Properties of Oil Palm Empty Fruit Bunch Fibre Filled High Density Polyethylene

Chinomso M. Ewulonu[#1], and Isaac O. Igwe[*2]

[#]Department of Polymer & Textile Engineering, Nnamdi Azikiwe University
P.M.B 5025, Awka, Nigeria
[1]ewulonuchinomso@yahoo.co.uk
[*]Department of Polymer & Textile Engineering, Federal University of Technology,
P. M. B. 1526, Owerri, Nigeria
[2]izikigwe@yahoo.com

***Abstract* – The properties of oil palm empty fruit bunch (OPEFB) fibre filled high density polyethylene (HDPE) have been investigated at filler loadings, 0 to 1.5 wt. %. Maleic anhydride–g–polyethylene (MAPE) was used as a compactibilizer. Oil palm empty fruit bunch fibre was prepared at three particle sizes namely, 0.15, 0.212, and 0.30 mm. The HDPE composites were prepared in an injection moulded machine. Results showed that for any given particle size of OPEFB fibre considered, the tensile strength and elongation at break of the HDPE composites decreased with increase in OPEFB loadings. However, the addition of MAPE was found to improve these properties. The hardness, and specific gravity of the composites were found to increase with increase in filler loadings and were further increased on addition of MAPE. The water sorption indices (24-h cold water and 2-h hot water) of the composites also increased with increase in OPEFB loadings, and particle sizes, but were decreased on addition of MAPE. OPEFB fibre was inefficient in reducing the flame propagation rate of HDPE; the incorporation of MAPE into the systems reduced the propagation rate of the composites.**

Keywords – high density polyethylene, maleic anhydride–graft–polyethylene, oil palm empty fruit bunch fibre, mechanical and end-use properties

I. INTRODUCTION

Polymers, such as polyethylene, have found many applications in our modern world. These polymers are frequently compounded with natural minerals so as to improve their properties. For example, glass fibre is used to improve the stiffness and strength of thermoplastics [1]. However, glass fibres and mineral fillers require a lot of energy to process since processing temperatures can exceed 1200 ^{o}C. These fillers also tend to abrade processing equipments and increase the density of the thermoplastic system. Similarly, the growing global environmental concern, the high rate of depletion of petroleum and mineral resources, as well as new environmental regulations have forced the search for new fibre reinforced composite materials that are compatible with the environment. Oil palm empty fruit bunch (OPEFB) fibres are natural fibres and represent an environmentally friendly alternative to conventional reinforcing fibres. These fibres are available in abundance, renewable, nontoxic, and their low cost are of industrial economic interest. The main limitation to the use of natural fibres in reinforcing polymers is the lower processing temperature permissible due to the possibility of fibre degradation and/or the possibility of volatile emissions that could affect composite properties, thus limiting the processing of natural fiber components to about 200 °C. [2]. Other drawbacks include the high moisture absorption of natural fibres, poor wetability, and general incompatibility with some polymeric matrices. Polyethylene is the most frequently used thermoplastic for the production of natural fiber plastic composites. This is due to its lower melting point, general availability, and low cost. [3].

Despite the limitations on the use of natural fibers in producing polymer composites, the use of these fibres in composite making is gaining importance nowadays and a number of research works are published in the scientific literature. Najafi et al [4] prepared composites of different lignocellulosic materials and high density polyethylene at 25 and 50 wt. % fibre, and 1 and 2 % compatibilizer contents respectively. Water absorption tests carried out on injection-moulded specimens at room temperature for five weeks showed that kenaf and newsprint fibres exhibited higher water absorption values, while wood flour and rice hulls showed the least. Najafi et al [5] prepared composites of sawdust, virgin and/or recycled high density polyethylene (HDPE). The flexural, tensile properties and impact strength of the prepared composites were determined by standard procedures. Results showed that the mechanical properties of samples containing recycled HDPE were statistically similar and comparable to those of composites made from virgin HDPE. The authors considered this as a possibility to expand the use of recycled plastics in the manufacture of wood plastic composites.

Kajaks and Reihmane [6] investigated the thermal, and water sorption properties of polyethylene and linen yarn production waste composites. The wastes were obtained at different stages of linen yarns production, both virgin and recycled polyethylene were used. It was found that the modification of composites with diphenylmethane diisocyanate gave considerable increase of thermal stability, decreased water sorption, and water diffusion coefficients in composites. Brahmakumar et al [7] studied the use of coconut fibre in making low density polyethylene composites. The effect of natural waxy surface layer of the fibre on fibre/matrix interfacial bonding and composite properties were studied by single fibre pullout test. The tensile properties of oriented, discontinuous fibre composites were determined. It was found that the waxy layer provided good fiber matrix bond such that removal of the layer resulted in drastic decrease of the pullout stress, increase of the critical fibre length, and corresponding decrease in tensile strength and modulus of the composites.

Rozman et al [8] studied the mechanical properties of high density polyethylene (HDPE) – oil palm empty fruit bunch (EFB) composites using three different particle sizes of EFB and at different filler loadings. The modulus of elasticity (MOE) and modulus of rupture (MOR) of the EFB – HDPE composites were found to increase, and decrease respectively with increase in filler loading. It was found that samples with smaller sized particles displayed higher MOE and MOR when compared to the larger sized particles. The flexural, tensile, and impact strengths of the composites were found to decrease with increase in the amount of filler incorporated. The oil palm empty fruit bunch (EFB) – polyethylene composites produced using an internal mixer was investigated by Rozman et al [9]. It was reported that the incorporation of EFB into the polymer matrix resulted in the reduction of flexural strength. Both the flexural and tensile modulus of the prepared composites were found to be improved upon addition of EFB. The water absorption and thickness swelling of the composites were found to increase on the incorporation of EFB as filler. This later observation was attributed to the presence of hydrophilic hydroxyl groups on the EFB filler.

Johnson et al [10] investigated the effect of wheat straw size and loadings on environmental degradation of filled polyethylene. It was found that filled polyethylene showed significantly less weathering degradation after 1,000 h than unfilled polyethylene. Furthermore, the 50 percent short fibre composite was found to degrade more than the other fiber composites. The water saturation level was found to increase, and saturation time decreased with increase in fiber loading.

Yuan [11] studied the properties of wood fiber reinforced polyethylene prepared using twin-screw extruder techniques. It was reported that the addition of maleic anhydride–graft–polyolefin as a compatibilizer improved the level of adhesion between the wood fiber and polyethylene matrix. The impact strength of the composites with compatibilizer was 60 % higher than those without compatibilizer. At 50 wt. % wood fiber content, the Youngs modulus of compatibilized wood flour/polyethylene was 4.4 GPa, while the impact strength was 44 J/m.

In this work is reported the investigation of oil palm empty fruit bunch (OPEFB) fibre as filler in compounding high density polyethylene. In these efforts, the central objectives are to:

(i). Investigate fully the properties of high density polyethylene composites made from oil palm empty fruit bunch fibre (OPEFB).
(ii). Determine the effects of filler particle size on the properties of high density polyethylene composites. Filler loadings of 0 to 1.5 wt. % were used for the purpose of this work.
(iii). Investigate the effect of the use of maleic anhydride–graft–polyethylene (MAPE) as a compatibilizer on the properties of high density polyethylene composites.
(iv). Determine the optimum dose of the compatibilizer for the oil palm empty fruit bunch – high density polyethylene system.

Besides the works cited above, the use of oil palm empty fruit bunch fibre (OPEFB) as filler for polymers has been reported in the literature. Thus, OPEFB has been used as filler in the production of the following composites: polypropylene [12,13], poly(vinyl chloride) [14], polyurethane [15,16], unsaturated polyester resin [17]. Beside the above cited works, oil palm empty fruit bunch (OPEFB) has also been utilized in the production of polyethylene composites [11,18]. In the work by Yuan [11], the end use properties of polyethylene composites were not determined nor were most of the mechanical properties investigated. Similarly, the end use properties of polyethylene composites were not fully studied by Rozman et al [18]. Only the water absorption tests were determined thus leaving important composite properties such as flame retardant property, hardness, and specific gravity undetermined. In all, none of the works by Yuan [11] and Rozman et al [18] investigated the effects of particle sizes of OPEFB on the properties of OPEFB – polyethylene composites. Oil palm empty fruit bunch (OPEFB) is one of the lignocellulosic materials, which has great relevance to Nigeria, since a large quantity of the biomass is generated by oil palm industries.

