Mechanical and End-Use Properties of High Density Polyethylene (HDPE) Filled with Plantain Peel Powder

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Abstract

The mechanical and end-use properties of plantain peel powder (PPP) filled high density polyethylene (HDPE) was studied at filler particle size of 0.075 and 0.30 mm. The filler content of 0, 2.5, 5, 10, 20, and 30 wt % were used in preparing the HDPE composite. Polyethylene-graft-maleic anhydride (MAPE) was used as the compatibilizing agent in this study. Three replicated specimens of each composition were tested for each property, and the resulting average data were reported. The composites were produced by extrusion method. The tensile strength and elongation at break reduced with increase in filler content however there was improvement in these two properties when the MAPE was added into the composites. The critical interfacial saturation concentration of MAPE was found to be 1.40 wt. % for PPP filler of particle size 0.075 mm and 1.75 wt. % for 0.30 mm filler particle size. Also the hardness, specific gravity, water absorption and flame propagation showed improved results with addition of MAPE into the composites.

Keywords – *plantain peel powder, specific gravity, water absorption, tensile strength. Elongation at break, high density polyethylene.*

I. INTRODUCTION

Polymer composites reinforced with natural fillers like wood fibre or flour has acquired general popularity over the two last decades [1]. Natural fibres offer many technical and ecological benefits and therefore present more advantages over synthetic fibres as reinforcements in composite materials [6]. These environmentally friendly composites have many remarkable properties in comparison with conventional composites using glass fibres and mineral fillers because of their low density and low cost [1].

It has been argued by some academic researchers that plant-based natural fibres can successfully compete with glass fibres in current market because of their attractive properties, which include low cost, low density, good specific strength properties, renewability, carbon dioxide neutrality emissions, and sustainability [2].

Composites based on natural fillers and polymer matrix exhibit some disadvantages like poor adhesion between matrix and filler that easily absorb moisture. Hence compatibility between the filler and the matrix is considered as the key to enhance properties of this composite [1]. A moisture buildup in the fibre cell wall can lead to thickness swelling and dimensional changes in the composite. The thickness swelling can lead to reduction in adhesion between the fibre and the polymer matrix. Hence the water absorption can have undesirable effects on the mechanical properties of the composites [4].

Chemical modifications have been used to improve the interactions between the natural fibres and matrix at the interface. Many researchers have carried out studies on the effects of chemical modification. One method that can generally be used to improve the interactions at the interface is the use of maleated polyethylene (MATE) as a compatibilizer. The effectiveness of the compatibilizer on enhancing the matrix-filler interactions at the interface has been reported by many researchers [5].

This study reports the mechanical and end-use properties of high density polyethylene filled with plantain peel powder using maleic anhydride-graft polyethylene as compatibilizer.

II. LITERATURE REVIEW

Thakore et al. ([8]) in their study on morphology, thermo mechanical properties, and biodegradability of low density polyethylene/starch/starch acetate blends reported that tensile strength, elongation at break, and izod impact strength of the blends decreased with increase in starch content. However, the incorporation of starch acetate along with starch improved all these properties, particularly, the elongation at break and toughness. The melt flow index was also improved on partial substitution of starch by starch acetate. Maximum biodegradability was observed for the blends containing 30 % (starch acetate).

Biodegradable blends of LDPE and cellulose acetate phthalate were prepared by Sailaja et al. ([9]), Maleic anhydride grafted LDPE was added as a compatibilizer to the blend. The elastic modulus and tensile strength were considerably improved by the addition of LDPE – g – maleic anhydride compatibilizer. Thermogravimetric analysis studies showed a two – stage degradation for the blends. Differential scanning calorimetry thermograms showed a loss of crystallinity for the LDPE phase.

Jacob et al. ([6]) reported their study on the mechanical and dynamic mechanical characterization of groundnut shell powder (GSP) filled recycled high density polyethylene composites. The composites were developed via melt mixing and compression moulding techniques. GSP was alkaline treated to increase compatibility with the matrix. The composites were subjected to mechanical and thermal characterization using 242E dynamic mechanical analyzer. The result showed that the storage modulus of all the composites increased with increase in weight percentage of GSP incorporated. The mechanical properties of the composites were enhanced.

