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Effect of Water Absorption on the Mechanical Properties of Oil Palm Empty Fruit Bunch (OPEFB) Reinforced Polymer Composite

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Abstract

Natural fibres are progressively picking up attention as their applications are diversified into multiple industries which includes the automotive industry where lightweight materials are of utmost importance. The demand for natural fibre reinforced polymer matrix composites was nevermore as predominant as it is today. Oil palm empty fruit bunch (OPEFB) fibres are natural fibres and contribute to an eco-friendlier substitute when compared to synthetic fibres. These fibres are obtainable in a very large quantity, are inexhaustible, nontoxic, and due to their low cost can best be suited to replace synthetic fibres to significantly reduce the weight of the vehicle thus decreasing the fuel consumption. In this experimental research the OPEFB reinforced polymer composite was fabricated to study the effect of water absorption on its mechanical properties. The OPEFB polymer composite was fabricated by using a 5% Mf of OPEFB along with an epoxy matrix. A hot compression moulding machine was used to fabricate the OPEFB polymer composite. The specimens were subjected to a water absorption test where they were immersed in water for a variation of days. After each number of days, a tensile and hardness test was conducted on the specimens. When comparing between the variation of days, it was observed that as the number of days increased it displayed a fluctuating trend towards the tensile properties while a deteriorating trend was observed for the hardness properties of the specimens that were subjected to the water absorption test. The hydrophilic nature, distribution, orientation and size of this fibre was the main contributor towards the increase of water absorption in the composite. From the experimental research conducted regarding the OPEFB polymer composite it is recommended that the fabricated OPEFB polymer composite could be used as a suitable substitute for synthetic fibres as a replacement for the interior materials of vehicles in the automotive industry.

Keywords: Oil palm empty fruit bunch (OPEFB), polymer composite, epoxy matrix, water absorption test, mechanical properties

INTRODUCTION

Increased ecological awareness and realization all around the globe has built up a continuous expanding awareness towards natural fibres and their implementation in multiple fields. Natural fibres presently are evaluated as a significant substitute compared to other artificial fibres for their application in different departments. Natural fibres are progressively picking up attention as their application is diversified into engineering fields, for example, vehicle structural parts and building materials where lightweight materials are required. Today, multiple studies are conducted based on the utilization of lignocellulose bio fibres instead of artificial fibres as reinforcing materials which are sought after enthusiastically. These bio fibres are widely utilized for the generation of financially

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savvy eco-friendly bio composites [1–5]. Composite materials have the possibility to replace multiple applications in the engineering field today [6]. The physical and mechanical properties and characteristics of composites can be altered by adding a filler stage to the matrix body amid the composite preparation process. The incorporation of filler in composites are to enhance their mechanical properties. Low cost, reduced tool wear, ease of availability and light weight amid its machining procedure are among the known benefits of plant fibres and the simplicity of recycling makes them an eco-friendly product [3]. Previously carbon and glass fibres were generally utilized as reinforcement materials. Considerable measure of research has gone into and has been conducted to obtain their properties and utilizations. In any case, these materials are extremely costly and their utilization is justified mainly towards the aviation and aerospace industries. Along these lines, a great deal of research has gone in and been conducted on a variety of different fibres, for example, jute and oil palm empty fruit bunch (OPEFB) fibres [6]. The use of green materials in composites provides an alternative method to overcome the agriculture waste issue that is taking a big toll in nations around the world [7, 8].

OPEFB fibres are natural fibres and contributes to an eco-friendlier substitute when compared to traditional reinforcing fibres. These fibres are obtainable in a very large quantity, are inexhaustible, nontoxic, and due to their low cost, they have caught the attention of industries where they utilize these natural fibres [4]. The utilization of natural fibres as reinforcing materials in both thermoplastic and thermoset matrix composites gives positive ecological benefit with respect to ultimate disposability and best utilization of raw materials [8]. The most frequently used thermoplastics for the production of natural fibre plastic composites are phenolics, epoxies, isocyanates, and unsaturated polyesters. OPEFB is a possible natural fibre to be further researched upon. New research suggests that the OPEFB reinforced polymer composite was found to have a yield strength that showed significantly improved characteristics [5].

The demand for natural fibre reinforced polymer matrix composites was nevermore as predominant as it is today. Natural fibres comprise of both cost effectiveness and a decrease in mass compared to other synthetic fibres. In spite of the fact that natural fibres' strength is not as great when compared to other synthetic fibres, their specific characteristics and properties are equivalent. Right now, natural fibre composite materials have two concerns that should be addressed which are the compatibility of the resin and the absorption of water. The following experimental research looks into the application of OPEFB as a fibre-reinforced polymer matrix composite.

EXPERIMENTAL PROCEDURE

Materials

The OPEFB fibre was procured and sponsored by the MPOB, Bangi, Selangor, Malaysia. The OPEFB when it was received was all tangled and had uneven branches and contained impurities. The OPEFB fibres were then handpicked for the best strands available. Later the OPEFB fibres were rinsed with distilled water to get rid of all the impurities. Then the washed OPEFB fibres were left to dry under the sun for approximately 12 hours [9, 10]. After leaving the OPEFB fibres to dry under the sun, the OPEFB fibres were sent for fumigation process. The OPEFB fibres were fumigated with methyl bromide at 48g per cubic meters for a duration of 24 hours at 25ºC. After the fumigation process was completed, the fibres were again sun dried for an additional 12 hours. The reason the fibres were sun dried once again was to eliminate any remaining moisture from the methyl bromide fumigation process. Then the fibres were inserted into a hammer mill which was provided by the MPOB. This was done to shred the fibres to obtain a short OPEFB fibre form. The chemical composition, physical properties, and mechanical properties of the short random OPEFB are shown in Tables 1–3, respectively. The short random OPEFB is shown in Figure 1.

