High Density Polyethylene (HDPE) composite mixed with Azadirachta excelsa (Sentang) tree waste flour: Mechanical and physical properties

A M Zakaria¹, M A Jamaludin¹, M N Zakaria¹, R Hassan², S A Bahari¹*

¹Faculty of Applied Sciences and ²College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

*Email: shahril721@uitm.edu.my

Abstract. This article presents the application of plantation waste materials (leaves, branches and trunks) of Azadirachta excelsa (Sentang) tree in order to evaluate and compare their suitability as reinforcement and filler for high density polyethylene (HDPE) thermoplastics. The aim of the study was to investigate the effect of different types of Azadirachta excelsa (Sentang) trunks flour, branches flour and leaves flour fillers on the mechanical and physical properties of HDPE composite. The composite samples were produced using 25%, 35% and 45% by weight of flour filler loading and 2% coupling agent (maleic anhydride) using a twin-screw extruder, followed by injection molding process. The flexural modulus and tensile strength of the composite filled with trunk flour were not significantly different with the composite-filled branch flour. However, there is a significant difference between composite-filled leaf flour when compared to both composite-filled trunk flour and composite-filled branch flours. Overall, composite samples with trunk flour show better mechanical properties, while composite samples with lower filler loadings of 25% exhibit better dimensional stability compared to the other such as 35% and 45% filler loadings. The study also indicated that composite filled with leaf, branch and trunk flours had better mechanical strength than virgin HDPE.

1. Introduction
Composite is comprised of two or more constituents that are combined together to form a material with entirely different properties from those of an individual material. The development of composite made from various materials such as bio-composite materials, polymer matrix composite (PMC), metal matrix composite (MMC) and ceramic matrix composite (CMC) have grown widely around the world. The most demanding composite in the industry is bio-composite because it is made from environmentally-friendly materials, composed with biological origins such as wood plastic composites, particleboards, cement boards, fiberboards and others. Wood plastic composite (WPC) is another example of composite products. It is composed of wood flours as reinforcement and thermoplastic as matrix through the injection molding machine between the temperature of 170°C to 200°C [1,2]. According to Fortune Business Insights, the market size for WPC is expected to rise in the year 2020 to 2027 due to the high demands of environmental-friendly material and the law of some countries to implement waste management in order to preserve natural resources. The largest countries that ranked first in the market share for WPC from now on are North America, China, India and Europe [3].
WPC has been popular among the industries because it has excellent properties of plastics and the aesthetic appearance similar like wood. There are a lot of advantage of WPC compared to the virgin plastics such as lightweight, low price, easy to decompose, good mechanical properties, sustainable and renewable. The presence of wood flour in WPC improves the biodegradability of the material because the number of plastics used is reduced compared to the virgin plastic with the compositions of 100% plastics. However, there are some drawbacks in WPC products. It is brittle, and it has high moisture absorption compared to the virgin plastics. Wood flour is hygroscopic as it is comprised of cellulose that has the hydroxyl groups and form the hydrogen bonds (H-bonds) with water. The formation of H-bonds will lead to the absorption of water and this will possibly reduce the durability of the WPC products. For example, decking product, that is exposed to the outside air such as direct sunlight, moisture and raining, will face this type of problem. The product will start to buckling and increase its size by swelling or expanding, due to the absorption of moisture and water. Thus, there are a lot of research that been carried to improve the weakness of WPC product. However, due to its great mechanical and physical properties, there are a lot of application that can be utilized by using WPC, such as automotive components (door panel, dashboard, booth trims and back parcel shelf), construction of structural applications (decking, fence, ceiling paneling and partition boards), packaging, aerospace, circuit boards and railway coaches [4,5].

WPC is an engineered innovative material that have almost the same mechanical and physical properties as solid wood. The component of WPC includes lignocellulosic materials (wood flour or natural fiber) and thermoplastics. Wood flour is composed of cellulose, hemicellulose, lignin and extractives. The amount of the components that exists in wood flour are different according to the species of the trees and the source of the wood such as the geographic location and parts of tree. Wood flour and natural fibers are preferable as the reinforcement of WPC because of its wide availability, renewable resources, easy to modify with chemical treatments due to the presence of hydroxyl groups, low cost, low density, non-abrasive to machining or processing equipment and sustainable [6].