Ismail et al. ([5]) carried out research on the effects of kenaf core loading and maleated polyethylene (MAPE) as a compatibilizer on high density polyethylene/soya powder. The samples were mixed in an internal mixer at 180 ^{0}C and 50 rpm rotor speed. The results indicated that the tensile strength and elongation at break decreased with increasing filler loading, whereas stabilization torque, tensile modulus, flexural strength, flexural modulus, and water absorption exhibited an increasing trend. The presence of MAPE also enhanced the tensile and flexural properties of the composites.

Ewulonu et al. ([3]) studied the properties of oil palm empty fruit bunch fibre filled high density polyethylene at filler loading of 0 to 1.5 wt. %, using maleic anhydride-g-polyethylene (MAPE) as compatibilizer. The composite was injection moulded and the result showed that the tensile strength and elongation at break decreased with increase in filler loadings. However, addition of MAPE improved these properties. Moreover, the hardness and specific gravity of the composite increased with increase in filler loadings and were further increased on addition of MAPE.

III. METHODOLOGY

A. MATERIAL

High density polyethylene

The high density polyethylene used in this research was obtained from Indorama Petrochemical Company Limited, Eleme, Rivers State, Nigeria. The melt flow index (MFI) and density of the polymer is 2.2 g/10 min and 0.965 g/cm^3 respectively.

Compatibilizer

Maleic anhydride graft polyethylene (MA-g-PE), a product from Sigma-Aldrich Cheme GmbH, Germany was used as the compatibilizing agent. Its characteristics are 3 wt % maleic anhydride, saponification value 32 – 36 mg KOH/g, viscosity 1,700 – 4,500 cP (140^{0}C) (lit), soluble in toluene and xylene, insoluble in water, melt flow index 1.5 g/10 min and has glass transition temperature (T_m) of 105 ^{0}C at peak.

Filler

Plantain peel powder (PPP) was used as a filler in the preparation of high density polyethylene composites. The plantain peels were collected from Ekeonunwa Market in Owerri, Imo State, Nigeria. The peels were washed thoroughly with distilled water to remove impurities, then sun dried, and dried at 300 ^{0}C for two hours in an oven. It was later crushed to fine powder and sieved to 0.075 and 0.30 mm mesh sizes respectively.

Equipments

The following equipments were used in this study,

1. Electronic weighing balance
2. Retort stand
3. Injection moulding machine
4. Instron Universal Testing Machine (Zwick Roell model Z005)
5. Rockwell hardness tester
6. Air circulating oven
7. Micrometer screw gauge
8. Dumbbell cutter
9. Weighing machine

B. METHODS

Preparation of High Density Polyethylene Composites

Three sets of samples were prepared, firstly 100 % high density polyethylene (as a control), secondly, high density polyethylene (HDPE) blended with plantain peel powder (PPP) at different filler contents, and thirdly, high density polyethylene/plantain peels composite in the presence of the compatibilizer, maleic anhydride graft polyethylene (MAPE). The blends of high density polyethylene and plantain peel powder composites at particle sizes of 0.075 mm and 0.30 mm respectively were prepared by thoroughly mixing 700 g of high density polyethylene with the approximate filler quantities (0.25, 0.50. 0.10, 0.20, and 0.30 wt. %). The high density polyethylene was first melted at 150 ^{o}C and then homogenized with the filler in an injection moulding machine. The resultant composites were then extruded as sheets of thickness, 2.10 mm.

The second set of composites were prepared at fixed quantities of high density polyethylene (70 wt. %), plantain peels filler (30 wt. %), calculated quantities of maleic anhydride graft polyethylene (0.35, 0.70, 1.05, 1.40, 1.75, and 2.10 wt. %). The measured weights were fed into an injection moulding machine, homogenized, and extruded as sheets,

Table I and II showed the compositions of the biocomposites prepared.

Table I: Composition of HDPE Composites with PPP

S/No.	Formulation	HDPE content wt. %	Filler content wt. %
1	Virgin HDPE	100	0.0
2	HDPE/PPP/2.5	97.5	2.5
3	HDPE/PPP/5.0	95.0	5.0
4	HDPE/PPP/10.0	90.0	10.0
5	HDPE/PPP/20.0	80.0	20.0
6	HDPE/PPP/30.0	70.0	30.0

Table II: Composition of HDPE/PPP in the Presence of MAPE

S/No.	Formulation	HDPE content, wt. %	PPP content, wt. %	MAPE content, wt. %
1	MAPE/0.35	70	30	0.35
2	MAPE/0.70	70	30	0.70
3	MAPE/1.05	70	30	1.05
4	MAPE/1.40	70	30	1.40
5	MAPE/1.75	70	30	1.75
6	MAPE/2.10	70	30	2.10

Tensile Strength Test of HDPE Composites

Instron Universal Testing Machine (Zwick Roell Model Z005) was used according to ASTM D-638 method. A Zwick cutting machine (model 7103) was used in cutting sample specimens from the obtained sheets according to standard method. A load cell of maximum capacity, 10 kN operating at a grip separation speed of 50 mm/min. The dimensions of the specimen were as follows; Specimen length (Lo) = 30 mm, Specimen thickness (a) = 2.18 mm, Specimen width (b) = 4.05 mm, Cross section area (Ao) = 8.83 mm^2.

