



## **Effect of Alkali-treated Bamboo Fibers on Some Mechanical Properties of Virgin High Density Polyethylene**

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### **Authors' contributions**

*This work was carried out in collaboration between all authors. Author POA designed the study and supervised it to conclusion. Author KJA collated all results and managed analysis of the study. Author OSA monitored experimental work and verified experimental results. Author RAO conducted laboratory experiments and managed the literature searches. All authors read and approved the final manuscript.*

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### **ABSTRACT**

The study investigated effects of chemically treated bamboo fibers on some mechanical properties of virgin high density polyethylene. Bamboo *fibers* and *particulates* treated with NaOH and KOH were blended by mixing with molten high density polyethylene to produce eight (8) different composition sets for standard tensile, impact and flexural tests. Results from the tests. Results

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obtained indicated that 2-14% volume addition of bamboo particulates or fibers as a reinforcement to virgin HDPE, improves service properties such as Young's modulus, UTS, toughness, flexural modulus and strength. Overall, alkali treated particulate bamboo wood demonstrated improved properties over fibrous bamboo wood within the scope of conduct of the study.

*Keywords: Bamboo; HDPE; eco-design; composite; fiber; filler.*

## 1. INTRODUCTION

Nowadays, the awareness in composite materials is increasing due to its advantages as compared to monolithic metal alloys. In general, composite materials are regarded as important engineering materials due to their outstanding mechanical properties. They are equally regarded as materials in which the desirable properties of separate materials are combined together mechanically or metallurgically. Delgado [1] noted that bamboo has become an alternative sustainable material for use in product design and has been incorporated into the concepts of eco-design. Bamboo belongs to the grass family and it takes little time to be renewed, producing stems asexually for years without replanting. Bamboo plantations benefit the community because, apart from allowing the infiltration of rain into the soil, they help control erosion, sedimentation and recovery of carbon dioxide from the atmosphere [2].

In practice, most composites consist of a bulk material (matrix), and a reinforcement of some kind, added primarily to enhance the strength and stiffness of the matrix. Bamboo – in addition to other materials - has shown a great potential in the context of materials design in modern science. It is a major material driving eco-design for shelter, household utensils, industrial designs and several artifacts. For instance, bamboo fiber-reinforced epoxy matrix composites were fabricated and filled with different weight proportions of red mud (a solid waste generated in alumina) [3]. On comparison with glass-epoxy composites, their erosion wear performance was better than that of the glass-fiber reinforced composites.

The arrangement/orientation of the fibers relative to one another, the fiber concentration and distribution, all have a significant influence on the strength and other properties of fiber reinforced composite [4]. Although it is difficult to extract bamboo fibers having its superior mechanical properties, given that the bamboo fiber is often brittle compared with other natural fibers and

because the fibers are covered with lignin [5], public attention has gone to natural fibers as a renewable resource due to their fast growth and relative abundance. Consequently, natural fibers, as reinforcement, have continued to attract the attention of researchers because of their advantages over other established materials [6-10].

Several studies have already been conducted on bamboo composites [11-13]. The effect of fiber length on the tensile properties of short bamboo fiber epoxy composites was investigated by [14]. Liu et al. [15] extracted bamboo cellulose crystals (BCCs), treated it with  $\text{HNO}_3\text{-KClO}_3$  and sulfuric acid hydrolysis and used it to produce glycerol plasticized starch composites. It was found that the Young's modulus and tensile strength of starch/BCC composite films were enhanced by the addition of the crystals owing to reinforcement of the BCCs and an attendant reduction in water uptake capacity.

A comparative study was conducted by Chen et al. [16] between the mechanical properties of bamboo fiber-reinforced polypropylene and commercial wood pulp-reinforced polypropylene. The bamboo has been adjudged excellent as a composite material in many respects. Ghavami et al. [17] submitted that the bamboo structure can be generally viewed as a functionally graded composite material. The understanding of the mechanical behavior of bamboo has caught the attention of engineers, architects, biologists and material researchers due to bamboo's great potential to be used as a construction material. In the present work, the effect of bamboo wood particulates and fibers on mechanical properties of virgin high density polyethylene was studied.

