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Physcio-Mechanical Properties of Aluminum Trihydrate Additive on Bamboo Dust Particle Reinforced Polyester Composite Panel

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Abstract
The effects of aluminum hydroxide (aluminum trihydrate (ATH)) flame retardant (FR) addition on the mechanical and physical properties of bambo dust particle (BDP) reinforced polyester composite were studied. Hand lay-up method was used in producing the composites. The surface morphology of the samples was studied using scanning electron microscope (SEM) micrographs. The result indicated that addition of ATH caused a marginal decrease in the tensile properties for all samples while the flexural properties and impact strength increased with ATH addition at 10wt% only. The density of the composites decreased with increase in the FR loadings, with a density of 1.68g/cm^3 and 1.21g/cm^3 for non retarded sample and 20wt% ATH loading respectively. It was also observed that the water absorption of the composites with ATH addition are lower than that of bamboo reinforced sample but higher than the unreinforced polyester. The SEM micrograph showed that the 10wt% ATH had better dispersion and less agglomeration of the particles than other panels. The overall results indicated that the composites can be applied in fabrication of collapsible ceiling and particle boards for building wall partitions and other industrial applications.

1. Introduction
There has been growing interest in development of natural fiber based composites because of their biodegradability, renewability, and recyclability advantages overs and above synthetic fibers such as glass and carbon fiber. Today many of new bio based composites have found applications in both domestic and industrial sector such as automobile components, electronic circuit boards, aerospace structures, building panels among others. [1-5]

Many researchers have reported extensively on flax, hemp, banana, jute, bast and coiras polymer reinforcement with proven performances [6-11]. These bio or natural fibers has two major disadvantages (1) abilitity to absorb water easily and (2) ability to burn easily. Solution to these two problems while keeping the properties of the composite intact is the focus of various researchers [12-15]. The issues of water absorption tendencies are been solved by various surface treatment methods while the fire tendencies are been solved by incorporation of retardants into the polymer matrices. There is an increasing attention on inorganic compounds such as metal hydroxide additives for use as flame retardants [16]. Sain et al. [17] reported that Magnesium Hydroxide [$Mg(OH)_2$] and Aluminum Hydroxide [$Al(OH)_3$] are the most widely used metal hydroxide flame retardant additives for polymers. Eze et al. [13] studied on the mechanical properties of bamboo powder filled virgin and recycled low density polyethylene composites and produced material with lower void content that decreased the water sorption level with slight increase in the specific gravity of the composites. The bamboo powder enhanced the flame retardant property but decreased the tensile strength of the composite.

Vahideh and Amir [9] reported the thermal properties and flammability of cotton/vinyl ester composites containing some flame retardant materials such as ammonium molybdate, aluminum hydroxide, antimony trioxide tested by thermos-gravimetric analysis and flame retardancy. They found out a reduced burning rate, improved interfacial bonding and elongation at break due to the retardants. Daulath and Vasanthakumari [10] reported that it is about 10% of DecaBromodiphenyl ether (DeBDE) and Sb_2O_3 in the ratio (3:2) with 25% of Aluminum trihydrate (ATH) that meet the required mechanical and flame retardant properties and it is more cost effective than the fire retardant formulation used by the FRP industry. The report further stated that addition of ATH alone improved mechanical properties but not give flame retardant property even up to 60% loading. Meanwhile addition of Tricresyl phosphate (TCP) alone did not improve both mechanical and flame retardant properties while its combination with DecaBromodiphenyl ether (DeBDE) and Antimony trioxide (Sb_2O_3) in a ratio of 3:2 ratio showed a considerable improvement in the flame retardant property but affected the mechanical properties negatively.

The main objective of this work is to study the effects of Aluminum trihydrate (Al $(OH)_3$) flame retardant on the physical and mechanical properties of bamboo dust reinforced polyester composites.

2. Materials and Methods

2.1 Materials

The unsaturated polyester resin, its catalyst and accelerator; Methyl Ethyl Ketone Peroxide and Cobalt Naphthalate respectively were purchased from Ndidiamaka Chemical Enugu, while the powder form of Aluminum hydroxide Al(OH)3 also known as ATH, whitish in color was supplied by Jeochem chemicals Nsukka, Nigeria. bamboo dust was used as prepared by ICE-JEB Technical Services Nsukka.

