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Bamboo Fibers Reinforced with Bauxite Red Mud and MAPE/HDPE: Physico-Mechanical and Thermal Properties from Thermal Insulator in Textile Material

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Abstract

The modern, dynamic world can't imagine its development without carrying the concept of advancement in composite materials. Various researches are going on in this field to achieve the desired standard. Natural Fiber Reinforced Polymer Composite (NFPC) has a huge affinity to interchange the composite made up of synthetic fiber. This is primarily because of the advantages like light-weight, non-toxic, non abrasive, easy availability, low cost and biodegradable properties. The specific mechanical properties like specific tensile modulus and other specific properties of natural fiber gives a satisfying result for compos ites as compared to synthetic fiber based composites. The general objective of this work was to develop a composite from bamboo fibers and HDPE reinforced with red bauxite mud residues to ensure good thermal stability and improve the physico-mechanical properties in traction and flexion. he morphology of the composites showed that there was a homogenous dispersion of BF at lower weight fraction, although fibre agglomeration was noticed at higher weight fraction. The results of this study revealed that treated bamboo fibres are suitable for reinforcing HDPE. It appears from these studies that the formulations produced are in accordance with the ASTM standard and can validly be used for the thermal comfort of buildings to improve the comfort of the population in sustainable habitats.

Keywords: *Bamboo fibers; Composite material; HDPE; Bauxite red mud and MAPE*

Introduction

A strong increase in environmental concerns has arisen in the last years. This fact, together with the continuous increase in petroleum prices and the overall depletion of fossil fuels, has encouraged researchers to develop new environ mentally friendly materials. One of the engineering fields that have expe rienced a more valuable growth is that related to composite materials with natu ral fillers/reinforcements such as natural fiber reinforced plastics [14]. Natural-Fiber-reinforced Polymer composite (NFP) is a composite material that is combined with natural fiber and polymer. Composite structures are generally a combination of two or more materials at the macroscopic level and both are insoluble. The natural fiber is a reinforcement material embedded in a polymer (matrix) where the polymer has two types of classes, namely thermoplastic and thermoset [1-3]. Over the past few decades, what can be seen around us is the production of a wide range of products that use natural f iber-reinforced polymer composites. This composite is one of the alternatives to produce environmentally friendly materials by combining polymers and natural fibers for use in various products applications [1,4,6]. The use of these natural fibers has a high impact on the manufacturing industry as these materials are readily available, low-cost, and easy to design and increase productivity. Nowadays, the use of petroleum-based plastics in human daily activities is increas ing [6]. With the increasing use of plastics among us, plastic disposal has become a major issue of environmental pollution, and, in addition, limited fossil fuel resources make manyresearchers look for alternative methods to reduce the use of petroleum-based ma trices [6]. Therefore, the solution to this problem is to combine both materials using polymers and natural fibers. Furthermore, the use of natural re-

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sources material is to reduce the abundance of waste and prevent open burning by farmers leading to air pollution [1]. Thus, the nature of awareness of environmental issues to the world community nowadays is increasing. This increase in awareness occurs when global warming occurs in the world, and when loss of biodiversity and garbage disposal problems occur around them. Therefore, various activities have been held among them, such as recycling programs, segregation of waste by type, and use of natural product materials. Natural-fiber-reinforced composite fibers are one of the alternatives to reduce envi ronmental problems, and there is a need to further enhance the capabilities of this green technology. Natural fiber composites are in high demand in manufacturing indus tries, such as transmission tower, automotive, construction, aerospace, as well as furniture and packaging. One of the natural resources emphasized is bamboo trees. Nowadays, many researchers have studied bamboo to be extracted into fiber and made this fiber a reinforced material in the polymer matrix. The selection of bamboo as a reinforcement is due to its good mechanical and thermal properties, extraction and fiber treatment, low cost, environment friendly nature, and ability to be used as a product in the industry. Bamboo fiber is identified to have strength and stiffness, and it contains microfibrillar angles and thick cell walls that are considered nature glass fiber [1,7].

Previous research has shown that Bamboo Pulp Fiber (BPF) and White Mud (WM) significantly improved the mechanical properties of polymer composites (Yu Xian et al.,2018). Bamboo Residue Fiber (BRF) reinforced High-Density Polyethylene (HDPE) caused the increase of tensile and flexural properties, but BRF-reinforced HDPE had lower impact strength [8,9]. For this reason, BPF and WM are used to improve the mechanical properties of Bamboo Plastic Composites (BPCs). Due to cost always being an important criterion that can restrict the development of a technology, this means that any new material or method developed takes this into account, which is a load of BRF and WM used can be used to reduce costs. Therefore, BPF and WM were used to reinforce BPCs that were manufactured using extrusion technology in this paper. The effect of BPF and WM loading on the flexural, tensile and impact properties were investigated with the macro test, the difference in the fracture toughness of BPCs was also studied by means of the EWF method based on the Charpy impact test results.

