A COMPARATIVE STUDY OF SOME MECHANICAL PROPERTIES OF BAMBOO POWDER FILLED VIRGIN AND RECYCLED LOW DENSITY POLYETHYLENE COMPOSITES.

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ABSTRACT

The effects of bamboo powder filler on some mechanical properties of pure and recycled low density polyethylene (VLDPE/BP and RLDPE/BP) composites were studied. In this work, composites of LDPE (VLDPE and RLDPE) and bamboo powder (BP) were prepared by melt extrusion. Pure water sachets and Bamboo stems were sourced. Recycling of the polymer (LDPE) and the preparation of the composites were carried out using locally made Laboratory-size Agglomerating Machine (agglomerator) and Single-Screw Extrusion Machine. The results of the mechanical tests carried out on the VLDPE/BP and RLDPE/BP samples showed that the tensile strength decreased with increasing filler loading for both VLDPE/BP and RLDPE/BP composites. Also the stiffness (Young's Modulus) of the composites increased with increasing filler loading for both VLDPE/BP and RLDPE/BP composites. These results produced materials with lower void content that decreased the water sorption level with slight increase in the specific gravity of the composites. Bamboo powder incorporation to the VLDPE and RLDPE, also, enhanced the flame retardant property of the composites. The effect of recycling on the mechanical properties of LDPE was observed. Comparatively, VLDPE showed better mechanical properties than the RLDPE for all filler loading. It was observed that the tensile strength of the RLDPE is 26 % less than that of VLDPE.

Keywords: Virgin Low Density Polyethylene (VLDPE), Recycled Low Density Polyethylene (RLDPE), Bamboo Powder (BP), Agglomerator, Extruder, Recycling, Filler.

INTRODUCTION

In the development of new materials, apart from the properties of the materials, the economic and ecological aspects are also of considerable importance. Traditional products whose manufacture requires expensive raw materials are being replaced with composite materials with alternative properties which display better qualities and perform in a better way. Composite materials are obtained from much cheaper components and possess significantly lower relative weight (Winandy, et al., 2004). Over the last few years different kinds of waste materials have been successfully utilized as filler in polymer composites with various applications. This not only reduces the production costs but also offers an opportunity for utilization of waste materials thereby reducing environmental pollution. Natural fibers can be classified according to their origin: vegetable, animal or mineral. Vegetable fibers include wood flour (or sawdust) from a huge variety of softwood and hardwood specimens and plant fibers, such as hemp, kenaf, curaua, coir, jute, sisal, bamboo, among others. Animal fibers include silk and leather. The most well-known mineral fibers are glass, boron and asbestos; the latter in disuse nowadays as it has been found to be harmful to humans (Soury, et al., 2009; Kalia et al., 2009).

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Over the past years sustainable eco-efficient practices and products have gained increasing attention and the use of natural fibers as reinforcement for polymers has been rapidly expanding (Bettini et al., 2010; Bonse et al., 2010).

Natural fibre composites have considerable potential to replace conventional materials like metal, plastics and wood in structural and non-structural applications, especially in furniture industry (Sapuan & Maleque, 2005; Bengtsson & Oksman, 2006). Such composites impart strength and stiffness to the product, besides having advantages such as low cost, environment friendliness, low density, abundant availability, renewable nature and allow reducing the use of non-biodegradable plastic material (Youngquist, et al., 1992).

Thermoplastic resins such as polypropylene, polyethylene, polystyrene and poly (vinyl chloride) soften when heated and harden when cooled. These characteristics allow other materials such as wood to be blended or mixed with the plastic to form a composite product (Adrian et al., 2002).

Currently, bamboo utilization is confined to domestic use due to lack of modern skills, inappropriate processing skills and technology. This has resulted in wasteful processing and utilization (Bhatnagar, 2004).

Plastics recycling involve the use of some machines such as agglomerating machine, extruder, injection moulding machine, blow moulding machine, etc. The machines can be foreign or locally made. The use of locally-made machines is advisable in order to encourage indigenous technology (Ehrig, 1992; Chanda & Roy, 2008; Reyne, 2008).

The most environmentally friendly alternative for plastic waste disposal – is the process by which we can re-utilize the energy content of the polymer in an ecologically acceptable way (plastic recycling). The other two alternatives are land filling, and incineration, which have, amongst others, the following constraints, especially because of increasing rapid accumulation of plastic waste: Lack of adequate and suitable sites for landfilling and the feared toxic emissions from inadequate equipment and inappropriate incineration conditions, and the resultant public resistance (http://www.envis-icpe.com/recycling projects.htm).

