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UTILIZATION OF TINDER FUNGUS AS FILLER IN MANUFACTURE OF HDPE COMPOSITES

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Abstract
Selected physical and mechanical properties of the high density polyethylene (HDPE) composites filled with various mixtures of the wood flour and the tinder fungus (Fomes fomentarius) were investigated. For this aim, the different mixtures of tinder fungus flour and wood flour (0/40, 10/30, 20/20, and 30/10, and 40/0) (by weight) were compounded with HDPE with a coupling agent (maleic anhydride grafted polyethylene (MAPE)) in a twin screw co-rotating extruder. The test specimens were then produced by injection moulding process. The thickness swelling and water absorption of the HDPE/wood composites significantly decreased with increasing content of the tinder fungus flour. The flexural strength of the HDPE composites filled with tinder fungus flour (10-30 wt%) did not decrease significantly as compared with the HDPE composites filled with wood flour (10-30 wt%). In addition, the tensile and flexural modulus of the HDPE composites filled with tinder fungus (10-40 wt%) did not show significant differences with the values of the HDPE composites filled with wood flour (10-40 wt%). Based on the findings obtained from the present study, the optimum physical and mechanical properties for the filled HDPE composites were found to be a 10/30/60/3 formulation of wood flour, tinder fungus, HDPE, and MAPE, respectively.

Key words: *wood plastic composites; mechanical properties; physical properties; tinder fungus; polyethylene.*

INTRODUCTION

Various wood species, including cherry, sweet gum, hickory, yellow poplar, walnut, eastern red cedar, pine, maple, eucalyptus, paulownia, and red oak are used in the production wood plastic composites (WPCs) (Clemons 2002; Ayrilmis and Kaymakci 2013; Mengeloglu and Karakus 2008; Kim et al. 2009; Gacitua 2008). In addition to wood, the possibility of many agricultural waste such as such as wheat, chestnut and walnut shell, sunflower seed, rice husk, kenaf, cornstalk, and plant fibers such as hemp and jute have been investigated (Rowell, 1996; Youngquist et al. 1996; Caulfield et al. 1998; Chow et al. 1999; Bledzki et al. 2004; Kaymakci and Ayrilmis 2012; Ayrilmis et al. 2013).

The raw material formulation, including the contents of wood, plastic and additives, and processing methods can significantly affect WPC properties (Hwang 1997; Lu et al. 2000; Stark and Rowlands 2003; Wolcott 2003; Caulfield et al. 2005; Gacitua 2008). A higher filler content results in better stiffness properties; however, the modulus of rupture (MOR) and maximum deflection decrease with increasing lignocellulosic material content (Hwang 1997).

The sustainable utilization of forest resources has been adversely influenced by increased population of the world. Fortunately, great progresses could be seen in the manner of looking for alternative raw material sources. Mushrooms are important in the ecosystem because they are able to biodegrade the substrate and therefore use the wastes of agricultural production. Fruit bodies of mushrooms are appreciated, not only for texture and flavour but also for their chemical and nutritional properties. These functional characteristics are mainly due to their chemical composition Ice man

(*Fomes fomentarius)* is a kind of mushroom of the genus Fomes, native to north of the temperate zone of the northern hemisphere. Crude extract of this mushroom has been used in traditional medicine because of its antioxidation, diuretic, alleviation of fever, antitumor, and anti-inflammatory properties (Lee, 2005). Besides, people has traditionally used it as tinder because of chemical content that it has called amadou (Ostry et al. 2011). This species can be cultivated on sterilized sawdust indoors and outdoors on logs following the same process as shiitake. The optimal temperature for the species' growth is between 27 and 30°C (81 and 86°F) and the maximum is between 34 and 38°C (Anonymous 2013). Tinder fungus (TF) may play an important role in the manufacture of WPC as filler and may be one of the most efficient uses of the TF.

OBJECTIVE

The goal of this study was to determine some physical and mechanical properties of the HDPE composites filled with various mixtures of the wood flour and the Tinder fungus (*Fomes Fomentarius*).