2.2 Preparation of the composite panel

Dry bamboo lengths were collected from building sites, cut into short lengths of about 100mm, thoroughly washed with sponge and soap and dried under sun for 3days. They were further cut into shorter lengths and pieces of not more than 20mm. it was ground to powder (Plate 1) in a local mill. It was sieved into various micro sizes but 300μm was used. Table 1 defines the mix ratio of the flame retardants and the polyester resin at constant volume fraction of the bamboo dust particles. A control sample of 100% polyester was properly prepared by mixing the resin with a corresponding ratio of the accelerator and the catalyst. It was thoroughly stirred and cast into moulds labeled **A**. Another sample of 20% volume fraction of bamboo dust and 80% polyester was prepared, thoroughly stirred and cast into mould labeled **B.** Sample with same composition of 20wt% fraction of bamboo dust and polyester resin were prepared, with 5wt%, 10wt%, 15wt% and 20wt% of ATH added into the composites, thoroughly stirred and cast into moulds labeled **C, D, E** and **F** respectively. The samples were allowed to cure for two days at room temperature. They were carefully removed from the moulds and cut into the required test sample dimensions.

2.3 Characterization of Samples

Tensile Properties

The tensile strengths were determined using the Universal Tensile Testing Machine (UTM) in accordance with ASTM D3039 standard using a Motorized Automatic Recording Tensometer (MosantoTensometer, (Type 'w' S/No. 9875) having a maximum force capacity of 5KN. The samples were subjected to axial loading until breaking point. The test was carried out using three samples in each category and their average taken.

 (a)  (b)

Plate 1: (a) dry bamboo stem (b) bamboo dust particles

Table 1: Weight t% of bamboo dust, ATH retardant and polyester resin

Sample code	wt% Bamboo dust	wt % Polyester resin	wt% ATH flame retardant
A	0	100	0
B	20	80	0
C	20	75	5
D	20	70	10
E	20	65	15
F	20	60	20

Flexural strength

The flexural strength testing was carried out according to the ASTM D790 standard test methods for flexural properties of plastics. Samples were tested using a manual griping universal testing machine model TUE-C100 with serial No 2010132 made by Fine Spavy Associates & Engineers Pvt Ltd WIRAJ 416410 India using an approximate cross head speed of 5mm/min. three samples were tested for each category of composite developed.

Impact Strength

The impact test was conducted to measure the toughness of materials using Samuel Demson Ltd Leeds LS102DE England SN-EXT94064/6705CE with an impact velocity of 5.24m/s. The test was carried out using a universal impact-testing machine based on charpy test method in which a hammer like weight strikes a specimen and the energy-to-break it determined from the loss in the kinetic energy of the hammer. In charpy test the specimen 10mm x 55mm x 4mm were given a 2mm notch.

Density test

The densities of the samples were determined by measuring the mass and the volume of a cut sample piece from each composition. The masses where determined with the digital weighing balance while the volumes were calculated.

Water Absorption

Pieces of samples were cut, one each from each variation. These were cleaned thoroughly and measured using a digital weighing balance. The mass of each sample was recorded. The samples were soaked in a clean water in different containers. Each sample was removed and properly dried; the new mass was recorded in an interval of 3 days. This was done for three times, the change in mass and the absorptivity was calculated thus;

Change in mass = initial mass – final mass (g)

$$W_w = \frac{W_t - W_O}{W_O} x100 \quad \text{........................ (6)}$$

Where W_t is the wet weight and W_o is the dry weight of the samples

Scanning Electron Microscope

The morphology of the composite samples was studied using high performance Scanning Electron Microscope (SEM) (VEGA 3 TESCAN, Czech Republic) at accelerated voltage of 20KV. Samples surfaces were coated with conductive carbon before viewing under the SEM. The morphology study of the samples was carried out to evaluate the interactions of the composite constituents and predict the properties of the composite which determines the overall performance of the composite. From the micrographs of SEM analysis, the morphological properties like powder dispersion and agglomeration can be visualized.

3.0Results and Discussions

3.1Tensile Properties

The results of the mechanical tests are presented in Figure 1 denoting the tensile properties and Figure 2 and Figure 3 denoting the flexural and impact properties respectively.It was observed from Figure 1a that the tensile strength decreased with increase in FR content. Also the tensile modulus decreased with addition of the dust and with 5wt% FR loading. It believed at this small level of loading, the FR content is acting as an interstitial defect instead of reinforcement causing the material to fail at lower stresses. This is because an increase in the tensile modulus was observed with 10% FR loading henceforth. This is an indication that its stiffness defined by the tensile modulus requires a minimum reinforcement threshold of 10% FR added to dust particles to fill the voids of the dust particles and contribute also as reinforcement. Again the SEM micrograph (Figure 5c) indicates that sample D with 10wt% of ATH had the best dispersion and less particle agglomeration than other samples hence its best performance among the samples.

