DEGRADATION, MECHANO-PHYSICAL, AND MORPHOLOGICAL PROPERTIES OF EMPTY FRUIT BUNCH REINFORCED POLYESTER COMPOSITES

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This research aims to study the effects of degradation on mechanical, physical, and morphological properties of empty fruit bunch (EFB) fiber-reinforced polyester composites. The unsaturated polyester resin has been used to produce thermoset polymer composites. The reinforcing effect in composites was evaluated at various fiber loadings, including an overall fiber content (by weight) of 20% and 40%. The mechanical (tensile, flexural, and impact) and physical (density, moisture content, and water absorption) properties were studied before and after the samples were buried in the soil for period of 12 months. Scanning electron microscope (SEM) analysis was conducted to visualize the effect of the quality of adhesion between the fibers and matrix. The soil burial investigation results revealed that EFB fiber-polyester composites showed highest degradation percentage as compared to polyester resin and fiberglass.

Keywords: *Oil palm empty fruit bunch fibers (EFB); Mechanical and physical properties; Scanning electron microscopy; Glass fibers; Polyester resin*

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INTRODUCTION

The rapid expansion of oil palm plantation in Malaysia has generated enormous amounts of vegetable waste, creating problems in replanting operations and tremendous environmental concerns (Abdul Khalil et al. 2006). It is reported that Malaysia alone produced during the recent past years about 30 million tones of oil palm biomass, including trunks, fronds, and empty fruit bunches (EFB) (MOA 2006; MPOB 2001). The empty fruit bunches (EFB) have traditionally been burnt and their ash recycled into plantation as fertilizer. However, due to air pollution problems, incineration of EFB has been discouraged. Instead EFB is returned to the field to act as mulch or used as a fuel to meet energy demand of the palm mills, although using EFB as fuel is not judged to be an effective application. This solution cannot be regarded as the end of the chain, because the amount of biomass is much too large to get rid of in this way (DTU 2009).

Over the last decade, composites of polymers reinforced with natural fibers have received increasing attention, both from the academic world and from various industries (Singha and Thakur 2009). The utilization of lignocellulosic materials in production of polymeric composites is attractive particularly because of low cost and high volume applications. Fiber reinforced polymeric composites have gained importance due to considerable processing advantages and improvement in mechanical properties (Suarez et

al. 2003).

The enzymatic action by living micro organisms leads to degradation. Most of the microbial degradations are carried out by both fungi and bacteria. There are four degradation environments for polymeric products, namely soil, aquatic systems, landfill sites, and compost. Each environment contains different microorganisms and has its special conditions for degradation. In soil, fungi are mostly responsible for degradation of organic matter including polymers (Baker and Mead 2000; Chandra and Rustgi 1998; El-Hadi Abdel Ghaffar 2002; Hodzic 2004; Sridach et al. 2006).

The degradation in lignocellulosic materials depends upon a number of factors including fiber content, the degradability of each component, and the quality of the interface. The fiber addition generally increases the degradation of composites, and alkaline treatment of fibers produce a slightly higher degradation rate than pure matrix (Plackett and Vazquez 2004). Other than that, the additives used (e.g. plasticizers, fillers, etc.) are important in degradation as well as the type of polymer reflected in molecular weight, structure, and crystallinity (Guilbert and Gontard 2005). Furthermore, degradability depends in general on the substrate structure, the substrate composition, and the existing microorganisms.

The aim of this paper is to investigate the EFB-polyester composite degradability. A soil burial test is used to determine the degradability on the composite samples. The effect of percent loading of EFB, in degradation of these composites, was also studied.

EXPERIMENTAL

Materials and Procedures

Unsaturated polyester resin with general usage grade C: 9509 supplied by Euro-Chemo Pharma Sdn. Bhd. Prai Industrial Estate, Prai Pulau Pinang, Malaysia was used in producing composite samples. Methyl Ethyl Ketone Peroxide (MEKP), supplied by the same company was used to enhance the curing process. E-glass chopped strand mats (CSM) were supplied by Euro-Chemo Pharma Sdn. Bhd.

Empty fruit bunch (EFB) was obtained from Malaysia Palm Oil Board (Formerly known as Palm Oil Research Institute Malaysia). At the palm oil mill, the sterilized fresh fruit bunches go through a threshing process to separate the sterilized fresh fruits from the bunch. The obtained fibers were dried for mat preparation.

Oil palm empty fruit bunch fibers (EFB) were washed with water and were air dried for 24 hours. The fibers were kept in an oven for another 24 hours at 80 ^{o}C. EFB were weighed in fixed quantities before fiber mat process. Via this process, fibers were dispersed into the sieve, which was placed in a tub of water. When the fibers had been scattered equally and formed into a uniform layer, the sieve was removed from the tub. Excess water from the mat was drained out by pressing the mat against a flat plate. The random fiber mat was subsequently dried in an oven at 80 ^{o}C for 24 hours. Finally, the dried fiber mat was then compacted under pressure at 8000 psi in a compression mold, followed by trimming the fiber mat edges in order to obtain a uniform shaped fiber mat.

An empty fruit bunch fiber mat was placed on the mold. The polyester and 0.5% MEKP was filled into the homogenizer on a Resin Transfer Molding (RTM) machine.

Then resin was transferred into the fiber mat at a pressure of 3.5 to 5.0 bar. The fiber mat were allowed to cured for 12 hours before its removal from the mold at room temperature. The dried board was kept vertically at room temperature for 24 hours to prevent it from becoming curved. The four types of composites were prepared with 20% , 40% natural fiber content, 40% of fiber glass, and 100% polyester resin, respectively.

Mechanical Tests

Tensile testing was performed according to ASTM D638 by using an Instron Universal Testing Machine Model STM-10". There were 10 samples with dimension 120 mm x 15 mm x 10 mm. The specimens were placed vertically, and the ends of both specimens were placed in the mechanical grips. The grips were tightened sufficiently to avoid slippage of the specimens. The speed to pull out the specimen was 5 mm per minute with a load cell rated for up to 10,000N and the distance between two holders fixed at 100 mm. Tensile tests produced stain force for the specimen. Four types of composite characteristics were studied, tensile strength, modulus tensile, elongation at break, and composite toughness content. The results were calculated by the instrument's software.

The flexural test measures the force required to bend a beam under 3-point loading conditions. The data is often used to select materials for parts that will support loads without excessive flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. The three points bending flexural test provides values for the modulus of elasticity in bending, flexural stress, flexural strain, and flexural stress-strain response of the material. Universal Testing Machine Model STM-10" based on ASTM D790, was used for testing. There were 10 samples with dimension 160 mm (length) x 20 mm (width) x 10 mm (thickness). The specimen is placed horizontally on a support span, and the load is applied to the center by the loading nose, producing three points bending at a specified rate. The parameters for this test are the support span, for which the length of the support spans was 128 mm, the speed of the loading (5 mm/min), and the maximum deflection for the test. The flexural strength, modulus, and toughness values were recorded and calculated by the instrument's software.

The Charpy impact test was carried out on polished samples with dimension of 70 mm x 15 mm x 10 mm, using the Impact Pendulum Tester (Zwick) Model CS-1370. The shape and the size of the test specimen were according to ASTM D-256. The samples were rigidly mounted on a vertical position and were struck using a pendulum with a force of 10J at the center of the sample.