MATERIAL, METHOD, EQUIPMENT

The tinder fungus (TF) was obtained from Belgrad forest in Istanbul. The TF was dried in an oven at 60^{o}C for 10 h to moisture content of 20-30% based on the oven-dry TF solid weight. Following the drying, the TF was then processed by a rotary grinder without adding additional water. Finally, the TF flour (TFF) passing through a U.S. 35-mesh screen and was retained by a U.S. 80-mesh screen. The TFF was dried in a laboratory oven at 100^{o}C for 24 h to moisture content of 1-2%. U.S. 80-mesh pine wood flour (*Pinus nigra* Arnold ssp. pallasiana) was obtained from a commercial WPC plant in Istanbul. Pine wood flour (WF) was dried in a laboratory oven at 100°C for 15 hours to the moisture content of 1-2% before manufacturing process.

The high density polyethylene (HDPE) (MFI/230°C/2.16kg = 5.0g/10min) supplied by a Petkim Petrochemical Corporation in İzmir, was used as the polymeric material. The MAPE (Optim-E156, MAH content: 1.2wt.%, MFI 190°C/2.16kg = 4.5g/10min, density = 0.95g/cm^3) as coupling agent was supplied by Pluss Polymers Pvt. Ltd. in India.

Composite Manufacturing

The TFF, WF and HDPE and with MAPE granulates were processed in a 30mm co-rotating twin-screw extruder with a length-to-diameter (L/D) ratio of 30:1. The barrel temperatures of the extruder were controlled at 170, 180, 190, and 190^{o}C for zones 1, 2, 3, and 4, respectively. The temperature of the extruder die was held at 200^{o}C. The extruded strand passed through a water bath and was subsequently pelletized. These pellets were stored in a sealed container and then dried for about 3-4h before being injection molded. The temperature used for injection molded specimens was 170-190°C from feed zone to die zone. The specimens were injected at 5-6MPa with cooling time about 30s. Finally, the specimens were conditioned at a temperature of 23°C and relative humidity of 50% according to ASTM D 618. The composite group consists of different amounts of HDPE, TFF, WF and MAPE. The formulations of the composites are given in Table 1.

Table 1

Compositions of the Composites

Composite code	Pine wood flour [wt%]	Tinder Fungus flour [wt%]	HDPE [wt%]	MAPE [wt%]
A	40	-	60	3
B	30	10	60	3
C	20	20	60	3
D	10	30	60	3
E	-	40	60	3

Determination of physical and mechanical properties

The thickness swelling (TS) and water absorption (WA) tests were carried out according to ASTM D 570. The test specimens were in the form of a disk 50.8mm in diameter and 3.2mm in thickness. The conditioned specimens were entirely immersed for 2-hours, 1-day, and 7-days in a container of water at 23±2°C. At the end of each immersion time, the specimens were taken out from the water and all surface water was removed with a clean paper towel. The specimens were weighed to the nearest 0.01g and measured to the nearest 0.001mm immediately.

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The flexural tests were conducted in accordance with ASTM D 790 using a Lloyd testing machine at a rate of 1.3mm/min crosshead speed. Dimensions of the test specimens were 3.5mm x 13.2mm x 128mm. The tensile tests were conducted according to the ASTM D 638. Tensile specimens were tested with a crosshead speed of 5mm/min in accordance with ASTM D 638. The izod pendulum impact strength of the notched specimens (notch tip radius: 0.25mm) was performed according to ASTM D 256 using a Devotrans impact testing machine. Seven specimens were tested for the tensile, flexural and impact properties of each composite formulation.

Statistical analysis

Analysis of variance (ANOVA) ($p<0.01$) was used to determine the effect of TFF content on some selected physical and mechanical properties of the HDPE composites using SPSS 17.0 statistical package program. Significant differences among the average values of the HDPE composite types were determined using Duncan's multiple range tests.

RESULTS and DISCUSSION

Physical properties

Adding the TFF or WF to the high density polyethylene increased the density of the composites. This was expected, because the cell density of the cellulose which is average 1.3g/cm^3 after extrusion and injection molding is much higher than injection molded high density polyethylene density. Similar results were reported in previous studies (Stark et al. 2004; 2013; Ayrilmis et al. 2012). The densities of filled composites ranged from 1.010 to 1.020g/cm^3 while it was found to be 0.899g/cm^3 for the unfilled high density polyethylene. The TS and WA values of the reinforced HDPE composites with the MAPE are presented in Fig. 1. The TS and WA values significantly decreased with increasing TFF content. Statistical analysis found some significant differences among the average values of TS and WA values. Significant differences were individually determined for these tests by Duncan's multiple-comparison tests and shown by letters in the columns of Fig. 1. The lowest TS value was found in the samples containing 40% TFF (Group E), while the highest TS value was found in the samples containing 40% WF (Group A) after 1-day of submersion in water. Similar trends were also observed for 7-days, and 14-days of submersions (Fig. 1).