The industrial potentials of oil palm empty fruit bunch have not been reported to our knowledge. The fruit bunches which are by products of oil palm processing are presently industrial wastes. The oil palm empty fruit bunch can be found littered everywhere in palm oil producing areas of Nigeria since the waste have presently no industrial application. Some palm oil processing mills in the country that use the empty fruit bunch as fuel create a great environmental hazard to the host communities and the practice has been discouraged. Its handling in the palm oil mills consumes unproductive loss and energy. However, oil palm empty fruit bunch is used locally to prepare local delicacies like ukwa (breadfruit), ugba (oil bean salad), abacha (slice cassava, popularly called African salad), and in rare cases now, in the production of local black soap because of the large potassium content of the bunch [19].

The present study, it is hoped, will help place the usefulness of oil palm empty fruit bunch as a filler in compounding polyethylene on a firm scientific basis.

II. MATERIALS AND METHODS

The high density polyethylene used in this study was obtained from Indorama Petrochemical Company Limited, Eleme, Rivers State, Nigeria. It has a melt flow index (MFI) of 2.16 dg/mm, and density of 0.946 g/cm^3. Oil Palm Empty Fruit Bunch fiber (OPEFB) was used as a filler in the preparation of the high density polyethylene composites. The OPEFB was collected from Adapalm Nigeria Limited, Ohaji, Imo State, Nigeria. The oil palm empty fruit bunch is among the waste produced in the processing of palm oil. The spikelet from OPEFB was cut out of the bunch, washed thoroughly with water to remove impurities, and later sun dried. They were subsequently crushed to fine powder and sieved to 0.150, 0.212 and 0.300 mm mesh sizes. Maleic anhydride-graft-polyethylene (MAPE) used as a compatibilizer in this study is a product of Sigma-Aldrich Cheme GmbH, Germany and was used as received.

III. PREPARATION OF HIGH DENSITY POLYETHYLENE COMPOSITES

Two different sets of high density polyethylene composites were prepared. Firstly, high density polyethylene (HDPE) – oil palm empty fruit bunch fiber (OPEFB) composites were prepared at different filler loadings. Secondly, HDPE – OPEFB composites in the presence of a compatibilizer, maleic anhydride – graft – polyethylene (MAPE) were prepared.

The high density polyethylene composites of oil palm empty fruit bunch (OPEFB) at the particle sizes of 0.150, 0.212, and 0.300 mm respectively were prepared by thoroughly mixing appropriate quantities of HDPE and OPEFB. The high density polyethylene was first melted and homogenized with the filler in an injection moulding machine at 150°C and the resultant composites were produced as sheets.

In the second sets of composite preparations, fixed quantities of HDPE, oil palm empty fruit bunch filler, and calculated quantities of maleic anhydride–graft–polyethylene (MAPE) were measured, fed into an injection moulding machine, and processed as was described above. The amount of MAPE used varied between 1 to 6 wt. % based on fixed amount (8 g) of OPEFB and HDPE (800 g).

IV. DETERMINATION ON PREPARED COMPOSITES

The mechanical and end-use properties of the oil palm empty fruit bunch (OPEFB) fibre filled high density polyethylene composites were determined. The tensile strength (ASTM D 638), Rockwell Hardness (ASTM D 785), elongation at break, specific gravity (ASTM D 792), water absorption (cold water, 24 h; hot water, 2 h), and flame propagation rate (ASTM D 4804 with modifications) were determined by standard procedure.

V. RESULTS AND DISCUSSION

A. Tensile Strength

Figure 1 shows the effect of oil palm empty fruit bunch fibre contents, and particle sizes on the tensile strength of HDPE composites. The tensile strength of unfilled high density polyethylene is determined to b 31.45 N/mm^2. From Figure 1, it is evident that the tensile strength of high density polyethylene composites decreased with increases in filler loadings at all the filler particle sizes investigated. The decrease of tensile strength with increase in filler loadings is in agreement with the findings of Rozman et al [18] who worked with oil palm empty fruit bunch/polypropylene blend and projected that the tensile strength of the composites decreased with increase in filler loadings. Poor filler – matrix interaction and, also, the size irregularity of the oil palm empty fruit bunch could be responsible for the observed decrease of tensile strength with filler loadings observed in this study.

Figure 1 also shows that the smaller the particle size of the filler (OPEFB), the higher the tensile strength of high density polyethylene composite at any filler loading investigated, and vice versa. The envisaged

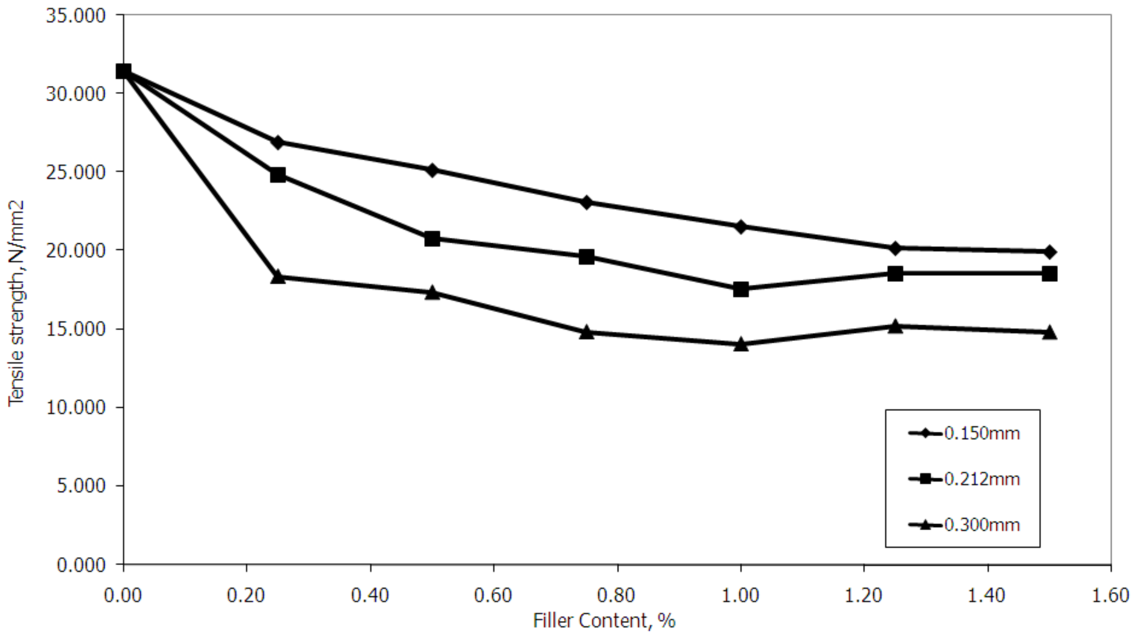

Fig. 1: Plot of Tensile Strength versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

better dispersion of smaller sized filler, and improved filler – matrix interaction may be the factors responsible for the observed trend. Similar observation on the variation of composite strength with filler particle size have been reported by Bigg [20] and Fuad et al [21] for other filled polymer systems.

Figure 2 shows the effect of the amount of MAPE on tensile strength of filled high density polyethylene. Figure 2 shows that the addition of small amount of MAPE (0.125 wt. %) generally improved the tensile strength of the composite significantly after which additional increases in the amount of MAPE led to small changes in the tensile strength of the composites.

The increase in the tensile strength of the composites on addition of MAPE is believed to be caused by maleic anhydride from the MAPE molecule which reacts with the hydroxyl groups of cellulose or hemicellulose, the two main constituents in oil palm empty fruit bunch fiber [22]. This reaction leads to an esterification reaction between the reinforcement and the matrix phase [23]. Furthermore, the long continuous chains in the MAPE molecules are compatible with the polymer matrix chains via physical entanglement [23]. The combination of both the chemical and physical bondings leads to improvement in composite tensile strength when the compatibilizer is added. As was stated above, further increase in the compatibilizer content beyond 0.125 wt. % has virtually little effect on the tensile strength of the composites. This suggests that there was not much stress transfer from the matrix to the fiber irrespective of MAPE content after 0.125 wt. % compatibilizer has been added.