Besides, thermoplastic is a group of polymers that softened when subjects to heat but hardened when cooled. This type of polymers can be recycled because the chains breaks and slide past each other when subjected to heat [7,8]. The most popular thermoplastic polymers in the production of WPC are high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and polyvinyl chloride (PVC). These polymers have good resistant to water and biological attack such as termites, beetles and fungi. However, the combination of wood flour and thermoplastic polymers are not compatible due to the poor adhesion between them. The addition of coupling agents help in increasing the composites strength by enhancing the interfacial adhesion between the wood flour and polymer matrix [9].

In this research, the components in making WPC are composed of wood flour from the waste materials of Azadirachta excelsa (Sentang) tree such as leaves, branches and trunks, whereas high-density polyethylene (HDPE) and maleic anhydride (MA) act as polymer matrix and coupling agent. The main objective of this research was to study the potential of waste materials such as leaf, branch and trunk reinforcing fillers for WPC in order to evaluate and compare their suitability as an alternative for HDPE polymers. In addition, this research also identifying the effects of fiber loading and MA content on the mechanical properties and physical properties of WPC.

2. Materials and methods

2.1. Materials

2.1.1. Wood flour materials. Azadirachta excelsa (Sentang) flour derived from different parts of Sentang tree: leaf, branch and trunk. The leaves and wood materials collected from a plantation area located at Negeri Sembilan, Malaysia. First, the branch and trunk were reduced to chips. The chips and leaves later air-dried to equilibrium moisture content. After air-drying, the materials were milled into small particles using the hammer-milling machine. The particles crushed using a laboratory grinder to form wood flours
or finer particles. After that, the wood flours (leaf, branch and trunk) were dried in an oven at 60°C for 24 hours to a targeted moisture content of 8%. The oven-dried flours (leaf, branch and trunk) then screened through a vibrating sieve to obtain the particles of size 50-mesh or 297 μm. The different types of 50-mesh wood flour were then oven-dried at 105 ± 2°C for 24 hours. The wood flours stored in sealed plastic bags before the compounding process.

2.1.2. Polymer matrix. High-density polyethylene (HDPE) supplied by PT Lotte Chemical Titan Nusantara (Malaysia) in the form of pellets with the density of 0.95 g/cm³, melt flow index (MFI) of 18.0g/10min and melting point of 190 °C.

2.1.3. Coupling agent. Maleic anhydride (MA) supplied by Sigma-Aldrich (Malaysia) in the form of powder and has a melting point of 52 to 54 °C.

2.2. Manufacture of injection moulded WPC test samples
The flour (leaf, branch, and trunk separately) used as filler in the HDPE composite were 25%, 35% and 45% by weight. The flours, HDPE and MA were compounded by using a twin-screw extruder. The barrel temperature of extruder was set at 190°C with twin-screw speed set at 4 rpm. HDPE was added into the barrel until it becomes totally melted, followed by MA and flours. The compounding of polymer matrix, coupling agent and flours took about 30 to 40 minutes until it blended together. After that, the compound was removed from the barrel and allowed to cool for 5 to 10 minutes. The compound was turned into pellets by using the crusher machine [10]. Next, the injection molding was set into the temperature of 190°C and the pellets were passed through the machine. The pellets were melted inside the cylinder and the molten pellets were forced out into a mold under high pressure. The molten material filled the cavity in the mold and solidified as it cooled the test samples. Finally, the samples were conditioned at a temperature of 23 ± 2 °C with a relative humidity of 50 ± 5%, as stated in ASTM D 618. The same steps apply to all groups of wood flours in the fabrication of HDPE composite. The compositions of HDPE composite are presented in Table 1.

2.3. Determination of mechanical properties
2.3.1. Three-point flexural bending test. This test was conducted in accordance to ASTM D790 for flexural elasticity (MOE) determination. The tests carried using a universal testing machine (UTM) at room temperature. The rate of crosshead speed was 2.0 mm/min using a 10kN load cell. The test samples are rectangular shape with a dimension of 80.0 × 10.0 × 4.0 mm.

2.3.2. Tensile test. This test was performed in accordance to ASTM D 638 (Type V) for tensile strength (MOR) assessment. A load-cell of 10kN and rate of cross head speed of 5.0 mm/min conducted using the UTM at the room temperature. The tensile samples were in dog-bone shape of dimension 75.0 × 4.0 × 2.0 mm with a gauge length of 30.0 mm.

2.4. Determination of physical properties
2.4.1. Water absorption. The test was performed in accordance to ASTM D570-98 for the determination of composite’s water absorption rate (%) with the modified sample size of 10.0 mm × 10.0 mm × 2.0 mm. The samples were immersed in the water for 24 hours at the room temperature (23 ± 2°C). Then, the samples were weighed using weighing balance before and after the immersion into the water.