## 2. EXPERIMENT

Chemically treated *bamboo fibers* were prepared by soaking shredded bamboo trees in a warm solution of 6 M NaOH and 6 M KOH in 300 ml distilled water for 30 minutes. The bamboo trees had their barks stripped prior to shredding and were sun-dried to constant weight after soaking.

*Treated bamboo particulates* were prepared from shredded and sun-dried bamboo trees whose barks have been removed. Shredded fibrous bamboo matter was sun-dried to constant weight over a 12-day period, crushed in a crushing machine and thereafter chemically treated as in the case of fibers. Treated bamboo particulates, 1.4 mm and below, were collected from a screen and kept for use.

The essence of the chemical treatment was to remove the moisture content present in the bamboo fibers/particulates, to improve the tensile strength of the fibers/particulates and to ensure ease of blending or compatibility of the fibers/particulates and the virgin High Density Polyethylene (vHDPE) matrix.

Casting method was employed for the production of the bamboo wood plastic composite. Particulate reinforced virgin HDPE was prepared by blending the treated bamboo particulates with molten HDPE followed by casting in stainless steel moulds. For the preparation of fiber reinforced polymer vHDPE composite, prepared bamboo fibers were aligned on the surface of molten vHDPE at 200°C before pouring in stainless steel mould. The moulds have been shaped to prepare standard test samples for tensile, impact and flexural tests.

The procedure described above was followed to produce composites of varying composition/volume percent keeping the volume of HDPE fixed. The eight compositions produced for both fiber and particulate composites are provided in Table 1.

**Table 1. Designation of composites according to % vol filler/reinforcement**

S/N	Filler (Vol %)	Particulate composite	Fiber composite
1	0	P-0	F-0
2	2	P-2	F-2
3	4	P-4	F-4
4	6	P-6	F-6
5	8	P-8	F-8
6	10	P-10	F-10
7	12	P-12	F-12
8	14	P-14	F-14

Tensile and flexural test was conducted for 24 prepared samples using Instron machine, flexural test was carried out using 3-point bend test while

impact test was performed on 24 standard v-notched samples using the Impact testing machine. Reported values are statistical averages of experimental data. The designation of composites according to % volume filler (particulate or fiber) is presented in Table 1.

### 3. RESULTS AND DISCUSSION

Fig. 1 shows that increase in volume % of both particulate and fiber reinforcement HDPE composite resulted in an increase in modulus of elasticity of the composite. The strength of polymer with a high degree of crystallinity is often limited by the size of the voids that develop between neighbouring spherulites during the material crystallization process (Schaffer et al.) [18]. It is probable that the reinforcement material partially filled such voids leading to an increase in stiffness of the reinforced composites. Both particulate and fiber reinforced composites have their maximum modulus of elasticity at 10% reinforcement with particulate composite showing the greater modulus (580.65 MPa).

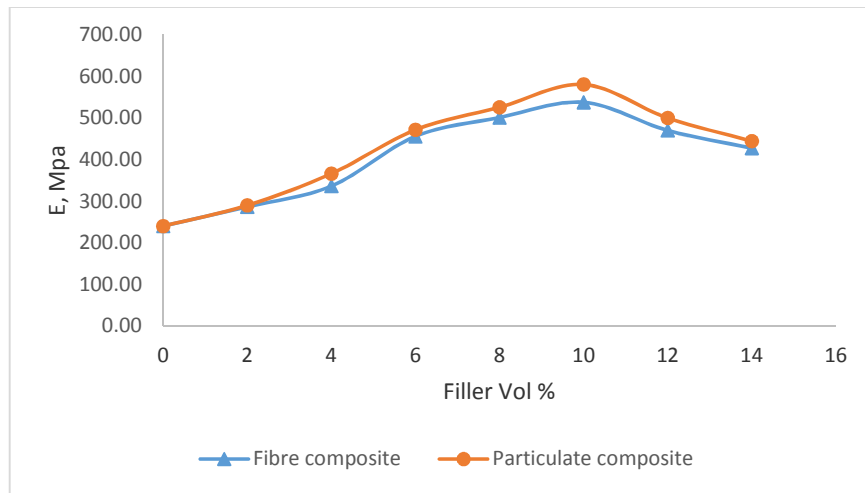
From Fig. 2, the results of tensile tests indicates that the higher the proportion of bamboo particulates and fibers in the composite blend, the higher the load required in fracturing the sample. The notable pattern of increase in the UTS (a gentle rise followed by a constant UTS and then a rise) observed for both particulate and fiber composites was as a result of resistance to separation of adjacent atoms i.e. interatomic bonding force. It was also observed that at 14% volume ratio, the fiber reinforced composite has a greater UTS (28.7880 MPa) than the particulate reinforced composite (26.4328 MPa). Thus, the fibrous composite is expected to offer a better load carrying capacity under a tensile loading.