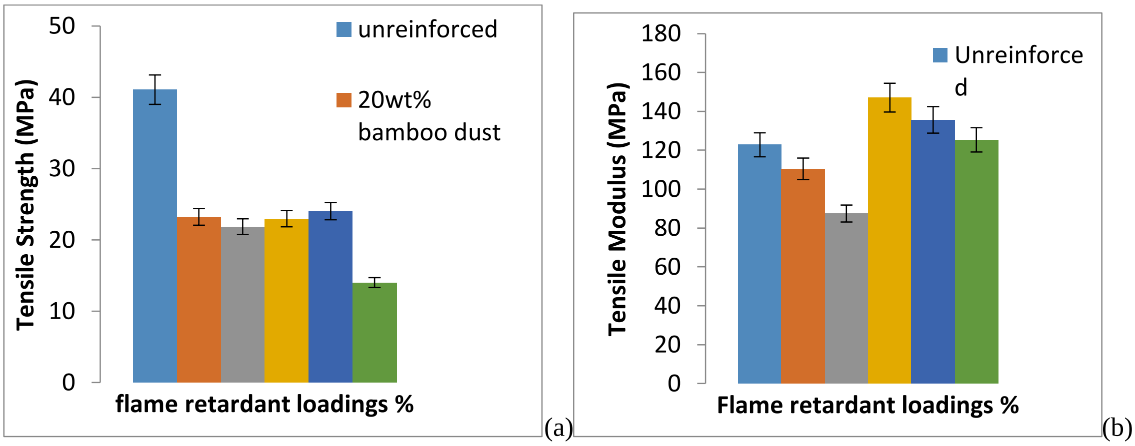

Figure 1: Effect of ATH retardant content on the (a) tensile strength (b) Young's modulus of bamboo dust reinforced polyester composite

3.2 *Flexural Properties*

Figure 2 presents the flexural properties of the developed composite samples. It was observed from the Figure 2 that the flexural strength and flexural modulus increased with the bamboo dust addition but reduced when addition of 5wt% ATH flame retardant was made. This also happened in the tensile properties and can be attributed to the FR which may have attacked the bond and acted as defect at the interfacial boundaries in the composite; however, a further increase in the ATH FR content to 10wt% caused the flexural strength to increase by 12.6% from 37.8MPa for polyester resin to 42.69MPa, and 40.56MPa for BDP reinforced polyester and 10wt%ATH addition respectively. Similarly, the flexural modulus increased by over 90% from 1.62GPa for unreinforced polyester resin to 3.08GPa and 3.68GPa for BDP reinforced polyester and 10wt%ATH addition respectively.

