From the analysis, it has been established that silica sand reinforcement enhanced the flexural modulus of the neat HDPE.
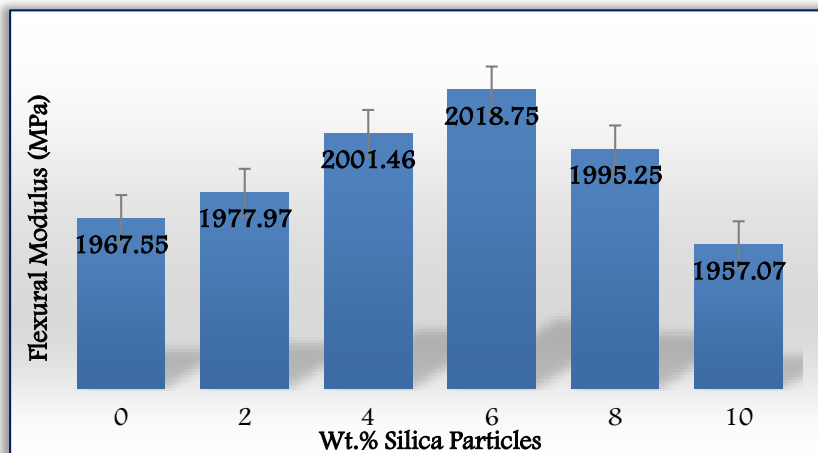

Figure 4: Variation of Flexural Modulus of neat HDPE/composite samples

Water Absorption Test

Water absorption plots of weight gained per time for various samples as shown in figure 5. From the graph, it was observed that water absorbed by varied composite samples increases with time although the rate of absorption differs with respect to each samples. 10 %wt silica/HDPE sample had the highest rate of water absorption, followed by 8 %wt silica/HDPE sample. This was attributed to the presence of large voids within the composites microstructure as a result of agglomeration. But after 96 hrs, it was noticed that all samples stop absorbing water. We assumed that all the samples had attained their saturation point, preventing further water penetration within the samples.
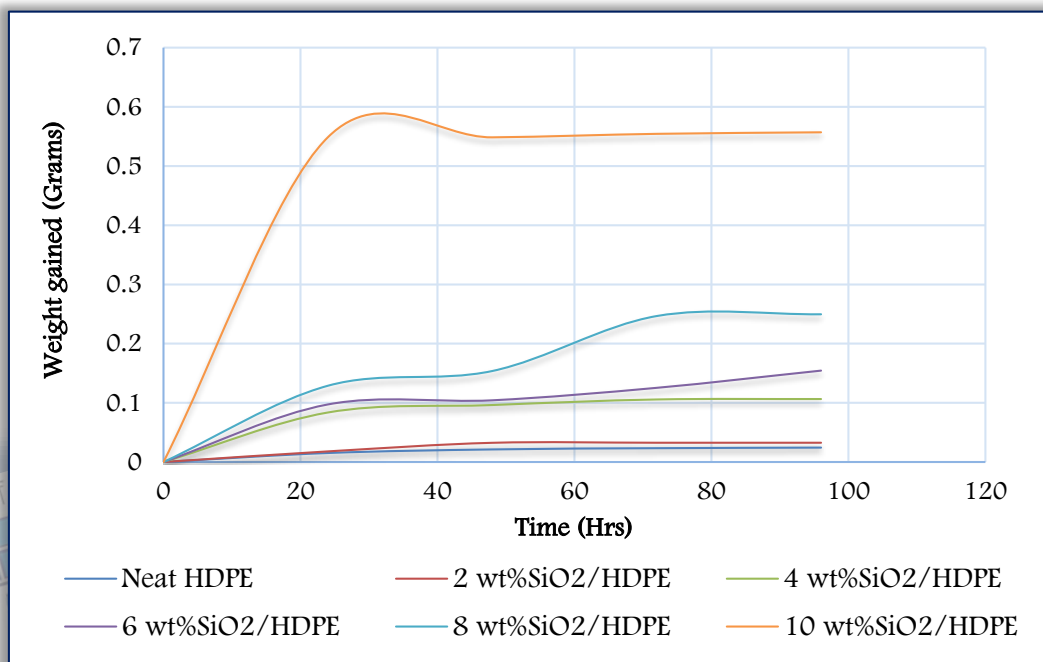

Figure 5: Variation of weight gained with time for Neat HDPE/composite samples.