2.4.2. Thickness swelling. The test was assessed in accordance to ASTM D570-98 for the determination of composite’s thickness swelling rate (%) with the modified sample size of 10.0 mm × 10.0 mm × 2.0 mm. The samples were immersed in the water for 24 hours at the room temperature (23 ± 2°C). After 24 hours, the samples were removed from the water and wiped using tissue papers. Then, the samples were measured for thickness swelling after 10 minutes removal from the water.
2.5. Statistical analysis
Analysis of variance (ANOVA) was used to determine the effect of filler types and filler loading/ratio from Sentang leaf, branch and trunk on the flexural modulus, tensile strength, water absorption and thickness swelling of the HDPE composite. In this study, the least significant difference (LSD) test was used to identify the significant differences between the filler types and filler loading on the mechanical and physical properties of HDPE composite.

Table 1. The compositions of HDPE composite.

| Formulation                  | Filler Type | Filler (%) | HDPE (%) | MA (%) | Code |
|------------------------------|-------------|------------|----------|--------|------|
| Virgin HDPE (vHDPE) Composite| -           | 0          | 100      | 0      | vHDPE|
| HDPE Composite               |             |            |          |        |      |
| 25% Leaf, 73% HDPE, 2% MA    | Leaf        | 25         | 73       | 2      | L25  |
| 35% Leaf, 63% HDPE, 2% MA    | Leaf        | 35         | 63       | 2      | L35  |
| 45% Leaf, 53% HDPE, 2% MA    | Leaf        | 45         | 53       | 2      | L45  |
| 25% Branch, 73% HDPE, 2% MA  | Branch      | 25         | 73       | 2      | B25  |
| 35% Branch, 63% HDPE, 2% MA  | Branch      | 35         | 63       | 2      | B35  |
| 45% Branch, 53% HDPE, 2% MA  | Branch      | 45         | 53       | 2      | B45  |
| 25% Trunk, 73% HDPE, 2% MA   | Trunk       | 25         | 73       | 2      | T25  |
| 35% Trunk, 63% HDPE, 2% MA   | Trunk       | 35         | 63       | 2      | T35  |
| 45% Trunk, 53% HDPE, 2% MA   | Trunk       | 45         | 53       | 2      | T45  |

3. Results and discussion

3.1. Mechanical properties
The flexural modulus and tensile strength of the virgin HDPE composite and HDPE composite filled with leaf, branch and trunk at different filler loading are presented in Table 2.

Table 2. Flexural modulus (MOE) and tensile strength (MOR) of virgin HDPE composite and HDPE composite filled with leaf, branch and trunk at different filler loading.

| WPC           | Flexural modulus (MPa) | Tensile strength (MPa) |
|---------------|------------------------|------------------------|
| vHDPE         | 587.7<sup>a</sup>,1    | 15.16<sup>b</sup>,3    |
| L25           | 1417.6<sup>a</sup>,2    | 16.05<sup>c</sup>,6    |
| L35           | 1702.8<sup>a</sup>,3    | 16.73<sup>c</sup>,6,7  |
| L45           | 2546.4<sup>a</sup>,4    | 17.05<sup>e</sup>,7    |
| B25           | 2085.2<sup>b</sup>,2    | 18.02<sup>d</sup>,6    |
| B35           | 2941.6<sup>b</sup>,3    | 22.47<sup>d</sup>,6,7  |
| B45           | 3771.0<sup>b</sup>,4    | 26.68<sup>d</sup>,7    |
| T25           | 2270.6<sup>b</sup>,2    | 20.26<sup>d</sup>,6    |
| T35           | 3124.6<sup>b</sup>,3    | 25.46<sup>d</sup>,6,7  |
| T45           | 3822.8<sup>b</sup>,4    | 27.91<sup>d</sup>,7    |

Note:
<sup>1,2,3,4,5,6,7</sup> Numbers with same superscript are not significantly different from each other (filler loading)
<sup>a,b,c,d</sup> Numbers with different superscript are not significantly different from each other (filler loading)
Numbers with same superscript letters are not significantly different from each other (filler type)
Numbers with different superscript letters significantly different from each other (filler type)