Physical Tests

The density of specimens was determined using the full thickness of composites. The density of oil palm fibers reinforced composites was calculated according to Eq. 1,

$$D = m / v \quad (g/cm^3) \tag{1}$$

where m is mass of the composite and v is its volume. Mass determination was carried out by weighing the composites to four decimal places (0.1 mg resolution) on an analytical balance (Mettler 5000). The dimensions of the samples were measured using a

digital veneer caliper (Mitutoyo). All samples were oven-dried at 50 ^{o}C for 24 hours. After oven drying, the experimental samples were cooled in desiccators over granulated silica gel before mass and volume determination was conducted.

Water absorption tests were conducted based on ASTM D 570 with 10 samples, measuring 20 mm x 20 mm x 10 mm. The composite samples were immersed in distilled water at room temperature (25 ^{o}C). The water absorption was determined by weighing the samples using a Mettler balance type AJ 150, with a precision of 1 mg. Samples were immersed in distilled water at an ambient temperature of 25 ± 3 ^{o}C for various time periods of up to more the 60 days. The samples were removed at specified intervals, gently blotted with tissue paper to remove the excess water on the surface, and the weight and thickness were recorded. The percentage of water absorption M_t was calculated using equation 2,

$$M_t = [(W_N - W_d) / W_d)] \text{ x } 100\% \quad (2)$$

where W_d is the weight of composite samples before immersion (meaning the original dry weight) and W_N is the weight of the composite samples after immersion. The sample were immersed until saturated. The percentage equilibrium water content was calculated as an average value of several consecutive measurements that showed no evidence of appreciable additional absorption.

Soil Burial Test

This test was performed for 12 months, which was adopted from the BS standard EN ISO 846:1997 (Plastic-evaluation of the action of microorganisms). The samples were completely buried in natural soil at 90% water holding capacity (WHC) and a 50% soil moisture content. The samples were in permanent contact with the soil and exposed to a temperature of 29°C ± 1°C. Shirley cotton strips were used to determine the biological activity of the soil (cotton material to monitor clearly microorganism attack in soil). The cotton strip retained less than 25% of its original tensile strength at the end of 7 days soil burial. The soil test was set up using a wooden box 100 cm x 60 cm x 55 cm. The sample assemblies are shown in Fig. 1. All the specimens of size 20 mm x 20 mm x 5 mm were vertically buried with a sorted distance of about 3 cm from each other.

Scanning Electron Microscopy (SEM)

The EFB fiber-polyester reinforced composites (before and after 12 month soil burial) were prepared for SEM observation. The adhesion strength between the fiber matrix surface and aperture formation was studied. The samples were cross cut using a microtome, carefully and securely. A light microscope was used to examine the smoothness and flatness of the end surface cross cut. The samples were mounted on the SEM holder using double sided carbon electrically conducting adhesive tape, to prevent surface charging when exposed to the electron beam. The samples (5 mm x 5 mm x 5mm) were then coated with gold to a thickness of 20 nm using a 'sputter coater' Fison SC 515. Then the samples were observed with a Leica Cambridge S-360

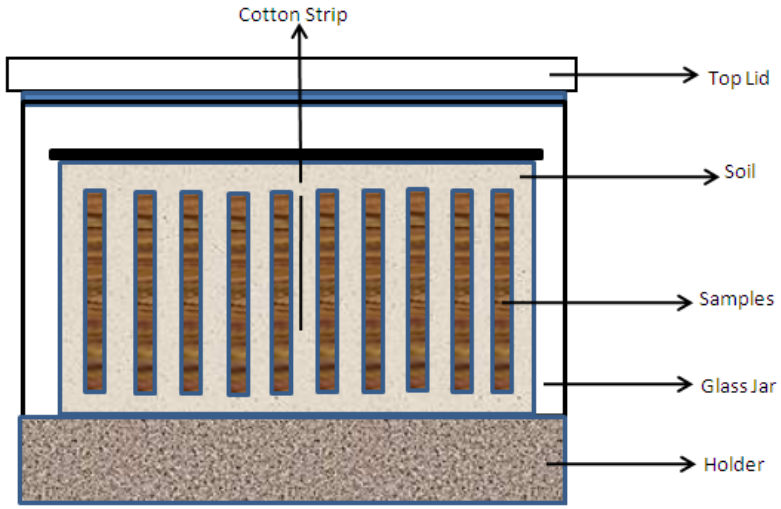


Figure 1. Test assemblies of soil burial test

RESULTS AND DISCUSSION

Tensile Properties

The variations in tensile properties of EFB-polyester, polyester, and fiberglass composites after being exposed to ground contact for 12 month are given Figs. 2 to 4. Figure 2 shows an increase in the tensile strength with addition of reinforcing fibers to the composites before ground contact exposure, and strength was observed to increase with an increase in the content of total fiber loading in composite. The increased content of fiber led to an increase in the interaction between fibers and the matrix and accordingly contributed to the effective stress transfer between fibers and the matrix.

After 12 months exposure, fiberglass samples showed the best resistance with the highest tensile strength (106.71 MPa), and the percentage of degradation was 7.66%. Within 3 month of exposure, the polyester sample showed that it was able to maintain 99.29% of its initial strength, with a tensile strength reading of 12.67 MPa as compared to the corresponding result before being exposed to soil (12.76 MPa). A polyester sample without fiber reinforcement was able to retain 95.38% of its original tensile strength, even though it had been exposed to burial testing for 12 months. Within a 12 month test, tensile strength for 20% and 40% EFB fiber degraded to 25.89% and 26.45% of the corresponding initial strength levels, respectively.

Increasing the EFB fiber content of composites may cause the percentage of degradation of tensile strength to become higher. This condition can be seen clearly for both types of EFB fiber composite samples and fiberglass composite. With additional 20% and 40% EFB fiber into composite each of these samples showed deterioration of 14.38% to 16.78% within 9 months of exposure. Besides that, fiberglass composite showed lower deterioration as compared to EFB fiber composite with a degradation of just 4.87%.

