

## EFFECTS OF FILLER LOADING ON THE FUNGAL ATTACK AND FLEXURAL PROPERTIES OF RECYCLED HIGH-DENSITY POLYETHYLENE / WOOD FLOUR COMPOSITES

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*Composites of recycled high-density polyethylene (HDPE) and Meranti wood flour (WF) at different filler loadings were soil buried for 6 months. HDPE/WF composites with high filler loading absorbed more moisture and experienced greater weight loss than composites with low filler loading due to inefficient encapsulation of the WF particles by the HDPE matrix. HDPE/WF composites showed relatively small but significant decrease in the flexural properties after the soil burial exposure. Weight loss was determined to be the most sensitive indicator than flexural strength and flexural modulus for early detection of fungal decay in HDPE/WF composites.*

**Keywords:** Wood-plastic composites, high-density polyethylene, fungal attack, weight loss, flexural properties

### INTRODUCTION

The use of wood-plastic composites (WPCs) is increasing, especially for outdoor applications [1] such as decking, window frames, and fencing. For applications like fencing the composites are directly exposed to soil and there is potential for these composites to be susceptible to biological degradation [1]. This is because the wood in WPCs provides a food source for a variety of biological organisms including insects, fungi, bacteria, and marine borers [2]. The thermoplastic polyolefins on the other hand, are highly resistance to biodegradation due to their backbone being solely built of carbon atoms [3]. The availability of moisture is a prerequisite for biological decay in a material [3]. Other basic requirements for biological organisms to grow and cause decay are food (for example, wood), temperature (10 - 35 °C) and oxygen (from the air) [4].

The first evidence for the presence of fungal decay and discoloration on WPC decking material in service (installed after 10 years) was presented by Morris and Cooper [5] and appears to have alerted the industry and the scientific community on the long-term outdoor durability of WPCs [6]. Biodegradation of WPCs can lead to several undesirable effects such as loss of aesthetic appeal, weight, and mechanical properties [7]. The most common way to protect WPCs from fungal decay is via addition of additives such as chemical biocides or

antimicrobials such as zinc borate [4].

In this work, recycled HDPE/WF composites were manufactured via a twin-screw extruder and compression molding. Field tests (under outdoor conditions) were conducted on these composites. Potential losses in weight and flexural stiffness and flexural strength of these composites were compared to determine the most sensitive indicator of fungal decay in the composites.

### MATERIALS AND METHODS

The HDPE used in this work was purchased as a recycled material from a local supplier. The density of HDPE is 0.96 g/cm<sup>3</sup> and its melt flow index is 0.72 g/10 min. Meranti WF (35 mesh) was obtained from Forest Research Institute of Malaysia.

Melt-compounding of HDPE/WF was accomplished using a Sino PSM30 co-rotating twin-screw extruder with seven temperature zones ranged between 171 and 193 °C. The screw speed was 200 rpm. Composite pellets containing 20, 40, 50, or 60 percent wood flour were produced. Compression molding of the composite pellets was carried out at 180 °C under 14 MPa of pressure for 10 minutes using a Kao Tieh Go Tech compression molding machine.

Flexural test specimens were buried in soil approximately 6 inches deep in Engineering Campus of Universiti Sains Malaysia (latitude 5°8'N, longitude 100° 29'E) on-site plots for 6 months from

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January to June 2009. Meteorology data for temperature and rainfall were obtained from the nearest meteorology station in Butterworth (latitude 5°28'N, longitude 100°23'E). The average daily temperature was between 31.5°C and 27.8°C while the average rainfall was approximately 167 mm. 5 test specimens of each composite formulation were removed from the ground every 2 months. The test specimens were scrapped clean with a piece of soft paper. The test specimens then were weighed (nearest 0.0001 g), oven-dried for 24 h at 105°C, cooled in a desiccators for 1 h and weighed again to determine both moisture content and weight lost. The calculation of weight loss was based on the amount of WF particles present in the composite, assuming that the HDPE matrix is not degradable.

Composite surfaces before and after the soil burial test were analyzed using a pressure field emission scanning electron microscopy (VPFESEM) model Ziess SUPRA 35VP.