Fig. 3 provides an indication that unreinforced virgin HDPE is more ductile and addition of reinforcement (fibers or particulates) will only make it more brittle or less ductile. Brittle fracture takes place without any appreciable deformation and by a rapid crack propagation Khana, [19]. Due to a strong covalent bond between molecules, the strain is observed to be low though there is a high stress. But a relatively small amount of stress would cause large amount of strain if the molecules are loosely bonded to each other. The fiber reinforced composite shows a larger degree of ductility than the particulate composite.

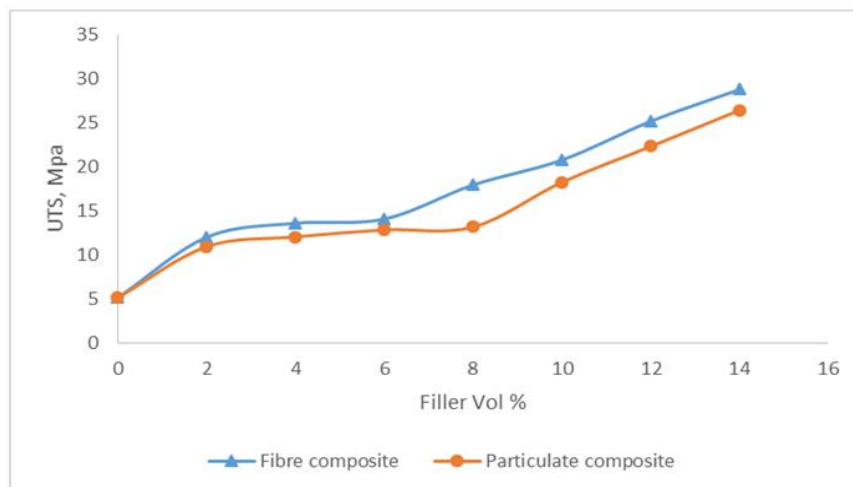
Fig. 4 shows the flexural strength of both fiber and composite reinforced composite from three point bend test. It was observed that at 14% filler content, the strength of particulate composite is higher (i.e. 42.972 MPa) than that of fiber reinforced composite which is 29.34 MPa. Apart from the fact that in wood (fibers and particulates) reinforced composite, the interfacial zone (interphase) plays a leading role in transferring the load between the reinforcement and matrix, which affects the mechanical properties such as strength (Mukherjee et al.) [20]; the dispersed particulate bamboo material reinforces the matrix of the composite by arresting motion of dislocation which gives rise to greater grain boundaries. As a result, a larger

force is required to fracture the restriction created by the dispersion.

Although polymer shows a moderately low impact strengths Callister [21], the impact test result shown in Fig. 5 indicates a difference in the energy absorbed in causing fracture to both fiber and particulate composite. The energy absorbed in fracturing composite test samples is higher than in the 100% virgin HDPE. The result shows that increasing particulate proportions in the blends yields increase in impact strength. The particulate composite could be adjudged tougher as it imposes more resistance to impact (or shock) loading.