The epoxen CP362 which contained the epoxy resin and hardener was obtained from Oriental Option Sdn.Bhd, Pulau Pinang, Malaysia which was utilized for this experimental research. The epoxy resin acted as a binding agent while the hardener acted as a curing agent for the curing of the composites.

The weight ratio of the epoxy resin (Part A) to hardener (Part B) was 100:50 and the volume ratio of epoxy resin to hardener was 2:1 correspondingly. One type of fibre to epoxy composition was used for this experimental research which was 95 wt% of epoxy with 5 wt% of short random OPEFB fibres. The reason for utilizing this specific composition of epoxy to fibre is because according to the previous research that has been conducted the composite loaded with 5% OPEFB fibres achieved the highest increase in the measured tensile strength [11, 12].

Table 1. The chemical composition of the oil palm empty fruit bunch (OPEFB) [11].

Composition	OPEFB
Cellulose	43–65
Hemicellulose	17–33
Holocellulose	68–86
Lignin	13–37
Xylose	29–33
Glucose	60–66
Ash	1–6

Table 2. The physical properties of the oil palm empty fruit bunch (OPEFB) [11].

Properties	OPEFB
Fibre length (mm)	0.89–142
Fibre diameter (µm)	8–300
Lumen width (µm)	8
Density (g/cm^3)	0.7–1.55
Fibre angle (°)	46

Table 3. The mechanical properties of the oil palm empty fruit bunch (OPEFB) [11].

Properties	OPEFB
Tensile strength (MPa)	50–400
Young's modulus (GPa)	0.57–9
Elongation at break (%)	2.5–18

Figure 1. The short random oil palm empty fruit bunch (OPEFB) fibres utilized in this experimental research.

Fabrication of the OPEFB Composite

First, before starting the experiment, the hot compression moulding machine was heated to 50ºC. Also, two coats of mould release agent (grease) was applied to the mould cavity [10]. The releasing agent was used to prevent the specimens from sticking to the mould. Then the short random OPEFB fibre, the epoxy resin (Part A) and the hardener (Part B) were weighed. For instance, the mass of the 5 wt% short random OPEFB fibre was calculated to be 11.343 g. The total mass for the epoxy and hardener was calculated to be 215.531 g. According to the weight ratio of 100:50 the epoxy resin and hardener mass was found to be 143.686 g and 71.843 g, respectively. The short random OPEFB fibres, epoxy resin and hardener were then filled into three separate beakers according to their specific mass fraction. Then the beaker containing the short random OPEFB fibre was poured into the beaker containing the epoxy resin. By using a stirring rod, the short random OPEFB fibre and epoxy resin was mixed for five minutes. After that the hardener was added to the beaker containing the short random OPEFB fibre and epoxy resin [13–17]. With the use of the same stirring rod the beaker containing the short random OPEFB fibre, epoxy resin and hardener was mixed again for another 5 minutes. Then the mixture of epoxy resin, hardener and short random OPEFB fibre was poured into an open mould.

The open mould which contained the short random OPEFB fibre, epoxy resin and hardener mixture was then sprayed with acetone. This process was done to eliminate the bubbles that were formed during the mixing process of the short random OPEFB fibre, epoxy resin and hardener. After that the open mould was placed on the hot compression moulding machine at a temperature of 50ºC for 15 minutes. After the 15 minutes were up the open mould containing the mixture of the short random OPEFB fibre, epoxy resin and hardener was once again sprayed with acetone. Then the mould was closed with the mould lid and the entire mould was compressed at a temperature of 50ºC and a pressure of 1000 psi for 2 hours [18–20].

This experiment was conducted at room temperature approximately at 25ºC. The reason the experiment was conducted at room temperature at 25ºC was because the pot life and cure time would have been reduced at higher temperatures. The composite took 3 hours to cure and it took 10 hours to completely solidify. However, according to the manufacturer, they suggested the composite to remain in the mould for an additional 48 hours on top of the 10 hours that it took the composite to solidify.

After the 48th hour the composite was carefully removed from the mould. Then the composite was cut into 15 specimen pieces with a dimension of 20 mm × 150 mm by using a handheld circular saw. After that the specimens were grinded by using a bench grinder to get rid of any excess resin and to get a uniform shape. Figure 2 represents the fabricated specimens after they were cut [21–24].

Water Absorption Test

The testing procedure for the water absorption tests are as follows. The short random OPEFB epoxy specimens were prepared with respect to the ASTM D3039 standard. The specimen was weighed by using a weighing scale. Then the prepared specimen was immersed in water at room temperature. The specimen was left to remain immersed in the water bath for 7 days.

Figure 2. The oil palm empty fruit bunch (OPEFB)/epoxy specimens for tensile and hardness tests.

After the seventh day of being immersed in water the specimen was removed, patted dry with a cloth and weighed using the weighing scale once again. After it was weighed the specimen that was immersed in water for 7 days was subjected to a tensile test and Rockwell hardness test. The specimens were secured and the tensile tester was switched on so that the testing of the specimen may begin. Finally, the tensile tester was switched off once the specimen reached failure and broke. The same went for the hardness tester. The specimens were placed on the hardness tester; the start button was pressed to initiate the hardness test. Once the major load was removed the hardness value was obtained and displayed on the monitor [25–27]. The water absorption test was repeated again with days varying of 14, 21, and 28 days. The percentage of the water content (M_t) was determined by using the following equation:

$$M_t\ (\%) = \left(\frac{Wt - Wo}{Wo}\right) \times 100$$

where W_o is the dry weight of the specimen before the water absorption test and W_t is the weight of the specimen after exposure to the water absorption test [28].