The specimens were stretched in the testing machine. The force exerted on the specimens was measured. The stress was calculated using the equation

$$Stress\left(\frac{N}{mm^2}\right) = \frac{Force}{Area} \quad (1)$$

Elongation at break (%)

The elongation at break was calculated using the equation

$$\%\ Elongation = \frac{L - L_o}{L_o} X \frac{100}{1} \quad (2)$$

Where L = Length of the specimen upon stretching (mm)

L_o = original length of the specimen (mm)

Determination of end-use properties of composites

Specific gravity

The specific gravity (Sg) was performed according to ASTM D-792. An electronic weighing balance, equipped with a stationary support necessary for holding the immersion vessel above the balance pan (Mettler Toledo AB204-S) was used to measure the specific gravity of the composites. The test specimen (filled or unfilled polyethylene, 40 X 20 mm) was first weighed in air, (a) and later, the specimen was completely immersed in water and the weight was noted (b). The specific gravity of the specimen was calculated as follows;

$$Sg = \frac{a}{b} \quad (3)$$

Where a = mass of the specimen in air (g)

b = mass of the specimen in water (g)

Hardness test

The hardness measurements were performed according to ASTM D – 785 specifications, using a Rockwell hardness tester (Wilson Instrument, Norwood, USA). Each sample was placed on a steel anvil, and a steel ball with a load of 10 kg was forced into it. The dial at this small load was set at zero. After another 15 sec, the hardness was read on the dial of the instrument.

Water absorption

The water absorption of the composites was measured using a pre-dried sample, according to ASTM D570-81. Each of the specimen already cut to dimensions of 40 X 20 mm was first weighed, and the dry weight was noted (wi). The specimen was later placed in a clean beaker, and 150 ml of distilled cold and hot water was poured into the beakers which was immediately covered with a filter paper (Whatman Grade 1) and placed in a safe place. The sample was allowed to stay for 24 h at room temperature (31 ± 2 ^{0}C). At the expiration of the required time, the wet specimen was gently removed from the beaker using tweezers. The water adhering on the surface of the specimen was cleaned using a filter paper. Care was taken during the whipping process not to remove the water absorbed by the specimen. The specimen was weighed again (wf), the percentage water absorption by the composite specimen was calculated using the expression:

$$\%\ water\ absorption = \frac{Wf - Wi}{Wi} X \frac{100}{1} \quad (4)$$

Where Wf = weight of the specimen after swelling (g)

Wi = weight of the dry specimen (g)

Flammability test

The method employed here was a modification of ASTM D4804. A 10 mm mark was made on each of the specimen measuring 60 X 10 mm, the specimen was then clamped horizontally on the retort stand with a mark 10 mm distance protruding out of the clamp. The free end of the specimen was ignited using a cigarette lighter, and the time taken for the sample to ignite was recorded as the ignition time (Lt). The specimen was allowed to burn to the mark (Dd). The relative rates of burning for the different specimens were determined using the expression

$$Rate\ of\ burning\left(\frac{mm}{s}\right) = \frac{Dd}{Ft - Lt} \quad (5)$$

Where Dd = propagation distance (mm)

Ft = flame propagation time (sec)

Lt = ignition time (sec)

IV. RESULT AND DISCUSSION

MECHANICAL PROPERTIES RESULTS

Table III: The Effects of Plantain Peel Powder (PPP) Contents on the Mechanical Properties of HDPE Composite at Different Loadings (particle size, 0.075 mm).

Filler content (wt. %)	Mechanical Properties	
	Tensile strength (TS) (MPa)	Elongation at break (EB) (%)
0.00	18.8 ± 3	790 ± 3
0.25	17.9 ± 3	636 ± 3
0.50	16.2 ± 3	507 ± 3
1.00	15.3 ± 3	297 ± 3
2.00	13.8 ± 3	168 ± 3
3.00	12.3 ± 3	88 ± 3

Table IV: The Effect of PPP Content on the Mechanical Properties of High Density Polyethylene Composites at Different Loading (particle size, 0.30 mm).

