Natural Fiber Reinforced Polymer for the Application of Sports Equipment using Mold Casting Method

EM Yusup$^{1,3,4,*}$, S Mahzan$^{2,3,4}$, MAH Kamaruddin$^4$

$^1$Sport Engineering Advancement Research (SPEAR)
$^2$Advance Dynamics Control Research Group (ADCARe)
$^3$Mechanical Failure Prevention and Reliability (MPROVE) Research Center
$^4$Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia
Parit Raja, 86400 Johor, Malaysia.

*E-mail: elizay@uthm.edu.my

Abstract. This study is focusing on fabrication of epoxy composite where oil palm empty fruit bunch is used as reinforcement agent. The aim of this research is to study the suitable duration for the alkaline treatment on the oil palm empty fruit bunch fiber towards their mechanical properties, physical properties and morphology of sample. Mold casting method is a method where the resin is poured into the mold to solidify. Different duration of oil palm empty fruit bunch fiber used which untreated, 12 hours treated and 24 hours treated. The treatment process had been done at room temperature of 27°C. Composite then fabricated by mixing the oil palm empty fruit bunch fiber and epoxy at 5 wt% of fiber and cured at room temperature for 24 hours to complete the process. The mechanical properties of the sample being tested by conducting flexural test and impact test. Studies of physical properties of the sample also conducted by density and porosity test. Morphology test also conducted to study the surface morphology of the tested sample. Flexural strength of the composite had been produced is between 46.77 MPa - 83.63 MPa with density and porosity at 1.1379 g/cm$^3$ - 1.1527 g/cm$^3$ and 1.57% - 2.02%. Impact strength produced by those composite is between 0.132 J/mm$^2$ and 1.1527 J/mm$^2$. The oil palm empty fruit bunch fiber/epoxy composite that went through 24 hours fiber treatment shows high potential to be used as reinforcement to epoxy as suitable material for sports equipment.

Keywords: Oil Palm Empty Fruit Bunch, mold casting method, epoxy resin, alkaline treatment.

1. Introduction

There are direct relationship between athletes and sports equipments and/or utilities performances. Nowadays, new generation of material has been introduced in the making of hockey sticks, which is carbon fiber. This new material has good mechanical properties with its good design in manufacturing. However, the development of new innovative materials for various end-use applications was due to the environmental consciousness. In the site of sport utility, the utilization of natural fibre reinforced polymer has an interest to take place in its manufacturing. This is due to the good properties and environmental friendly material compared to synthetic fiber [1].

In this research, epoxy resins from thermosets polymer was used as the matrix, while natural fibers as reinforcement material. Natural fibers can be extracted from natural resources such as plants and animals [2]. Oil palm empty fruit bunch (OPEFB) fibres have been selected. Staying in this view, this
research is about developing a polymer matrix composite (epoxy resin) using OPEFB as reinforcement and discover some of its mechanical properties and performance in the application for sports utility. Natural fibre has been proved to have good strength, light-weight and low cost which they are replacing the glass and synthetics fibres [3-5]. The OPEFB fibers have depicted a great potential in use as reinforcing materials in a polymers [6]. Mechanical testing was performed on the sample of composite to determine the performance of the material. Comparison of the results were determined on the material with different wt% of OPEFB.

2. Methodology

2.1. Materials and Methods
Raw OPEFB as fiber was supplied by Sime Darby Plantation Sdn. Bhd. Epoxy resin and hardener as matrix from Syarikat Saintifik Bersatu Sdn. Bhd., Malaysia. Alkali solution from mixture of Sodium Hydroxide (NaOH) pallets with water was selected as the treatment solution was provided by Material Science Laboratory, UTHM.