Mechanical Testing: Tensile Test

The procedures involved for conducting the tensile test in this experimental research was done according to the American Society for Testing and Materials (ASTM). The fabricated ASTM D3039 specimen was first secured tightly at both ends of the jigs. After the specimen was secured the entire tensile testing setup was switched on. The area, gauge length, testing speed and load was then inserted into the tensile testing software. The tensile tester was then initiated so that the testing of the specimen may begin. Finally, the tensile tester was switched off once the specimen reached failure and broke. Then the process was repeated for the balance specimens that were fabricated. The gauge length, testing speed and load applied for this experimental research was 80 mm, 2 mm/min and 20 kN, respectively [29–33].

Rockwell Hardness Test

The OPEFB composite specimen was placed on the surface of the Rockwell hardness tester. A minor load of 300 HRB was applied. Then a start button was pressed to initiate the hardness test. The round bearing then made an indention onto the composite. After 6 seconds the minor load was removed. The specimen was then allowed to recover for another 6 seconds. The hardness value was read directly from the monitor with the B scale. The hardness unit applied for this experimental research was in HRB. Also, the hardness value for all the specimens was obtained within the gauge length of the tensile test specimens which was 80 mm. The process was then repeated for the balance specimens that were fabricated [34].

RESULTS AND DISCUSSION

The results obtained from this experimental research can be divided into three sections which are the effect of water absorption on the composites physical, water content percentage and the mechanical properties.

Effect of Water Absorption on the Physical Properties

From Figure 3 it can be seen that the initial weight of the specimens and the final weight of the specimens showed that the specimens have increased in weight due to the prolonged submersion in water and obtained an increase in weight up to a maximum weight gain value of 0.30 g. However, from the graph created based on the average weight of the specimens it can be seen that the average weight of the specimens was seen to be exhibiting a fluctuating trend with each variation of days. This fluctuation was caused due to the defects and errors while fabricating the specimens. The errors include inconsistent fibre distribution which resulted in some specimens having more or less OPEFB fibres hence causing the average weight fluctuation. Because of this some specimens exhibited a more resin rich morphology while others had a more fibre rich morphology [35–38].

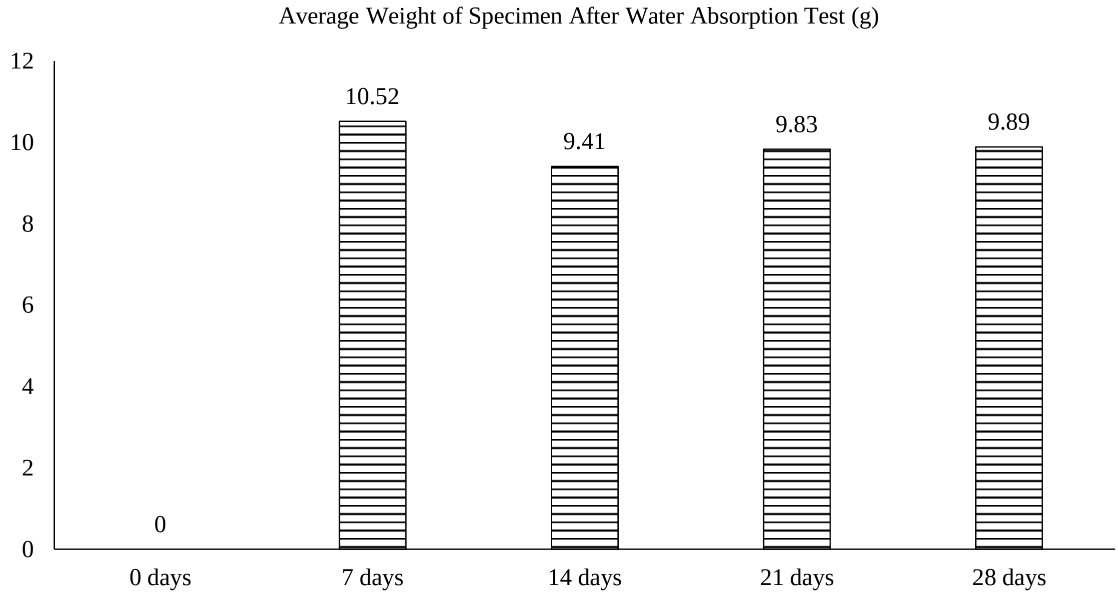

Figure 3. Comparison between the average weight of specimens after the water absorption test with variation of days.

Effect of Water Absorption on the Water Content Percentage

Figure 4 demonstrates the average water content percentage of the OPEFB polymer composite specimens based on the variation of days immersed in water. It very well may be seen that the average water content percentage increased as the number of days increased. From Figure 4 it is visible that an increasing trend was formed. This increasing trend was due to the submersion in water for up to 28 days. This led to a weaker strength between fibre and matrix. The average water content percentage of the specimens was low in the initial phase of water exposure, after which it increased due to the extended time period the specimens were immersed in water. The greatest water intake and the diffusion coefficient values increased for every single composite specimen as the number of days the specimens was immersed in water increased. The initial average water content percentage was low with a value of 2.0896% and the final average water content percentage of the composite specimens was 2.9487%. Another contributing factor towards the increasing average water content percentage was due to the specimens that were more fibre rich. Generally, when natural fibre polymer composites are exposed to water, the hydrophilic nature of the fibre causes it to absorb water. It can be concluded that as the specimens were immersed in water for a longer period of time, the greater the water content percentage of the specimens. This occurrence can be clarified by considering the water absorption nature of OPEFB fibres [39–42].