3.1.1. Flexural Modulus (MOE). The WPC filled with leaf, branch and trunk shows higher flexural modulus compared to the virgin HDPE. WPC comes from trunk wood flour (T45) has the highest flexural modulus with 3822.8 MPa, followed by B45 and T35 with 3771.0 MPa and 3124.6 MPa.
respectively. According to the graph shown in Figure 1, the WPC filled with 45% filler loading ranked first as the best composition in producing WPC. The flexural modulus of the composites increased at 45% filler loading and remained unchanged for all the formulations. Flexural modulus is important in determining the material properties because it measures the materials elasticity and the resistance of the materials to the deformation. In making the composites, the addition of wood fibre and the increasing of fibre content influenced the flexural modulus of the materials. This can be proved by some research conducted by Huda et al. and Alshammari et al. [11,12]. Based on the results in Table 2, the flexural modulus is significantly different when compared with the amount of filler loading. This means that the filler loading affects the flexural modulus of the WPC filled with leaf, branch and trunk flours. Besides, the flexural modulus of WPC-filled trunk flour (WPCT) was not significantly different from that of WPC-filled branch flour (WPCB). On the other hand, the flexural modulus of WPCL was significantly different to that of WPCT and WPCB. The flexural modulus of virgin HDPE was not significantly different from that of WPC-filled leaf flour (WPCL). This inferred that the leaf flour did not significantly contribute to increase in flexural modulus. Therefore, leaf flour is not recommended to enhance the flexural modulus of polymer composites. However, trunk and branch wood flour are highly recommended for this purpose. Most of the nutrients in plants are stored in the leaves. These nutrients may have hindered the effective interface cohesion or adhesion of constituents of the polymer composites. Thus, lower mechanical properties of WPCL compared to WPCT and WPCB. The trunk and branch also have more fibers compared to the leaves. This may have contributed to the higher strength properties of the WPCT and WPCB.

![Figure 1. Flexural modulus of the virgin HDPE and WPC-filled with leaf, branch and trunk (WPCL, WPCB and WPCT) at different filler loadings.](image)

### 3.1.2. Tensile strength (MOR)

WPC filled with trunk wood flours (T25) ranked first as the highest in tensile strength with 27.91 MPa, followed by B45 and T35 with 26.68 MPa and 25.46 MPa respectively. The results shows that the virgin HDPE has the lowest tensile strength compared to the WPC filled with leaf, branch and trunk wood flours (WPCL, WPCB and WPCT). As stated above, the presence of filler or wood flour helps in increasing the properties of materials especially in tensile strength. Tensile strength plays vital role in identifying the properties of the materials because it measures the pressure that the material can withstand without breaking and when it begins to deform plastically. From the above results, 27.91 MPa is the maximum stress that T25 can withstand before it starts to break. Some
studies also stated that the filler type also influenced the strength properties of the materials because of the chemical composition inside the fillers such as cellulose, lignin, extractives and ash content. Alshammari et al. reported that the increasing amount of cellulose and hemicellulose content influenced the interfacial adhesion between the filler and the polymer [13]. Based on the results, the tensile strength of WPCT was not significantly different from the tensile strength of WPCB. However, the tensile strength of WPCL was significantly different from that of WPCB and WPCT. The virgin HDPE had significantly difference tensile strength compared to the same properties of WPCB and WPCT. In contrast, the tensile strength of virgin HDPE and WPCL were not significantly different. Therefore, the leaf wood flour did not contribute significantly to the increase in tensile strength. It can only function as filler, but not as reinforcement in WPC production. Thus, it will only contribute to smooth out the surface and fill-out voids. The function of fillers is to fill-out the voids in the polymer composite, thus making the composite denser, consequently increasing the mechanical strength properties. In this study, WPC filled with leaf, branch and trunk flours had higher mechanical strength than virgin HDPE.

![Filler type & Filler loading of WPC](image)

**Figure 2.** Tensile strength of the virgin HDPE and WPC-filled with leaf, branch and trunk (WPCL, WPCB and WPCT) at different filler loadings.

