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Effects of Compatibilization on Mechanical Properties of Pineapple Leaf Powder Filled High Density Polyethylene

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Abstract. The effects of compatibilizer (maleic anhydride-graft-polyethylene) on the mechanical properties of pineapple leaf powder (PALP) filled high density polyethylene (HDPE) composites were studied. HDPE and PALP composites in the presence, or absence of the compatibilizer, maleic anhydride -graft- polyethylene (MA-g-PE) were prepared by injection moulding technique. The filler (PALP) contents investigated were 2, 4, 6, 8, and 10 wt%, while the MA-g-PE content was 3 wt% of the filler content for each formulation. The result of the mechanical tests carried out on the HDPE/PALP composites showed that the tensile strength, tensile modulus, abrasion resistance, and hardness of the composites increased as the filler content increases both in the presence, or absence of the compatibilizer (MA-g-PE) for all the filler contents investigated, while the elongation at break (EB) for PALP/HDPE composites was found to decrease as the filler content increases both in the presence, or absence of MA-g-PE for all the filler contents investigated. It was also observed that PALP/HDPE composites in the presence of MA-g-PE exhibited better mechanical properties than that of PALP/HDPE composites in the absence of MA-g-PE for all the filler contents investigated. The present study has proved that the mechanical properties of PALP/HDPE composites can be enhanced by incorporating a compatibilizer (MA-g-PE) into their formulations. This is so because the chemical composition of the compatibilizer (MA-g-PE) allows it to react with the fibre surface, thereby forming a bridge of chemical bonds between the fibre and matrix.

1.0. Introduction

Studies on the use of natural fibres as replacement to man-made fibres in fibre-reinforced composites have increased and opened up further industrial possibilities. This is due to their (natural fibres) high performance in terms of mechanical properties, significant processing advantages, low cost, environmental friendliness, biodegradable, low density, and renewability [1]. In this new era of technology, availability of bio-based composites offers the opportunity for environmental gains, reduced energy consumption, light weight, insulation and sound absorption properties, reduction in volatile organic emissions, and reduction in the dependence on petroleum based and forest product based materials. The development of sustainable materials as an alternative for petroleum based materials is being studied so as to decrease the dependence on petroleum [2].

The major drawback on the use of natural fibres in making polymer composites is the problem of incompatibility between the hydrophilic natural fibres, and the hydrophobic thermoplastic matrices. This has led to certain undesirable composite properties such as low tensile strength, low flexural strength, and low tensile modulus because of poor interfacial adhesion between the natural fibre and the polymer matrix [3]. To overcome this problem, fibre surfaces are being modified so as to improve the adhesion between the fibre and matrix [4]. The use of coupling agents (compatibilizers) has greatly improved the adhesion between the hydrophilic filler and the hydrophobic polymer matrix.

The hydrophilic nature of natural fibres is incompatible with hydrophobic polymer matrix, and has a tendency to form aggregates. These hydrophilic fibres exhibit poor resistant to moisture, which lead to high water absorption, subsequently resulting in poor tensile properties of the natural fibre reinforced composites. Moreover, fibre surfaces have waxes and other non-cellulosic substances such as hemi-cellulose, lignin and pectin which create poor adhesion between matrix and fibres. Therefore, in order to improve and develop natural fibre reinforced polymer composites with better tensile properties, it is necessary to increase fibre hyphobicity by subjecting the natural fibres to surface chemical modifications. The fibre modification is attempted to improve fibre hydrophobicity, interfacial bonding between matrix and fibre, roughness and wettability, and also decrease moisture absorption, thereby leading to the enhancement of tensile properties of the resulting composites [5].

The chemical coupling method is also one of the important chemical methods which improve the interfacial adhesion. In this method the fibre surface is treated with a compound that forms a bridge of chemical bonds between the fibre and matrix. The chemical composition of coupling agents allows them to react with the fibre surface to form a bridge of chemical bonds between the fibre and matrix [6]. Among different coupling agents, maleic anhydride is the most commonly used.