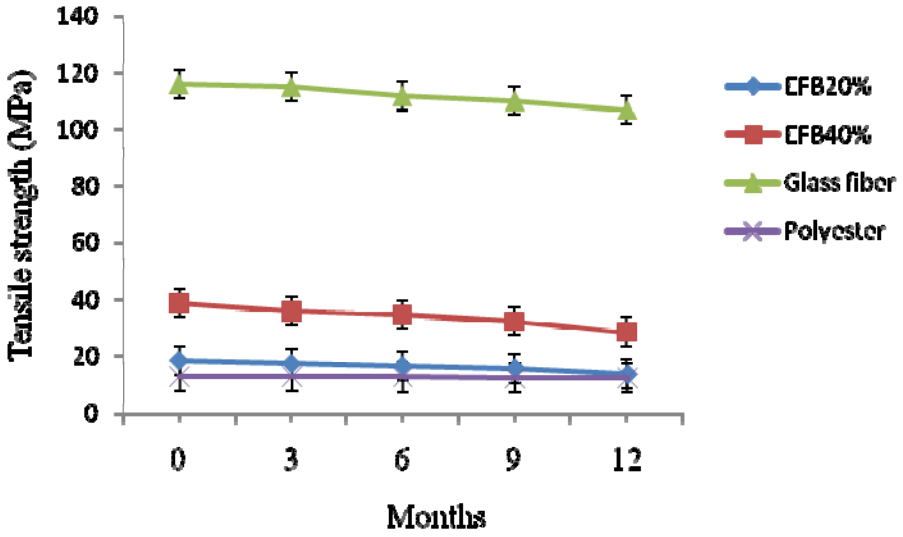


Figure 2. Tensile strength result on EFB fiber composite, fiberglass composite, and polyester sample after biological testing from 0 to 12 months

Tensile modulus showed the same pattern of strength deterioration (Fig. 3). Generally, deterioration increased with the total fiber weight in the composite and time of exposure. The tensile modulus of composites with 20% and 40% EFB fiber content exhibited a decrease of 3.15% to 3.66% after 3 months of burial. However, polyester sample without EFB fiber showed a good tensile modulus with a final result (after 12 months) of 1.02 GPa as compared to control results (1.10) GPa, which implies a percentage degradation of only 6.98%. By comparison, EFB fiber composites (20% and 40% EFB fiber content), each showed a degradation of 3.15% to 21.32% and 3.66% to 23.66%, respectively after 12 months burial. Over the same period, fiberglass composite showed the lowest deterioration rate from 0.62% to 3.16% after 12 months.

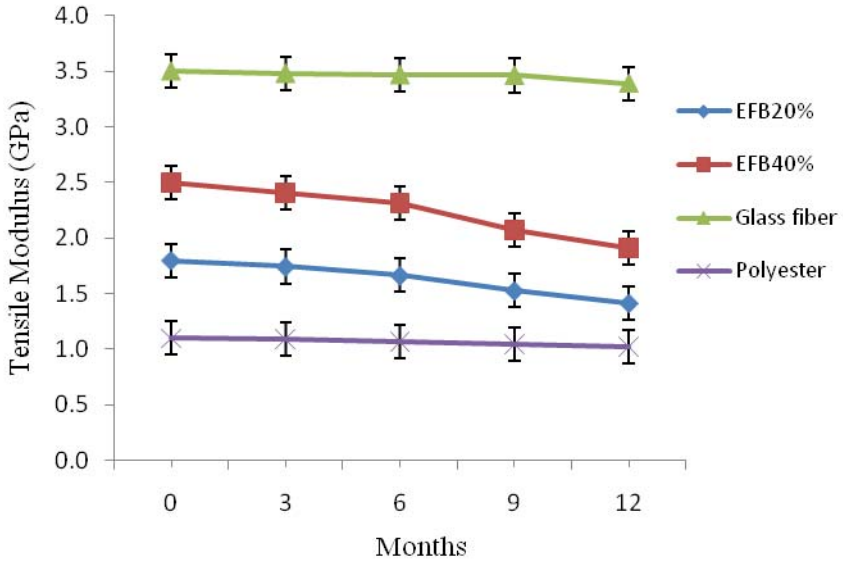


Figure 3. Tensile modulus result on EFB fiber composite, fiberglass composite, and polyester sample after biological test from 0 to 12 months

Elongation at break percentage and toughness of sample exhibited the highest deterioration in the case of the EFB fiber composite (Figs. 4 and 5). Elongation at break degradation percentage for both samples (20% and 40% EFB fiber composite) after 12 months was 16.11% and 17.48%. Therefore, with increasing fiber content in composites they are more prone to degradation. The fiberglass composite samples showed lowest result of 1.56%, and this was followed by the polyester sample with 4% EFB fiber.

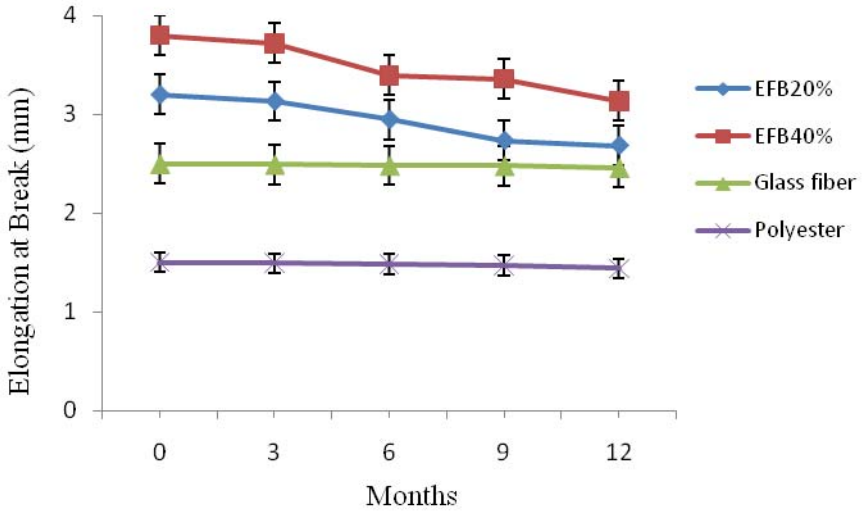


Figure 4. Elogation at break result on EFB fiber composite, fiberglass composite, and polyester sample after biological test from 0 to 12 months

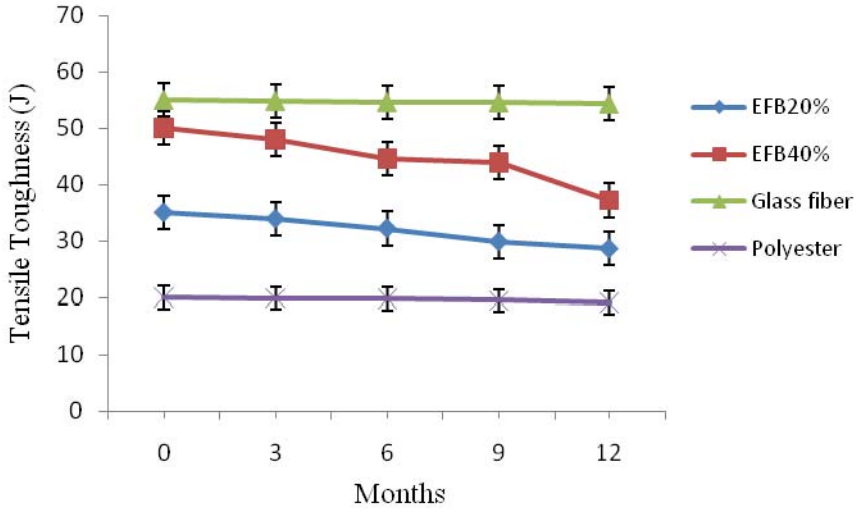


Figure 5. Tensile toughness result on EFB fiber composite, fiberglass composite and polyester sample after biological test from 0 to 12 months

Figure 5 also shows the deterioration behavior on tensile toughness of the composites. The toughness of the polyester sample with EFB fiber was reduced from 20 J to 19.15 J within 12 months of sample burial. This reduction in tensile toughness was 4.23%, and it is lower as compared to EFB fiber composite results. EFB fiber composite toughness for 20% and 40% was reduced from 3.20% to 18.25% and 4.06% to 25.68% over the same period. However, the fiberglass composite showed stable deterioration of

the toughness value with 0.28% to 1.26% and had the highest toughness result as compared to EFB fiber composite and polyester.

