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PHYSICAL PROPERTIES OF ULTRAFINE CLAY-WOOD DUST HYBRID REINFORCED RECYCLED POLYETHYLENE TEREPHTHALATE MATRIX COMPOSITE FOR SEMI-STRUCTURAL APPLICATIONS

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ABSTRACT

This research involves the production of polymer matrix composites as a combination of ultrafine clay, wood dust and recycled Polyethylene Terephthalate (PET) where the matrix is recycled Polyethylene Terephthalate, and the dispersed phase (hybrid fillers) are ultrafine clay and wood dust. The proportion of recycled PET used for composite production varied from 97 wt% - 99 wt%, while that of wood dust varied from 0.5 wt% - 2 wt% and ultrafine clay from 0.5 wt% - 2 wt%. Physical tests including porosity, water absorption and flammability tests were also carried out on the developed samples. Results obtained from physical tests revealed that the densities of ultrafine clay-wood dust hybrid reinforced recycled PET composites (1.051 - 1.209 g/cm3) were relatively higher than those of ultrafine clay reinforced recycled PET composites and wood dust reinforced recycled PET composite. The WD2 composite sample has the least experimental density value of 0.793 g/cm3. The percentage water absorption rate of the wood dust reinforced recycled PET composites were relatively higher than the ultrafine clay reinforced recycled PET composites. The percentage water absorption rate of the hybrid reinforced recycled PET composites were in between those of the wood dust reinforced and ultrafine clay reinforced fillers. The UFC0.5 composite sample (0.5 wt% ultrafine clay, 0 wt% wood dust reinforced 99.5 wt% recycled PET composite sample) has the least percentage water absorption value of 0.12846535 when compared to other samples. The porosity of the hybrid reinforced recycled PET composite samples were relatively lower than the control sample and separately reinforced samples with ultrafine clay and wood dust. However, HB1 composite sample has the least % porosity value of 1.1563. UFC2 has the least flame propagation rate of value of 0.05482456 mm/s.

Keywords: Ultrafine Clay, Recycled Polyethylene Terephthalate, Polymer Matrix Composite, Wood Dust.

INTRODUCTION

Particle-reinforced polymer matrix composites have gained noticeable scientific and industrial interest due to their ability to improve the physical, mechanical, and optical properties, thermal stability, and flame retardancy compared with unreinforced polymers (Gupta *et al.*, 2009). In a composite, a load carrying material, referred to as reinforcement is embedded in a weaker material known as matrix. Reinforcement provides strength and rigidity helping to support structural load while the matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. The reinforcement may be platelets, particles or fibres and are usually added to improve mechanical properties, such as stiffness, strength and toughness of the matrix material (Lilholt *et al.*, 2010).

The use of both Thermoplastics (TPs) and Thermosets (TSs) has been reported as a matrix for reinforcing natural fibers (Faruk *et al.*, 2017). However in contemporary time, there is a tendency to diminish the use of TSs and increase the use of TPs (Barkoula *et al.*, 2010). Sarasini *et al*. 2017, explained that TPs composites possess certain key advantages over TSs, such as improved impact and abrasion properties; improved environmental, moisture, and corrosion resistance; unlimited shelf life; absence of toxic or solvent emissions; suitability for low as well as high volume manufacturing; rapid cycle times; recyclability; and the ability to fabricate near net-shape components with very complex shape..

Waste plastic composites (WPCs) are a form of composite combining wood based elements with polymers (Gardner *et al.*, 2015). Recycled plastics can also be used for manufacturing of wood polymer composites depending on their melting temperature (Stark *et al.*, 2010). The utilization of recycled plastic in wood polymer composite manufacturing is still limited, and a major portion of global municipal solid waste includes post-consumer plastic materials such as HDPE, LDPE, PVC, and PET which have the potential for being used in the wood polymer composites (Rahman *et al.*, 2013). These post-consumer plastics also pose a serious threat to the environment unless they are recycled.

Objective / Significance of Study

The specific objectives of the study are to:

a. develop hybrid composite of recycled polyethylene terephthalate matrix reinforced with ultrafine clay and wood dust; and
b. determine the physical properties of the developed polymer matrix composites.

MATERIAL & METHODS

Experimental Materials

The materials used for this research were sourced locally. They include: clay, wood dust [Iroko (Melicia exclesa)] and Waste Polyethylene Terephthalate (PET). Collection of 500 PET drinking water bottles locally. The collected bottles were washed, dried and shredded. Gathering of ten (10) kg wood dust from a local sawmill. The gathered wood dust were dried and sieved.