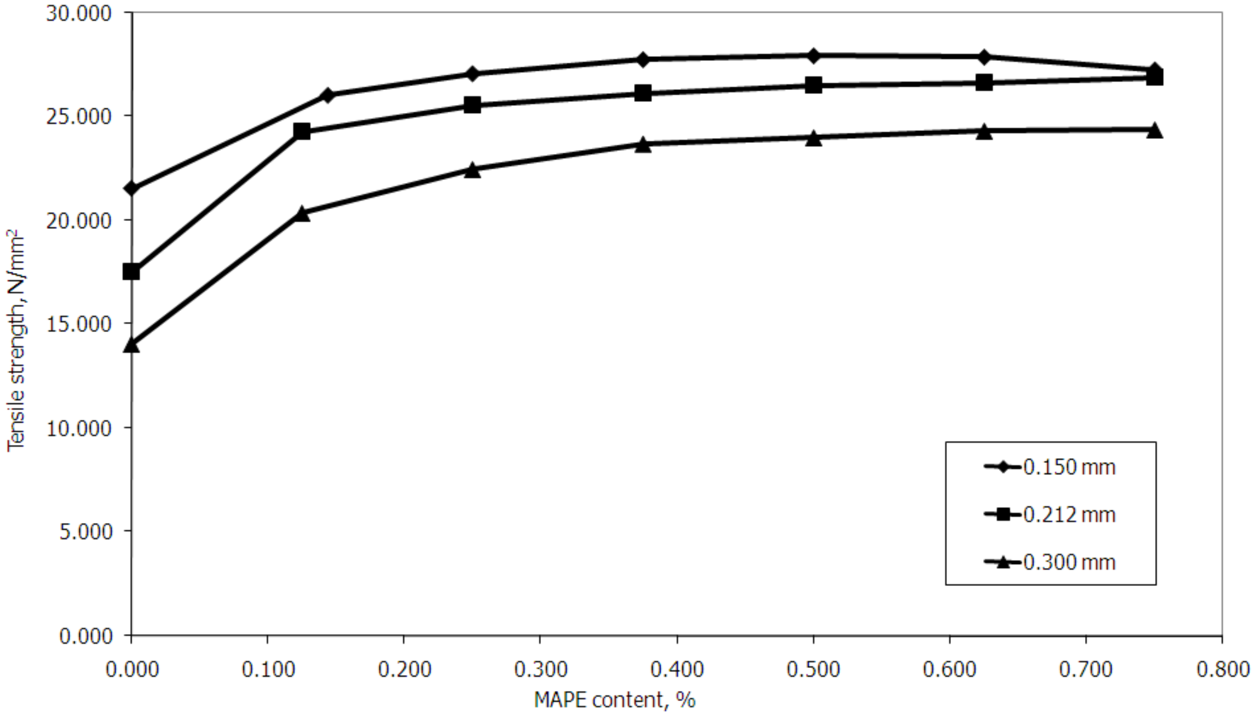

Fig. 2: Plot of Tensile Strength versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

The drop in tensile strength of OPEFB – HDPE composites when 0.625, and 0.750 wt. % of OPEFB were added (filler particle size, 0.150 mm) is probably due to the change in molecular morphology of the polymer near the fiber surface or in the bulk of the plastic phase. It is important to note that trans-crystallization and changes in the apparent tensile strength of the bulk matrix can result to changes in the contribution of matrix to the composite tensile strength. The reduction in tensile strength of the HDPE composites at high MAPE concentrations (0.625, and 0.750 wt. %) could also be attributed to a plasticising effect exerted by MAPE on the composites since it is possible that MAPE has a lower molecular weight compared to the matrix HDPE.

B. Elongation at Break (EB)

Elongation at break (EB) is a measure of ductility of a material. Figure 3 shows the effect of OPEFB loading and particle size the on elongation at break (EB) of high density polyethylene. The EB of unfilled high density polyethylene is 951.50 %. An examination of Figure 3 also reveals that the EB of oil palm empty fruit bunch filled high density polyethylene decreased with increase in filler loading at any filler particle size considered. Fillers can be considered as structural elements embedded in the polymer matrix, and at the concentrations of the OPEFB investigated (0.0 to 1.50 wt. %), the concentration might not be too high to significantly restrain the mobility of high density polyethylene molecules. Figure 3 also shows that the EB of OPEFB – HDPE composites of particle size, 0.150 mm were higher than those of 0.212, and 0.300 mm particle size at any filler loading considered.

Data on elongation at break (EB) of oil palm empty fruit bunch (OPEFB) – high density polyethylene (HDPE) composites in the presence of the compatibilizer (MAPE) are illustrated in Figure 4. The elongation at break of OPEFB – HDPE composites were significantly improved on addition of MAPE compatibilizer. At high MAPE content (0.625 to 0.750 wt. %), decreases in EB were however observed for the OPEFB – HDPE composites. The decrease in EB of the OPEFB – HDPE composites at high MAPE contents could be attributed to the migration of too much of the compatibilizer around the fibers, causing self – entanglement among the compatibilizers rather than the polymer matrix, resulting in slippage [1,24]. The initial increases in EB of OPEFB – HDPE composites with increases in MAPE contents could be attributed to improved adhesion between the OPEFB fiber and the polyethylene matrix.

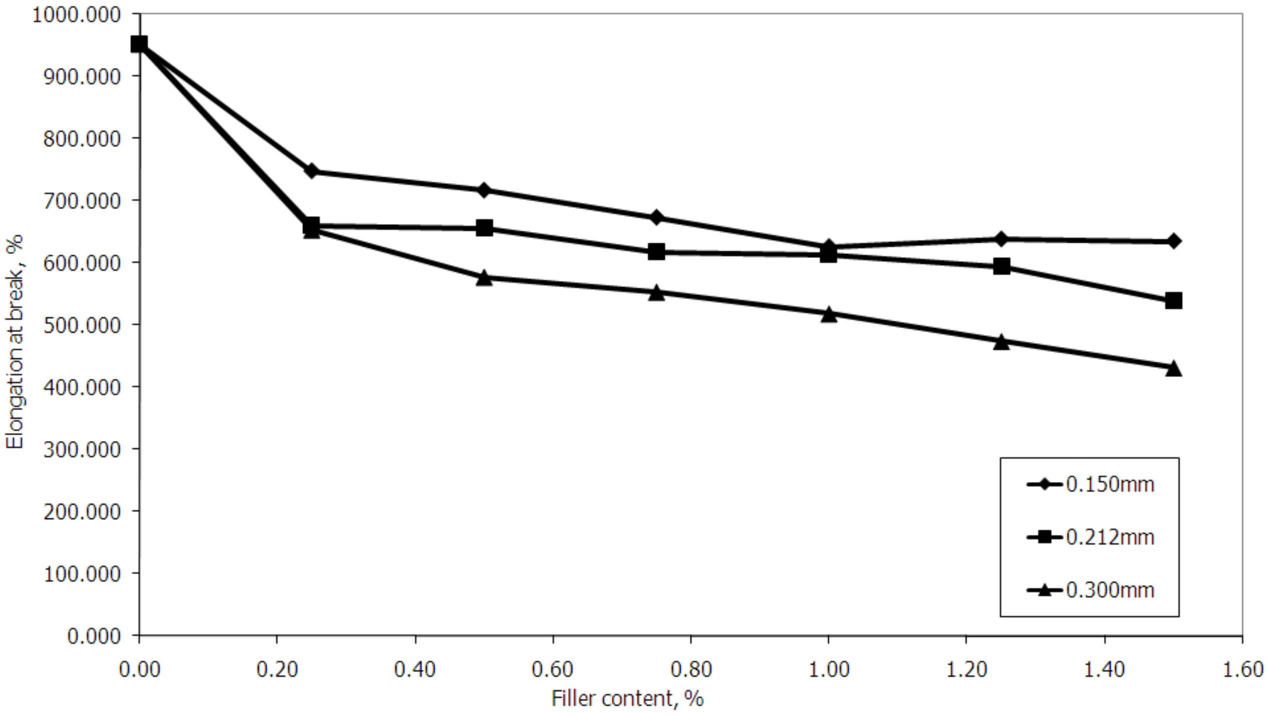

Fig. 3: Plot of Elongation at Break versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