Filler content (wt. %)	Mechanical Properties	
	Tensile strength (TS) (MPa)	Elongation at break (EB) (%)
0.00	18.8 ± 3	790 ± 3
0.25	17.1± 3	612 ± 3
0.50	15.1 ± 3	495 ± 3
1.00	13.3 ± 3	193 ± 3
2.00	11.9 ± 3	108 ± 3
3.00	10.7 ± 3	55 ± 3

Table V: The Effects of MAPE Compatibilizer on the Mechanical Properties of HDPE Composites at Fixed Filler Loading of 30 wt. %, (Filler particle size, 0.075 mm).

Filler content (wt. %)	HDPE content (wt. %)	Compatibilizer content (wt. %)	Mechanical properties	
			Tensile Strength (MPa)	Elongation at break (%)
30.0	70.0	0.0	12.3 ± 3	88 ± 3
30.0	70.0	0.35	17.3 ± 3	266 ± 3
30.0	70.0	0.70	18.8 ± 3	476 ± 3
30.0	70.0	1.05	20.9 ± 3	613 ± 3
30.0	70.0	1.40	24.9 ± 3	697 ± 3
30.0	70.0	1.75	23.5 ± 3	703 ± 3
30.0	70.0	2.10	23,2 ± 3	691 ± 3

Table VI: The Effects of MAPE Compatibilizer on the Mechanical Properties of HDPE Composites at Fixed Filler Loading 30 wt. %, (filler particles size, 0.30 mm).

Filler content (wt. %)	HDPE content (wt. %)	Compatibilizer content (wt. %)	Mechanical properties	
			Tensile strength (MPa)	Elongation at break (%)
30.0	70.0	0.0	10.7 ± 3	55 ± 3
30.0	70.0	0.35	13.0 ± 3	153 ± 3
30.0	70.0	0.70	15.5 ± 3	365 ± 3
30.0	70.0	1.05	18.2 ± 3	472 ± 3
30.0	70.0	1.40	19.1 ± 3	588 ± 3
30.0	70.0	1.75	19.9 ± 3	581 ± 3
30.0	70.0	2.10	19.7 ± 3	578 ± 3

END-USE PROPERTIES RESULTS

Table VII: Effects of PPP Contents on the End-Use Properties of HDPE Composites at Filler Particle

Filler content (w/w %)	End Use Properties			
	Hardness (Shore D)	Specific Gravity	Flame propagation rate (mm/sec)	Water Absorption (24 h)
0.00	65.00	0.965	1.08	0.0030
2.5	67.40	1.017	1.11	0.0032
5.0	68.50	1.019	1.14	0.0033
10.0	69.80	1.022	1.19	0.0035
20.0	71.20	1.023	1.21	0.0036
30.0	72.70	1.024	1.22	0.0037

Size, 0.075 mm.

Table VIII: Effects of PPP Filler Contents on the End – Use Properties of HDPE Composites at Filler

Filler content (w/w %)	End Use Properties			
	Hardness (Shore D)	Specific Gravity	Flame Propagation rate (mm/sec)	Water Absorption (24 h)
0.00	65.00	0.965	1.08	0.0030
2.5	65.5	1.007	1.13	0.0033
5.0	66.70	1.010	1.17	0.0035
10.0	67.10	1.011	1.21	0.0036
20.0	68.00	1.012	1.23	0.0038
30.0	69.50	1.012	1.24	0.0039

Particle Size, 0.30 mm.

Table IX: Effects of MAPE on the End – Use Properties of HDPE Composites at Filler Particle Size, 0.075 mm.

HDPE/ Filler content (wt. %)	Compatibilizer (MAPE) (wt. %)	End Use Properties			
		Hardness (Shore D)	Specific Gravity	Flame Propagation rate (mm/sec)	Water Absorption (24 h)
70/30	0.00	72.70	1.015	1.22	0.0037
70/30	0.35	74.20	1.021	1.19	0.0035
70/30	0.70	75.00	1.023	1.17	0.0034
70/30	1.05	75.46	1.024	1.16	0.0034
70/30	1.40	75.88	1.025	1.14	0.0033
70/30	1.75	76.10	1.026	1.13	0.0032
70/30	2.10	76.12	1.026	1.12	0.0032

Table X: Effects of MAPE on the End – Use Properties of HDPE Composites at Filler Particle Size, 0.30 mm.