EXPERIMENTAL

Materials

In this research, Virgin Low Density Polyethylene resins (from Indorama PLC, Rivers State, Nigeria), discarded pure water sachets (made from a commercially Low Density Polyethylene with density of 0.923g/cm^3 and melt flow index of 2.25g/min.) and Bamboo (Dendrocalamus strictus) Powder were used. The discarded pure water sachets were collected from a pure water production company, La Mimi Pure Water Company Limited, Nekede, Imo State, Nigeria. The density of the Bamboo used is 0.649g/cm^3. The processing equipments used includes Laboratory-size Agglomerating machine, Laboratory-Size single-screw extruder, Instron machine (Universal Testing Machine), cutlass, Shredding machine, Grinding machine, Electronic weighing balance, Beakers, Analytical weighing machine, Scissors, Stop watch, Sample bottles, Filter paper, Cigarette lighter, Permanent marker (Ink), Personal Protective Equipment (PPE).

Preparation of Recycled Low Density Polyethylene Composites

The bamboo stems were shredded and the dust from the shredded bamboo stems was collected, sun-dried for three days to remove moisture from it. Then a locally-made grinder was used to manually grind the bamboo dust to powder. The bamboo powder was later sieved at the Erosion Control Laboratory in FUTO. The Pure water Sachets were torn open, washed in clean water to remove impurities and sun-dried. Then a laboratory-size agglomerating machine installed in the processing laboratory of the Department of Polymer and Textile Engineering in the Federal University of Technology, Owerri (FUTO) was used to shrewd the dried pure water sachets into pellets. The virgin and recycled low density polyethylene composites of the bamboo powder (BP) filler of particle size 75um (0.3mm size) were prepared by thoroughly mixing 200g of low density polyethylene with appropriate filler quantities (0, 1, 3, 5 and 7 wt %) loadings. Then a laboratory-size single-screw extruder, also, installed in the Processing Laboratory of the Department of Polymer and Textile Engineering, FUTO was used for the extrusion of VLDPE/BP and RLDPE/BP composites films (sheets) of 2mm in thickness. The prepared blend compositions were each extruded at the same temperature (145^0C).

Measurement of Mechanical Properties

Tensile properties of the composites were determined by an Instron Electromechanical Universal Testing Machine (UTM) - LR10K, model 3 type; using ASTM D5323 test method. 5 identical dumb bell samples for each composite were used to determine the tensile properties. Tensile Strength, Elongation at Break and Young's Modulus were recorded and calculated automatically by the instrument's software.

Water Sorption Test

The extruded samples sheet was cut into identical average dimension of about 12mm * 15mm * 2mm.Then the cut samples were weighed with electronic weighing balance and it is recorded as the initial weight. The test piece was loaded into a container (sample bottles) filled with water and they were immersed in water for 24 hours (one day) at 32^{o}C (room temperature).The test piece was then removed from their container, dried with filter paper to remove excess of water and weighed. The percentage of water sorption (24hours) was calculated using the expression:

$$\text{Water Sorption (\%)} = \frac{W_f - W_i}{W_i} \times 100 \quad \text{.. (1)}$$

Where W_i is the initial dry weight of the sample and
W_f is the final weight of the sample after 24hours of immersion in water.

Specific Gravity Test

An analytical weighing balance was used for specific gravity estimation. A beaker is used as an immersion vessel. A light thread was used in suspending the specimen in air, and water during weighing. A test specimen (filled or unfilled low density polyethylene) was first weighed in air (n), and later in water (m).The specific gravity of filled or unfilled low density polyethylene was calculated using the expression:

$$\text{Specific Gravity (S.G.)} = \frac{n}{m} \quad \text{... (2)}$$

Where n = weight of specimen in air
m = weight of specimen in water.

Flammability Test

A modification of ASTM D4804 method was used here. Since low density polyethylene (virgin or recycled) filled or unfilled is a thermoplastic, flame spread is regarded as the rate of melt-burn, i.e. the rate at which the original length of the specimen decreases as flame/heat is applied or plays among the specimens. A 6mm mark was made on each of the sample

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specimen. The specimen was then clamped horizontally in a retort stand with the mark 6mm distance protruding out of the clamp. The free end of the sample was ignited using a cigarette lighter, and the time taken for the sample to ignite was recorded as the ignition time (I_t). The sample was allowed to burn to the 6mm mark (D_p).