### 3.2. Physical properties

The water absorption and thickness swelling of the virgin HDPE and WPC filled with leaf, branch and trunk at different filler loading presented in Table 3.

| WPC   | Water absorption (%) | Thickness swelling (%) |
|-------|----------------------|------------------------|
| vHDPE | 0                    | 0                      |
| L25   | 2.8                  | 1.8                    |
| L35   | 2.1                  | 2.7                    |
| L45   | 3.0                  | 4.2                    |
| B25   | 0.6                  | 1.9                    |
| B35   | 4.9                  | 2.5                    |
| B45   | 2.4                  | 7.1                    |
| T25   | 0.3                  | 0.7                    |
| T35   | 0.5                  | 0.9                    |
| T45   | 3.1                  | 7.1                    |
3.2.1. Water absorption. The results in Table 3 shows that the WPC-filled leaf, branch and trunk flours have the highest percentage of water absorption compared to virgin HDPE. Figure 4 shows that the WPC with filler loading of 45% has the highest absorption of water compare to other filler loadings of 25% and 35%. The outcomes obtained in this research is correspondingly similar to Ashori et al. and Bujjibabu et al. They stated that the absorption of water into WPC influenced by the increasing of the wood flour content or filler loading. From the research, it is clear that the filler loading and polymer content is one of the factors that causes the water absorption of WPC to increase. The study from the previous literatures shows that the absorption of water inside the WPC is mainly because of the anatomical properties of the wood flours such as the presence of lumens, fine pores and hydrogen bonding (H-bond) that formed between the wood flour and water. Besides, the water absorption of WPC affected by the wood flours that is rich in cellulose and contains many hydroxyl (OH) groups. These hydroxyl groups tend to form H-bonds with water and it causes the absorption of water. The abundance of free hydroxyl groups eases the passes of water into the amorphous region of cell wall and this causes the increase of the absorption of water into the WPC [14][15]. On the other hand, the WPC filled with trunk and branch flours exhibits the highest water absorption compared to the WPC filled leaf flours and virgin HDPE. This is due to the highest cellulose contents that presents in the trunk and branch compare to the other parts such as branches and leaves. The high absorption of water causes the WPC to deform by swelling or creating voids and this will lead to the increasing of the mass and reduction of strength in terms of mechanical and physical properties. The development of voids and free spaces will contribute to the fracture mechanisms in these WPC.

3.2.2. Thickness swelling. The thickness swelling of the WPC-filled leaf, branch and trunk flours increases as the filler loading increases. The results in Figure 4 shows that the virgin HDPE maintain its thickness even though it had been immersed in water for 24 hours whereas T45 and B45 shows the highest value of thickness swelling at 45% filler loading. The thickness swelling occurs because of the absorption of water inside the WPCs and the trend between these two mechanisms are similar. The samples with lower filler content such as 25% filler loading show the thickness swelling of the WPC is reduce. This is due to the lower filler loading and free hydroxyl groups compare to 45% filler loading. There are many numbers of free hydroxyl groups (OH) that attracts the water and this causes the increase in the thickness swelling of the WPC at 45% filler loading. One of the factors that causes the increase in thickness swelling is due to the poor compatibility between the hydrophilic wood flour and hydrophobic properties of the polymers. The presence of voids and pores will absorb water and this also leads to the increase of thickness of the WPCs. Thus, the voids and pores inside the WPCs increases as the filler loading increases. Figure 3 proved that the morphology structure of the WPCs samples such as WPC-filled trunk, branch and leaf flours have voids and pores compared to virgin HDPE. Overall, the virgin HDPE has lowest thickness swelling and the presence of the leaf, branch and trunk flours as fillers in WPC increases the thickness of the WPC when it immersed in water.
Figure 3. FESEM images on the morphology of virgin HDPE and WPC-filled with trunk, branch and leaf flours (WPCT, WPCB and WPCL) at 45% filler loadings: (a) vHDPE; (b) T45; (c) B45; (d) L45.

Figure 4. Thickness swelling and water absorption of the virgin HDPE and WPC-filled with leaf, branch and trunk (WPCL, WPCB and WPCT) at different filler loadings.
4. Conclusions