Materials and Methods

Materials and Preparation

Chemical Extraction of Bamboo: The chemical extraction methods such as chemical retting and alkali or acid retting are used to remove or reduce the lignin content from the fibres. These chemical extraction methods also have effects on other fibre components such as pectin and hemicelluloses [12]. The method of extracting bamboo fibers initially harvested in the town of Bagangte in the West Cameroon region and transported to the laboratory is described by Kumar et al., (2010). In this procedure, bamboo culm without any nodes was cut into strips and then soaked in water for 24 hours. Then those drenched strips were cut into smaller pieces with a knife. In chemical procedure after removing the bamboo nodes the internodes are sliced into the defined dimensions. Bamboo strips with the size of chips was soaked in 4% mass over volume of NaOH for 2 hours to influence on cellulosic and non-cellulosic parts. This method was repeated several time under a certain pressure for extracting fibre in the form of pulp. Bamboo chips were dried for 30min at 150ºC and dipped in water at 60ºC for 24 hours and then dried in air. Later, the fibres were washed with hot water and then treated with xylanase. After, cooking and bleaching bamboo fibres, they were treated in sulphuric acid solution. The size of obtained fibre was 2.5mm. In order to produce a long fibre some cell parts of the plant such as pectin and lignin were needed to be connected [11].

High-Density Polyethylene (HDPE) was purchased from OK Plast Plastic Company Ltd. (Douala, Cameroon). Its density is 0.945g/cm^3 (DGDK-3364), and melting mass flow rate is 0.75g/10 min (190°C, 2.16kg). Maleic Anhydride grafted Polyethylene (MAPE), used as interfacial compatibilizer, was utilized to improve the compatibility between the polymer matrix and wood fiber [14] and bauxite red mud used in this work was produce by the process describe by [14].

Fibers

Bamboo fiber was used as primary reinforcement material. Composite samples were fabricated using hand lay-up method followed by compression. The samples were prepared as per ASTM standards for testing. Tensile test was performed as per ASTM D638 standard with a test speed of 2 mm/min. Flexural test and Impact test were performed by ASTM D790 and ASTM D256, respectively (ASTM,1995).

Materials Used

The materials that are used in the present study and the methods by which these materials are processed. The materials that are used in the present concern of study are 1. Epoxy Resin, 2. Bamboo Fiber and 3. Hardener.

Fabrication Methods

Hand Layup is the simplest polymer processing techniques. Fibers can be laid onto a mold by hand and the resin (unsaturated polyester, epoxy resin are the most common) is sprayed or brushed on. Frequently, resin and fibers (chopped) are sprayed together onto the mold surface. In both cases, the deposited layers are den sified with rollers. Accelerators and catalysts are frequently used. Curing may be done at room temperature. The desired fish scale powder and epoxy were mixed in a container and stirred well for 5–7 min. After adding the hardener, the mixture was again stirred for 10 min to obtain homogeneous mixture. Before the mixture was placed inside the glass mould (120mm 120mm 4mm), the mould has initially been polished with a release agent to pre vent the composites from sticking onto it upon removal. Finally, the mixture was poured into the mould and left at room tempera ture for 24 h until the mixture was hardened. To investigate the mechanical and physical properties of composites, the samples were fabricated with various PSP loadings (10 to 35 wt%) When the composite was hardened, it was removed from the mould and placed inside an oven for 12 h at 40°C for curing. The tensile, flexural and impact specimens were cut from the prepared composite sheets according to ASTM standards. The following steps are used to fabricate the composites. In the first step, the raw materials were mixed according to the formulations listed in Table1. (i) Placing the bottom mould plate with silicon rubber, (ii) Adding catalyst, accelerator, promoter to resin, (iii) Mixing resin to the fiber and (iv) Closing with the top mould plate.

BPF Characterization Table 2 shows the mean length, diameter and ratio of individual BPF. These properties affected the ultimate mechanical properties of BPCs. These results were lower than that previously reported for bamboo fiber [8,17,18].

Table 1: Formulation of bamboo plastic composites (BPCs).