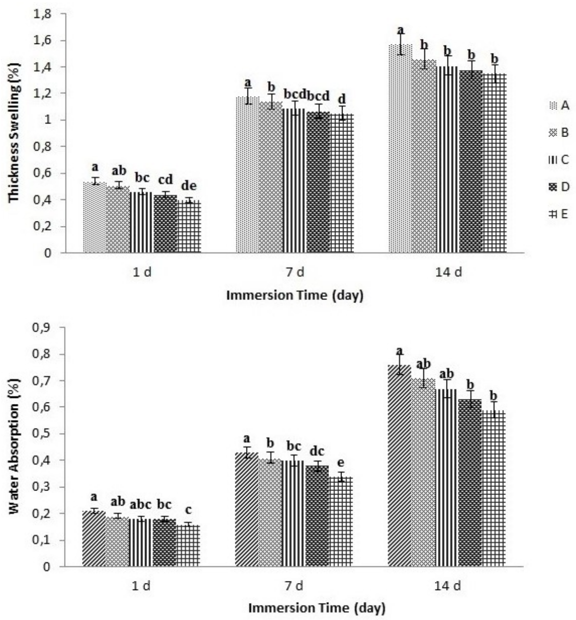

Fig. 1.

Effect of the tinder fungus flour loading on the thickness swelling and water absorption of HDPE composites (The vertical lines through the* bars *represent the* standard deviation *from the average value of ten LVL specimens; Same letters in each column indicate that there is no statistical difference (p<0.01) among the composite groups according to Duncan's multiply range test)

The lowest WA value was determined for the samples containing 40% TFF (Group E), while the highest WA value was determined for the samples containing 40% WF (Group A) after 1-d of submersion in water. The similar trends were also observed for 7-days, and 14-days of submersions (Fig. 1). The moisture absorption in composites is mainly due to the presence of lumens, fine pores and hydrogen bonding sites in the wood flour, the gaps and flaws at the interfaces, and the micro cracks in the matrix formed during the compounding process (Stokke and Gardner 2003). But for the composites produced in this study, low water absorption values indicated that the TFF and WF were satisfactorily encapsulated by the HDPE matrix, suggesting that no significant change occured in the microstructure of the composites.

Mechanical properties

The HDPE composites filled with WF or TFF showed no significant difference in the MOE while they had significant differences ($p< 0.01$) in the MOR. Significant differences between composite groups were also determined individually for MOR and MOE tests by Duncan's multiple-comparison tests as displayed in Fig. 2. The MOR and MOE generally decreased with increasing TFF content from 10 to 40% in the composite (See Table 1). For example, the average MOR and MOE values of the composites containing 40% WF (composite code: A) was 46.2MPa and 3674MPa as compared to composites containing 40% TFF (composite code: E) which is about 39.2MPa and 3395MPa, respectively. In a previous study, MOR and MOE values were found to be 48.1MPa and 5005.2MPa for polymer composites produced from 57% polypropylene and 40% beech wood flour, and 3% coupling agent, respectively (Dundar et al. 2010). In the same study, the MOR and MOE were found to be 41.9MPa and 4355MPa for polymer composites manufactured from 57% PP and 40% pine cone flour, and 3% coupling agent, respectively.