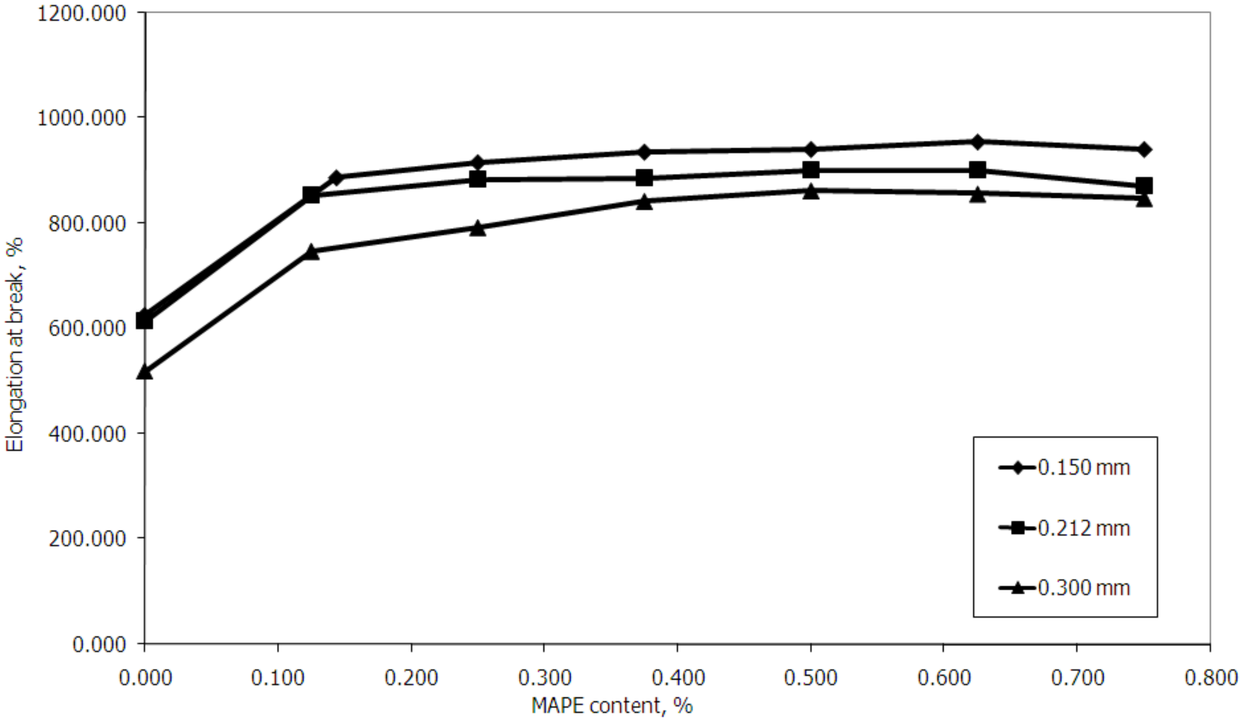

Fig. 4: Plot of Elongation at Break versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

C. Rockwell Hardness

Figure 5 shows the effect of OPEFB filler content and particle size on the hardness of filled high density polyethylene. The hardness of unfilled high density polyethylene is 63.0. The Figure shows that the hardness of all filled high density polyethylene at a given filler particle size increase with increase in the amount of filler incorporated into the polymer matrix. This result indicates enhancement of abrasion and impact strength of the composites. For a reinforcing filler, the composite becomes stiffer and harder with increasing filler content which results to increases in composite hardness. Such increases in composite property with increasing filler content have been reported by Chakraborty et al [25]. Also, Igwe and Njoku [26] who studied corn hub, and coconut fiber filled polypropylene found that the addition of these fillers raised the hardness of polypropylene composites and which increased with increases in filler content.

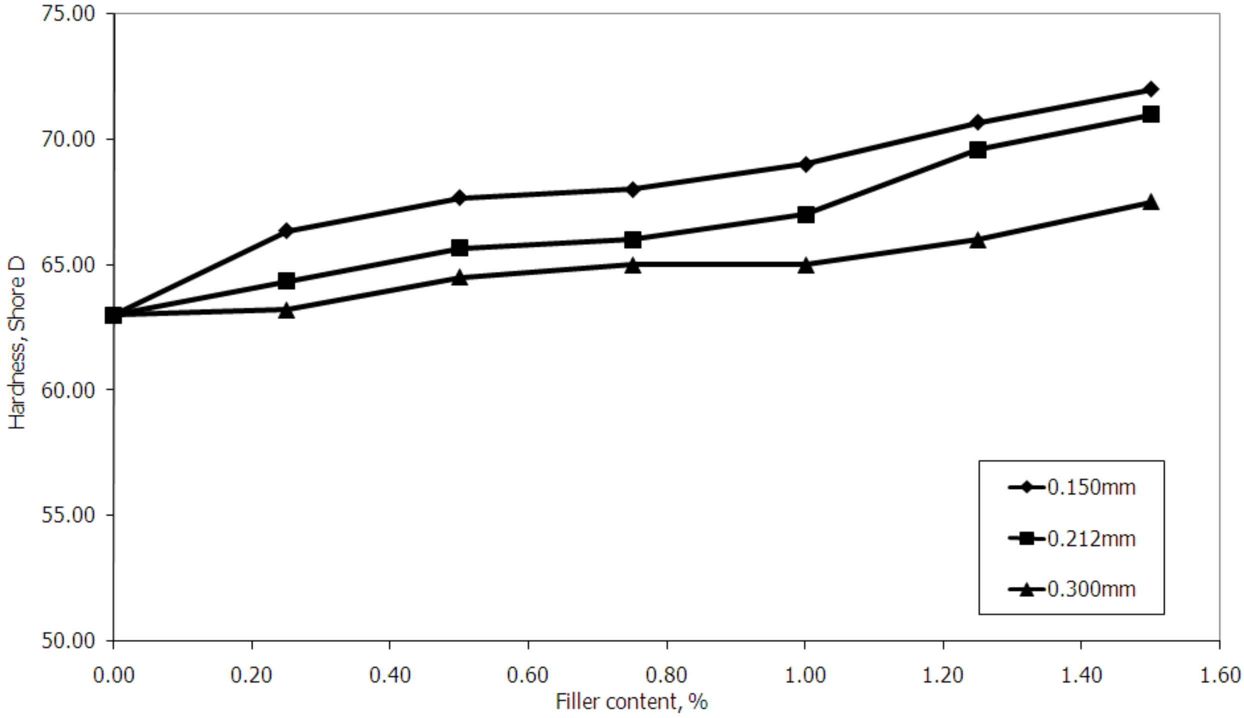

Fig. 5: Plot of Shore D Hardness versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

Generally, the hardness of the composites could be observed to decrease with increases in the particle sizes of the OPEFB at any given OPEFB loading. Such a decrease in the hardness of a polymer composite with particle size had been reported by Machiadikwe [27]. The decrease in hardness of a composite with increase in filler particle size could be attributed to decreases in the degree of polymer – filler interaction associated with larger filler particle size. The effect of MAPE on the hardness of oil palm empty fruit bunch fiber filled high density polyethylene at a fixed OPEFB loading, 1.0 wt. % is illustrated in Figure 6. A general increase in the hardness of HDPE composites with increase in MAPE content is observed from Figure 6. The addition of MAPE increased the interfacial bonding between the HDPE matrix and the OPEFB filler and this could modify the microstructure of the surrounding matrix with increases in composite hardness.