SEM Observation

A detailed investigation of the filler morphology within the matrix is a key parameter to impart desired mechanical properties of polymer-based composites. To have a clear images of the fractured patterns of the composites, SEM images of the cryo-fractured surfaces of the composites at different filler contents are shown in Figure 6. Figure 6(a) revealed the cryo-fractured surface image of neat HDPE which has a relatively smooth fractured surface in association with terraced markings, indicating weak resistance to crack propagation. In the case of SiO_2/HDPE composites with silica content of 2-6wt%, it is very clear that there is good dispersion of filler in HDPE

matrix. The silica particles were uniformly distributed in the matrix with little agglomerates as shown in Figure 6 (b), Figure(c) and Figure(d). When the content of silica sand particles approaches 8wt%, the morphologies of the composites' fractured surfaces become somewhat different as shown in Figure6 (e) and Figure6 (f); a number of cavities appear on the surface of SiO_2/HDPE composites. These cavities are produced due to the debonding of the silica particles as illustrated by the arrow in Figure 6 (e) and Figure 6 (f). In general, an increased content of SiO_2 would lead to a larger agglomerates and hence greater probability of debonding due to the poor interfacial adhesion. As there is not enough time for inducing matrix yielding after excessive particles debonding, the matrix beside the cavities seems to be rather flat.
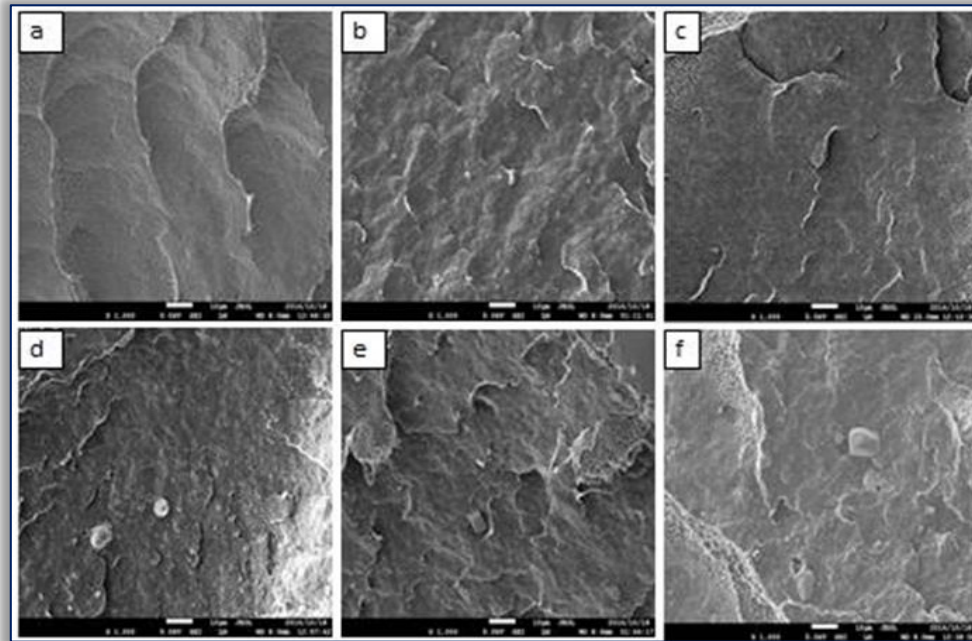

Figure 6: SEM surface morphology of the cryofractured Surfaces of neat HDPE and SiO_2/HDPE composites: (a) neat HDPE (b) 2wt. % SiO_2/HDPE Composites (c) 4wt. % SiO_2/HDPE Composites (d) 6wt. % SiO_2/HDPE Composites (e) 8wt. % SiO_2/HDPE Composites (f) 10wt. % SiO_2/HDPE Composites.

4. CONCLUSION

Silica sand particulate reinforced high density polyethylene (HDPE-SiO_2) was successfully developed by compression molding technique. The research outcomes show that the addition of silica sand particles as reinforcement in HDPE causes an enhancement in the mechanical properties of HDPE-SiO_2 composites. It has been established that 6 %wt silica-HDPE composite gave the best tensile and flexural properties results. Regarding the water absorption properties, HDPE-SiO_2 composites with low silica sand content absorb less water compared to HDPE-SiO_2 composites with high silica sand content. However, due to agglomeration of 8-10 %wt silica sand particles, no obvious enhancement was shown except that it only enhance the tensile modulus of the HDPE-SiO_2 composites. The addition of dispersant is recommended for further study to reduce the effect of agglomeration in composites development as this was beyond the scope of our work.

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