Thirty (30) kg of clay were gathered locally. The gathered clay was processed into ultrafine clay using hydration and stratification process. Subsequently, ultrafine clay was sieved.

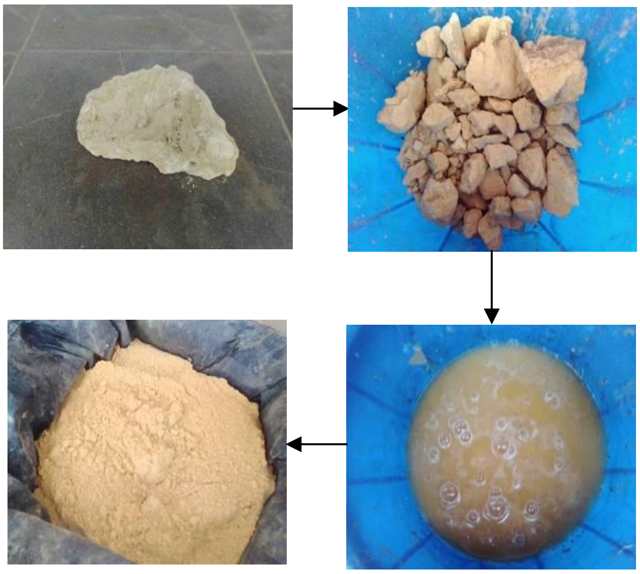

Figure 1. Ultrafine clay Filler preparation.

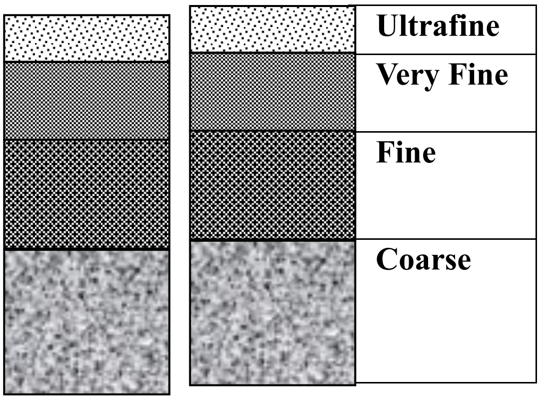

Figure 1B: Clay Stratification Layers

Composite Preparation and Production

The processed ultrafine clay, wood dust and PET were mixed based on the rule of mixture as shown in equation 1 and table 1 to produce homogenous mixture that was used for the development of the composite samples.

Rule of Mixture Equation

$$\rho_c = \rho_f V_f + \rho_m V_m \quad (1)$$

Table 1

Ultrafine Clay-Wood dust Hybrid Reinforced PET Composite Preparation

	Composite matrix composition based on % weight		
Formulation	**Wood Dust (%)**	**Ultrafine clay (%)**	**Recycled PET (%)**
Control	0	0	100
UFC-0.5	0	0.5	99.5
UFC-1	0	1	99
UFC-2	0	2	98
WD-0.5	0.5	0	99.5
WD-1	1	0	99
WD-2	2	0	97
HB-1	1	2	97
HB-2	1.5	1.5	97
HB-3	2	1	97

UFC: Ultrafine clay, WD: Wood Dust, HB: Hybrid Reinforcement

The ultrafine clay, wood dust, and PET dust mixture is placed in a steel mold and subjected to a maximum pressing temperature, pressure, and total pressing time of 160°C, 4MPa, and 2 minutes, respectively. After hot pressing, the polymer composite matrix samples were removed from the press for further cooling. A two-stage molding process was used for composite production. The first stage involved the compounding of composition materials, after which the first molded composite was crushed and remolded in the second stage. This was done to ensure homogeneity and proper distribution of fillers within the composite matrix. A total number of one hundred (100) experimental samples were produced, comprising thirty (30) tensile test samples, thirty (30) flexural test samples, thirty (30) impact test samples, and ten (10) water absorption samples.

Physical Tests

Physical tests were performed on the developed polymer matrix composite samples to evaluate their physical properties.