D. Water Sorption (24 h Cold and 2 h Hot)

The water sorption (24 h cold water, and 2 h hot water) indices of OPEFB fiber filled high density polyethylene are illustrated graphically in Figures 7 to 10. All the high density polyethylene composites generally showed increases in both cold and hot water absorption with increase in OPEFB content. It is also observed that the amount of water absorbed at any given filler loading increased with increase in the particle size of OPEFB fiber filler. The hydrophilic nature of OPEFB fiber filler is believed to be responsible for the water absorbed by the composites. The amount of water absorbed increased with increase in OPEFB loading. Generally, the polymer matrix (HDPE) has small water absorption index as indicated by the amount of water absorbed by pure HDPE.

The use of the compatibilizer MAPE, in this study, decreased the amount of water absorbed by the composites OPEFB at any OPEFB particle size considered (Figures 9 and 10). This decrease in water absorption is attributed to some of the hydrophilic – OH groups reacting with acid anhydride of MAPE to form ester linkages, with the resultant decrease in water absorption values. Similar to our findings, Bogoera-Gacera et al [28] who studied jute fiber filled polypropylene reported that the water absorption values of the composites increased with increase in jute fiber loading, and in the presence of the compatibilizer MAPP, the amount of water absorbed was found to decrease with increase in MAPP content.

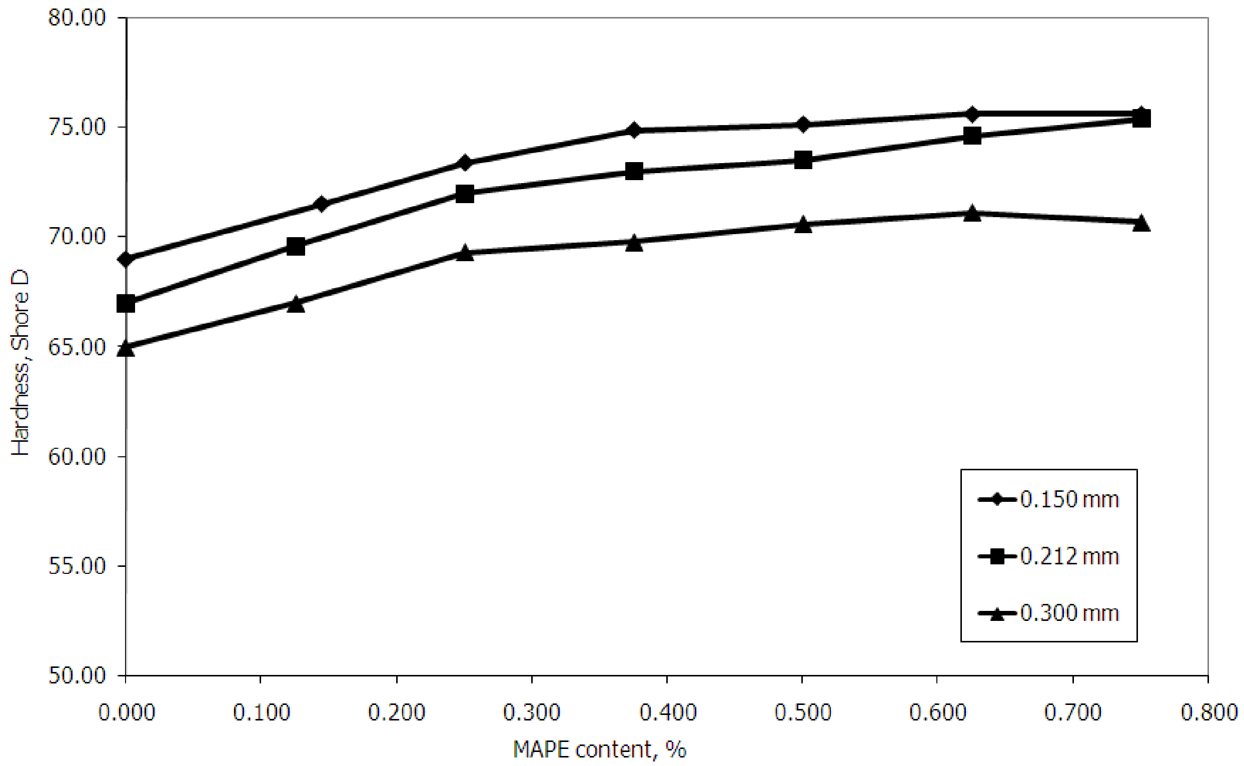

Fig. 6: Plot of Shore D Hardness versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

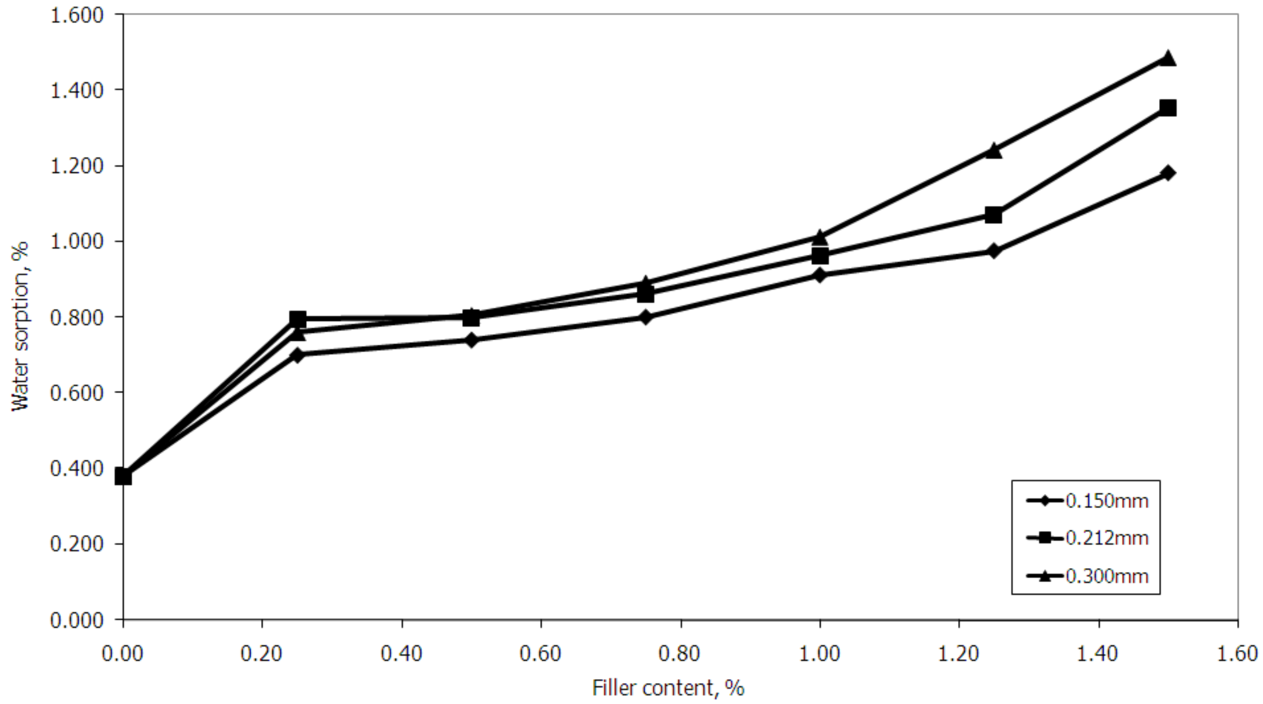

Fig. 7: Plot of Cold Water Sorption versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