Compatibilizers are often used as additives to improve the compatibility of immiscible polymers, and thus, improve the morphology and resulting properties of the blend. It is often difficult to disperse fillers effectively in the polymer matrix of a composite. Continued progress in the development of compatibilization technologies is, hence, crucial in enabling the polymer industry to reap the full benefits of such approaches to obtaining materials with optimum performance and cost characteristics [7].

The aim of this study is to determine the effect of compatibilizer (MA-g-PE) on the mechanical properties of PALP/HDPE composites.

2.0. Materials and Methods

2.1. Materials

The high density polyethylene (HDPE) used in this study was obtained from Ceeplast Industries, Aba, Abia state, Nigeria. It has a density of 0.97 g/cm^3, and melt flow index of 9.0 g/10 min. at 170 ^{0}C. The pineapple leaves from where the powder was prepared were collected from a pineapple orchard near Umuagwo Polytechnic, Owerri, Imo State, Nigeria. Maleic anhydride-g-polyethylene (MA-g-PE) was used as a compatibilizer in this study, and was obtained from a chemical store (Rovet Scientic Limited) at 1 wire Road, Benin city, Nigeria. It is a product of Sigma Aldrich, USA. The processing equipments used includes Mesh sieve (0.3 mm), cutlass, injection moulding machine (Negri Bossi, Italy), instron machine (Instron ltd., United Kingdom), electronic weighing balance (Contech, India), shredding machine, permanent marker (Ink), grinding machine, personal protective equipments (PPEs).

2.2. Pineapple Leaf Powder preparation

Pineapple leaves collected from Umuagwo, Imo State, Nigeria were cut into smaller sizes and sun-dried for fourteen days. The dried leaves were later oven-dried for 24 hrs at 80^{o}C prior to grinding. A manual grinder was used to grind the chopped dry pineapple leaves into powder. The pineapple leaf powder (PALP) obtained was sieved with a sieve grid of 0.3 mm (75 μm).

2.3. Preparation of High Density Polyethylene Composites

High Density Polyethylene composites of the pineapple leaf powder (PALP) were prepared by thoroughly mixing 200 g, 198 g, 196 g, 194 g, 192 g and 190 g of high density polyethylene with 0, 2, 4, 6, 8 and 10 wt % filler contents respectively. The formulated blend compositions were each processed at the same temperature (165^{o}C) using an injection moulding machine. The process was repeated with the incorporation of MA-g-PE in each formulation. The MA-g-PE content was 3 wt% of the filler content for each formulation.

2.4. Measurement of Mechanical Properties

The mechanical properties of the composites were determined by using an Instron Testing Machine (Lloyds, capacity 1-20 kN) according to standard method (ASTM D638). The tehsile properties that were determined are: tensile strength, elongation at break, and tensile modulus. Other properties of the composites that were determined are: abrasion resistance (ASTM D1044), and hardness (ASTM D2240). During tensile testing, 5 identical standard dumb bell shape samples of dimensions: 165mm of length x 19 mm of width x 3.3 mm of thickness were cut from each composite and used to determine the tensile properties the composite.

3.0. Results and Discussions

3.1. Mechanical properties

3.1.1. Effect of Compatibilizer on Tensile Strength of composites

Fig. 3.1 showed that the tensile strength of composites increased as the filler content increases for both the uncompatibilized and compatibilized PALP/HDPE composites. It was also observed that the tensile strength of the compatibilized composites was higher than that of the uncompatibilized ones for all the filler contents investigated. This finding is attributed to better interfacial adhesion between the filler and matrix arising from chemical modification of the interface on addition of MA-g-PE [6]. The chemical composition of the compatibilizer (MA-g-PE) allows it to react with the fibre surface, thereby forming a bridge of chemical bonds between the fibre and matrix. MA-g-PE has a hydrophilic group that is compatible with the filler, and a hydrophobic group that is compatible with HDPE. This property enables it to react with the surface of HDPE to form bonds. Without the MA-g-PE (compatibilizer), there will be simple adhesion of the polymer to the filler through weak bonding, i.e. Van der Waals or induction interactions. The determined chemical composition of pineapple leaf powder showed that it contains cellulose and holocellulose, both polar groups which are capable of bonding with MA-g-PE for improved adhesion in composites. Most researchers have reported that the incorporation of MA-g-PE improved the interfacial bonding between the organic filler and inorganic matrix [8].