Effect of Water Absorption on the Mechanical Properties

The effect of water absorption on the mechanical properties of the fabricated OPEFB reinforced polymer matrix composite specimens was evaluated after being submerged in water for a variation of days of up to 28 days.

Tensile Strength

There was a considerable amount of difference between the average tensile strengths of each specimen. The greatest tensile strength average was obtained for the composite specimen that was subjected to the water absorption test with a duration of 7 days with an average value of 25.5061 N/mm^2. The specimens that were not subjected to the water absorption test obtained a tensile stress value of 21.7621 N/mm^2 which was lower than the specimens that were immersed in water for a period of 7 days.

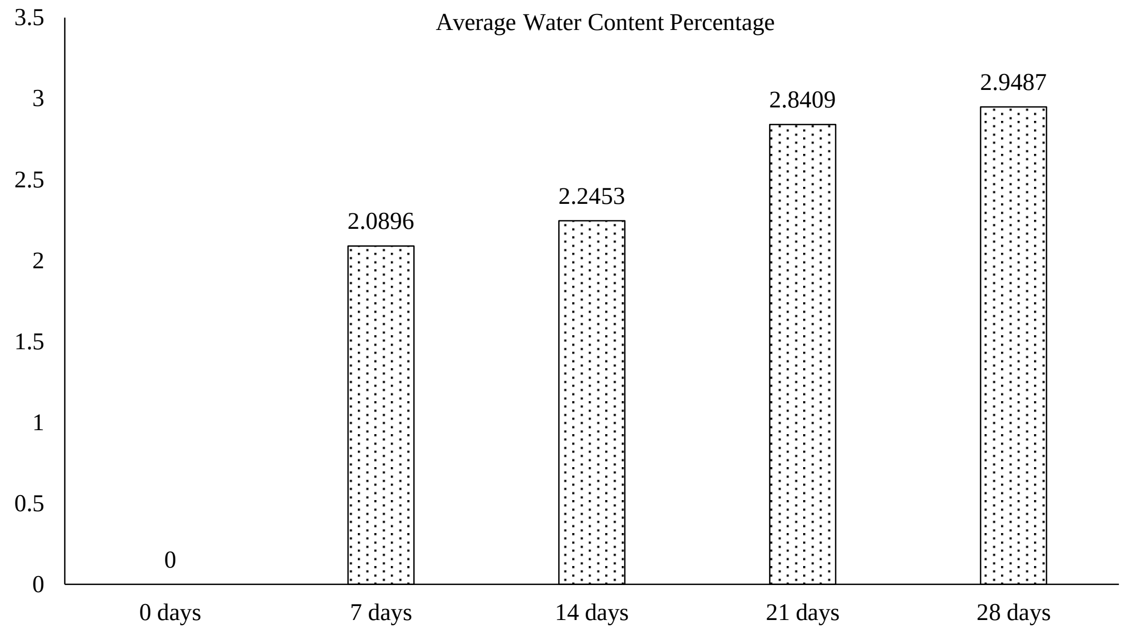

Figure 4. Comparison between the average water content percentage of specimens after the water absorption test with variation of days.

From the previous study conducted by Yusoff et al. [12] regarding the mechanical properties of short random oil palm fibre reinforced epoxy composites where they obtained an average ultimate tensile strength value of 29.9 MPa with a 5% fibre volume ratio. The fatigue behaviour of oil palm fruit bunch fibre/epoxy and carbon fibre/epoxy composites that was carried out by Kalam et al. [6] where they obtained an ultimate tensile strength value of up to 47.78 MPa with a fibre volume ratio of 35% [6]. Finally, Yeow et al. [10] who studied the effects of fibre weight fraction on mechanical behaviour where the ultimate tensile strength value of 40MPa with a fibre mass fraction ratio of 27% was achieved. The best average tensile strength in this experimental research was lower than that obtained by Yusoff et al., Kalam et al., and Yeow et al.. The tensile strength of the specimens that were not subjected to the water absorption test was also lower than the three researchers stated above. The reason behind the low tensile strength obtained was due to the difference in fabrication methods, preparation of the fibre and matrix, fibre orientation, fibre distribution and the type of thermoset that was utilized [43, 44].

For this experimental research short random OPEFB fibres were utilized with an epoxy matrix mixture. This was one of the reasons that this experimental research obtained a lower average tensile strength value. It was because along these lines, the fibre could not hold the load when the epoxy matrix was transferred. The fibre length also played a crucial role in the natural fibre reinforced polymer composites mechanical properties. The fibre isn't consummately aligned and the existence of voids in the composite may likewise be the factor adding towards the lower experimental value. From the research done by Baiardo regarding the flax fibre-polyester composite where they investigated the effect of processing conditions on the fibre length distribution and the dependence of the composites mechanical properties on fibre content, stated that the mechanical properties of short random reinforced composites depends upon the inherent properties of the fibre and matrix. It also depends on the aspect ratio, content, fibre distribution and fibre orientation within the composite. Finally, the fibre matrix bond that is in charge of the efficiency of the composites load transfer is also a factor that contributes to the mechanical properties of the composite [45].