Sample	%BPF	%BRF	%BRM	%HPDE	%MAPE	%PE-Wa
1	20	30	0	45	4	1
2	25	25	0	45	4	1
3	30	20	0	45	4	1
4	35	15	0	45	4	1
5	40	10	5	40	4	1
6	45	5	10	35	4	1
7	50	0	15	30	4	1

BPF: Bamboo Pulp Fiber; BRF: Bamboo Residue Fiber; BRM: Bauxite Red Mud; HDPE: High-Density Polyethylene; MAPE: Maleic Anhydridegraft Poly Ethylene; PE-wax: Polyethylene Wax

Table 2: Mechanical and physical properties on bamboo fiber.

Tensile strenght (MPa)	Young modulus (MPa)	Fiber diameter (µm)	Fiber lenght (µm)	L/D Ratio	Density (g/cm³)
399±155	27.8±12.5	238±121	1134.47 ± 590.12	4.76	1.3±0.123
Cellulose (%wt)		hemicellulose (%wt)			Lignin (wt%)
38		27			24

This may be due to the main constituents of bamboo cell wall being different, the contents of cellulose, hemicelluloses and lignin, which provide the specific mechanical properties and ultimately affect the properties of the BPF [8].

The chemical composition of bauxite red mu dis given by table 3 [16].

The presence of Al_2O_3 and SiO_2 is responsible for the good mechanical beha viour, shrinkage of a sample and Fe_2O_3 in constitution determines the colour of the composite. It is basically characterized by high amount of SiO_2 and Al_2O_3. Raw materials present low amount of SiO_2 and considerably amount of Al_2O_3.

Flexural modulus of neat BRF-reinforced HDPE composites showed 1.46 GPa, and the flexural modulus of BPCs with 20% BPF was increased to 2.68 GPa. The addition of BPF tends to increase flexural modulus of BPCs which was due to high modulus/high aspect ratio of BPF acting as framework in the HDPE matrix. flexural strength, BPF-reinforced BPCs showed outstanding improvements with incorporation of BPF into BPC. When 20% of BPF was added, the flexural strength of BPCs was 1.60 times higher Flexural strength and modulus of BPCs are illustrated in table 5. The Modulus of Rupture (MOR) flexural strength values of BPF- reinforced BPCs exhibited an increasing trend with incorporation of BPF into BPCs. Flexural modulus of neat BRFreinforced HDPE composites showed 1.46 GPa, and the flexural modulus of BPCs with 20% BPF was increased to 2.68 GPa.

Table 3: Chemical composition of the Bauxite Red Mud determined by XRF.

Element %	LOI[a]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	T_iO_2	M_nO_3
Red mud %	20.26	7.68	19.6	37.21	2.75	0.08	0.08	4.71	0.06	0.12	1.07	0.09

[a]Loss on ignition.

Crossbridged structure of BPF played an important role depending on the flexural strength of BPCs. The flexural strength and modulus of BPCs increased with increasing content of BPF, when BPF content was up to 40%, and it came to 56.47 MPa and 2.80 GPa, which were close to the 20% BPF loading in the BPCs. The flexural strength and modulus of BPCs increased with increasing content of BPF, when BPF content was up to 40%, and it came to 56.47 MPa and 2.80 GPa, which were close to the 20% BPF loading in the BPCs. The results indicated the heterogeneous dispersion of the BPF and weak interface between BPF and HDPE. However, the flexural strength of BPCs is enhanced by the addition of BPF to some extent. In view of the cost, it was found that flexural property of the BPCs filled with the content of 20% BPF loading in composites is good. The tensile properties of BPF-filled BPCs with different BPF concentration are shown in Figure 3b. It can be found that the tensile strength of BPCs was improved to some extent with adding 20% BPF to the BPCs. Comparing to the neat BRF-reinforced HDPE, it made an increase of 51.88%. After that, when 30% and 40% of BPF was added into thec omposites, the tensile strength of BPCs will increase to 26.17% and 61.53%, respectively, which indicated an improvement from tension transfer to the The tensile properties of BPF. The combination of bamboo fiber with thermoplastics, such as High-Density Polyethylene (HDPE), with MAPE reinforced by bauxite red mud shows an improvement in their mechanical properties up to optimum value.Therefore,the characteristics of size, uniformity,and fiber content are closely related to good mechanical properties of the bamboo composite.