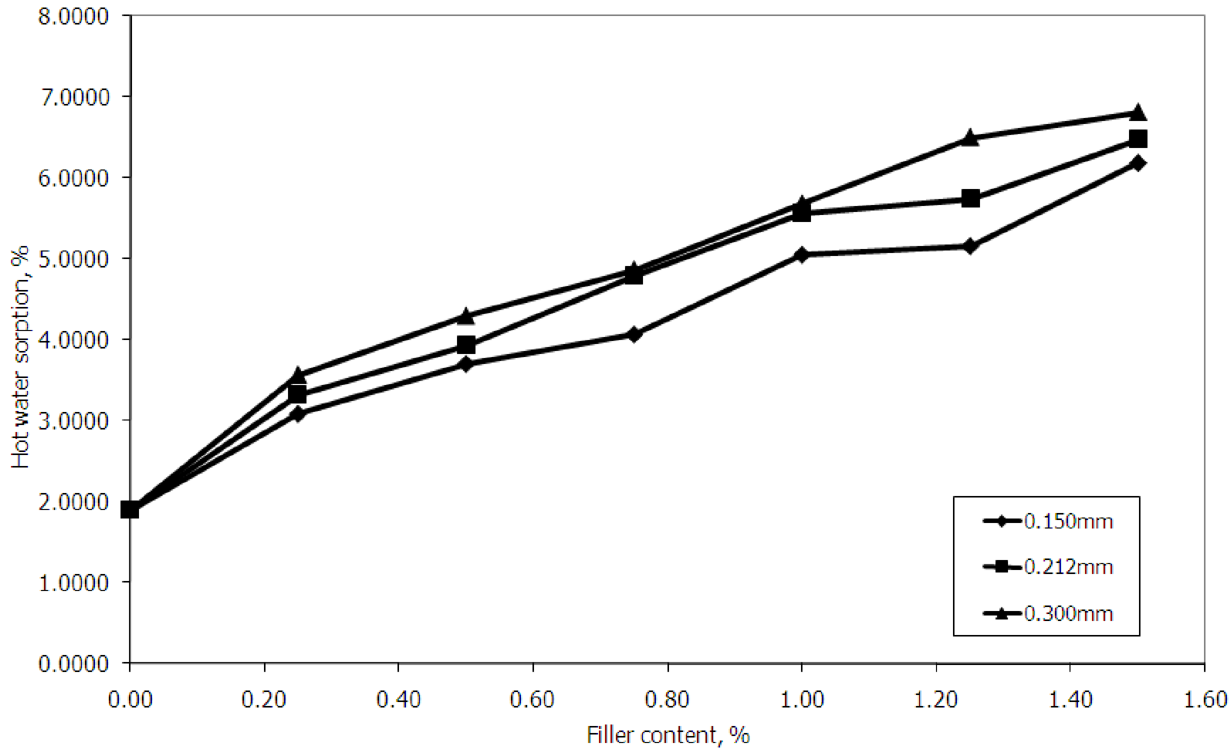

Fig. 8: Plot of Hot Water Sorption versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

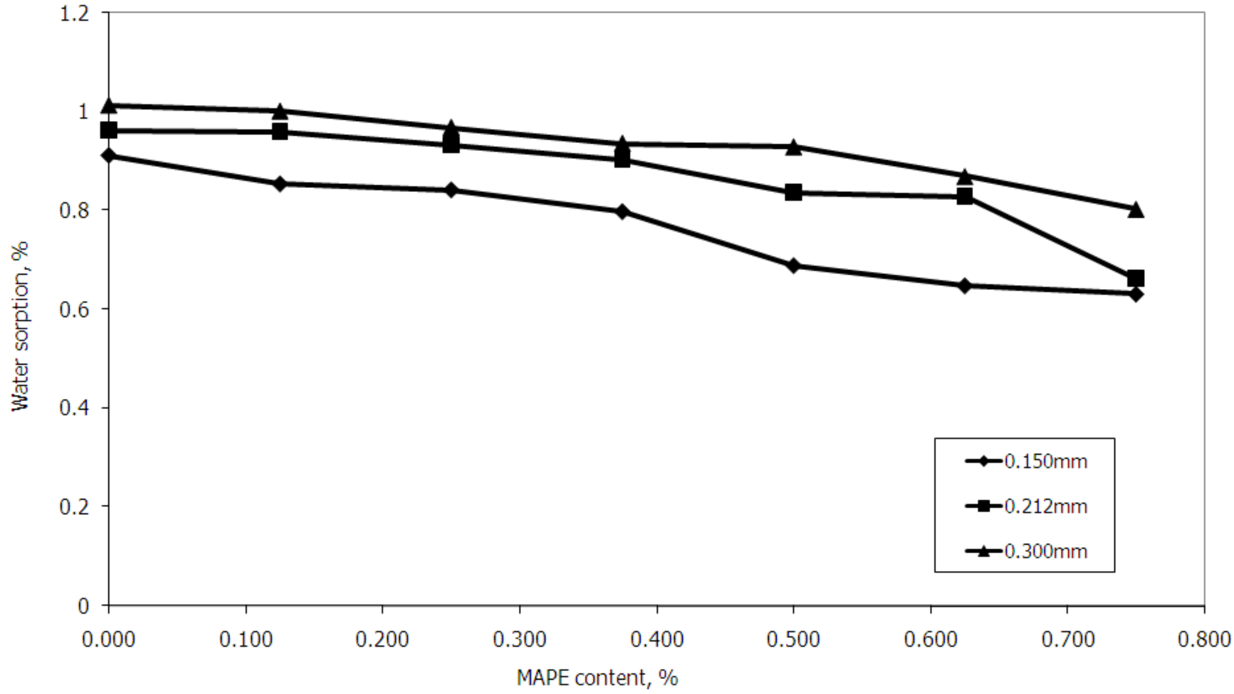

Fig. 9: Plot of Cold Water Sorption versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Size.

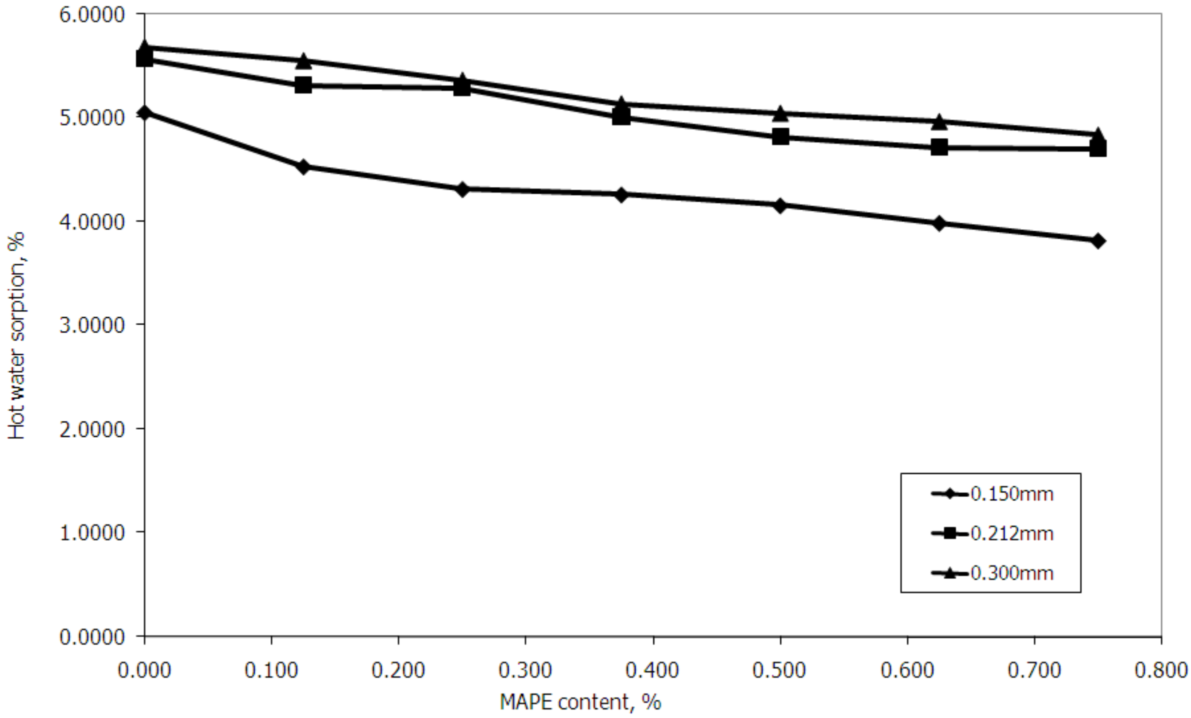

Fig. 10: Plot of Hot Water Sorption versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Size.