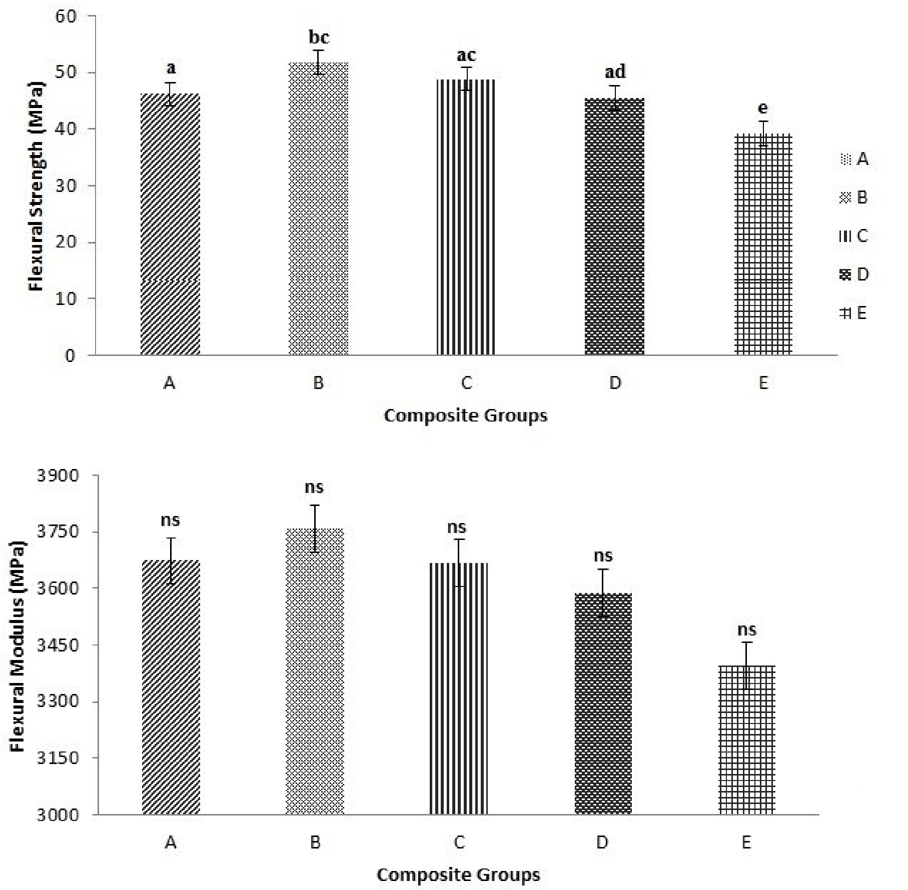

Fig. 2.
Effect of the tinder fungus flour loading on the flexural strength (MOR) flexural modulus (MOE) of HDPE composites (Same letters in each column indicate that there is no statistical difference (p<0.01) among the composite groups according to Duncan's multiply range test); (ns: there is no signficant differences among the composite groups)

The tensile strength and tensile modulus of the composites are presented in Figure 3. Significant differences between groups determined individually for the tensile strength and tensile modulus are displayed in Fig. 3. The tensile elongarion at break values of the composites are presented in Fig. 4. The tensile strength, tensile modulus, and elongation at break generally decreased with increasing TFF content from 10 to 40wt% in the composite (See Table 1). For example, the average tensile strength, tensile modulus, and elongation at break values of the composites containing 40wt% WF (composite code: A) was 27.2MPa, 4279MPa and 3.7% as compared to composites containing 40% TFF (composite code: E) which is about 15.9MPa, 3533MPa and 2.1%, respectively. This result could be due to the dissimilarities and lack of adhesion between the nonpolar HDPE matrix and polar TFF and WF filler. Similar results were also reported in previous studies (Dundar et al. 2010; Ayrilmis et al. 2013; Özmen et al. 2013). The tensile modulus progressively increased with addition of both the wood flours, probably caused by the fact that the WF and TFF was more rigid than the plastic. However, the decreases in tensile strength and elongation at break were probably caused by a number of reasons, as suggested by several researchers (Dundar et al. 2010; Ayrilmis et al. 2013; Nourbakhsh and Ashori 2008).