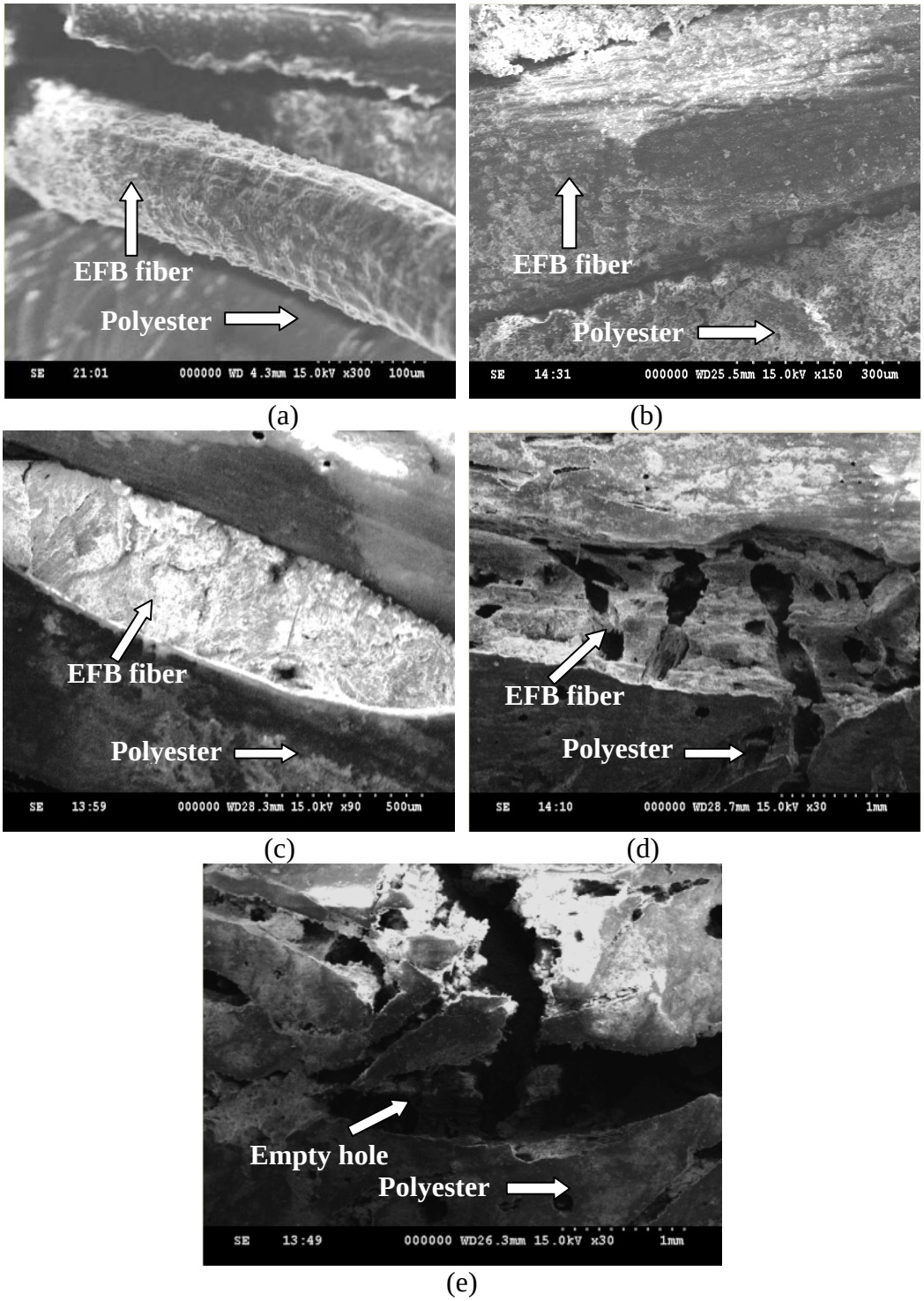


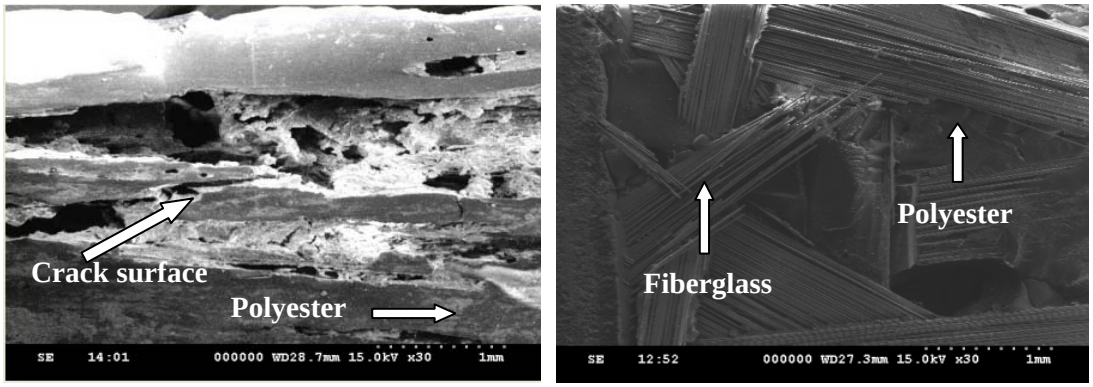
Figure 6. Scanning electron microscope (SEM) morphology changes on 40% EFB fiber composite surface after soil burial test (a) 0 month (300x), (b) 3 month (150x), (c) 6 month (90x), (d) 9 month (30x), (e) 12 month (30x).

After 12 months, composite samples recorded the highest deterioration in toughness, and the EFB fiber composites still exhibited the highest deterioration among all of the samples. The deterioration rate increased when there was higher EFB fiber content in the composite. Due to this result, composites with maximum EFB fiber content (40%) and buried for a long period showed the highest characteristic degradation.

Biological attack on internal and external composite structures such as fiber, matrix, and the fiber-matrix interface were major factors that contribute to the mechanical characteristic sample composite failure (Figs. 6a-e). Biologically, a lignocellulosic fiber such as EFB fiber will degrade once it buried into the ground. This is because some organisms are able to detect polysaccharide polymer or phenolics inside the cell wall (Abdul Khalil and Rozman 2004). Based on Khalil and Rozman 2004, the capability to hydrolyze certain polymers to digest the unit can be done with specific enzyme systems.

The ability to absorb a large amount of moisture by EFB fiber may increase the degradation process on EFB fiber composite. This is because microorganisms need water for their growth in order to degrade the polymer.

Molecular water rejection may protect fiberglass composite from serious damage in the ground. Figure 7(a-b) shows the biological attack on 40% EFB fiber composite and fiberglass composite after being exposed to ground contact for 12 month. Surface cracks can be seen on the 40% EFB fiber composite sample. Meanwhile in the case of the fiberglass composite there was no sign of microbial attack, and the fiberglass was in good condition.