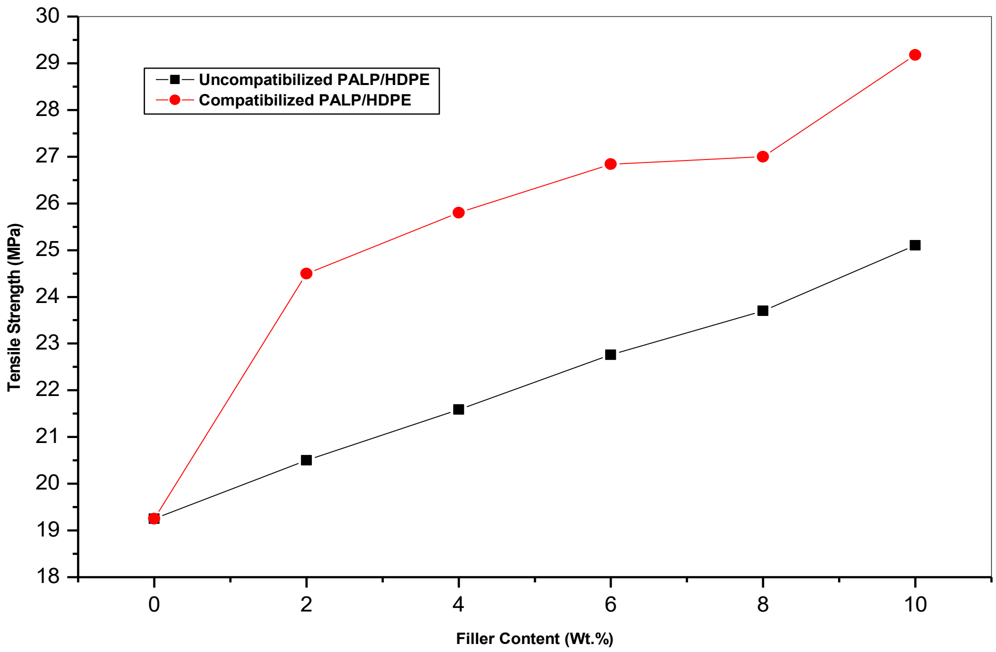

Figure 3.1. Effect of Compatibilizer on the Tensile Strength of composites.

3.1.2. Effect of Compatibilizer on Tensile Modulus of Composites

The tensile modulus of compatibilized PALP/HDPE composites was observed to be higher than that of the uncompatibilized composites for all the filler contents investigated as can be seen in Fig. 3.2. Other researchers have reported that maleated coupling agents (compatibilizers) are widely used to strengthen composites containing fillers [9]. According to reports Mohanty et al [10], after treating cellulose fibres with maleated anhydride, the surface energy of cellulose fibres is increased to a level very close to the surface energy of the matrix. This results in better wettability and higher interfacial adhesion of the fibre and the matrix; thereby, increasing the stiffness of the composites.