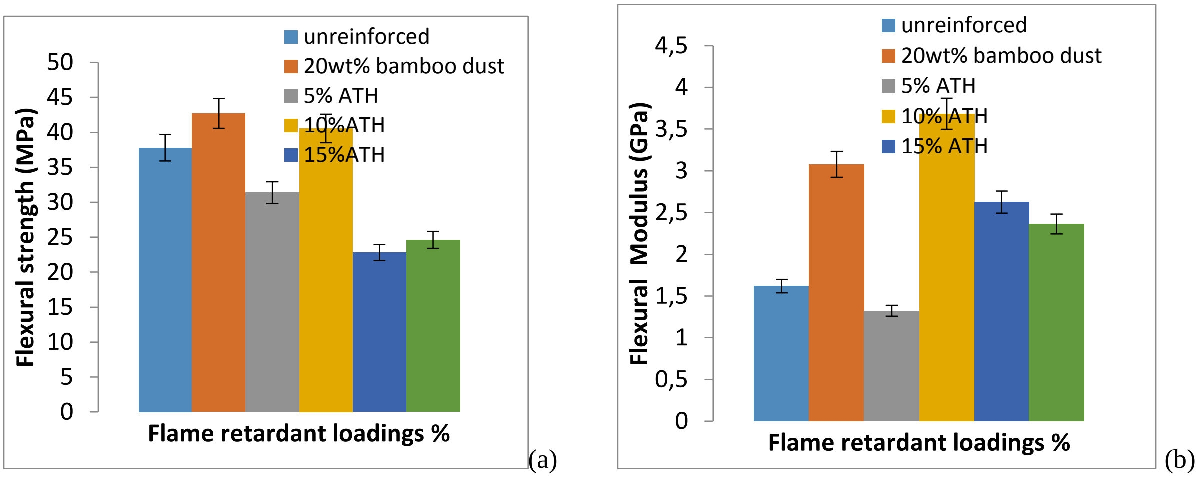

Figure 2: Effect of retardant content on the (a) flexural strength (b) flexural modulus of ATH flame retarded bamboo dust reinforced polyester composite

3.3 Impact strength

Figure 3a presents the results of the impact strength of the developed composites. It was observed that the impact strength increased from 135J/m^2 to 150J/m^2 due to dust reinforcement. The addition of the 10wt% of ATH flame retardant increased the impact strength further to 160J/m^2. Above 10wt% of ATH, the impact strength decreased, this is believed to be due to agglomeration of the particles at higher than 10wt% as seen in the Micrograph Figure 5d.

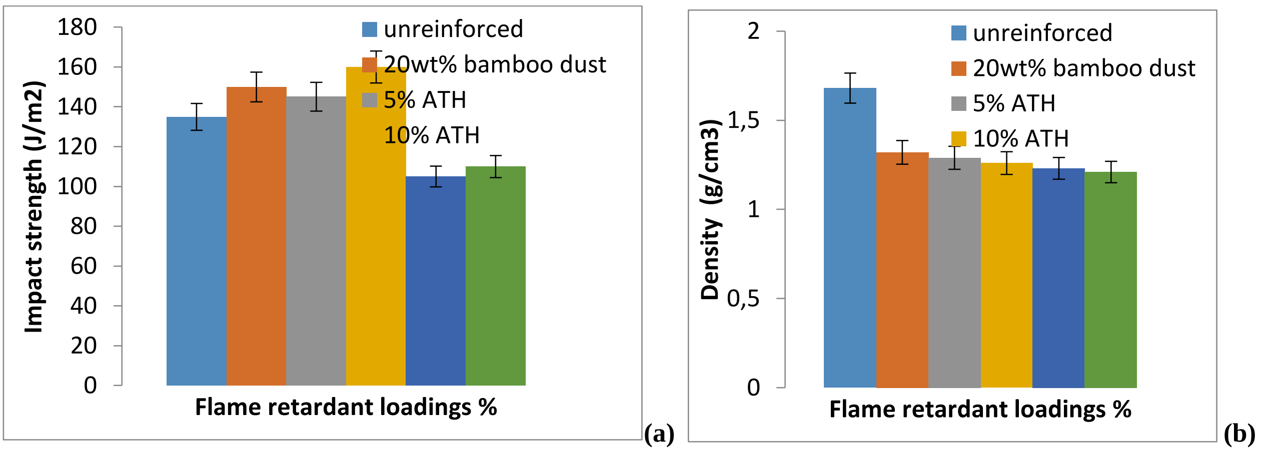

Figure 3: Effect of retardant content on (a) impact strength (b) density of ATH flame retarded bamboo dust reinforced polyester composite

Density Test

Figure 3b presents the densities results of the developed composites. It was observed that the addition of bamboo dust particle reduced the density of the composites to 1.32cm^3 from 1.62cm^3 for the unreinforced polyester resin. Addition of the ATH flame retardants further decreased the composite densities to 1.29cm^3, 1.26cm^3, 1.23cm^3, and 1.21cm^3 respectively for 5wt%, 10wt%, 15wt% and 20wt%

ATH loadings. Low density is a good criterion as being light weight is one of the most desired properties of any composite formulation.

Water absorption

Figure 4 presents the water absorptivity of the developed composites. It was observed that the unreinforced polyester had the least water absorptivity, thus its reinforcement increased the absorption capacity thereby making it more biodegradable. Further addition of ATH FR increased the hydrophobicity of the composite and therefore reduced the quantity of water absorbed, however above certain value of the FR (>20wt%ATH) this reduction seems not to hold believing that more porosity must have been created with higher volumes of the FR. This is in line with the theory that natural fibers/particulates have high affinity for water and moisture.