Thermal Properties of Composites

It is well known that the degradation of natural fibers and the polymer plays an important role in the performance of a composite. The thermal degradation of fibers leads to poor mechanical performance and deterioration of color. Moreover, the surface chemistry changes of fibers may affect the interfacial adhesion between fibers and polymer. Thermogravimetric analysis can be used to study the reactions and physical changes in the specimens by detecting mass loss. A summary of $T_{5\%}$, T_{p1} and T_{p2}, and carbon residue at 600°C are shown in Table 6 High-density polyethylene was degraded in the range of 386.69 to 500°C, and the maximum degradation temperature was 469.84°C. BPF degraded from 250 to 500°C, and the degradation rate reached a maximum at 358.18°C.

The execution of bamboo-fortified polymer composites is more often than not mea sured by their physical and thermal properties, such as water assimilation, pliability, Thermogravimetric Analysis (TGA), Differential Scanning Calorimetry (DSC), and energetic mechanical investigation (DMA). TGA on composites can determine the reactions and physical changes in the composite with the mass loss. The thermal properties of bamboo composites have also been proven from previous studies

Table 4: Shows the mechanical and physical properties of bamboo-reinforced thermoplastic polymers.

Formulation	Flexural strenth (MPa)	Flexural modulus (GPa)	Tensile strenth (MPa)	Tensile modulus (GPa)	Impact strength (KJ/m²)
1	32.23±09	1.8±0.2	22.23±02.13	2.87±0.9	4.71±0.10
2	34.46±03	1.89±0.34	24.12±02.45	2.75±0.51	4.69±0.42
3	53.12±11	2.84±0.43	33.08±01.58	3.24±0.36	6.27±0.98
4	55.09±05	2.63±0.29	31.90±01.29	3.18±0.24	6.07±0.81
5	50.09±07	2.52±0.21	26.09±03.42	3.17±0.56	7.62±1.12
6	54.11±12	2.47±0.51	34.56±04.37	3.97±0.50	7.98±1.33
7	52.41±14	2.53±0.28	32.80±03.73	4.27±0.12	8.24±1.12

Table 5: TGA Data for BPF, HDPE, and BPF/HDPE and BF/HDPE Composites.

Sample	T5%°C	Tp1°C	Tp2°C	Residue at 600°C%
1	341.36	356.16	466.48	2.19
2	339.37	358.85	474.55	2.58
3	321.03	356.16	473.55	3.02
4	304.13	354.15	472.53	3.60
5	297.72	356.16	470.45	4.02
6	277.53	343.24	468.34	16.43
7	425.99	469.84	435	0.49

$T_{5\%}$ is the temperature of the materials at 5% loss weight, i.e., the onset degradation temperature of the materials. T_{p1} andT_{p2} represent the first and second peak of DTA curves of BPF, HDPE, BPF/HDPE composites, and BF/HDPE composites.

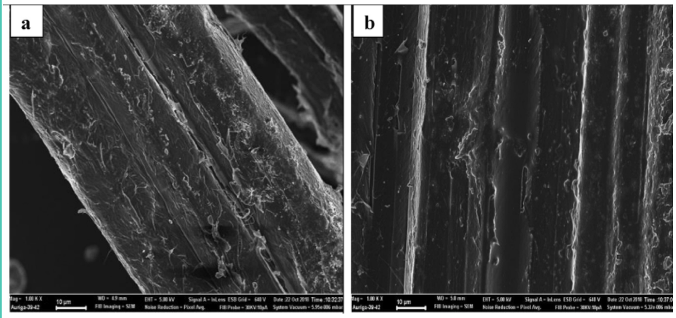

Figure 1: SEM images of [a] treated bamboo fiber [b] untreated bamboo fibers (1000X).

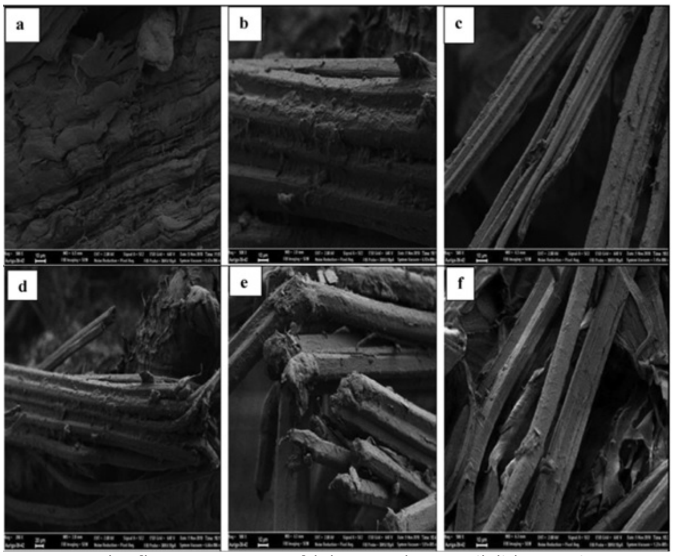

Figure 2: (a–f): SEM images of (a) HDPE (Control) (b) sample 2 BF-HDPE (c) sample 3 BF-HDPE (d) sample 4BF-HDPE (e) sample 5 BF-HDPE (f) sample 6 BF-HDPE.