The relative rates of burning for the different samples were determined using the expression:

$$\text{Rate of burning (mm/s)} = \frac{D_p\,(\text{mm})}{P_t - I_t\,(\text{s})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

Where D_p = Propagation distance measured in millimeter

P_t = Flame propagation time measured in seconds

I_t = Ignition time measured in seconds.

RESULTS AND DISCUSSION

Mechanical Properties

Table 1: Some mechanical properties of bamboo powder filled VLDPE composites.

Sample	*Wt. % of Filler*	*Tensile Strength (MPa)*	*Elongation at Break (%)*	*Young's Modulus (MPa)*
1	0	7.788	1169.372	5.304
2	1	5.007	1032.825	8.098
3	3	4.531	78.092	15.665
4	5	4.028	63.749	15.980
5	7	3.441	58.490	16.219

Table 2: Some mechanical properties of bamboo powder filled RLDPE composites.

Sample	*Wt. % of Filler*	*Tensile Strength (MPa)*	*Elongation at Break (%)*	*Young's Modulus (MPa)*
1	0	5.764	1172.305	7.152
2	1	3.438	1081.541	7.843
3	3	3.314	124.415	8.006
4	5	2.291	84.978	8.927
5	7	1.098	63.768	9.796

Tensile Strength

Tables 1 & 2 showed the effects of filler loading on the tensile strength of bamboo powder (BP) filled virgin low density polyethylene (VLDPE) and recycled low density polyethylene (RLDPE) composites respectively. It can be seen from the Tables 1 and 2 that the tensile strength decreased with increasing filler loading for both VLDPE and RLDPE composites. According to (Salmah et al., 2005), the decrease in tensile strength is due to the poor adhesion of the filler-matrix and the agglomeration of filler particles. Since the filler particles are very small, a high interfacial surface exists between the polar filler and the apolar matrix. As this area increases, the worsening bonding between them decreases the tensile strength. It has been shown that for irregularly-shaped fillers, the strength of the composites can decrease due to the inability of the filler to support stresses transferred from polymer matrix (Ismail et al., 2002). On the other hand, poor interfacial bonding causes partially separated micro-spaces between the filler particles and the polymer matrix. Bamboo powder filler is known for easy agglomeration. The presence of agglomerates can generate flaws and create additional voids between the filler and the polymer matrix thus diminishing tensile strength (Yang et al., 2004). From Fig.1, it can be seen that the tensile strength of the VLDPE/BP composites is higher than that of RLDPE/BP composites for all filler loading. This is because recycling of LDPE (polymer) is known to cause decrease in its tensile strength, due to the loss of some energy content (decrease in the intermolecular bond strength) of the LDPE through:

i. Thermal, chemical, stress and ultraviolet degradation during indoor and outdoor service and

ii. Contaminants or impurities that might be present in the LDPE which may occur during its processing, outdoor and indoor service or during recycling.

The tensile strength of the RLDPE is found to be 26% less than that for VLDPE .The intermolecular bond between the molecules of the VLDPE is greater than that for the RLDPE which is affected by degradation and the presence of some contaminants or impurities that create voids between the RLDPE molecules thereby obstructing stress propagation when tensile stress is loaded and induce increased brittleness (Yang, et al, 2004).

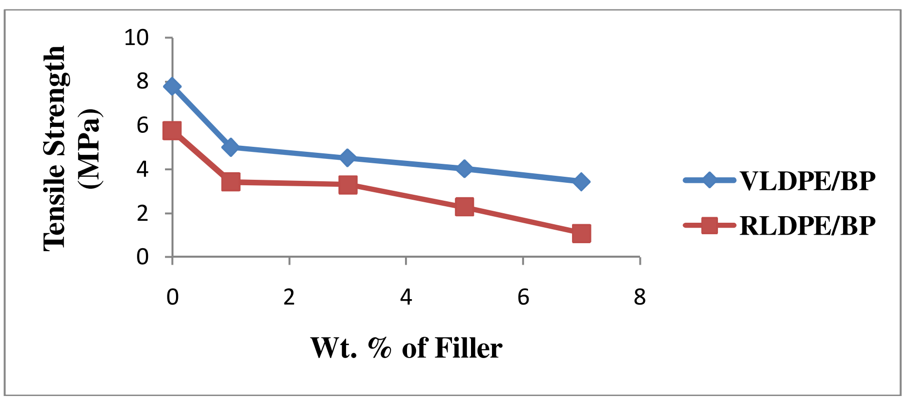

Fig. 1: Effect of Filler Loading on the Tensile Strength of VLDPE/BP and RLDPE/BP Composites.