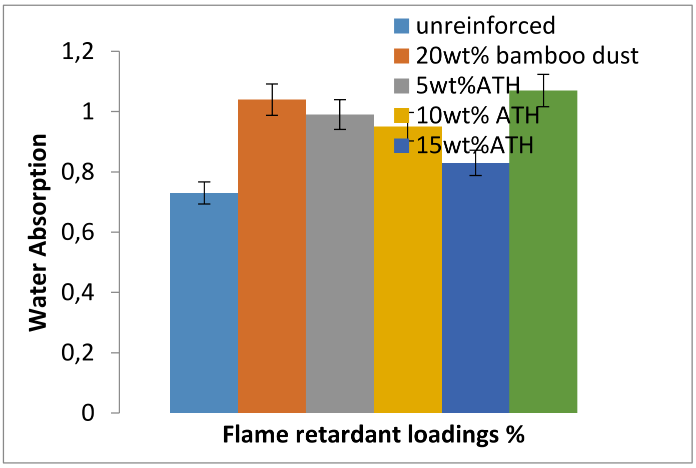

Figure 4: Effect of retardant content on the water absorption of ATH flame retarded bamboo dust reinforced polyester composite

Scanning Electron Microscope (SEM)

The Scan Electron Microscope (SEM) images of the ATH flame retarded bamboo dust/polyester composite at filler loading of 20wt% dust particles and 5wt %, 10wt% and 15wt% of ATH are shown in Figures 5(a)- (d) respectively. The magnification was at uniform 50µm for all the samples. From figure 5a it can be seen that dispersion of the bamboo dust particle was very even devoid of any segregation on the particles with a uniform dark colour throughout. Addition of the ATH flame retardants can be noticed to be the white portions of the micrograph, it was observed that the particles are more uniformed dispersed in Figure 5c with 10wt%ATH than Figures 5b and 5d for 5wt%ATH and 15wtATH respectively. It was observed that dispersion is a factor to be seriously considering during particle reinforcements of polymers. Long and hard stirring of the mixture is very important to ensure good dispersion and avoid agglomeration of the particles which affects its performance.

From these images, Figure 5a, clearly denotes that there were no distinct cluster and gaps between polymer matrix and bamboo dust particles, indicating a good dispersion and blending of polymer matrix and bamboo dust particles. This confirms the increase in properties due to bamboo particle addition. Figure 5b to 5d presents the addition of ATH flame retardants with traces of poor dispersion leading to agglomeration of the retardants except for Figure 5c which has a better uniform distribution of the retardants (white) in the polymer matrix composite (black). This uniform dispersion observed caused the better tensile modulus and flexural properties exhibited by 10wt% of ATH sample among all others.