Densities of the compacted samples of known weight were determined from Equation (2).

$$\rho = \frac{\mathrm{m}}{v} \qquad (2)$$

where: ρ – density of sample

m – mass of sample

v - volume of sample

The porosity test was done through calculations by determining the theoretical and experimental density, and inputting the values obtained from the two (2) aforementioned densities to calculate the percentage porosity of the developed composite samples as shown in Equations (3-5).

$$\rho_{\mathrm{theo}} = (\mathrm{W_{pet}}\ \mathrm{x}\ \rho_{\mathrm{pet}}) + (\mathrm{W_{ufc}}\ \mathrm{x}\ \rho_{\mathrm{ufc}}) + (\mathrm{W_{wd}}\ \mathrm{x}\ \rho_{\mathrm{wd}}) \qquad (3)$$

where: ρ_{theo} is the theoretical density of composite in $\mathrm{g/cm^3}$

$\mathrm{W_{pet}}$ is the weight of polyethylene terephthalate

$\mathrm{W_{ufc}}$ is the weight fraction of ultrafine clay

$\mathrm{W_{wd}}$ is the weight fraction of wood dust

ρ_{pet} is the density of Polyethylene Terephthalate in $\mathrm{g/cm^3}$

ρ_{ufc} is the density of ultrafine clay in $\mathrm{g/cm^3}$

ρ_{wd} is the density of Wood in $\mathrm{g/cm^3}$

$$\rho_{\mathrm{exp}} = \frac{\mathrm{m}}{v} \qquad (4)$$

where m is the mass (g) and v is the volume ($\pi r^2 h$) ($\mathrm{cm^3}$)

$$\%\ \mathrm{P} = \frac{\rho\ \mathrm{theo}}{\rho_{\mathrm{exp}}} \times 100\%$$

(5)

where: % P is the % porosity

ρ_{theo} is the theoretical density of composite in $\mathrm{g/cm^3}$

ρ_{exp} is the experimental desity of composite in $\mathrm{g/cm^3}$

Water absorption test is the test of a materials ability to absorb water from its immediate environment, this may be when immersed in water or surrounded by water. Water absorption was performed in accordance with ASTM D 5229M-12 standard (American Society for Testing and Materials, 2012). The dried composite samples were first weighed using a weighing balance in order to determine the initial weights. After the initial weights have been obtained, a flexible cable was passed through the drilled composite samples to secure them together. The samples were then be immersed in water and maintained at room temperature at a time interval of 24 hours, the samples were later removed for water, cleaned and dried with a cloth before weighing. The average percentage of water absorption of the composite was determined using Equation (6).

$$W\ (\%) = \frac{Wt - Wo}{Wo}\ x\ 100\% \qquad (6)$$

where: W (%) is the average percentage water absorption,

W_o is the initial weight of sample

W_t are final weights of the samples after time t.

Flammability testing is an assessment of how easily a material or finished products will ignite or burn when exposed to fire or heat or when used near them. For flammability test, a 50mm mark was measured on the samples. These samples were clamped horizontally on a bench vice with the 50mm mark protruding out of the vice. The protruding ends were ignited and the time taken for each sample to ignite was recorded as ignition time (I_t). The samples were allowed to burn up to the 50mm mark (D_p). The relative burning rate of the individual sample was obtained using the formula in Equation 7.

$$P_V = \frac{D_p}{P_t - I_t} \qquad (7)$$

where: P_v is the flame propagation rate

D_p is the propagation distance (mm)

I_t is the ignition time (s)

P_t is the flame propagation time (s)

Percentage Enhancement Determination

The percentage of enhancement was determined by using the formula below:

$$\%\ E = \frac{\mathrm{Tp} - \mathrm{Cp}}{\mathrm{Cp}}\ x\ 100\% \qquad (2)$$

where:

% E is the percentage enhancement

Tp is the sample with the topmost performance

Cp is the control sample

RESULTS AND DISCUSSIONS

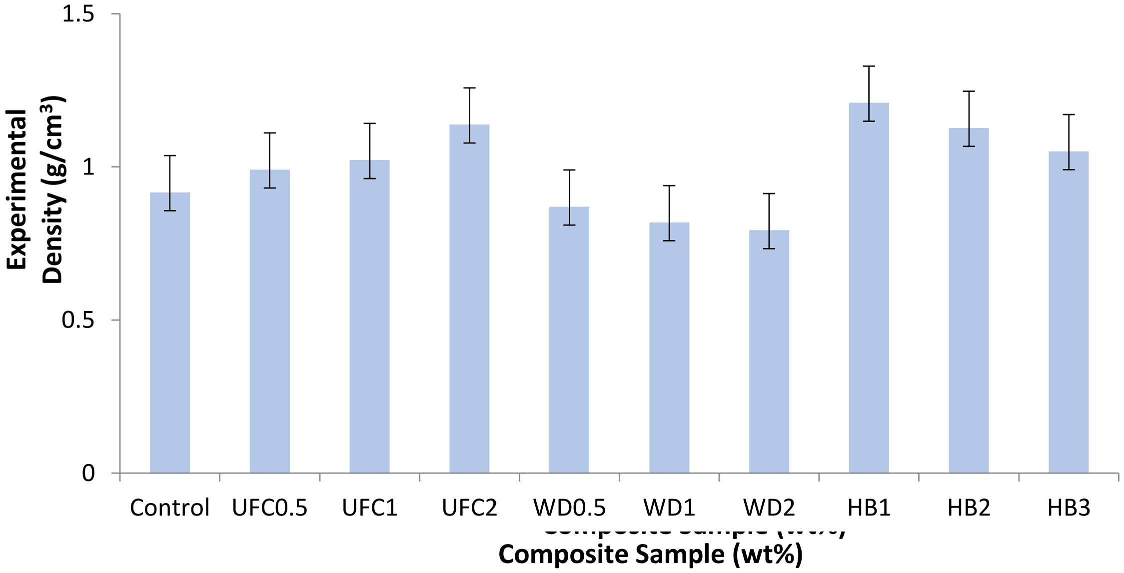

Figure 2: Experimental Density (g/cm^3) of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample

From the result, it was observed that the composite sample with 2wt% Ultrafine clay with 1 wt% wood dust reinforced 97wt% recycled PET composite sample has the highest experimental density value of 1.209g/cm^3, followed by 2 wt% Ultrafine clay, 0 wt % wood dust reinforced 98wt% recycled PET composite sample with a value of 1.238 g/cm^3. The composite sample with 0 wt% ultrafine clay with 2wt% wood dust reinforced 98wt% recycled PET composite sample has least experimental density value of 0.793 g/cm^3.

The higher experimental density of ultrafine clay and hybrid reinforced composite samples may be attributed to higher concentration of a relatively higher density ultrafine clay particulate reinforcement in the matrix.

The experimental densities of the wood dust reinforced composite samples were relatively low, indicating their suitability for applications that require weight reduction.

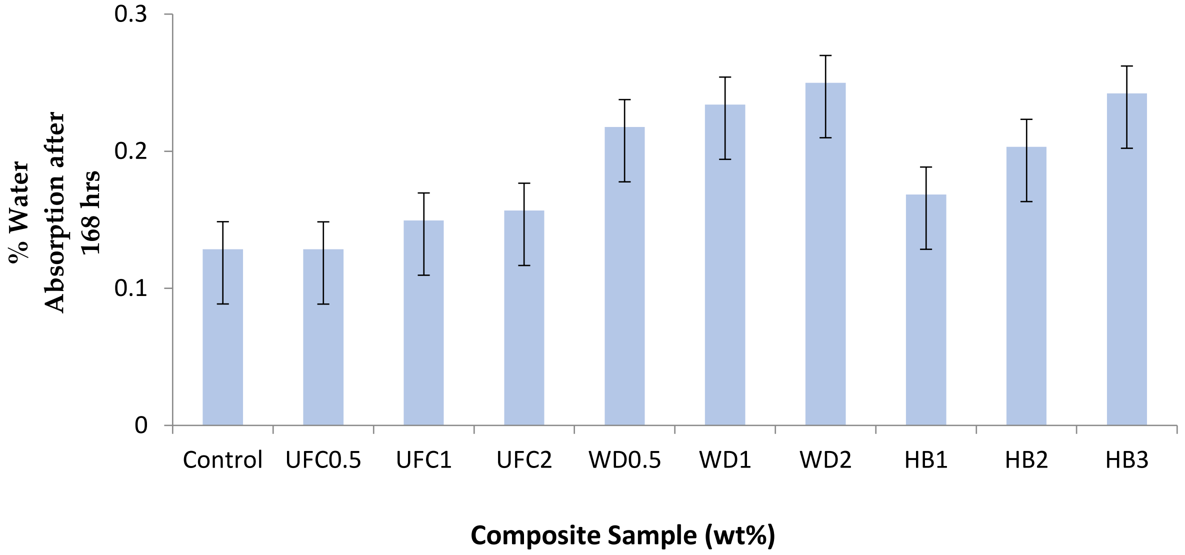

Figure 3: (7days) of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample

Figure 3 shows the percentage water absorption after 168hrs (7days) of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample. The figure shows that the WD_2 sample (0wt% Ultrafine clay with 2 wt% wood dust reinforced 98wt% recycled PET composite sample) has the highest percentage water absorption after 168hrs when compared to other samples. In terms of percentage water absorption, the WD_2 sample was followed by HB_3, WD_1, $WD_{0.5}$, HB_2, HB_1, UFC_2, UFC_1, $UFC_{0.5}$, and the control sample