The effect of water absorption towards the average tensile strength of the fabricated OPEFB polymer composite with the variation of days the specimens were immersed in water are shown in Figure 5. From Figure 5 it was observed that the specimens exhibited a fluctuating trend as the variation of days increased. It was also seen that the tensile specimens that were subjected to the water absorption test for seven days showed a greater tensile strength average with a value of 25.5061 N/mm^2 as compared to the other specimens which were and were not subjected to the water absorption test. When compared with the composite specimens that was not subjected to the water absorption test the tensile strength obtained by the seven days water absorption specimen was higher. Then the tensile strength decreased with each following variation of fourteen and twenty-one days the specimens were immersed in water where the specimens obtained an average tensile value of 21.9879 N/mm^2 and 21.7433 N/mm^2, respectively. Subsequently, the average tensile strength of the 28 days water absorption test specimens increased up to a value of 23.8022 N/mm^2.

The leading reason towards the average tensile stress results exhibiting a fluctuating trend was due to the inconsistent fibre distribution during the OPEFB composite fabrication. Because of the inconsistent fibre distribution when the specimens were cut according to the ASTM D3039 standard some specimens received more OPEFB fibres while others received less. This led to some composite specimens to be more resin rich while others were more fibre rich specimens. For instance, three out of the 15 tensile specimen displayed the greatest tensile stress value of 27.9533 N/mm^2, 26.2140 N/mm^2, and 27.3001 N/mm^2 as these specimens were more resin rich compared to the other tensile specimens. The reason that these specimens demonstrated the best tensile values even after being subjected to the water absorption test was due to the lack of OPEFB fibres present in them. The specimens that had more fibres showed a lower tensile result. This is understandable as natural fibres are very hydrophilic by nature. This means that natural fibres have high capabilities of absorbing water and storing it like a reservoir.

Based on Figure 5 the utilization of the OPEFB fibres has been seen to increase the water content percentage of the composites. The free hydroxyl groups present in the cellulose and lignin structure of the OPEFB fibre was a major contributor towards the water absorption. The lignocellulosic fibres initiated the water absorption process by creating hydrogen bonds amongst water and hydroxyl groups which includes cellulose, hemicellulose and cell wall lignin [28]. The OPEFB fibres also had high possibilities to retain more water because of the pore structures in the fibre [46].

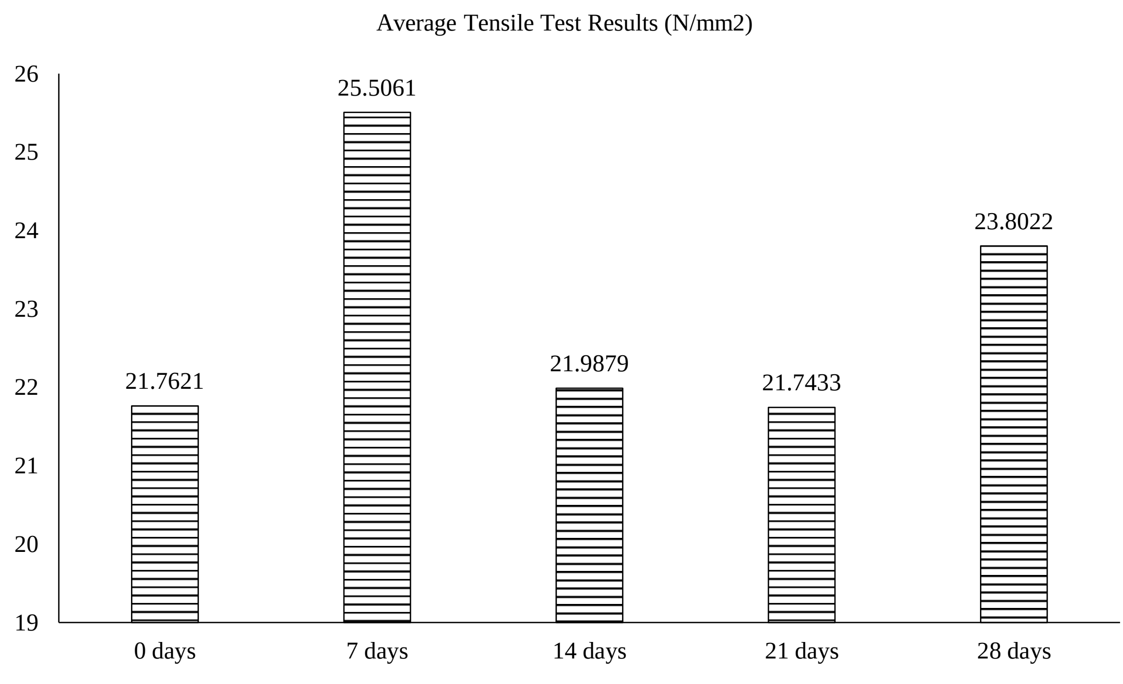

Figure 5. Comparison between the average tensile test results of specimens after the water absorption test with variation of days.

The OPEFB reinforced polymer composite specimens when exposed to water activated the hydrophilic nature of the fibre which resulted in water absorption and swelling. Because the OPEFB has a high cellulose content this led to the OPEFB fibres to absorb more water which in return broke through the interfacial bond through micro cracks within the composite. This ultimately led to the failure of the composite. The greater the composite cracks, the greater the capillarity and transportation of water occurs. Capillarity allows the water molecules to flow throughout the composites interface. Due to this the water molecules attack the interface which results in debonding of the fibre and the matrix [20]. This then led to the deterioration of the mechanical properties or in this experimental research the tensile strength. Also due to the utilization of short random OPEFB in this experimental research, poor interfacial bonding was developed.