2.2. Preparation of Samples
The schematic of composite preparation is described in Figure 1. The fiber is extracted from the raw OPEFB and washed with water. Fiber then was dried in room environment for two days until it is fully dried. The fiber then was cut into 3 mm-5 mm long. Alkali solution was prepared by using NaOH pallets with the ratio of 5:95 to water. The cut fibers was immersed in the alkali solution for 12 hours and 24 hours to clean the surface of the fibers from impurities and to increase the fiber surface roughness [7]. To wash the OPEFB fiber after treatment, distilled water was used as titration until pH 7 is reached. Oven was used to dry the fiber out from water at 80 °C for 12 hours. Then, proceed to mix with epoxy and hardener. Ratio of epoxy to hardener used was 1:2 as recommended by manufacturer. Composite, 5 wt% of OPEFB fiber was loaded into the known amount of epoxy and hardener. The mold used was 3D printed according to ASTM specification for the mechanical tests. The mold then poured natural shoes wax as mold release agent to ease the cured composite to remove from the mold. Right after the wax is solid but tacky; the mixed composite is poured in the mold. Then composite is left to cure in room temperature for 24 hours. Finally the cured composite was de-mold and ready for the testing.

Figure 1. Flow chart process of composite preparation using mold casting method.
2.3. Mechanical and Morphological Testing
Several mechanical tests was carried out to the specimen. All experiment was conducted at room temperature.

2.3.1. Flexural Test
The flexural sample dimension was measured as referred to ASTM D790-15. It was tested for flexural strength by using Universal Testing Machine 10 kN by Shimadzu. The support span was 51.2 mm while the speed of crosshead was 2 mm/min. All five specimens were tested to obtain the average flexural strength of the sample.

2.3.2. Impact Test
All of the samples were measured as referred to ASTM D6110-10 standard before being tested. The Charpy impact test organizes to determine the impact resistance absorbed by the samples. It was tested using Wolpert Charpy testing machine provided in the Polymer Laboratory, UTHM. The test was using 4 J hammer. Five identical samples were tested to obtain the average impact strength.

2.3.3. Density and Porosity Test
Density and porosity test was performed to obtain the material density properties as well as the porosity of all samples. Test was performed using the electronic balance provided in the Material Science Laboratory, UTHM.

2.3.4. Interfacial Morphology Analysis (SEM)
Fracture surface of impact testing and flexural testing were observed using a scanning electron microscope (SEM) model of JEOL JSM-6380LA. The sample was coated with copper to improve the interface conductivity.

3. Results and Discussion
3.1. Flexural Test
For the flexural test, the sample size and testing procedure were referred to the ASTM D790-15. The results of the testing are shown in Table 1. Figure 2 was constructed based on the data given in Table 1 for more detail.

| Duration of Alkali Treatment (hour) | Maximum Load (N) | Flexural strength (MPa) |
|-----------------------------------|------------------|-------------------------|
| 0                                 | 73.57            | 67.90                   |
| 12                                | 50.67            | 46.77                   |
| 24                                | 90.60            | 83.63                   |
Referring to the data obtained subjected to flexural test, the value of flexural strength of untreated OPEFB fiber was 67.90 MPa followed by NaOH 12 hours treated was 46.77 MPa and 24 hour treated was 83.63 MPa. The 12 hours treated OPEFB composite shows the lowest value of flexural strength. This may due to bubbles contain inside the epoxy that lead to the weakness of the composite.

According to the graph in Figure 2, it can be seen that the OPEFB fiber/epoxy with 24 hours treatment results as the highest flexural strength compared to the other treated OPEFB fiber. However, the flexural strength of the OPEFB composite with treated fibers decreasing as it going through longer fiber treatment, which was contrary to the statement that good interfacial adhesion should have higher flexural strength of composites. It is probably the treatments have a lasting effect on natural fibers, such as the removal of amorphous components in the fibers, especially on the fiber stiffness [8]. Based on the results, OPEFB fiber that going through 24 hours treatment, show increasing of strength and modulus of OPEFB and influenced the modulus of the composite.

3.2. Impact Test

The impact strength also parts of the objective in this research. The impact force and the impact strength result shown in Table 2.

| Duration of Alkali Treatment (hour) | Impact Force (J) | Impact strength (J/mm²) |
|------------------------------------|-----------------|-------------------------|
| 0                                  | 0.218           | 0.132                   |
| 12                                 | 0.276           | 0.167                   |
| 24                                 | 0.320           | 0.193                   |
Figure 3. Impact strength results against different fiber treatment duration.