The higher percentage porosity of the WD_2 sample (0wt% Ultrafine clay with 2 wt% wood dust reinforced 98 wt% recycled PET composite sample) may be attributed to higher volumes of wood dust filler with hydrophilic properties within the polymer matrix composite. The reduction in the percentage water absorption at higher filler loading of ultrafine clay in the ultrafine clay reinforced composite samples may be attributed to higher concentration of hydrophobic fillers within the Polyethylene Terephthalate matrix.

Figure 4 shows the percentage porosity of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample. From the result, it was observed that the control sample with 100 wt% recycled PET composite sample has the highest %porosity value of 1.7448, followed by 0 wt% Ultrafine clay, 2 wt % wood dust reinforced 98 wt% recycled PET. The composite sample with 1 wt% Wood Dust, 2 wt % ultrafine clay and 97 wt% Recycled PET) has the least % porosity value of 1.1563.

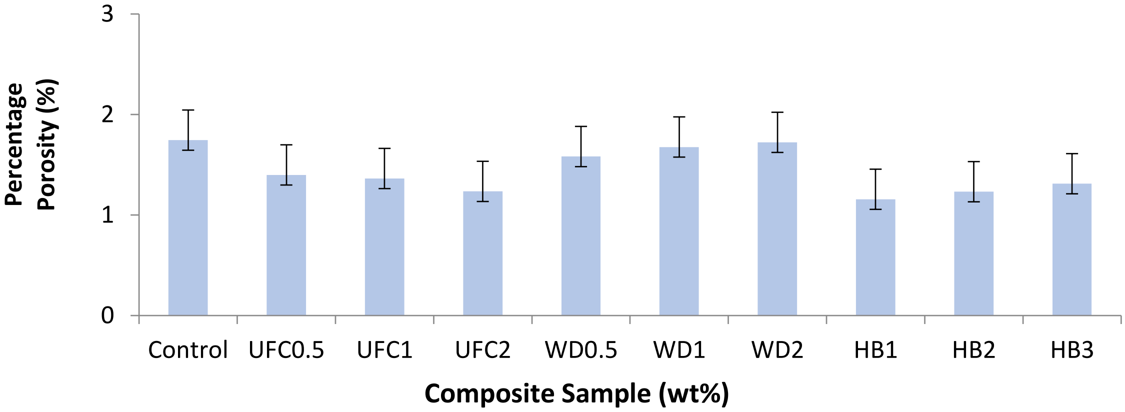

Figure 4: Percentage porosity of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample

Reduction in the percentage porosity at higher filler loading of ultrafine clay in the ultrafine clay reinforced composite samples may be attributed to effective filling of empty spaces within the Polyethylene Terephthalate matrix. The least percentage porosity of the HB_1 sample (1 wt% Wood Dust, 2 wt % ultrafine clay and 97 wt% Recycled PET) may be attributed to a relatively higher level filling of the empty spaces by ultrafine clay particles and micro wood dust particles. The higher percentage porosity of the control sample may be attributed to higher volumes of empty space within the polymer matrix composite due to zero filler content.