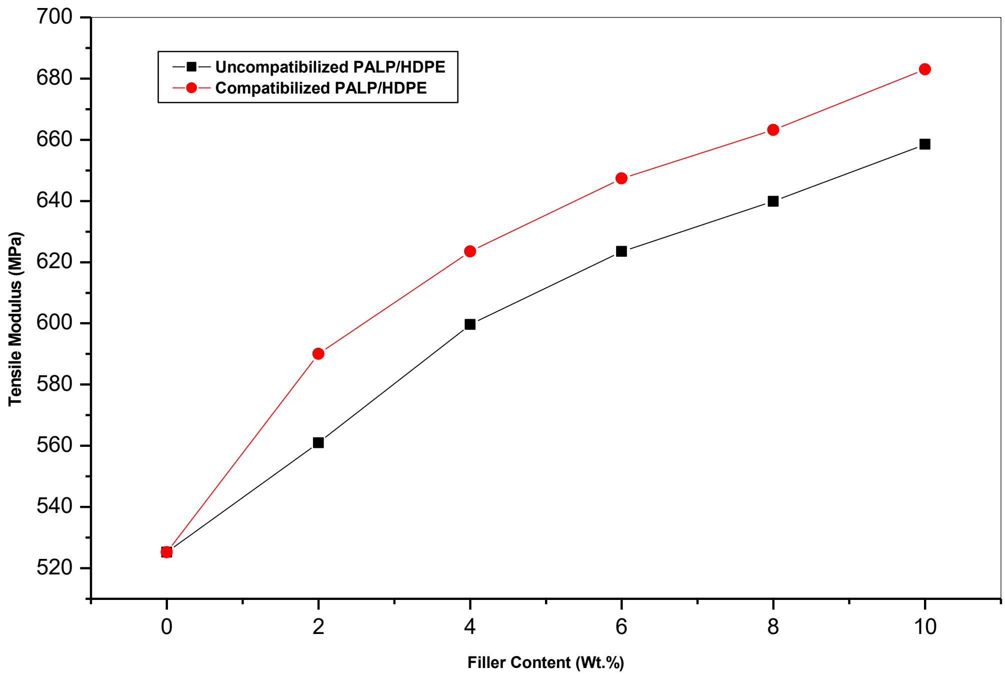

Figure 3.2. Effect of Compatibilizer on the Tensile Modulus of Composites.

3.1.3. Effect of Compatibilizer on Elongation at Break of Composites

From Fig. 3.3, it can be observed that the elongation at break of the compatibilized PALP/HDPE composites was lower than that of the uncompatibilized composites for all the filler contents investigated. Generally, the addition of a compatibilizer to fillers make the fillers to become stiffer than the uncompatibilized fillers [11]. Therefore, this effect of compatibilizer (MA-g-PE) on the fillers makes the composites to be stiffer (higher modulus), thereby, further reducing their elongation at break [12]. From this study, it can be inferred that as the tensile modulus of PALP/HDPE composites increases, the elongation at break decreases.