**Fig. 1. Young's modulus of elasticity for reinforced composites**



**Fig. 2. Ultimate tensile strength for reinforced composites**

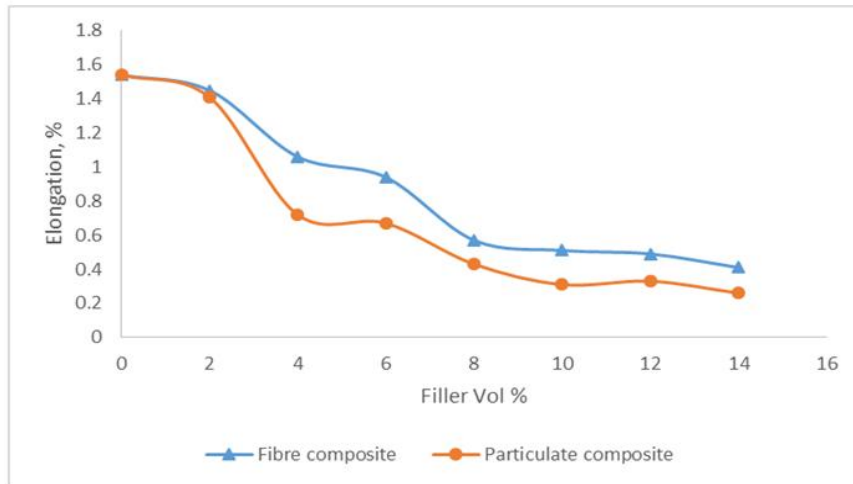


Fig. 3. Elongation for composites

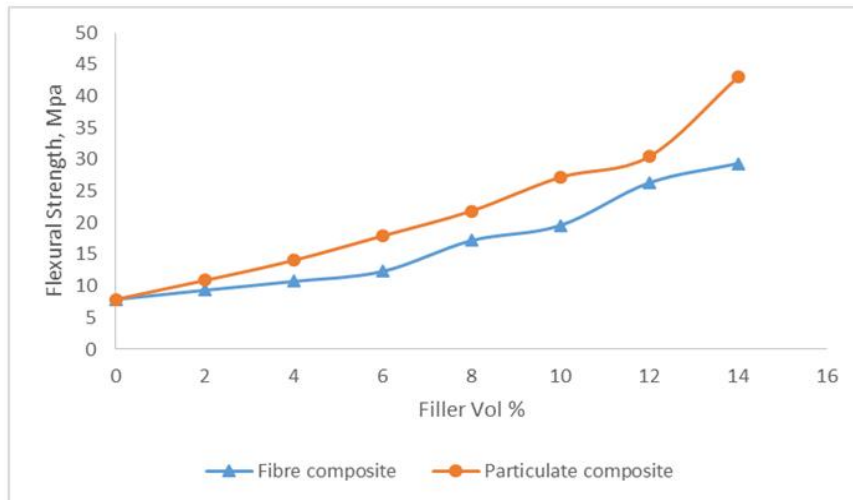


Fig. 4. Flexural strength (MPa)

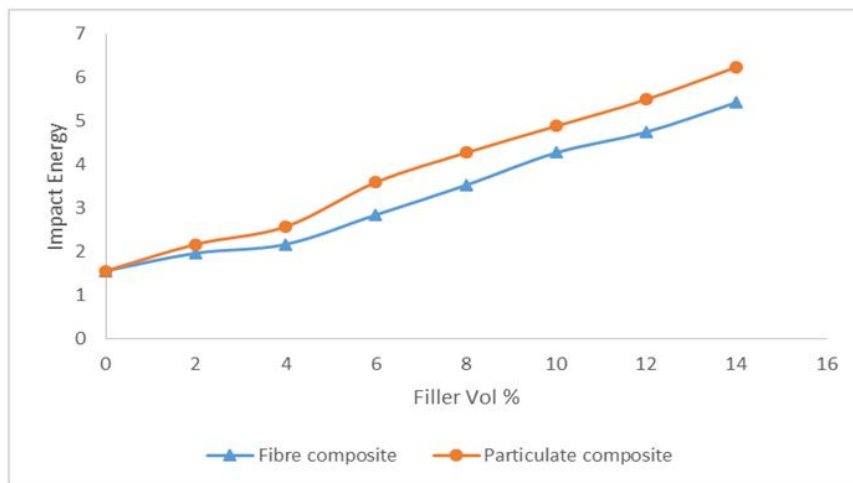


Fig. 5. Energy absorbed at impact

#### 4. CONCLUSION

Results obtained from this work lead to the conclusion that 2-14% volume addition of bamboo particles or fibers as a reinforcement to virgin HDPE, improves service properties such as Young's modulus, UTS, toughness, flexural modulus and strength. The study is however limited to some mechanical properties but excludes wear and delamination to which plastic wares are prone to. Overall, alkali treated particulate bamboo wood showed better properties than fibrous bamboo wood within the scope of conduct of the study.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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