Rockwell Hardness Test

There was a large amount of difference between the average hardness values of the composite specimens. The most exceptional average hardness value was achieved for the composite specimens that was not exposed to the water absorption test with an average hardness value of HRB.

The outcome of this present experimental research is lower compared to the outcome obtained by Sufizar, Ewulonu and Edwin Raja Dhas. The aftereffects of the present experimental research were compared with the aftereffects of previous research conducted, for example by Sufizar and Emran [47] who studied the effect of empty fruit bunch (EFB) fibre reinforced low density polyethylene (LDPE) composites on mechanical properties obtained the best hardness value of 46.04. Ewulonu and Igwe [33], however, conducted the research on the properties of oil palm empty fruit bunch fibre filled high density polyethylene stated that the composite specimen with a small particle size of 0.150 mm and a higher fibre content of 1.5 wt% obtained the highest hardness value compared to the other composites specimens fabricated. Finally, the mechanical property evaluation of palm/glass sandwiched fibre reinforced polymer composite in comparison with few natural composites that was conducted by Dhas and Pradeep [44] where they obtained the best hardness value of 63 HRB. From this experimental research, it may be concluded that the weak bond between the OPEFB fibre and the epoxy matrix added to the poor hardness properties. The proficiency of stress exchanged among OPEFB fibre and epoxy diminished from the weakened interfacial areas. The main components that decide the nature of interfacial bonding involves the characteristics of the OPEFB fibre and matrix and in addition their compositions, the fibres aspect ratio, mixing methods and preparation of the fibre and polymer matrix [12].

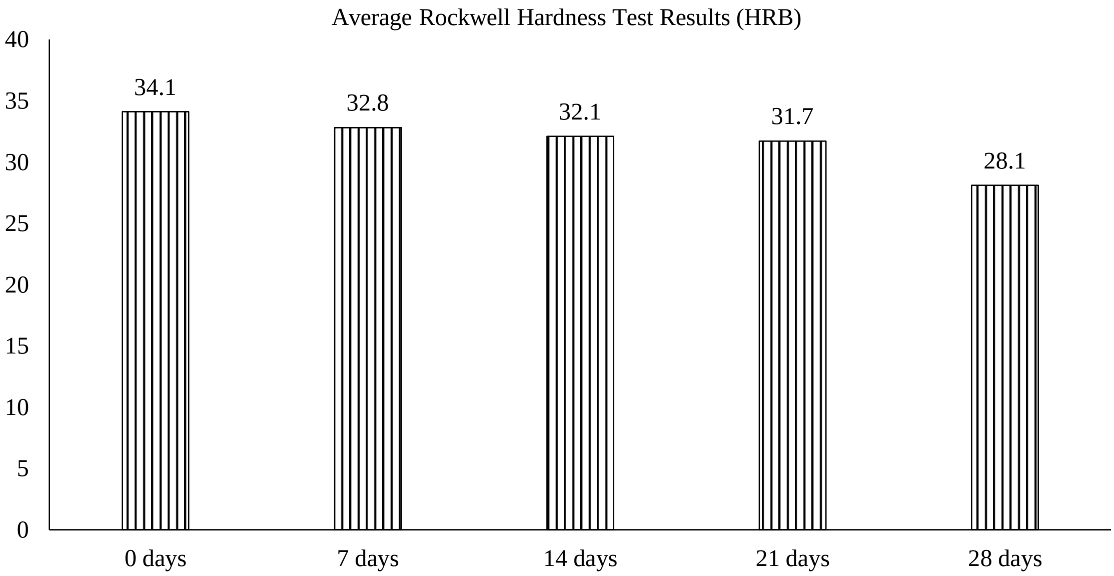

Figure 6. Comparison between the average hardness test values of specimens after the water absorption test with variation of days.

The impact of water absorption on the OPEFB reinforced polymer composites average hardness is presented in Figure 6. From the results the specimens that was not subjected to the water absorption test revealed a greater hardness value when compared with the other specimens that were immersed in water for the variation of days. Figure 6 illustrates that the hardness value demonstrated a decreasing trend as the number of days the specimens were immersed in water increased. The most astounding hardness value was for the composite specimen that was not immersed in water with an average value of 34.10 HRB.

However, the specimens that were immersed in water for twenty-eight days obtained the lowest average value of 28.10 HRB. The average hardness value for the specimens immersed in water decreased from 34.10 HRB to 28.10 HRB, respectively, as the variation of days increased from 7 to 28. This decrement in hardness was caused by the increased perforation of the ball bearing on the composites surface, thus decreasing the hardness of the OPEFB composite. Be that as it may, the hardness values were influenced by water retention, as in Figure 6 which shows the decreasing trend of the test specimens. Hardness values in all the specimens subjected to the water absorption test were seen to be decreasing when in wet conditions. This is related to the weak OPEFB fibre and epoxy matrix interface that was formed due to the water absorption.

This decline in hardness value has also been accounted for by other researchers working with natural fibre reinforced polymer composites. Alomayri et al. [20] conducted a research study on the effect of water absorption on the mechanical properties of cotton fabric-reinforced geopolymer composites which detailed that as the water absorption increased, the hardness of the cotton fabric-reinforced geopolymer composite decreased. They also found that the deformation profundity elevated for the specimens immersed in water compared to the specimen that was not immersed in water.