In general, the different types of Azadirachta excelsa (Sentang) wood flour filler enhanced the mechanical properties of virgin high-density polyethylene (vHDPE) composites. The WPC-filled with leaf, branch and trunk flours (WPCL, WPCB and WPCT) had higher mechanical properties compared to virgin HDPE. WPCT exhibits the highest flexural modulus and tensile strength followed by WPCB and WPCL. The function of the filler is to fill-out the voids in the polymer composite, thus making the composite denser, consequently increasing the mechanical strength properties. Most of the nutrient in the plants is stored in the leaves. These nutrients may have hindered the effective interface cohesion or adhesion of constituents of the polymer composites. Thus, lower mechanical properties of WPCL compared to WPCT and WPCB. The trunk and branch have more fibers compared to the leaves. This may have contributed to the higher strength properties of the WPCT and WPCB. WPCT and WPCB had not significantly different in terms of flexural modulus and tensile strength. This suggested that the wood flour from trunk and branch of Sentang tree can be mixing and combining together in the production of WPC. However, the separation of leaves flours from trunk and branch wood flours has to be done since WPC with leaf fillers had significantly different mechanical strength compared to WPC with trunk or branch wood flour fillers. Besides, virgin HDPE exhibits the lowest water absorption and thickness swelling because it made up of plastics that do not have pores or voids. Thus, there is no movement of water inside the polymers and there is no change of thickness of the virgin HDPE. However, WPC-filled trunk, branch and leaf flours at 45% fiber loading shows higher water absorption and thickness swelling compared to 35% and 25% filler loading. Higher filler contents will increase the water absorption and thickness swelling of WPCs. Some modifications have to apply in terms of enhancing the dimensional stability of the WPC such as heat treatment of the fiber and adding water repellant chemicals during the production.

References

[1] Alshammari B A, Saba N, Alotaibi M D, Alotibi M F, Jawaid M and Alothman O Y 2019 Morphological Properties of Epoxy Composites Reinforced with Different Date Palm Fillers Materials (Basel). 12 2145

[2] Huda M S, Drzal L T, Misra M and Mohanty A K 2006 Wood-Fiber-Reinforced Poly ( lactic acid ) Composites: Evaluation of the Physicomechanical and Morphological Properties J. Appl. Polym. Sci. 102 4856–69

[3] Kurkani A 2020 Wood Plastic Composite Market Size, Share & Industry Analysis, By Material (Polyethylene, Polypropylene, Polyvinyl Chloride and Others), By Application (Decking, Automotive, Sliding & fencing, Technical Application, Furniture, Consumer Goods and Others), Mark. Res. Rep. 1–8

[4] Hamdan M H M, Siregar J P, Bachtiar D, Rejab M R M and Cionita T 2018 9. Mechanical Properties of Mengkuang Leave Fiber Reinforced Low Density Polyethylene Composites (Elsevier Ltd)

[5] Verma D and Senal I 2019 Natural fiber-reinforced polymer composites (Elsevier Ltd)

[6] John M J and Thomas S 2008 Biofibres and biocomposites 71 343–64

[7] Kusumiyati, Munawar A A and Suhandy D 2021 Fast and contactless assessment of intact mango fruit quality attributes using near infrared spectroscopy (NIRS) IOP Conf. Ser. Earth Environ. Sci. 644 012028

[8] Abubakar A, Yusuf H, Syukri M, Nasution R, Karma T, Munawar A A and Idroes R 2021 Chemometric classification of geothermal and non-geothermal ethanol leaf extract of seurapoh (Chromolaena odorata Linn) using infrared spectroscopy IOP Conf. Ser. Earth Environ. Sci. 667

[9] Salleh F M, Hassan A, Yahya R, Lafia-Araga R A, Azzahari A D and Nazir M N Z M 2014 Improvement in the mechanical performance and interfacial behavior of kenaf fiber reinforced high density polyethylene composites by the addition of maleic anhydride grafted high density
polyethylene. J. Polym. Res. 21

[10] Munawar A A, Yunus Y, Devianti and Satriyo P 2020 Calibration models database of near infrared spectroscopy to predict agricultural soil fertility properties Data Br. 30

[11] Oladejo K O and Omoniyi T E 2017 Dimensional Stability and Mechanical Properties of Wood Plastic Composites Produced from Sawdust of Anogeissus leiocarpus ( Ayin ) with Recycled Polyethylene Teraphthalate ( PET ) Chips Eur. J. Appl. Eng. Sci. Res. 5 28–33

[12] Mohammad S, Zeinaly F and Dabbagh F 2014 Composites : Part B Date palm wood flour as filler of linear low-density polyethylene Compos. Part B 56 137–41

[13] Adhikary K B, Pang S and Staiger M P 2008 Dimensional stability and mechanical behaviour of wood – plastic composites based on recycled and virgin high-density polyethylene ( HDPE ) 39 807–15

[14] Bujjibabu G, Das V C, Ramakrishna M and Nagarjuna K 2018 Mechanical and Water Absorption Behavior of Natural Fibers Reinforced Polypropylene Hybrid Composites Mater. Today Proc. 5 12249–56

[15] Ashori A and Nourbakhsh A 2009 Characteristics of wood – fiber plastic composites made of recycled materials Waste Manag. 29 1291–5