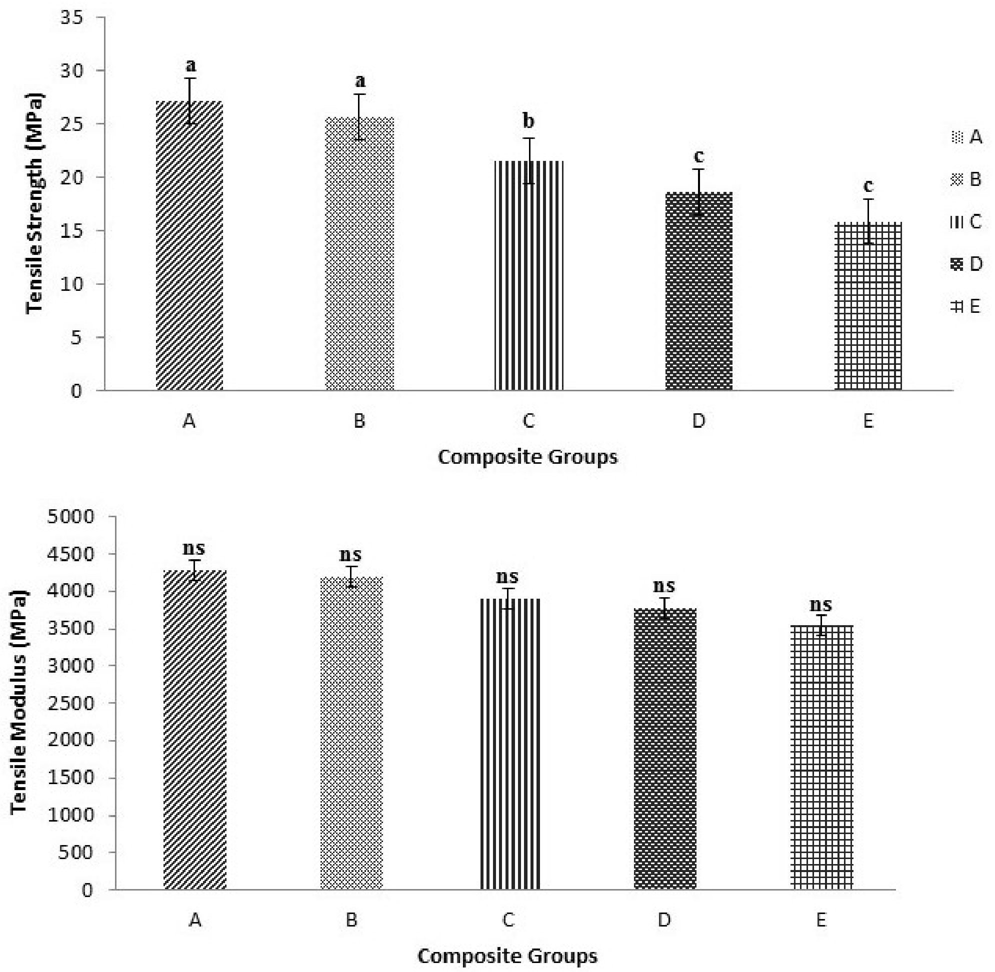

Fig. 3.
Effect of the tinder fungus flour loading on the tensile strength and modus of HDPE composites

The tensile strength of the HDPE composites containing the WF was significantly higher than that in composites containing the TFF. This could be explained by a strong interfacial adhesion between the HDPE and the WF due to their higher cellulose content, since cellulose is the main component providing the wood's strength and structural stability (Dundar et al. 2010). From the experimental results presented, it was found that effect of wood was notable in material properties of the composites. Wood is a lignocellulosic material made up of three major constituents (cellulose: 42–44%, hemicelluloses: 27–28%, and lignin: 24–28%) with some minor constituents (extractives: 3–4%) (Bhaskar et al. 2011). According to Bledzki et al. (1998) and Bledzki and Gassan (1999), an increase in the composite's strength can be ascribed to higher cellulose and lignin contents, as well as better dispersion and adhesion to the matrix. The better interfacial adhesion between WF and HDPE, due to the high cellulose content, increases the toughness or ductility (Marcovich and Villar 2003). Moreover, the ratio of lignin and cellulose can also play a role the higher it is, the better the interfacial adhesion that can be achieved since lignin acts as a natural adhesive within the cellulose (Shebani et al. 2009). The Tinder Fungus fruit body contains proteins and polysaccharides, triterpene saponins, coumarins and phenolic compounds. The protein content in the dried extract of the fruiting body of mushroom Tinder fungus ranged from 7.0 to 8.4% and polysaccharides from 53.2 to 68.2% (Troshkova et al. 2012). But the black pine (*Pinus nigra*) contains holocellulose (71.53%), α-cellulose (50.41), lignin (26.74%) and ash (0.19%) (Kilic et al. 2010). Reduction in the flexural, tensile properties and water resistance of the HDPE composites containing the TFF can be attributed to lower contents of the holocellulose in the TFF than in the wood.