Water absorption is one of the important characteristics of natural fiber – polymer composites that determine their end-use applications. It could lead to a decrease in some of the composite properties, and needs to be considered when selecting applications for possible use of composites. Although water absorption could lead to a decrease in the end-use applications of the composites studied, there is reason to believe that by understanding the limitations and benefits of the OPEFB filled HDPE, the filler (OPEFB) is not likely to be ignored by the composite industries for use in automotive, building appliance and other applications.

E. Specific Gravity

Data on the specific gravity of the various OPEFB filled HDPE are illustrated graphically in Figures 11 to 12. The specific gravity of unfilled HDPE is 0.974. Figure 11 shows that there was a general increase in the specific gravity of the composites with increase in filler loading at any OPEFB particle size considered. The figure also shows that there was a general decrease in the specific gravity of the HDPE composites with increases in the particle size of OPEFB filler. The increase in specific gravity with a reduction in filler particle size is attributed to the envisaged greater, and more uniform dispersion of the smaller sized filler in the polymer matrix. The observed decreases in the specific gravity of HDPE composites with increase in OPEFB fiber filler particle size is small at any OPEFB loading considered.

The effect of MAPE on the specific gravity of HDPE composite at a fixed OPEFB loading is shown in Figure 12. The use of MAPE is observed to increase the specific gravity of the composites. This observed increase is attributed to improved interaction, and adhesion between the polymer matrix and OPEFB filler particles. The general increase in the specific gravity of OPEFB – HDPE composites with increase in filler/compatibilizer loadings as observed in this study is in general agreement with the work of Dean [29].

F. Flame Propagation Rate

The rate of burning of filled HDPE composites are illustrated graphically as shown in Figures 13 and 14 respectively. Figure 13 shows that the OPEFB fibre is inefficient as a filler in decreasing the rate of burning of HDPE composites at the loadings investigated. It is important to note that the introduction of small amount of OPEFB (0.20 wt. %) into HDPE significantly increased the rate of burning of the composites.

The increase in the rate of burning of HDPE composites with increase in OPEFB fibre particle sizes is again attributed to the envisaged poor dispersion of the larger sized OPEFB fillers in the composites, which resulted in less absorption of energy. The present flame propagation properties of OPEFB fibre investigated in this study could be attributed to the fact that a good percentage of the contents of OPEFB fibre might be combustible, and so, provide environments favourable to flaming. Igwe and Njoku [26] who studied natural fiber – polypropylene composites found that the flame propagation rates of corn hub, and wood saw dust fiber filled polypropylene were not particularly good at all the fiber loadings investigated. However, newsprint fibre filled polypropylene showed good flame retardant property at all the fibre loadings investigated.

The incorporation of MAPE into HDPE composites generally decreased the flame propagation spread and which decreased with increase in MAPE content. The use of MAPP appeared to decrease the energy needed to initiate burning in the system, and which increased with increase in MAPE content.

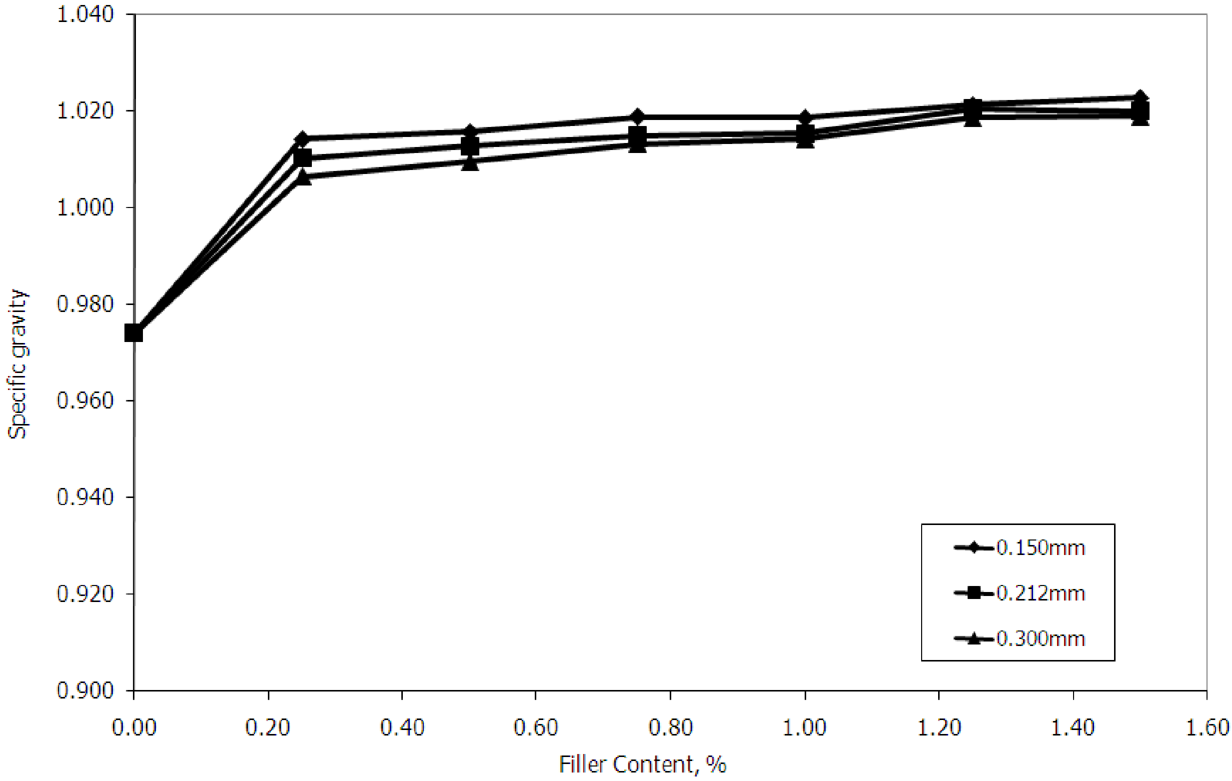

Fig. 11: Plot of Specific Gravity versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

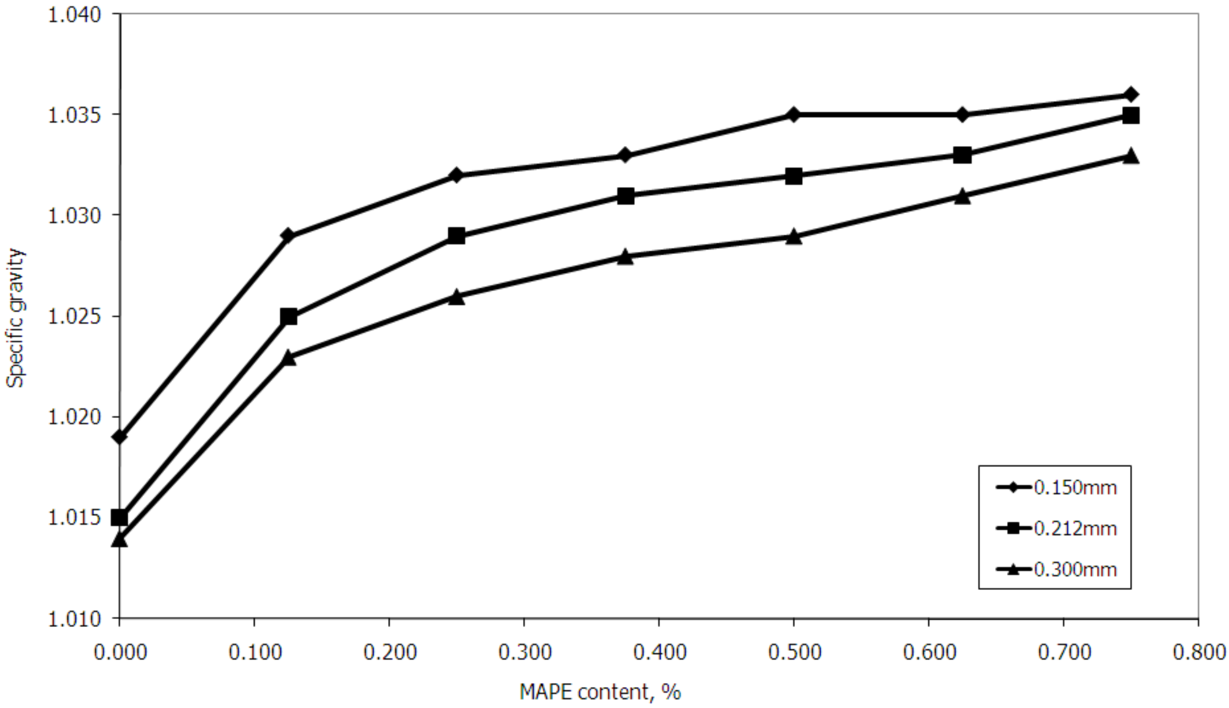

Fig. 12: Plot of Specific Gravity versus MAPE Content for HDPE/OPEFB Composites at various Filler Particle Size.