HDPE/ Filler content (wt. %)	Compatibilizer (MAPE) (wt. %)	End Use Properties			
		Hardness (Shore D)	Specific Gravity	Flame Propagation rate (mm/sec)	Water Absorption (24 h)
70/30	0.00	69.50	1.012	1.24	0.0039
70/30	0.35	71.00	1.016	1.21	0.0037
70/30	0.70	72.30	1.019	1.19	0.0036
70/30	1.05	72.70	1.021	1.18	0.0035
70/30	1.40	73.10	1.023	1.16	0.0034
70/30	1.75	73.10	1.023	1.15	0.0034
70/30	2.10	73.00	1.024	1.14	0.0034

DISCUSSION

The tensile strength and the elongation at break decreased with increase in the filler content as shown in Table III and IV. These properties were also shown in Figure I and Figure III for tensile strength and elongation at break respectively. Also Rozman et al. ([10]) in their work on oil palm fruit bunch/polypropylene system found that the tensile strength of the prepared composites decreased with increase in filler content. Moreover, the decrease in tensile strength with increase in filler contents may be attributed to the likely heterogeneous dispersion of plantain peel powder in HDPE matrix and the resulting incompatibility of plantain peel powder and HDPE.

Thakore et al ([8]) in their research on starch blended low density polyethylene reported that the elongation at break decreased with increase in starch particle size. In synthetic polymer blends, the addition of the immiscible component to a ductile matrix generally decreases the elongation properties of the blends considerably at the break point.

However, when MAPE was added the tensile strength of the composite improved as shown in Table V and VI and Figure II. It is believed that the MAPE increased the adhesion between the HDPE and the PPP filler. These results also supports the assumption that the interaction between PPP filler and the MAPE was a chemical one between hydroxyl groups in cellulose and anhydride groups in MAPE ([11]).

The increases in the burning rate of HDPE composites with increased PPP filler particle size shown in Table VII, Table VIII and Figure V could be attributed to the poor dispersion of the large size filler in the HDPE matrix with its attendant consequences. The poor flame propagation of PPP filler observed in this study could be attributed to the fact that a good percentage of the contents of PPP filler might be combustible, and so, provide environments favorable to flaming. In Table IX, Table X and Figure VI however, it was noticed that increase in the MAPE content reduced the flame propagation in the composite.

The water absorption of HDPE composites was observed to increase with increase in PPP content at any particle size considered as shown in Table VII, Table VIII and Figure VII. Since polypropylene does not react with cellulose nor exhibit any compatibility with it, PPP filler tends to absorb water because of its

hydrophilic nature owing to its hydroxyl group contents.

However, the incorporation of MAPE into the HDPE was observed to decrease the amount of water absorbed by the composites at any filler particle size considered. This decrease in water absorption value could be as a result of the ester linkage formed in the reaction between hydrophilic – OH groups in the PPP filler and the anhydride. Similarly, decrease in water absorption by composites on incorporation of a compatibilizer has been reported by ([12]) and ([13]).

Table IX, Table X and Figure IX showed that there is a gradual increase in the specific gravity of the composites with increase in PPP filler. At any filler content considered, the specific gravity of the composites was observed to decrease with increase in the filler particle size. The increase in specific gravity with a reduction in filler particle size could be as a result of more uniform dispersion of the smaller sized filler in the polymer matrix. Furthermore, the specific gravity of the composites was observed to increase in MAPE content at the filler particle size studied and is shown in Table IX, Table X and Figure X. The increase in the specific gravity of the HDPE composites with increase in MAPE content is attributed to improved interaction and adhesion between the polymer matrix and filler particles. The observed increase in the specific gravity of the HDPE composites with increase in filler/compatibilizer contents is in agreement with work of Dean (2006).

The hardness result in Table VII, Table VIII and Figure XI indicate an enhancement of the abrasion and impact strength of the composites. For reinforcing fillers, the composite becomes stiffer and harder with increase in filler content, and this results to increase in the composite hardness. Such increases in the hardness property of a composite with increasing filler content had been reported by ([15]) who studied corn hub, and coconut fibre filled polypropylene. They found that the addition of these fillers raised the hardness of polypropylene composites and which increased with increased with increase in filler content. Finally, on addition of MAPE, the hardness equally increased with increase in the MAPE content as shown in Table IX, Table X and Figure XII. This indicates that the addition of MAPE increased the interfacial bonding between the HDPE matrix and the PPP filler. This could modify the microstructure of the surrounding matrix with the increase in the composite hardness.