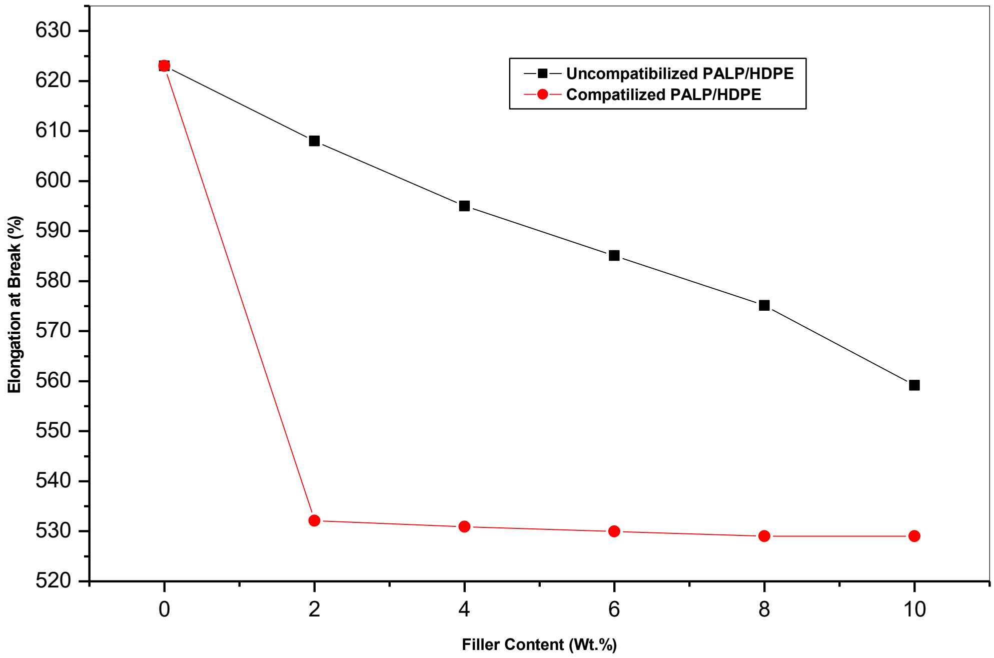

Figure 3.3. Effect of Compatibilizer on the Elongation at Break of Composites.

3.1.4. Effect of Compatibilizer on Abrasion Resistance of Composites

The abrasion resistance of the compatibilized PALP/HDPE composites was observed to be higher than that of the uncompatibilized composites for all the filler contents investigated. This can be seen in Fig. 3.4. Our findings in this study is similar to the observation by Fuqua and Ulven [13]. The presence of compatibilzer (MA-g-PE) in natural fibre reinforced plastic composites helps to improve the abrasion resistance of the composites when compared to the abrasion resistance of the composites in the absence of MA-g-PE [8]. The incorporation of compatibilizer into composites containing fillers makes the fillers stiffer and harder, thereby bringing about substantial improvement in the abrasion resistance and hardness of the composites. This is because of the better wettability and higher interfacial adhesion of the fibre and the matrix brought about by the presence of the compatibilizer.

3.1.5. Effect of Compatibilizer on the Hardness of Composites

Fig. 3.5 shows the effect of compatibilizer on the hardness of PALP/HDPE composites. It can be observed that the hardness of the compatibilized composites was higher than that of the uncompatibilized ones. Maleated coupling agents (compatibilizers) are widely used to strengthen composites containing fillers, and fibre reinforcements [14]. This explains why the compatibilized composites, in this study, have higher hardness values than the uncompatibilized composites. Just like in the case of abrasion resistance, the presence of compatibilizer in fibre reinforced plastic composites makes the filler/fibre to become stiffer and harder which, in turn, increases the hardness of the composites. It has been reported that the higher the tensile modulus of fibre, the higher will be the hardness of natural fibre/polymer composites [15].