They then concluded that this was because of the hydrophilic characteristics of the fibres and in the end prompted towards the weak bond between the fibre matrix interface [20]. According to Figure 6, the instance of the fabricated OPEFB reinforced polymer composite in this experimental research where when the water intake achieves saturation level, the bound water and the free water stay within the composite as a storage area. This prompts to the softening of the fibres as well as weakening of the fibre matrix attachment which led to the decreased hardness properties.

Limitations

While conducting this experimental research, there were a few limitations that were observed during the fabrication process as well as before and after conducting the mechanical properties testing. The limitations stated below are useful for future researchers to improve the current work that was carried out.

Fibre Orientation and Distribution

Fibre orientation and distribution play a very important role towards the mechanical properties of natural fibre polymer composites. The orientation affects the maximum stress that can be achieved by the fabricated composite. In this experimental research the fibre orientation was in random order which may have been the cause to the lower tensile stress that was achieved. The tensile properties of the short fibre polymer composites were strongly based upon the fibre orientation. Also, the fibre distribution was inconsistent. So, some specimens were more resin rich as shown in Figure 7 while others were more fibre rich as shown in Figure 8. This can be considered a contributing factor towards the low experimental values obtained. Because the specimens which had more fibres displayed a lower experimental value opposed to the specimens that were more resin rich. The irregular sizes of the OPEFB fibres also caused poor fibre distribution in the fabricated composite specimens. According to previous studies conducted the aspect ratio, content, length distribution and orientation of the fibres in the composite led to the uneven fibre distribution of the composite. Both the random fibre orientation and the inconsistency of fibre distribution was a contributing factor towards the fluctuating average tensile values that was obtained.

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Figure 7. Specimen with a resin rich morphology.

Figure 8. Specimen with a fibre rich morphology.

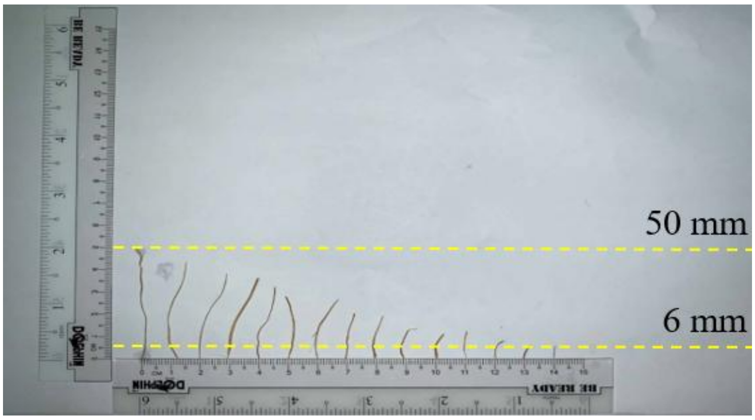

Figure 9. Fibre size variation utilized in this experimental research.

Fibre Size

The random fibre size implemented in the fabrication of this experimental research was a limitation as it led to a lower experimental value. According to previous researchers, the greater the OPEFB fibre size, the greater the percentage of water absorbed by the fibres. This is because of the poor interfacial bonding of the composite as well as the hydrophilic characteristics of the of OPEFB fibres. The increase of water retention in the composite specimens may also be because of the pore structures of OPEFB fibres, hence developing a greater water retention within the composite. Figure 9 shows the different fibre sizes that was used in this experimental research.

Gauge Length Fracture

After conducting the tensile test both the fibres and the resin of the specimens failed in a brittle manner. Also, some of the fabricated tensile specimens did not fracture within the centre of the gauge length. This was due to the increased void formation as the maximum weight percentage may have been surpassed where the amount of matrix present was not enough to occupy the gaps between the fibres which caused specimen inconsistency. Also, the short random orientation of the fibres that was applied in this experimental research and the inconsistent fibre distribution during fabrication was a contributing factor which caused a decrease in the experimental values as well as the fluctuating tensile properties over the entire variation of days. The short random orientation and distribution also caused the presence of voids within the specimen during the fabrication of the OPEFB composite. Damages were found on the tensile specimens which was due to the voids within the specimens.

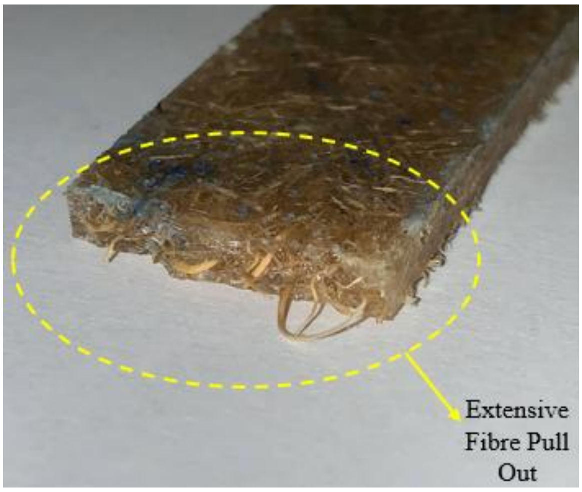

Figure 10. Fibre rich specimen with extensive fibre pull out.