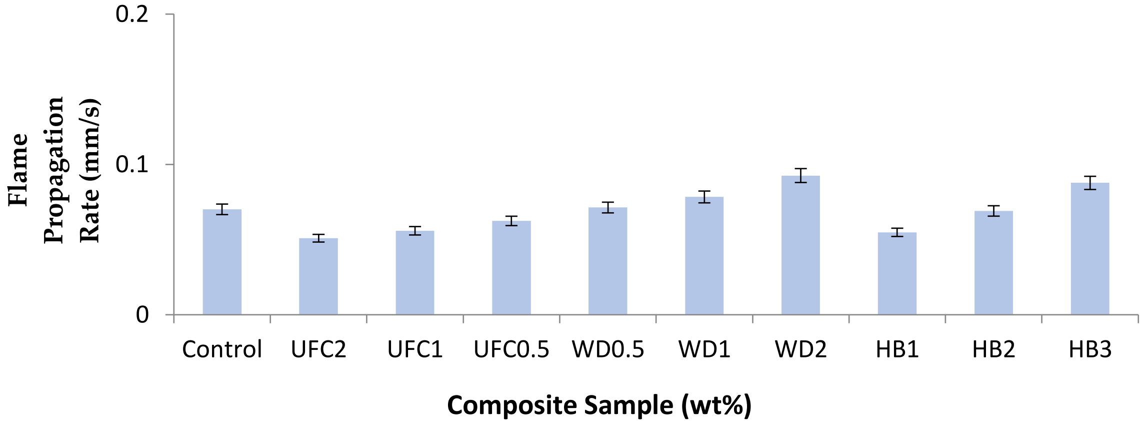

Figure 5: Flammability test result of the developed ultrafine clay-wood dust hybrid reinforced recycled PET composite and the control sample

Figure 5 shows the flammability test results of the developed ultrafine clay-wood dust reinforced recycled PET composite and the control sample. The figure shows that UF_2 sample (2 wt% ultrafine clay, 0 wt% Wood Dust, 98wt% Recycled PET) has the lower flame propagation rate of 0.0509165 mm/s when compared to other samples and the control sample. Reduction in the flame propagation rate at peak at higher filler loading of ultrafine clay may be attributed to the ability of ultrafine clay particles to resist ignition and combustion. On the other hand, the increase in the flame propagation rate at peak at higher filler loading of wood dust may be attributed to high flammability of wood dust particles.

From the result, it was observed that UFC_2 composite sample (2 wt% ultrafine clay with 0 wt% wood dust reinforced 98wt% recycled PET composite sample) has the lowest flame propagation rate at the value of 0.0509165 mm/s, followed by HB_1 (2wt% ultrafine clay with 1wt % wood dust reinforced 97wt% recycled PET composite sample) with a value of 0.05482456 mm/s. The control sample has a flame propagation rate of 0.07012623 mm/s. Percentage enhancement between HB_2 (the sample with the lowest flame propagation rate) and the control sample is 27.39%.

CONCLUSION AND RECOMMENDATION

Ultrafine clay-Wood Dust Hybrid Reinforced Recycled Polyethylene Terephthalate Matrix Composite was developed, studied, and analyzed to confirm the potentials of reinforcing Polyethylene Terephthalate (PET) Matrix with hybrid fillers comprising organic particle (wood dust) and inorganic particles (ultrafine clay) in the production of polymer matrix composites with optimum physical (density, porosity, water absorption and flammability) properties. From the results, the following findings were obtained:

The HB_1 composite sample with 2 wt% Ultrafine clay with 1 wt% wood dust reinforced 97wt% recycled PET composite sample has the highest experimental density value of 1.209g/cm^3.

The density of ultrafine clay reinforced recycled PET composites were relatively higher than wood dust reinforced recycled PET composites which makes wood dust reinforced recycled PET composites more attractive from the light weight perspective. The density of ultrafine clay-wood dust hybrid reinforced recycled PET composites were relatively higher than those of ultrafine clay reinforced recycled PET composites and wood dust reinforced recycled PET composite due to a relatively higher filler loadings.

The percentage water absorption rate of the wood dust reinforced recycled PET composites were relatively higher than the ultrafine clay reinforced recycled PET composites. The percentage water absorption rate of the hybrid reinforced recycled PET composites were in between those of the wood dust reinforced and ultrafine clay reinforced fillers. The percentage water absorption rate of the $UFC_{0.5}$ containing 0 wt% Wood Dust, 0.5 wt % ultrafine clay and 99.5 wt% Recycled PET was the least with a value of 0.12846535.

The percentage porosity of the ultrafine clay-wood dust hybrid reinforced recycled PET composites were relatively lower than the ultrafine clay reinforced, wood dust reinforced and the control sample due to effective filling of the spaces within the matrix by ultrafine clay and wood dust. The HB_1 composite sample with 1 wt% Wood Dust, 2 wt % ultrafine clay and 97 wt% Recycled PET has the least % porosity value of 1.1563.

The percentage porosity of the ultrafine clay -wood dust hybrid reinforced recycled PET composites were relatively lower than the ultrafine clay reinforced, wood dust reinforced and the control sample. UFC_2 composite sample (2 wt% ultrafine clay with 0 wt% wood dust reinforced 98wt% recycled PET composite sample) has the lowest flame propagation rate at the value of 0.0509165 mm/s, followed by HB_1 (2wt% ultrafine clay with 1wt % wood dust reinforced 97wt% recycled PET composite sample) with a value of 0.05482456 mm/s.

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Conflict of Interest Statement

No conflict of interest among the authors.