(a) (b)

Figure 7. Scanning electron microscope (SEM) images (a) 40% EFB fiber composite (30x) and (b) fiberglass composite (30x) surface after 12 months.

Flexural Properties

The fiberglass composite showed the best flexural strength results with the highest reading and the lowest degradation percentage compared to EFB fiber composite and polyester without fiber reinforced sample (Figs. 8-9). The second highest reading was recorded for 40% EFB fiber composite with final reading was 24.31 MPa following 12 months of ground contact exposure. The fiberglass composites were able to retain flexural strength up to 98.9%. Besides that, the deterioration rate increased with increasing EFB fiber content from 20% to 40% by weight of the composite.

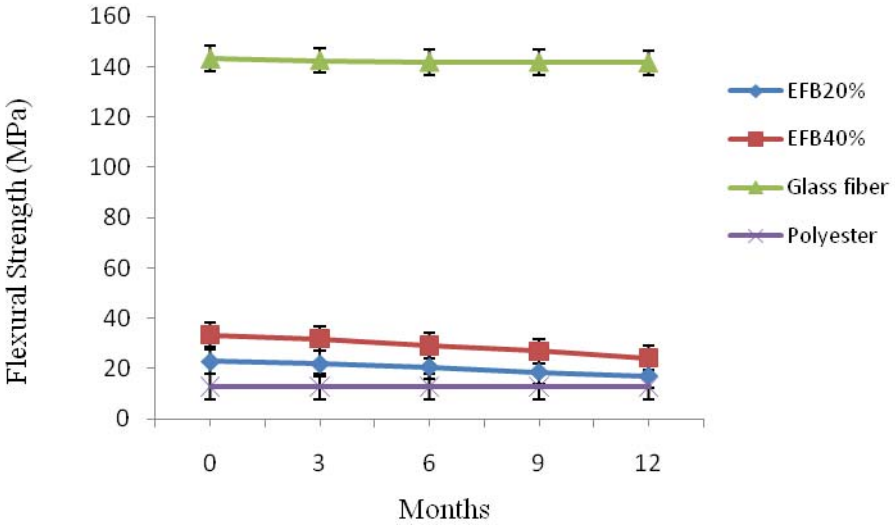


Figure 8. Flexural strength result on EFB fiber composite, fiberglass composite and polyester sample after biological test from 0 to 12 months

EFB fiber composite and fiberglass composites showed the same pattern of degradation. The deterioration was detected on EFB fiber composite after 6 months until 12 months of exposure. After 3 to 6 months, composite samples showed deterioration from 4.76% to 13.23% and 4.06% to 9.50% each for 40% and 20% EFB fiber composite.

After 12 months, EFB fiber composites exhibited degradation from 4.06% to 25.08% and 4.67% to 27.33% for 20% and 40% EFB fiber composites. The fiberglass composites results revealed that it had a stable deterioration rate from 0.45% to 1.10%.

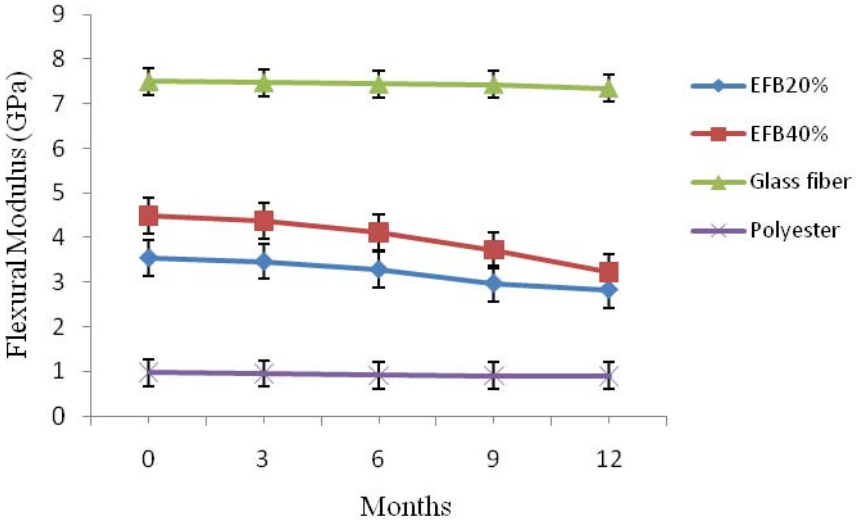


Figure 9. Flexural modulus result on EFB fiber composite, fiberglass composite, and polyester sample after biological testing from 0 to 12 months

Fiberglass composite showed the highest modulus value as compared to the other samples (Fig. 9). This sample also possessed the highest resistance as compared to EFB fiber composite and polyester without fiber reinforcement. The percentage of loss in for

fiberglass composite was 0.33% to 2.04% after 12 months of ground contact exposure. Meanwhile 20% and 40% EFB fiber composite showed a close result, from 3.55 GPa to 2.83 GPa and 4.49 GPa to 3.22 GPa from 0 to 12 months. For the first 3 months result, these composite samples exhibited only low levels of deterioration, however they showed a high escalation in the rate of deterioration after 12 months of exposure. In contrast with EFB fiber composite, the fiberglass composite showed stable degradation even after 12 months of biological exposure.

Polyester samples without fiber reinforcement exhibited a degraded modulus value of 0.95 GPa after 3 months, and this was reduced to 0.90 at the end of biological testing (12 months). The modulus reading for the polyester sample was the lowest compared to the other composites, even though it showed low percentage degradation for the modulus value. This condition was caused by the inability of the polyester matrix to resist shape changes in the absence of fiber reinforcement. The modulus value of polyester composite increased with total fiber reinforced weight and also showed a huge deterioration with additional total fiber reinforcement added to the composite. After 6 months of burial of the sample in the ground, EFB fiber composite and fiberglass composite showed degradation levels of 7.46% (20% EFB fiber composite), 8.54% (40% EFB fiber composite), and 0.77% (fiberglass). The increase in deterioration of modulus characteristics with increasing EFB fiber content in the reinforced composite was compared to the fiberglass composite.

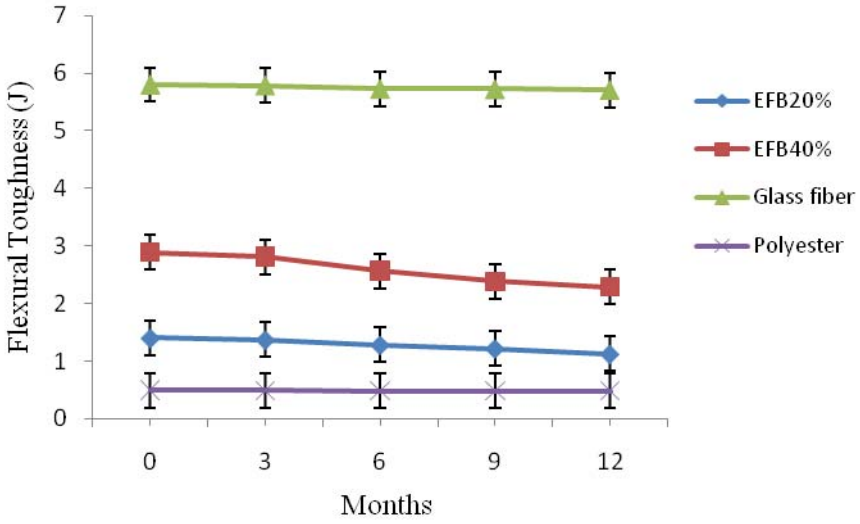


Figure 10. Flexural toughness result on EFB fiber composite, fiberglass composite and polyester sample after biological test from 0 to 12 months

The intermediate flexural toughness values obtained from EFB fiber composite were compared to fiberglass composite and polyester without fiber reinforcement. At 40% fiber content, EFB fiber composite showed an average degradation of 20.77%, while fiberglass composite and polyester showed a relative degradation of 1.67% and 10.45% at 12 month ground contact exposure, respectively. However, all samples showed a small deterioration already after 3 months of ground contact, and exhibited huge deterioration after longer exposure, especially in the case of EFB fiber composite and polyester

without fiber reinforcement. The fiberglass-reinforced composite did not show any beginning of obvious degradation until at the end of the 12 month test.