Elongation at Break

The elongation at break for the VLDPE/BP and RLDPE/BP composites decreases with increasing filler loading as can be seen in Tables 1 & 2. Increased filler loading in the VLDPE and RLDPE matrixes resulted in the stiffening and hardening of the composites. This reduced its resilience and toughness, and led to lower elongation at break (Jacob, Thomas &Varughese, 2004). The reduction of the elongation at break with increasing filler loading indicates the incapability of the filler to support the stress transfer from the filler to the matrix. We can also see from Fig.2 that the elongation at break for the RLDPE/BP composites is higher than that of the VLDPE/BP composites for all filler loading. This can be attributed to the effect of recycling on the mechanical properties of LDPE (polymer).

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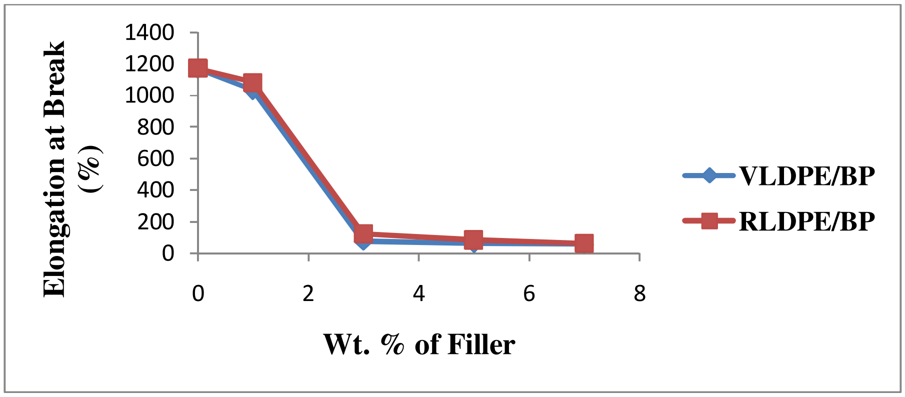

Fig. 2: Effect of Filler Loading on the Elongation at Break of VLDPE/BP and RLDPE/BP Composites.

Young's (Tensile) Modulus

From Tables 1 & 2, it can be seen that the Young's modulus for the composites increases with increasing filler loading for both VLDPE/BP composites and RLDPE/BP composites. The increased modulus corresponds to more filler where its intrinsic properties as a rigid agent exhibit high stiffness (modulus) compared to polymeric material (Jacob, Thomas & Varughese, 2004).This is because at a high filler loading, the composites will be able to withstand greater loads. This behaviour is similar to a result reported by (Ardhyananta et al., 2007). This is a common behaviour when rigid fillers are incorporated into softer polymer matrices. Natural lignocellulosic fillers have been found as having elastic modulus higher than PE, PP, and some other polymer materials (Wang et al., 2006). Because of this, the rigidity of its composites tends to strongly increase with addition of these fillers. Some other authors have also related the increase in composites' rigidity with the reduction of polymer chains mobility in the presence of the filler (Rana et al., 1998). Fig.3 showed that the Young's modulus for the RLDPE/BP composites is less than that of VLDPE/PE composites for all filler loading. This is as a result of the effects of degradation, impurities or contaminants on the chain mobility and interactions of the molecules of the RLDPE. From Fig.3, it can also be observed that at 0% filler loading the Young's Modulus of the RLDPE was higher than that of VLDPE which is not supposed to be so. This may be attributed to any of the following: processing error, error from the tensile testing machine or human error.

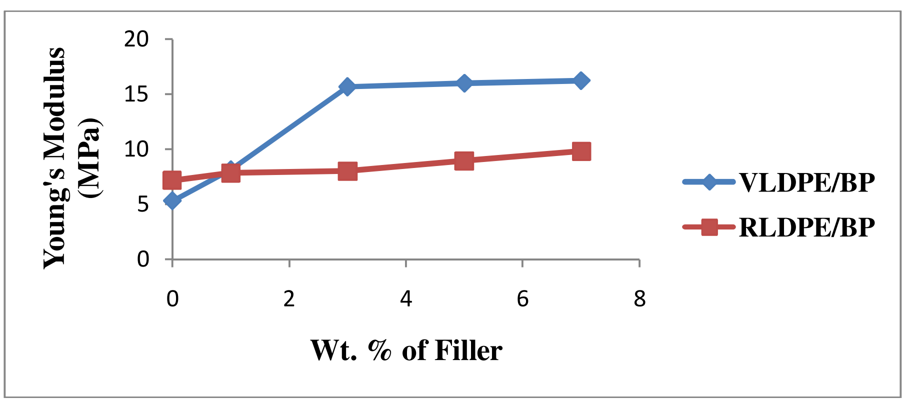

Fig.3: Effect of Filler Loading on the Young's Modulus of VLDPE/BP and RLDPE/BP Composites.