Flexural properties of the composites were measured on an Instron 3366 testing machine according to ASTM D 790. The capacity of the load

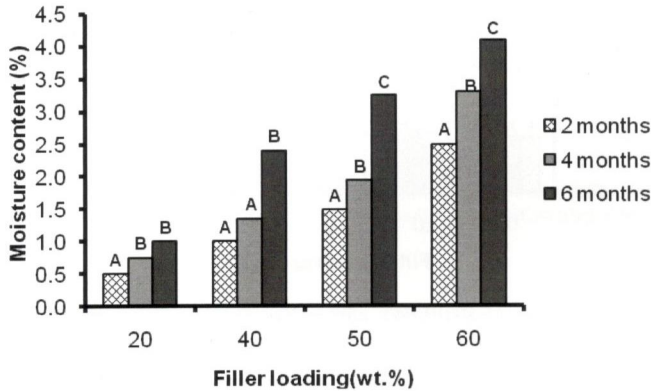
cell is 10 kN. A three-point loading system was utilized with a crosshead speed of 1.5 mm/min.

Results from the soil burial and flexural tests were statistically analyzed with Tukey's multiple comparisons test ( $\alpha = 0.05$ ) by means of MINITAB™ (Release 15.1) software.

**RESULTS AND DISCUSSION**

*Moisture Absorption*

Fig. 1 shows the average moisture content of HDPE/WF composites after the soil burial test. The moisture content of the composites increased with increasing filler loading due to the increasing number of the accessible hydroxyl groups of WF particles in the composites. At high filler loading, some of the WF particles might not be totally encapsulated by the HDPE matrix. The partially encapsulated WF particles then can readily absorb moisture from the environment and from the rainfall. Another observation from Fig. 1 was an increased in the average moisture content of the composites with increasing soil burial exposure time.



**Fig. 1** Average moisture content of HDPE/WF composites due to soil burial test. Means with the same letter designation are not significantly different at alpha level of 0.05 within the filler loading.

HDPE matrix is a hydrophobic material. It is therefore can be assumed that all the moisture was absorbed by the WF particles and voids. Table 1 shows the average moisture content of the WF particles in the composites. The diffusion of water into WPCs is slow [2]. A moisture gradient then may well exist through the thickness of the composite sample. The core then may have very low moisture

content while the composite surface may be saturated by moisture. The moisture contents of the WF particles in the HDPE/WF composites are therefore might be higher than those in Table 1. The WF particles particularly those are not totally encapsulated by the HDPE matrix might have high moisture contents (above 25%) that make them vulnerable to fungal attack.

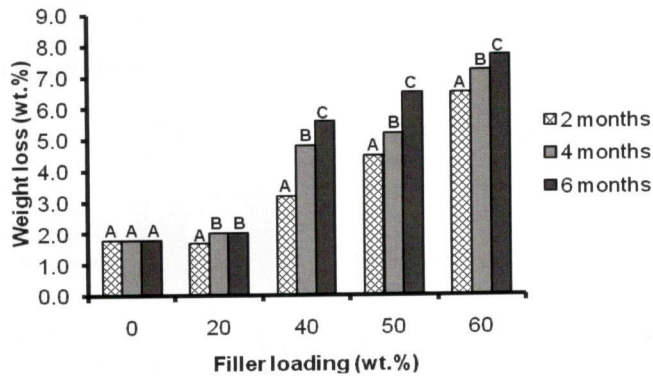
**Table 1.** Average moisture content of the WF particles in the HDPE/WF composites after the soil burial test.

Materials	Filler loading (wt.%)	Average moisture content (%)		
		2 months	4 months	6 months
HDPE/20WF	20	2.5	3.8	5.0
HDPE/40WF	40	5.0	6.8	12.0
HDPE/50WF	50	7.5	9.7	16.2
HDPE/60WF	60	12.5	16.5	20.5

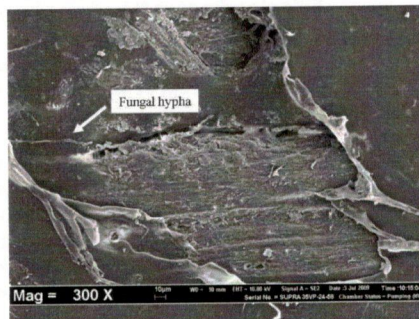
**Weight Loss**

In general, Fig. 2 shows that HDPE/WF composites with high filler loading are more susceptible to fungal attack. A dramatic increase in the weight loss was observed for composites with 40, 50 and 60 wt.% filler loading. Composite with 20 wt.% filler showed relatively small weight loss and insignificant increase in the weight loss after 4 and 6 months of soil burial exposure. This was probably

due to effective encapsulation of the WF particles by the HDPE matrix which protect the particles from fungal attack. At high filler loading, some of the WF particles may not be totally encapsulated by the HDPE matrix. These partially encapsulated WF particles that are exposed on the composite surface are susceptible to fungal attack. The presence of fungal on the HDPE/WF composite with 40 wt.% filler loading is shown in Fig. 3.