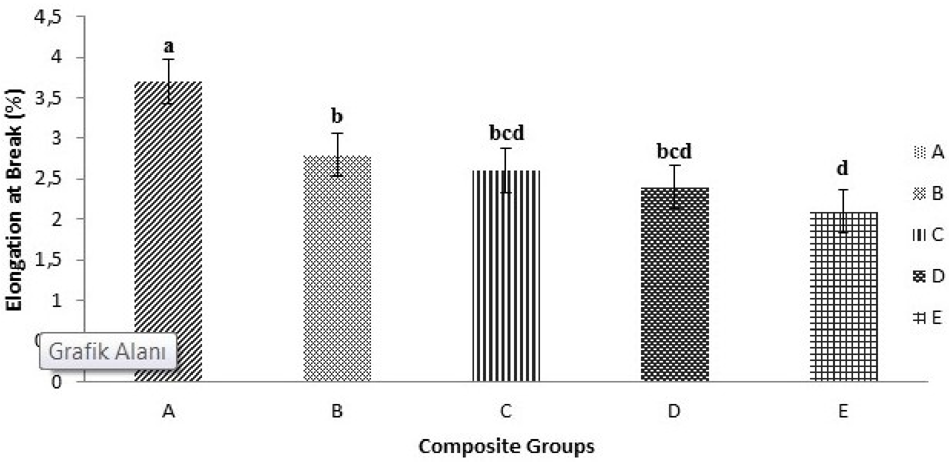

Fig. 4.
Effect of the tinder fungus flour loading on tensile elongation at break of HDPE composites

The impact strength of HDPE composites decreased with increasing the TFF content (Fig. 5). The impact strength of the uncoupled specimens decreased by 22.2% when WF content increased from 0 to 40wt%. The incorporation of TFF into the HDPE composite can create the regions of stress concentration that require less energy to initiate a crack in the composite, thereby decreasing the impact strength (Gacitua 2008; Rowell et al. 1997). For example, the impact strength of the specimens containing 40wt% WF was 45.5 J/m while it was 38.45J/m for the specimens containing 40wt% TFF. The TFF reduces the polymer chain mobility and therefore its ability to absorb energy during fracture propagation. The poor interfacial bonding between the TFF and HDPE causes micro-cracks to occur at the point of impact, which cause cracks to easily propagate in the composite (Nourbakhsh et al. 2011). The presence of the MAPE improves the TFF and WF dispersion and led to a more uniform distribution of the applied stress. Therefore, more energy for debonding and fiber pullout is required and thus the impact strength increases. As suggested by many studies (Ayrilmis and Kaymakci 2013; Tisserat et al. 2013; Zabihzadeh and Dastoorian 2009), the interaction between HDPE and wood flour can be improved by the MAPE.

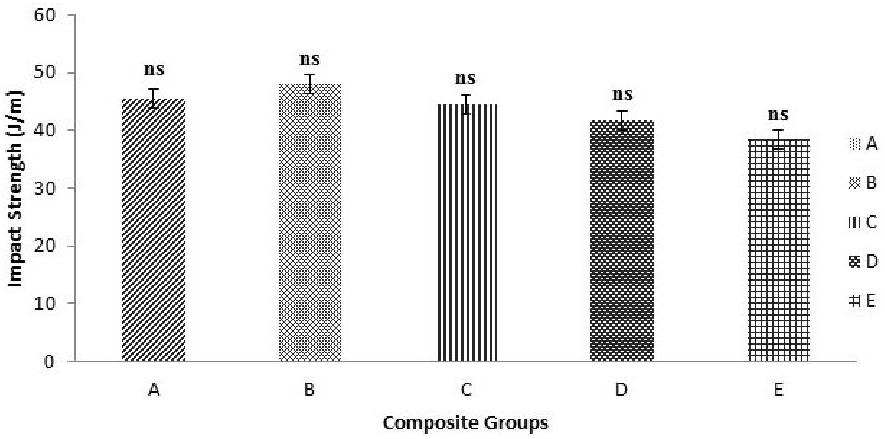

Fig. 5.
Effect of the tinder fungus flour loading on the impact strength values of HDPE composites

CONCLUSIONS

The TS and WA of the wood/HDPE composites significantly decreased with increasing content of the TF flour. This was mainly attributed to the lower amounts of the hygroscopic materials, cellulose and hemicelluloses, in the cell walls of the TF flour. The incorporation of 10wt% tinder fungus improved the flexural properties. Further increment in the amount of TF flour decreased the mechanical properties of wood/HDPE composites, but there were no significant differences up to 30wt% TF flour content, except for the tensile strength. Based on the findings obtained from the present study, the optimum physical and mechanical properties for the filled HDPE composites were found to be a 10/30/60/3 formulation of WF, TF, HDPE, and MAPE, respectively. The TF flour can be incorporated into the WPC formulation to improve dimensional stability of the WPC used for outdoor decking or siding.

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