Generally, degradation of flexural characteristics of the composite samples was caused by fiber-matrix interface failure and moisture absorption into the composite by interaction with the fiber reinforcement. Weak interfacial bond formation between EFB fiber and the polyester matrix was the main cause of a high rate of decay of composite attributes in comparison with the fiberglass composite. Incomplete wetting of the EFB fiber surface by the polyester matrix resulted in a substantial proportion of uncoated fiber completely separated from the matrix. This condition opened way to moisture and decay agents to penetrate into the composite and attack the exposed fiber. By this mechanism the decay process affects the whole composite sample. A tendency towards more voids formation and cracks caused by weak wetting also open ways for moisture to penetrate and other organisms can enter into the internal structure of the composite. Capillary reaction and resultant breaks in the matrix area increase the absorption rate of environmental moisture. Because groundwater contains various types of chemicals and minerals, it is able to react with EFB fiber and weaken its strength.

Impact Test Properties

The impact test results towards EFB fiber composite, fiberglass composite, and polyester without fiber after having been buried with ground contact for 12 months are given in Fig. 11. However, EFB fiber composite samples underwent the fastest deterioration compared to the other samples. Even though the impact strength of the polyester sample was low, it exhibited a relatively small degradation percentage result compared to the EFB fiber composite. After a 3 month period, the EFB fiber composite sample showed deterioration up to 14.09kJ/m^2 to 13.43kJ/m^2 with fiber content 20% and 21.42 kJ/m^2 to 20kJ/m^2 for 40% EFB fiber content. Meanwhile, fiberglass and polyester showed impact strength deterioration of 50.32kJ/m^2 to 50.04kJ/m^2 and 4.40kJ/m^2 to 4.77kJ/m^2.

Similarly, in other samples impact strength also decreased with time of exposure. EFB fiber composite showed the highest degradation compared to the other samples after 12 months of biological testing. Besides that, the degradation rate increased with increasing fiber reinforcement weight in the composite. Due to this condition, the sample with the highest fiber content (40% EFB fiber) showed the highest degradation after 12 months biological test compared to the other samples.

After 12 months of the experiment, the highest degradation of impact strength was 40% EFB fiber composite, which showed a decrease of 27.85%. This was followed by 20% EFB fiber composite with a percentage of 25.24%. Meanwhile for polyester and fiberglass composite, showing a low degradation of 4.40% and 0.85%.

Impact strength characteristics were influenced by the structure and adhesion between the reinforcing fibers and the matrix. Biological testing caused composite samples to become weak due to moisture reaction and microorganism attack on the composite sample. Effects from biological reactions caused damage and decay, affecting the fiber-matrix interface bonding and matrix polymer structure.

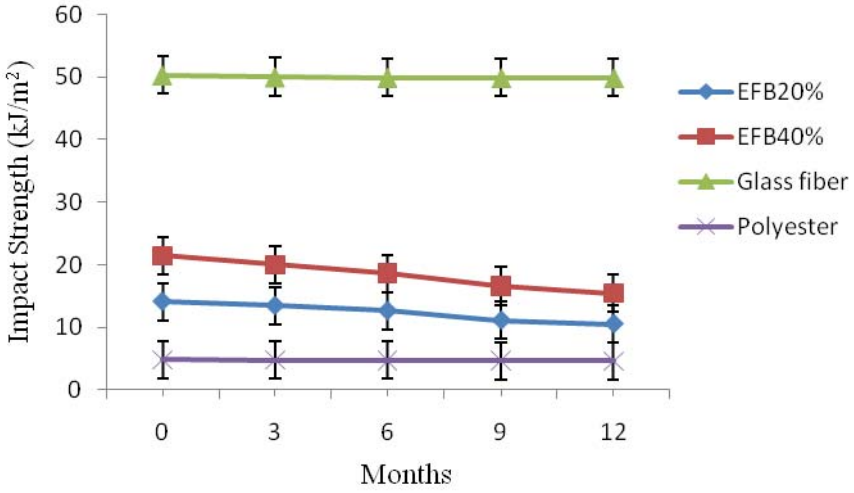


Figure 11. Impact result on EFB fiber composite, fiberglass composite and polyester sample after biological test from 0 to 12 months

Biological changes also were evident in the case of polyester without fiber reinforcement. However this sample did not experience serious damage compared to the EFB fiber composite. Figure 12 shows a surface comparison between unburied samples (0 month) with buried samples (3, 6, 9, 12 months) for polyester without fiber reinforced surface.

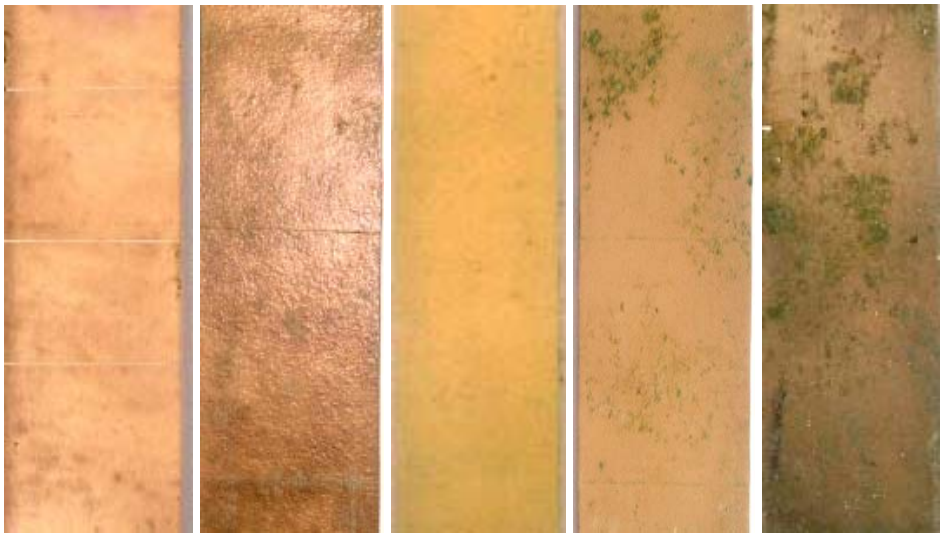


Figure 12. Polyester without fiber reinforced (Impact strength sample) after been exposed to ground contact. (a) 0 months (b) 3 months (c) 6 months (d) 9 months (e) 12 months

Physical Properties

The effects of fiber type on the density of EFB fiber composite and fiberglass composite density are given in Fig. 13. The polyester matrix had a density of 1.251 g/cm^3, and the composite density decreased relative to the matrix with the addition of EFB fiber into the polyester matrix. Increasing the fiber weight percentage from 20% to

40% in the polyester matrix caused the density value to decrease from 1.15g/cm^3 to 1.052 g/cm^3. The 20% EFB fiber composite showed a higher density value compare to the 40% EFB fiber composite. This is attributed to a high content of fiber, which created micro-voids in the composite, and it also was a main factor contributing to composite blemishes.