where the effect of heat also influences the behavior of bamboo and composites. Ren et al. (2015) investigated the effect of bamboopulpfiber-reinforced PE composites with different fiber loading. TGA thermal was performed on bamboo and PE and was supported by Derivative Thermogravimetric (DTG) analysis. The TGA and DTG showed four-phase degradation of the bamboo-reinforced PE composites, i.e., loss of moisture content, degradation of hemicellulose, degradation of cellulose/lignin, and residual ash. Additionally, the thermal stability increased when the bamboo content increased, as compared to neat PE and bamboo flour. Result is comparable to [1]. Table 5 shows the TGA results for bamboo–HDPE composites and neat HDPE.

The thermal stability of composites containing bauxite red mud was studied by ATG. The decomposition temperatures of the composites are shifted to higher temperatures compared to the composite without red bauxite mud, indicating that the addition of red bauxite mud increases the thermal stability of the system with a dependence on mud concentration. bauxite red. Residues at temperatures above 500°C are higher in the case of composites with red bauxite mud simply because of the greater thermal stability of the latter compared to organic matter: the red bauxite mud is transformed progressively by dehydroxylation (loss of -OH from the sheets) into a mixture of oxides between 600 and 850°C. The mechanical properties of composites made from natural fibers can be influenced by the size of the fibers, the modification of the surface of the fibers and also the fiber content.

SEM Images of HDPE Matrix and the Composites

Observation of SEM images of the surface of the tensile-produced composites at different fiber contents are shown in Figure 2(a-f). The SEM image of the control sample (HDPE), as shown in Figure2 (a), has a loose and flaky structure with the presence of micropore, reflecting a fully waterproof surface with mechanical properties that can be weakened due to the presence of pores within the composite, this can be explained by the absence of reinforcement or poor mixing of the reinforcement in the matrix. When introducing reinforcement, as can be seen in the SEM images in Figure. 2 (sample 1b-f), the laminated structure is less pronounced as the fibers take place in the HDPE matrix, the fiber-matrix adhesion then becomes the appreciable focal point. up to 25% wt% fiber reinforcement, after which congestion is observed for 30 wt%, 35 wt% and 40 wt% fiber reinforced composites, causing eventual delamination and pullout, such as shows Figure 2 (d-f). It is also observed that due to random orientation, certain fibers exhibit a degree of elongation at break as seen for composites reinforced with fibers at 25% by weight, justifying the tensile properties imparted to the matrix by reinforcement, which is in agreement with Daramola et al. (2019). Other fibers exhibit a rough brush-like tip at the point of failure, as seen for the 8 wt% fiber-reinforced composites in Figure 2(e), which also indicates appreciable deformation before failure, the fiber surfaces appear rough, indicating one of the effects of alkaline treatment, as explained previously, to improve the interfacial adhesion between the matrix and the fiber. The congestion observed for the 10 wt% fiber reinforced composites means that more of the load is absorbed by the fibers, which explains the trend in Figure 2(f) which was reinforced by 40% in weight, poor adhesion observed for the 40% by weight.

Conclusion

The exploitation of bamboo fibres in various applications has opened up new avenues for bothacademicians as well as industries to design a sustainable module for future use of bamboo fibres. Bamboo fibres have been extensively used in composite industries for socio-economic empowerment of peoples. The fabrication of bamboo fibre based composites using different matrices has devel oped cost effective and eco friendly biocomposites which directly affecting the market values of bamboo. To design such composites thorough investigation of fundamental, mechanical, and physical properties of bamboo fibres are necessary.

The mechanical, morphology and therrmal properties of HDPE composites reinforced with treated bamboo fibres and bauxite red mud have been studied. From the results, the following conclusions can be drawn; i. Treated BF enhances the tensile, flexural, and hardness properties of the composites. The major enhancement was observed at 2 wt% BF. ii. With increasing BF fraction, these properties tend to reduce, apparently due to fibre agglomeration at higher loading fraction. Nevertheless, these properties show significant enhancement when compared with the control sample. iii. Finally, the results of this study have shown that treated bamboo fibres are suitable for reinforcing HDPE.

Author Statements

Data Availability

Data used for the fndings of the study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conficts of interest.

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