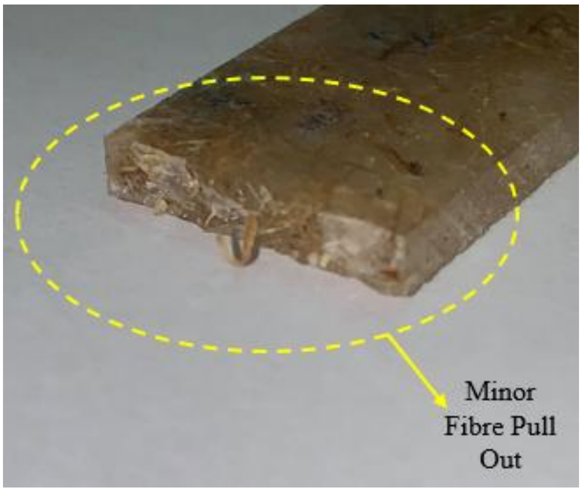

Figure 11. Resin rich specimen with lesser fibre pull out.

Fibre Pull Out

The difference between all the fabricated OPEFB specimens was the presence of the increasing number of fibre pull outs. By observing the fracture surface of the OPEFB fibre composite specimen with a more fibre and resin rich area as appeared in Figures 10 and 11, respectively, a comparison could be made. The OPEFB composite specimen which was more fibre rich displayed extensive fibre pull outs at the fractured region while the resin rich specimen had minor fibre pull outs. Fibre debonding was the main contributor towards the fibre pull out because of the weak adhesion and interfacial bonding between both the fibre and the matrix. Short fibres have a lesser length to diameter ratio and is most likely to fail due to fibre pull outs because of the decreased fibre matrix bond efficiency.

Morphological Behaviour

This was another issue that was faced in this experimental research. Morphological behaviour is when the surface of the specimen looks good and flawless but brittleness is found within the composite structure. The reason for the brittleness may be due to the void formation within the composite structure.

CONCLUSION

In this experimental research OPEFB reinforced polymer composite was fabricated. The OPEFB epoxy composite specimens were prepared in accordance with the ASTM 3039 standard and was subjected to mechanical tests. The effect of water absorption on the mechanical properties of the composite was evaluated. The tensile properties, hardness properties and water absorption behaviour was conducted based on the fabricated short random OPEFB reinforced polymer composite which was examined, measured, analysed, and compared.

Both the tensile and hardness properties of the OPEFB polymer composite had a lower experimental value compared to previous researchers. In light of the results, it was discovered that the average tensile properties showed a fluctuating trend while the average hardness properties of the OPEFB reinforced polymer composite demonstrated a decreasing trend as the number of days the specimens were submerged in water increased. The presence of water diminished the mechanical properties of the composite specimens due to the prolonged submersion of the OPEFB epoxy composite [10]. The water content percentage of the OPEFB reinforced polymer composite at room temperature was found to increase with increasing fibre content and number of days the specimens were immersed in water. This was due to the hydrophilic characteristics of the OPEFB fibres which have poor resistance to water absorption. A credible reason for this would be that the bond at the fibre matrix interface deteriorated because of water retention [20]. It was additionally discovered that void, fibre length, fibre dispersion and interfacial adhesion between fibre and matrix influenced the mechanical properties of the composites [12].

Moreover, the contributing factor towards the low experimental value for the both mechanical properties tested was due to the short random fibre size implemented, the inconsistent fibre distribution and orientation. This is connected to the poor interfacial bonds between OPEFB fibre and epoxy matrix due to the irregular fibre size. The inconsistent fibre distribution caused the formation of some specimens to have more fibre rich and some to have more resin rich morphology. Similarly, it was noted that the fracture portion of the composite with a fibre rich morphology was seen to have an extensive fibre pull-out, which indicates poor fibre matrix bonding.

Finally, from this experimental research the following conclusions were drawn. The results from this research conducted demonstrates that the best mechanical properties for OPEFB reinforced polymer composite in terms of the average tensile strength was for the tensile specimens that was subjected to 7 days of water absorption test while the best hardness properties was obtained by the composite specimens that was not immersed in water, which makes it better suited for automotive applications where high tensile and hardness properties are a requirement [48]. By increasing the number of days that the OPEFB reinforced polymer composite was submerged in water, an increase in the water content percentage was determined. The fibre size and distribution effects the water absorption behaviour and the mechanical properties of the composite. In spite of the fact that the fabricated composite has a few benefits and flaws, the blend of the valuable properties of two unique materials results in faster processing time and low cost of manufacture which makes them a resourceful material in the engineering field and industry. Henceforth to conclude, it is certain that the natural fibre composites are the most needed material in the present technological advancement trends.

Recommendations

- Silane treatment or sodium hydroxide treatment should be implemented by future researchers to obtain an improved adhesion and bond between OPEFB fibre and polymer matrix.
- Vacuum bagging technique should be used instead of the hot compression moulding method which was applied in this experimental research, this is to ensure that future researchers achieve a more uniform fibre distribution throughout the composite.
- To prevent void formations, future researchers should ensure that the OPEFB fibre is dry before mixing by using an oven to dry the fibres, slowly mixing the resin, fabricate the polymer composite within the stated gel time and in a controlled environment and finally a greater pressure above 1000 psi should be applied.
- To obtain a uniform fibre size an optical microscope should be used to obtain a specific fibre size. On a separate note, to determine which fibre size has the better mechanical properties, future researchers should carry out this experimental research by varying the sizes or by using just one uniform fibre size.

- Future researchers should use a test sample cutter which accurately cuts the specimen based on the dimensions and structure required to obtain a consistent specimen dimension.
- Future researchers may continue this experimental research by implementing multiple mechanical tests which include fatigue test, flexural test, Izod notched impact test, Charpy impact test, Vickers hardness test or scanning electron microscope (SEM) test.

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