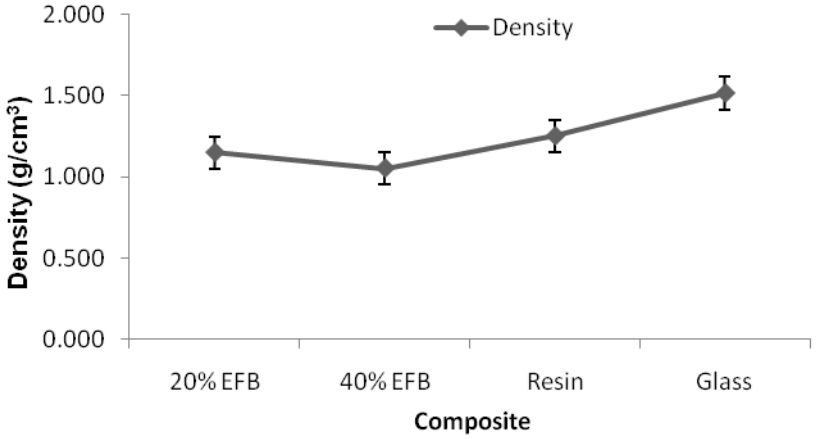


Figure 13. Density EFB fiber reinforced and fiberglass composite polyester

The influence of density value on fiber content and the void content of the composites is evident in scanning electron microscope (SEM) images of the surface, as shown in Figs. 14(a) and (b).

As compared to EFB fiber composite, there was a significant difference where fiberglass composite shows increases in density value. An increase to 1.516 g/cm^3 was achieved with addition of 40% of fiberglass into the polyester matrix. According to Fan et al. (2006), higher density value, tensile stiffness, and tensile strength also increase due to higher content of the reinforcing fiber and low void content. Good wettability on fiberglass by polyester matrix produced a good interfacial bonding surface and reduced the tendency for formation of small holes, which can result in the observed effects on fiberglass composite density.

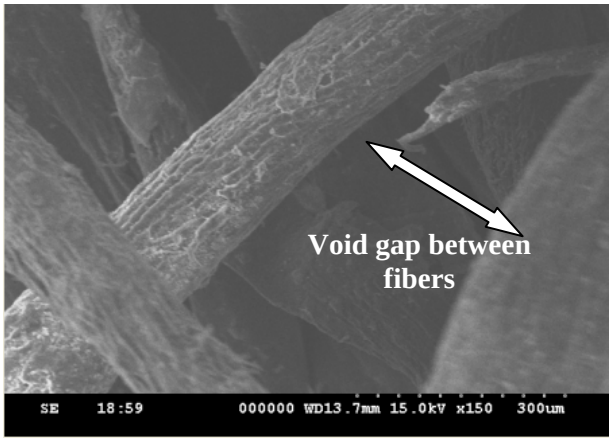


Figure 14 (a). Scanning electron microscope (SEM) images of the surface, influence of density on fiber and void content, 20% of EFB fiber reinforced composite. (150x)

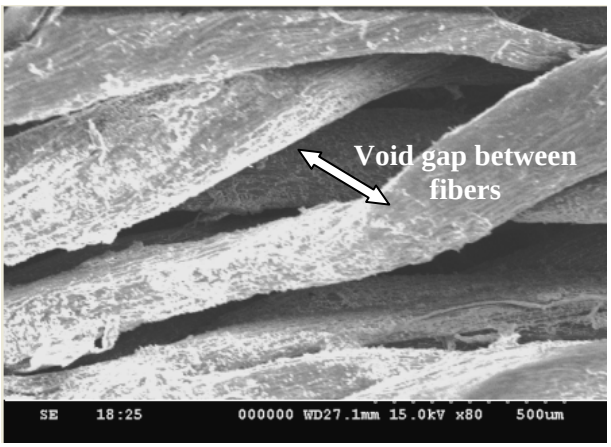


Figure 14 (b). Scanning electron microscope (SEM) images of the surface, influence of density on fiber and void content, 40% of EFB fiber reinforced composite. (150x)

Moisture Content

The polyester matrix had the lowest moisture content percentage with 0.055%, with increase in the amount of fiber reinforcement in the polyester matrix; the moisture content percentage also increased. Escalation of moisture content can be seen on EFB fiber 20%, 40% fiberglass composite. From Fig. 15 it can be seen that moisture content percentage increased with the addition of EFB fiber reinforcement from 20% to 40%. The highest value was recorded in the case of composite with a total percentage fiber reinforcement of 40%. This is due to presence of hydroxyl and other polar groups in the fiber, when moisture absorption is high (Khalid et al. 2008).

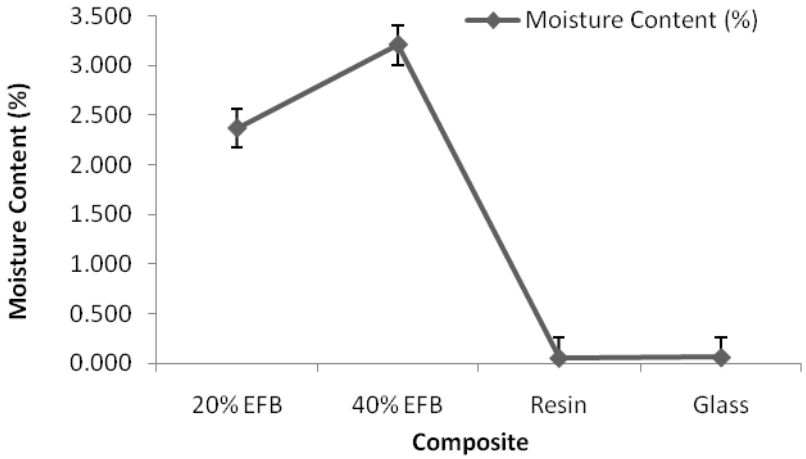


Figure 15. Moisture content percentages of empty fruit bunch composite and fiberglass composite polyester

Lignocellulosic materials change their dimensions with changes in moisture content because the cell wall polymers contain hydroxyl and other oxygen-containing groups that attract moisture through hydrogen bonding. The hemicelluloses are mainly responsible for moisture sorption, but the accessible cellulose, non-crystalline cellulose, lignin, and surface of crystalline cellulose also play major roles (Prasad et al.1998)

The rate of increase in moisture content for fiberglass was low compared to EFB fiber composite. This is attributed to the fact that the polyester matrix was more suitable with fiberglass, where it achieved a good interfacial contact. These factors contribute to the good physical and mechanical properties on fiberglass composites. Low moisture absorption on fiberglass composite resulted in more consistent contact between the materials within the interfacial area and natural fiberglass properties itself not tending to absorb moisture.