**Fig. 2.** Average weight loss of HDPE/WF composites due to soil burial. Means with the same letter designation are not significantly different at alpha level of 0.05 within the filler loading.



**Fig. 3.** A SEM micrograph of HDPE/WF composite with 40 wt.% filler loading showing the present of fungal on the composite surface.

**Flexural Properties**

Fig.4 and 5 show the flexural strength and flexural modulus of HDPE and HDPE/WF composites before and after the soil burial test. While insignificant change in the flexural properties was observed for the neat HDPE, significant change, i.e. a decrease in both the flexural strength and flexural modulus was observed for HDPE/WF composites after 4 and 6 months of soil burial exposure. Although significant, HDPE/WF composites showed relatively small decrease in the flexural properties between 1 to 16%. This is not surprising since the weight loss results (Figure 2) suggested little fungal decay. In addition to fungal

decay, the decrease in the flexural properties of HDPE/WF composites was also probably due to the microracks formed in the HDPE matrix due to the swelling of the WF particles resulted from moisture absorption. Comparing between the results of weight loss, flexural strength, and flexural modulus of HDPE/WF composites after the soil burial test, weight loss is found to be the most sensitive indicator for early detection of fungal decay in the composites. This is because significant weight loss can be observed as early after 2 months of soil burial exposure and the weight losses too are significantly different between the following months of exposure.

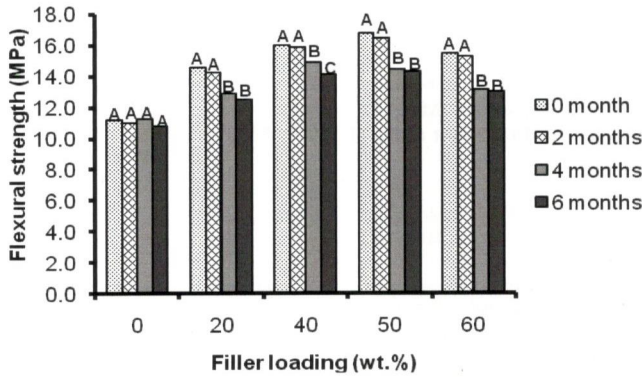


Fig. 4. Flexural strength of HDPE and HDPE/WF composites before and after soil burial test. Means with the same letter designation are not significantly different at alpha level of 0.05 within the filler loading.

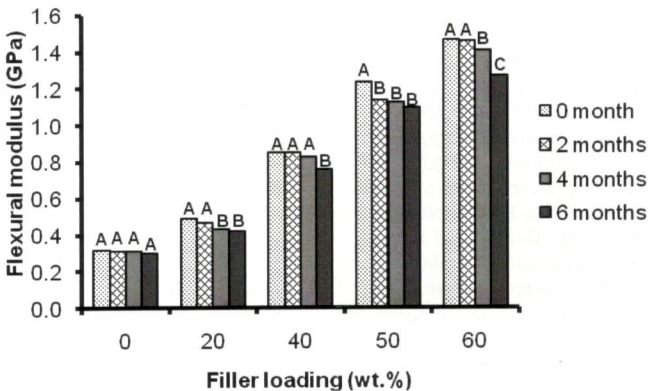


Fig. 5. Flexural modulus of HDPE and HDPE/WF composites before and after soil burial. Means with the same letter designation are not significantly different at alpha level of 0.05 within the filler loading.

## CONCLUSIONS

Filler loading has an effect on the fungal attack of HDPE/WF composites. Composites with high filler loading exhibited greater moisture content and weight loss than composites with low filler loading. A good correlation was observed between the weight loss and moisture content confirming the importance of moisture to initiate fungal attack. The flexural properties of HDPE/WF composites decreased due to fungal attack and microcracks formed due to moisture absorption. Weight loss was determined as the most sensitive indicator than the flexural strength and flexural modulus for early detection of fungal decay in the composites.

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