Table 3: Some end-use properties of bamboo powder filled VLDPE composites

Sample	*Wt. % of Filler*	*Water sorption (24hrs) (%)*	*Specific gravity*	*Flame propagation rate (mm/s)*
1	0	0.75	0.938	0.35
2	1	1.99	1.020	0.30
3	3	2.34	1.220	0.27
4	5	2.48	1.267	0.23
5	7	2.67	1.311	0.18

Table 4: Some end-use properties of bamboo powder filled RLDPE composites

Sample	*Wt. % of Filler*	*Water sorption (24hrs) (%)*	*Specific gravity*	*Flame propagation rate (mm/s)*
1	0	0.77	0.941	0.33
2	1	2.26	1.023	0.28
3	3	2.73	1.287	0.26
4	5	2.92	1.299	0.21
5	7	3.21	1.320	0.17

Water Sorption

Tables 3 & 4 show the percentage of water sorption (for 24 hours) for the VLDPE/BP and RLDPE/BP composites with different filler loading respectively. Composites with higher BP loading show more water sorption capabilities. This is due to the higher contents of filler loading in the composites that can absorb more water. As the filler loading increases, the formation of agglomerations increases due to the difficulties of achieving a homogeneous dispersion of filler at higher filler loading (Wang et al., 2006). The agglomeration of the filler in composites increases the water sorption of the composites. The composite containing 7 wt % of BP showed the expected behaviour of highest level of water sorption attained by the composite with the highest concentration of the hydrophilic filler for both VLDPE/BP and RLDPE/BP composites (Vera et al., 2007). This suggests that water penetration into the filler voids can be the more important mechanism of water uptake as the BP level increases in the composites (Qunfang et al., 2002). From Fig. 4, it can be seen that the percentage of water sorption for RLDPE/BP composites is higher than that of the VLDPE/BP composites for all filler loading. This may be attributed to the distortions in the molecular chains of the RLDPE due to degradation, impurities or contaminants present in the RLDPE.

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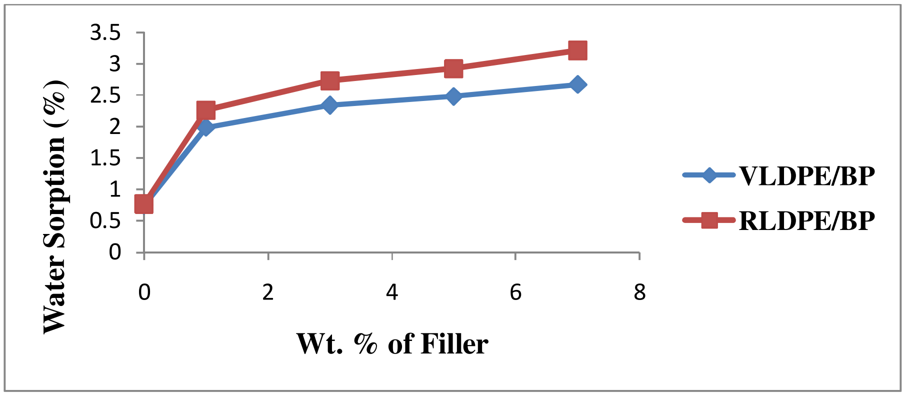

Fig. 4: Effect of Filler Loading on the Water Sorption of VLDPE/BP and RLDPE/BP Composites**.**

Specific Gravity

There was a continuous increase in the specific gravity for all the composites as the filler loading increases as can be seen in Tables 3 & 4.In solid-like composites, the specific gravity of natural fibres is a key for determining the specific gravity of the composites (Shibata et al., 2006). It can be seen that there is a slight tendency of increasing specific gravity with increasing bamboo powder concentration. From Fig.5, it seems that the specific gravity of the RLDPE/BP composites is slightly higher than of VLDPE/BP composites. This is due to the presence of some impurities in the RLDPE which may be responsible for the slight increases.