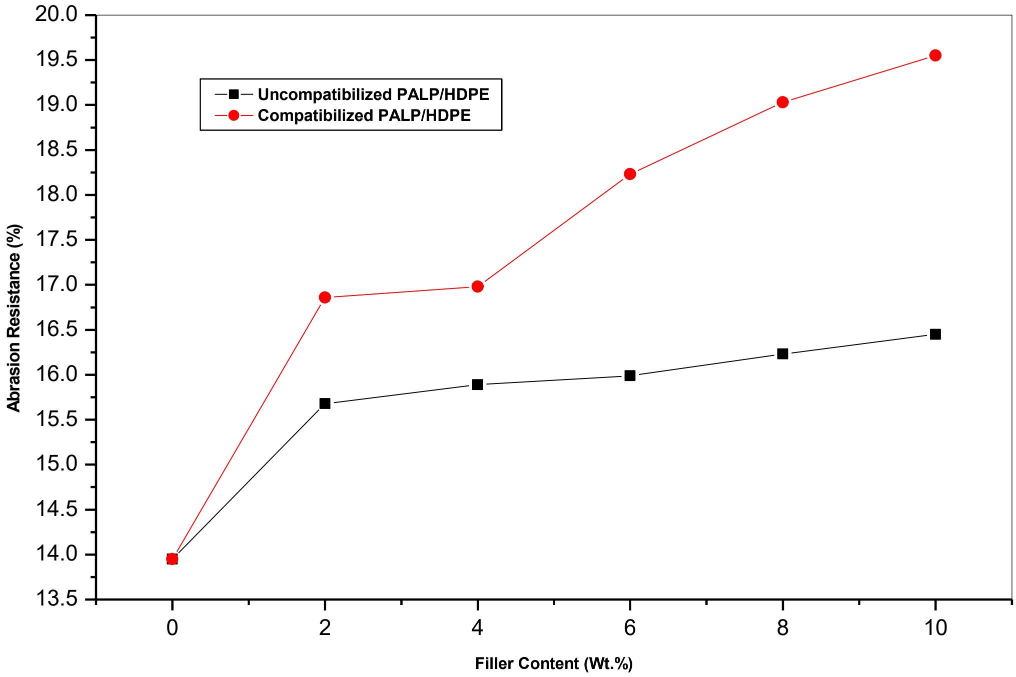

Figure 3.4. Effect of Compatibilizer on the Abrasion Resistance of Composites.

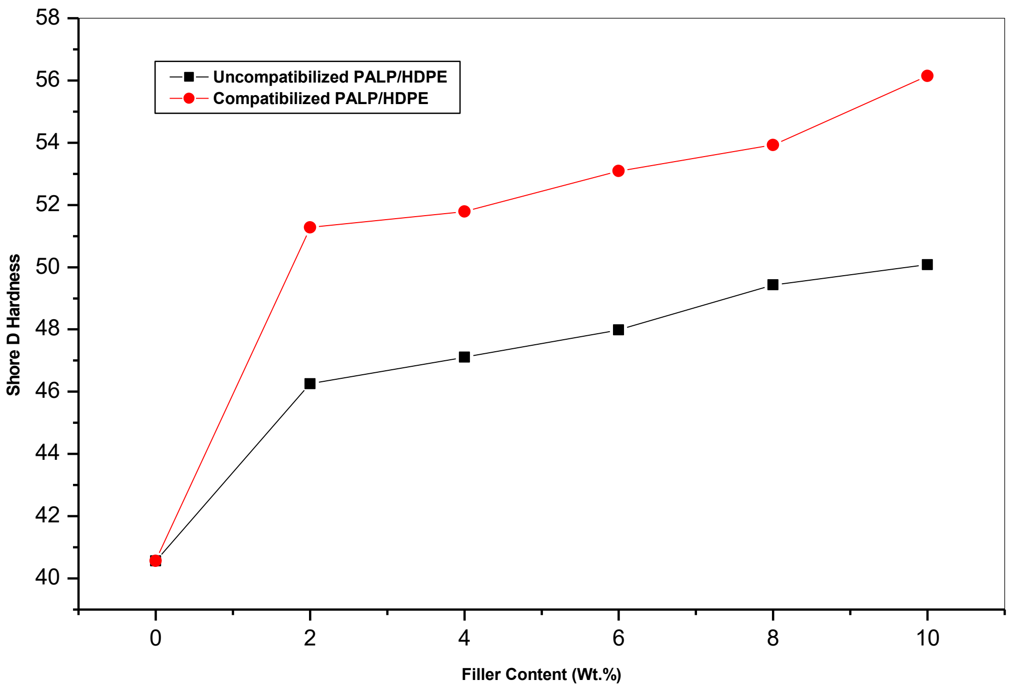

Figure 3.5. Effect of Compatibilizer on the Hardness of Composites.

4.0. Conclusion

This study has proved that the mechanical properties of PALP/HDPE composites can be enhanced by incorporating a compatibilizer (MA-g-PE) into their formulations. This can be justified from the results of this study which showed that PALP/HDPE composites in the presence of MA-g-PE had higher tensile strength, tensile modulus, abrasion resistance, and hardness than PALP/HDPE composites in the absence of MA-g-PE for all the filler contents investigated. The elongation at break of the PALP/HDPE composites in the presence of MA-g-PE was lower than that of PALP/HDPE in the absence of MA-g-PE. It is recommended that more work should be carried out using different compatibilizers on various fillers/polymer composites in order to ascertain the one(s) with the most promising result or outcome.

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