V. CONCLUSION

This research has shown the successful utilization of locally sourced material, plantain peels as waste material on our road sides and various market places to modify and improve certain properties of a polymeric material – high density polyethylene. Using plantain peels to partially replace some available biodegradable synthetic plastics will not only reduce the dependence on petroleum but also reduce cost of production.

The tensile strength and elongation at break of PPP filled HDPE have been determined and showed decreases with increase in PPP filler contents. This result is an indication that PPP filler is not reinforcing filler. The addition of MAPE into the composites at a filler content of 0.35 wt. % was found to improve the tensile strength, and elongation at break of the composites at the two particle sizes investigated. The critical interfacial saturation concentration of MAPE was found to be 1.40 wt. % for PPP filler of particle size 0.075 mm, and 1.75 wt. % for 0.30 mm filler particle size. Generlly, the smaller the filler particle size, the higher the tensile strength and elongation at break.

Both the composite hardness (Shore D) and Specific gravity were found to increase in PPP filler contents at all the filler particle sizes investigated. Generally, the smaller the particle size of the filler, the higher the composite hardness and specific gravity. The specific gravity was further improved upon addition of MAPE compatibilizer to the composites.

The Flame propagation rate of the composites was found to increase in PPP filler content irrespective of the filler particle size. The addition of MAPE decreased the flame propagation rates of the composites. Flame propagation of the composites tends to increase in PPP loading. The addition of MAPE decreased the flame propagation of the composites.

The water absorption indices of the composites were found to increase with increase in PPP filler content and decrease in filler particle size. The water absorption indices were improved upon by the addition of MAPE into the systems. This resulted to decreases in the amount of water absorbed by the composites. Although, water absorption could lead to a decrease in the end-use properties of these composites, there is reason to believe that by understanding the limitations and benefits of PPP filled HDPE, the filler PPP is not likely to be ignored by composite industries for use in automotive, building appliance, and other applications.

Generally, the level of improvement observed in the properties of the composites determined in this study on addition of MAPE showed that MAPE is a good compatibilizer for use in PPP /HDPE composites.

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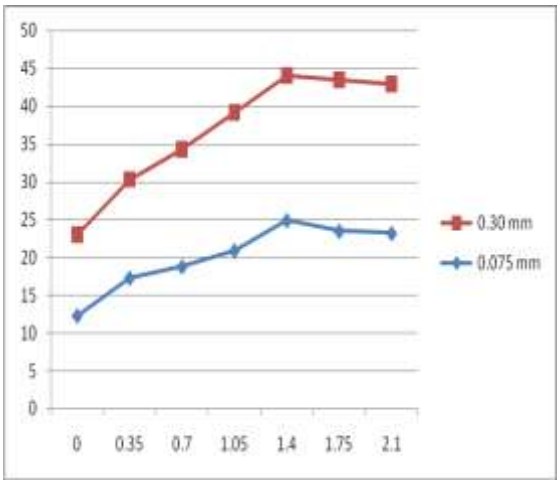

Figure II: Plot of Tensile Strength versus Compatibilizer Content.

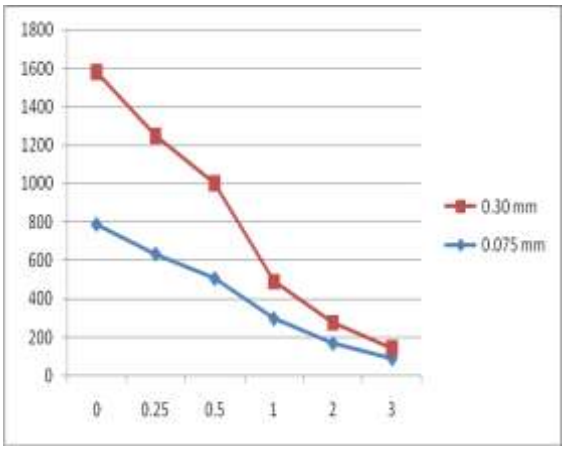

Figure III: Plot of Elongation at Break versus Filler Content for HDPE/PPP Composites at Different Filler Particles.