Water Absorption

Figure 16 shows effect of increasing fiber weight percentage into composite and fiberglass composite towards water absorption for 60 days. It can be seen that the water absorption of composites increased with an increase in soaking time. Moreover, increasing amounts EFB fiber in EFB/polyester composites increased the water absorption percentage of the composites. This is due to the highly hydrophilic nature of the nature EFB fiber owing to the free hydroxyl group present in the cellulose and lignin structures. In this case, the increased number of hydroxyl groups was more pronounced in cellulose structures due to the high cellulose content (49.6%) in EFB fiber.

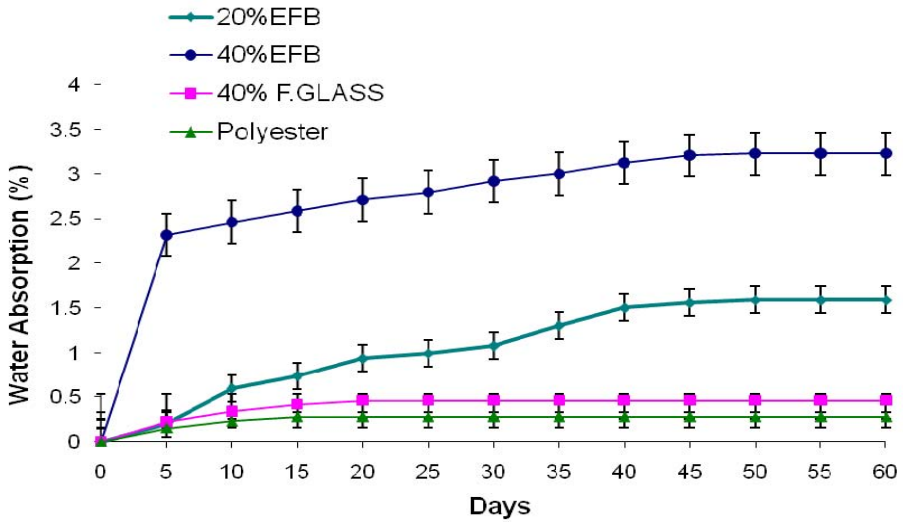


Figure 16. Percentage of water absorption on empty fruit bunch composite and fiberglass composite polyester

Weak bonding between matrix and fiber (Fig. 17), agglomeration of the EFB fibers, and incomplete encapsulation of the matrix over the EFB fibers are factors that contribute to poor water resistivity of a material (Khairiah and Khairul 2006). As can be seen from Fig. 15, 40% EFB fiber composites showed the highest value of water uptake. This was followed by 20% EFB fiber, where the water absorption was lower compare to 40%. The presence of coupling agent and compatibility has also affected the amount of water absorbed. The water absorption decreased as the loading of coupling agents increased.

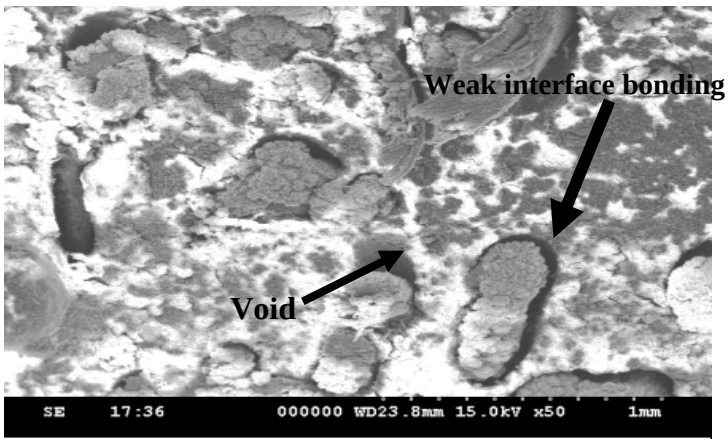


Figure 17. Scanning electron microscope cross section EFB fibers composite (50x)

Initial percentage of water absorption from day one to two were much higher, which was attributed to the porous structure of EFB fibers (Fig. 18) which transport the water via the capillaries in the fiber strands into the gaps and flaws at the interfaces between fibers and matrix (Khairiah and Khairul 2006).

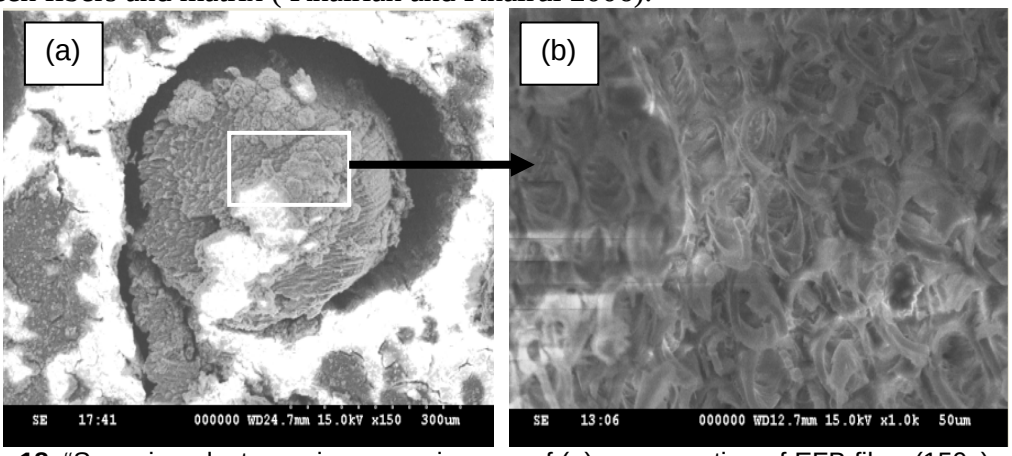


Figure 18. "Scanning electron microscopy images of (a) cross section of EFB fiber (150x) and (b) EFB fiber bundle (150x)

Water absorption on fiberglass composite also showed an increase following long immersion in water. During the water immersion, water molecules first enter the free space of micro-voids formed by cavities and cracks in the matrix. At the same time, water molecules can rapidly penetrate and diffuse along the interface because of the capillarity, and this process would increase the weight of the sample (Huang and Sun 2008). However, fiberglass composite showed lower water absorption compared to EFB fiber composites. This due to the non-hygroscopic character of fiberglass, which is partly a consequence of the good interfacial contact between the fiberglass and polyester matrix. Good wettability between fiber matrixes reduced empty space or voids, which are usually evidence of weak interactions between the materials contacting each other at an interface.

CONCLUSIONS

From the present experiments it is concluded that degradation affects the mechanical, physical, and morphological properties of EFB fiber-polyester reinforced composites. Results revealed that variation occurs in both mechanical and physical properties with different levels of fiber loading in composites. SEM analysis was carried out to see the effect of the quality of adhesion between the fibers and matrix. The soil burial test revealed that in EFB fiber-polyester composites (40% by weight) had the highest degradation percentage as compared to polyester resin and fiberglass.

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