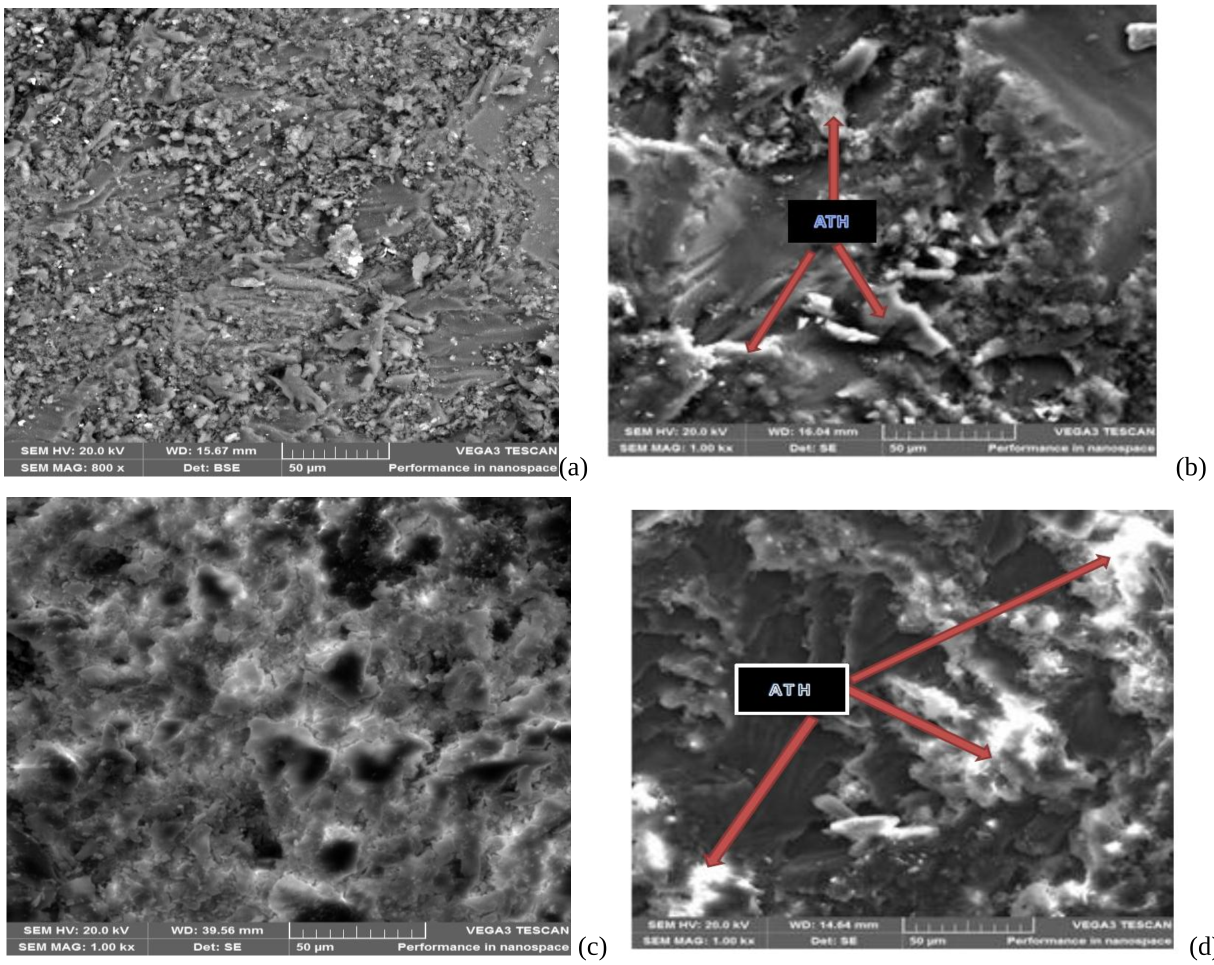

Figure 5: SEM of (a)) 20% bamboo dust reinforced polyester composite, (b) 5wt% ATH, (c) 10% ATH, and (d) 15% ATH bamboo dust reinforced polyester composite

Good dispersion brings about increase in the strength of the composites because of mechanical interlocking, but poor dispersion leads to agglomeration such that the polymer matrix was no longer continuously distributed and many of the particles (bamboo sawdust/ATH) were in direct contact with one another, resulting in poor bonding and adhesion at the interface.

Conclusion

The action of ATH at various weight percentages on selected physical and mechanical properties of bamboo dust particle reinforced polyester composite was studied using the Cone Calorimeter apparatus at a heat flux of 35KW/m^2 and the following conclusions drawn;

(1) The tensile strength decreased with increase in FR content from 41.077 MPa for polyester resin to 14.006MPa for 20wt%ATH, while the tensile modulus increased from 122.807 MPa and 110.417MPa for polyester resin and BDP reinforced polyester to 147.03 MPa, 135.59 MPa and 125.34MPa respectively for 10wt%ATH, 15wt%ATH and 20wt%ATH.

(2) The flexural strength and flexural modulus increased from 1.62GPa to 3.078GPa to 3.684GPa respectively for polyester resin, BDP reinforced polyester and 10wt%ATH addition respectively.

(3) The impact strength increased from 135J/m^2 to 150J/m^2 due to dust reinforcement. The addition of the 10wt% of ATH flame retardant increased the impact strength further to 160J/m^2. Above 10wt% of ATH, the impact strength decreased

(4) the density of the composites decreased as ATH flame retardant content increased.

(5) The BDP reinforcement increased the water absorption of the polyester making it more biodegradable. However, addition of ATH FR increased the hydrophobicity of the composite and therefore reduced the quantity of water absorbed, however above certain value of the FR (>20wt%ATH) this reduction seems not as the water absorption further increased with the 20wt%ATH.

(6) The SEM indicated uniform distribution of the of the BDP reinforcement while sample D with 10wt%ATH had the best dispersion without any agglomeration that caused its superior performance.

(7) The developed composite can be applied to production of collapsible ceilings boards, wall partitions in buildings and fabrication of kitchen/office cabinet panels such as desktop tables, classroom desks and cupboards among others.

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