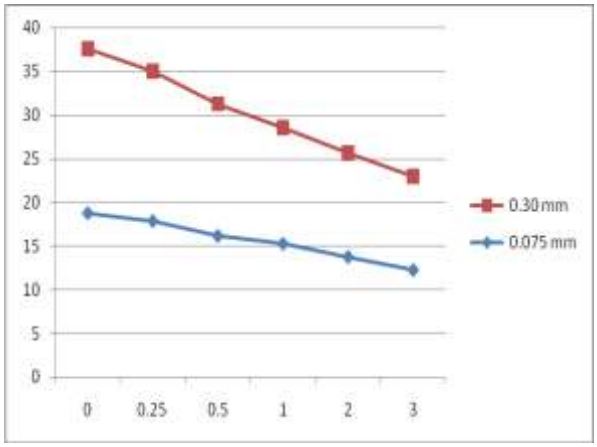

Figure I: Plot of Tensile strength versus Filler Content for HDPE/PPP Composites at Different Filler Particles.

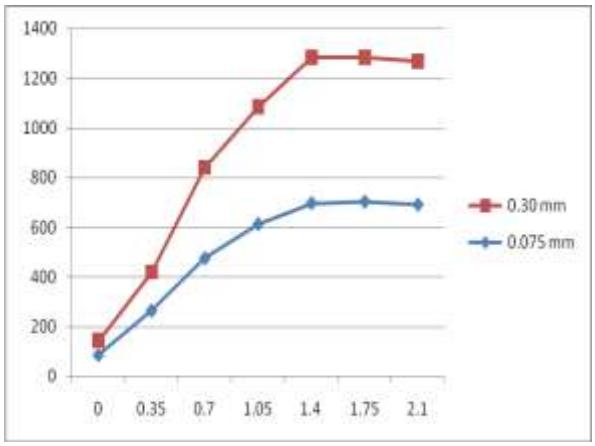

Figure IV: Plot of Elongation at Break versus Compatibilizer Content.

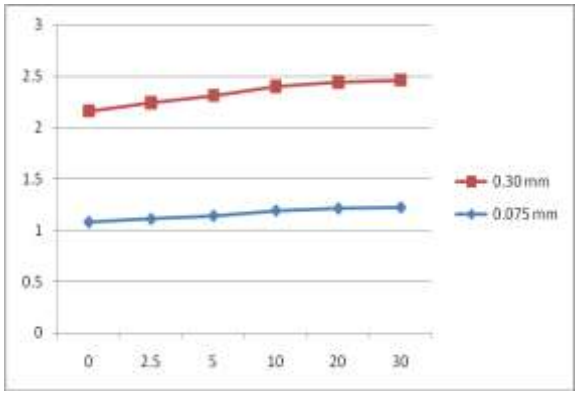

Figure V: Plot of Flame Propagation Rate versus PPP Content.

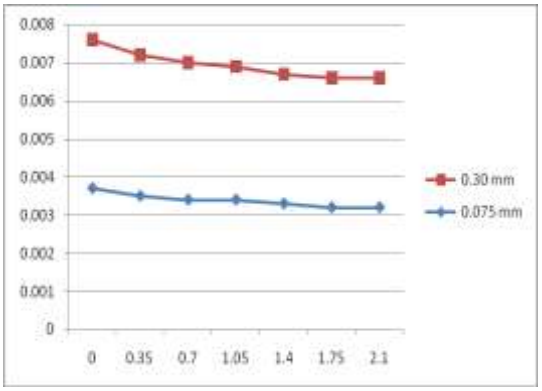

Figure VIII: Plot of Water Absorption versus Compatibilizer Content.

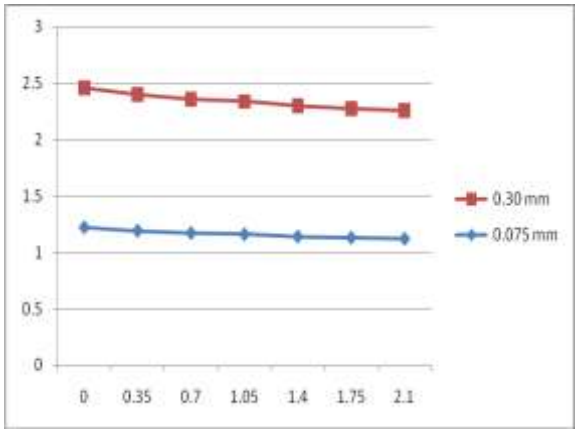

Figure VI: Plot of Flame Propagation Rate versus Compatibilizer Content.