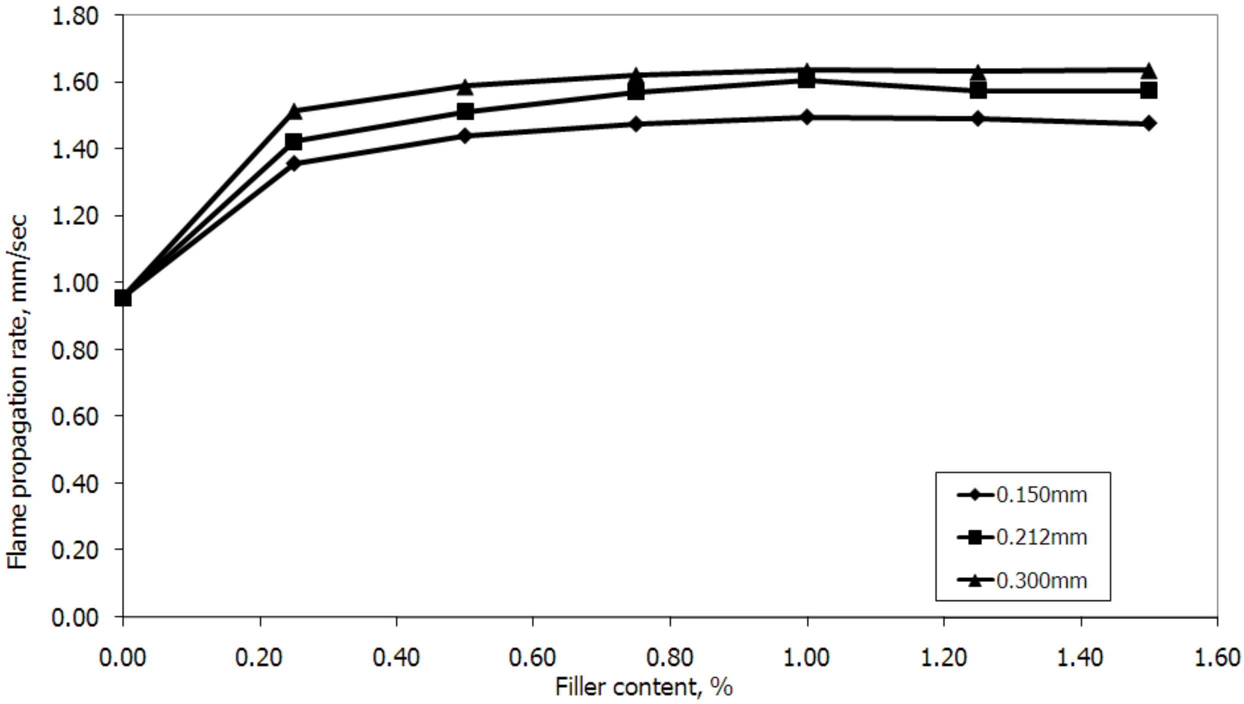

Fig. 13: Plot of Flame Propagation Rate versus Filler Content for HDPE/OPEFB Composites at various Filler Particle Sizes.

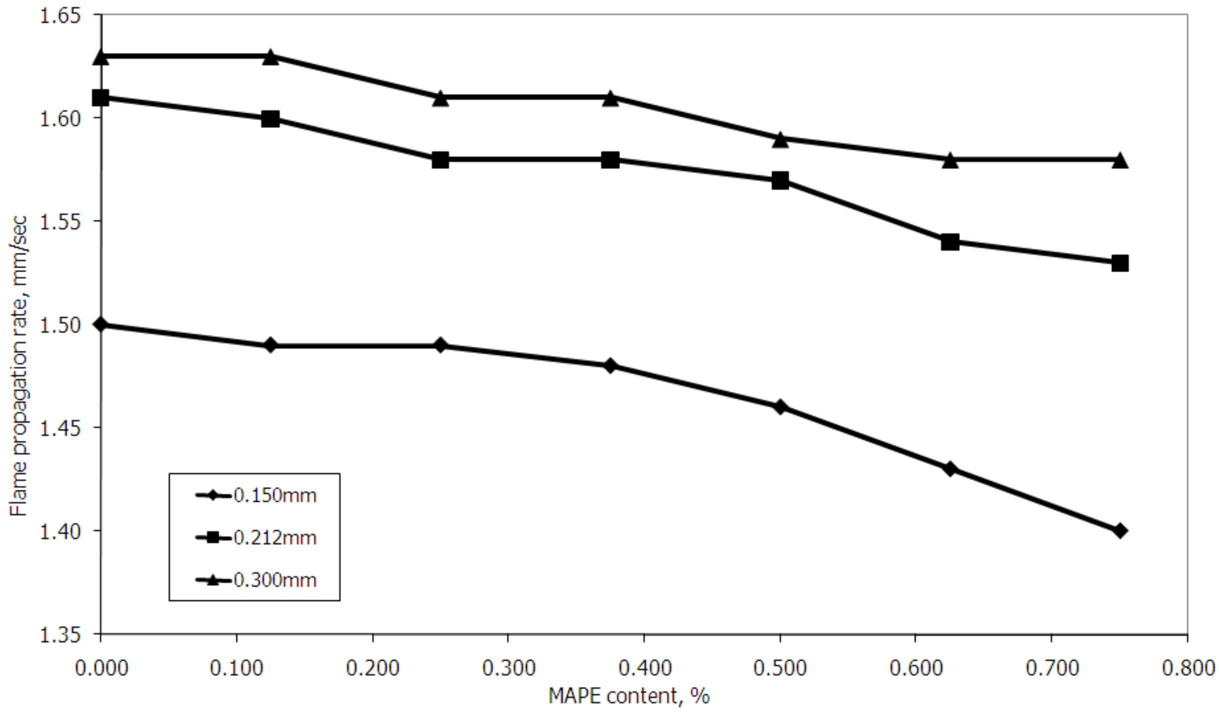

Fig. 14: Plot of Flame Propagation Rate versus MAPE Content for HDPE/OPEFB Composite at various Filler Particle Size.

VI. CONCLUSIONS

The tensile strength, and elongation at break of oil palm empty fruit bunch fibre filled high density polyethylene showed decreases with increase in oil palm empty fruit bunch fibre loadings. The addition of MAPE into HDPE composites at OPEFB loading was found to significantly improve the tensile properties of composites. The hardness, and specific gravity of the composites were found to increase with increase in OPEFB fibre loadings, and decrease in fibre particle size. These properties were further improved upon by the addition of MAPE compatibilizer. The water absorption indices of the composites were generally poor, and were decreased on addition of MAPE. The OPEFB fibre was inefficient in decreasing the flame propagation rates of HDPE. However, the incorporation of MAPE into the systems led to reductions in the rate of burning of the composites.

The cost of oil palm empty fruit bunch fibre is less than that of HDPE matrix in the cellulosic-based composites. The envisaged reduced equipment abrasion on the use of OPEFB fibre is definitely a factor that needs to be considered by the plastic industry when evaluating OPEFB fiber as a filler. The level of water sorption by maleated HDPE composites is less than that of the unmaleated HDPE composite. It is therefore very important to select applications where this level of water absorption by HDPE composite is not a critical factor such as in electrical housing components. Generally, the level of property improvement observed in the tensile strength, elongation at break, hardness, specific gravity, flame retardancy, and water sorption shown by maleated HDPE composites is good that OPEFB fibre hoped, will definitely develop its niche in the plastic filler market in the future.

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