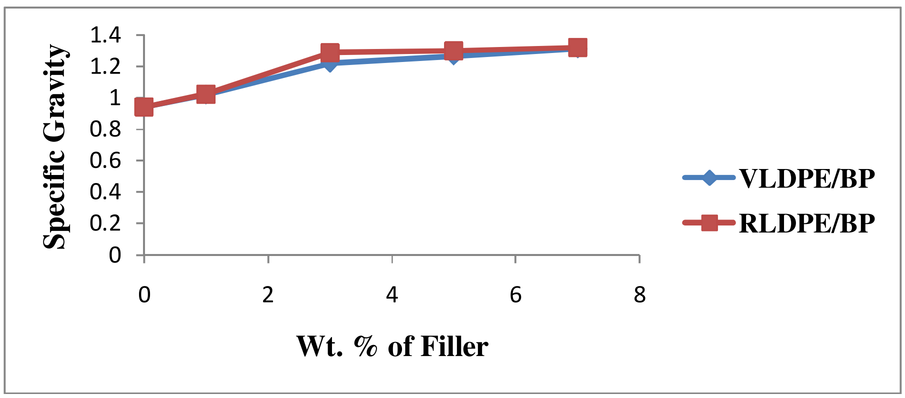

Fig. 5: Effect of Filler Loading on the Specific Gravity of VLDPE/BE and RLDPE/BP Composites**.**

Flame Propagation

The flame retardant property of VLDPE and RLDPE is enhanced by bamboo powder filler as can be seen in Tables 3 & 4. It can be observed that the rate of flame spread of the composites decreases with increase in filler loading for all the composites. Thermo plasticity is observed as shrinkage and softening or melting when such materials are subjected to heat (Morreale et al., 2007). This behaviour ensures energy removal, decrease in surface area exposed, and hence, reduction in flame accessibility. The flame retardant property of the filler investigated could be attributed to the fact that a good percentage of the filler contents might not be combustible, and so provide environments unfavourable to flaming. From Fig.6, it can be seen that the rate of flame spread of the RLDPE/BP composites is slightly lower than that of VLDPE/BP composites for all filler loading. This might be attributed to the fact that some of the impurities, contaminants, and additives present in the RLDPE composites might not be combustible or do not support combustion or needs more heat for its constituents to break down before it begins to burn; hence enhancing the flame retardant property of the RLDPE/BP composites (Ismail et al., 2002).

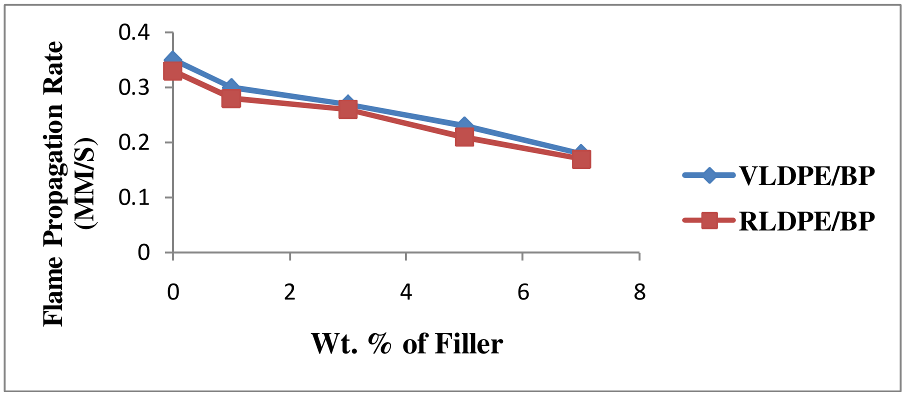

Fig.6: Effect of Filler Loading on the Flame Propagation Rate of VLDPE/BP and RLDPE/BP Composites.

CONCLUSION

The results obtained showed that VLDPE has better mechanical and end-use properties than the RLDPE and that it is feasible to use bamboo powder as low cost filler in both virgin and recycled low density polyethylene. The tensile strength of the VLDPE is found to be 26% higher than that of RLDPE. The results also showed that through recycling of polymer (LDPE) it is possible to re-utilize the energy content of the polymer in an ecologically acceptable way thereby helping in no small measures to reduce the problems of plastic wastes disposal and management. The composites' stiffness was seen to increase with increasing filler loading while there is slight decrease in the tensile strengths and elongation at break with increasing filler loading for both VLDPE/BP and RLDPE/BP composites. The percentage of water sorption by the VLDPE/BP and RLDPE/BP composites is so small making these materials suitable for use in damp environments.

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