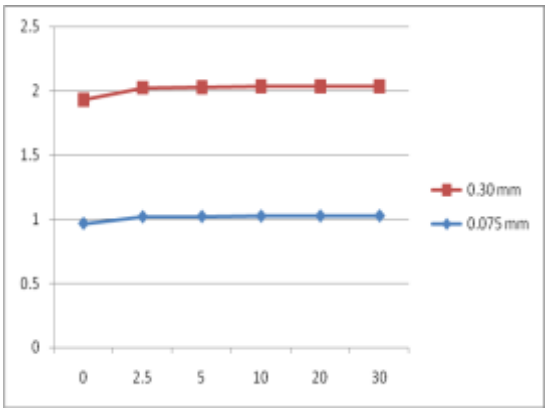

Figure IX: Plot of Water Specific Gravity versus PPP Content.

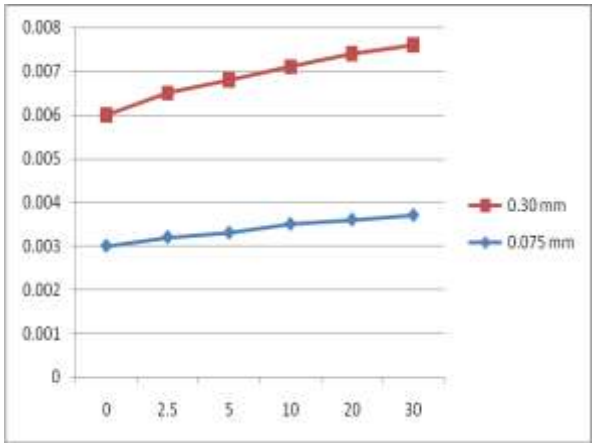

Figure VII: Plot of Water Absorption versus PPP Content.

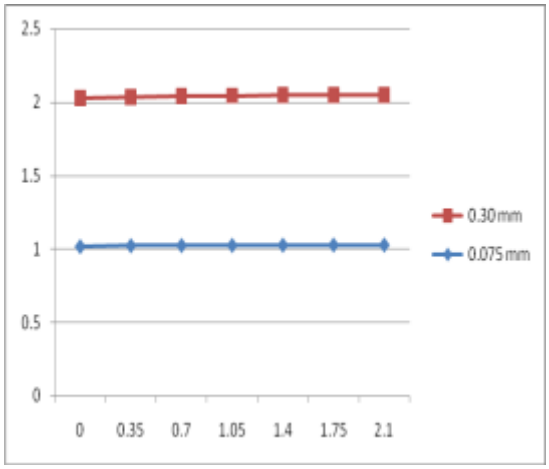

Figure X: Plot of Specific Gravity versus Compatibilizer Content.

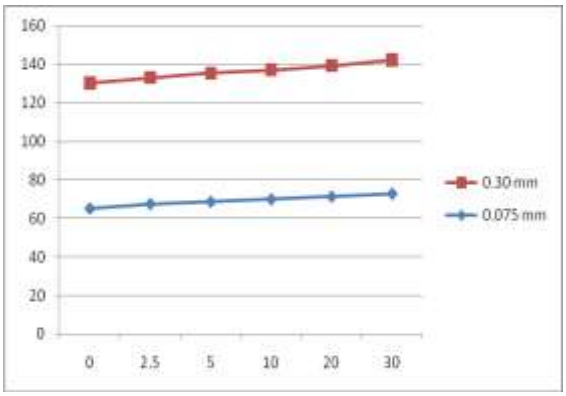

Figure XI: Plot of Water Hardness versus PPP Content.

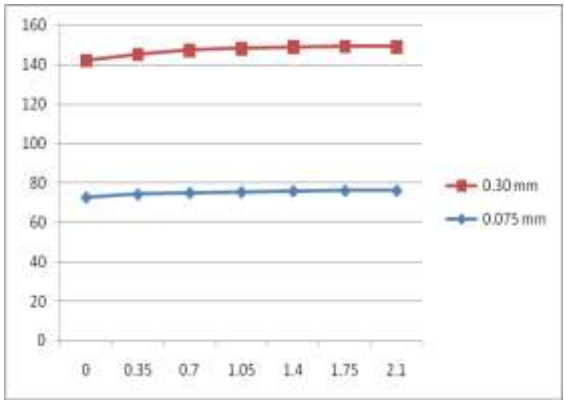

Figure XII: Plot of Hardness versus Compatibilizer Content.