The strength properties of OPEFB fiber by 24 hours treatment shows the highest impact strength which followed by 12 hours OPEFB fiber treatment and untreated OPEFB fiber. The results show that the treated OPEFB fiber produces higher strength comparing to the untreated OPEFB fiber. The surface of the 12 hours treated fiber demonstrate an increasing of impact strength property which is 0.167 J/mm², an increase of 26.5% value of as the natural untreated OPEFB fiber composites. This is followed by the OPEFB that treated for 24 hours which is 0.193 J/mm², an increase of 46.2% strength compared to the untreated OPEFB fiber 0.132 J/mm². It is due to the increasing of interfacial adhesion strength between fiber and the matrix (epoxy). This was due to the removal of foreign particle and decrease in the lignin level in treated fiber compared to the untreated fiber [9].

Figure 3 shows the Charpy impact strength result. The graph shows that the impact strength of the longest treated composite value is higher compared to untreated composite. The 24 hours fiber treatment of OPEFB shows the highest impact strength and followed by the 12 hours OPEFB fiber treatment and the untreated OPEFB fiber. It is proved that every treatment on OPEFB fiber is improving the impact strength composite. The highest impact strength is obtained by the composite with the 24 hours OPEFB fiber treatment because the alkali was removing the first layer of the fiber which was given a good interfacial of fiber to the matrix. The function of alkali improves the degree of cross-linking in the interface region and increases the fiber surface area, allowing for stronger bonding between fiber and matrix.

3.3. Density and Porosity

All results was recorded in the Table 3. Based on the information, a graph of average density versus fiber treatment was plotted to make a comparison between the different duration of treated OPEFB fiber composite.

Table 3. Density test result

| Duration of Alkali Treatment (hour) | Density (g/cm³) | Porosity (%) |
|------------------------------------|-----------------|--------------|
| 0                                  | 1.1379          | 1.98         |
| 12                                 | 1.1431          | 2.02         |
| 24                                 | 1.1527          | 1.57         |
As refer to Table 3, it can be seen that the porosity of 12 hours treated composite has the higher percentage which is 2.02% followed by the untreated fiber treatment 1.98% and 24 hours fiber treatment 1.57%. Porosity is identified as air-filled cavities inside the material, and also often unavoidable part in all composites, and is developed during the mixing of the matrix and fiber. From the research by Bo Madsen et. al the high fiber content and low porosity content need optimal combination for high performance composites, which is high stiffness and strength. According to this research, the porosity might be cause from the composition of matrix and fiber is not suitable which the matrix is not fully covered the fibers.

### 3.4. Interfacial Morphology Analysis (SEM)

Morphology test has been carried out on Fracture sample of flexural test and impact test specimens to observe the surface morphology. SEM photography of the cross section of the OPEFB fiber reinforced epoxy composite shown in Figure 5(a) and 5(b) it can be seen that those fibers are detached from the resin interface due to poor adhesion produce by the porosity existed between fiber and the resin interfaces. The non-smooth surface was indicating that the compatibility between fibers and epoxy is not good. The presence of uneven fibers in the composites presumably the fundamental driver of poor flexural quality [10].

![Figure 4. Density and porosity result test](image-url)
Figure 5. SEM micrograph of flexural testing (a) untreated OPEFB fiber (b) 12 hours treated OPEFB fiber.
Figure 6. The fiber pull-out on the surface fracture of OPEFB fiber/epoxy composite after impact testing.

SEM image on the Figure 6 shows a lot of fibers on the specimen surface. This presents that the mixture between OPEFB fiber and epoxy matrix are not in uniform and have different density. The casting of the slurry into the mold was not typically reasonable in light of the fact that the distinction between the resin and the fibers makes the fibers float or sink unless the viscosity of the epoxy is deliberately balanced or controlled [11].

4. Conclusion
Based on the results obtained according to the mechanical and physical properties, the composite of OPEFB fiber/epoxy has the strength of flexural between 67.90 MPa to 83.63 MPa which is in the range of field hockey stick requirement [12]. While for the impact strength was between 0.132 J/mm² and 0.193 J/mm². For the density this composite has the density from 1.1379 g/cm³ to 1.1527 g/cm³. The duration of 12 hours and 24 hours alkali treatment shows high potential to be used as sports equipment but there are several flaws that need for further study.

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