Effect of the orientation carbon-glass fiber reinforced polyester composite on bending strength for runner foot prosthesis applications

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Abstract. An alternative way for increasing the strength of the runner’s prosthesis is by utilize the direction of fiber orientation. The aim of this research is to determine the effect of the orientation carbon-glass fiber reinforced composite on its bending strength. The main materials used in this study are carbon and glass fiber. The independent variable in this study is the direction of fiber orientation (0°, 45°, 90°, 0°/90°/0° and 90°/0°/90°). The dependent variables in this study are the bending strength and fracture micro photographs. This study is controlled by the method of manufacturing composites with vacuum assisted resin infusion (VARI) and unsaturated polyester yukalac® 157 BQTN-EX with a density of 1.12 g cm⁻³. Polyester composite are reinforced with carbon and glass fiber with varying fiber orientation. Each composite was reinforced carbon-glass fiber with orientation 0°, 45°, 90°, 0°/90°/0° and 90°/0°/90°. The results showed that the bending strength of composite reinforced carbon glass fiber with orientation of 0°, 45°, 90°, 0°/90°/0° and 90°/0°/90° respectively 1.32 MPa, 1.65 MPa, 0.93 MPa, 1.25 MPa and 4.46 MPa. While, the deflection values for composites reinforced carbon glass fiber with orientation of 0°, 45°, 90°, 0°/90°/0° and 90°/0°/90° respectively 9.65 mm, 8.7 mm, 13.45 mm, 10.59 mm and 3.83 mm. The lowest bending strength occurs in carbon-glass fiber reinforced composites with fiber orientation 90° is 0.93 MPa with the deflection of 13.45 mm. The highest bending strength occurs in carbon-glass fiber reinforced composites with fiber orientation 90°/0°/90° is 4.46 MPa with a deflection of 3.83 mm. The results of fracture testing using scanning Electron Microscopy (SEM) showed mixed failure due to delamination and fiber pull out.

Keywords: direction of fiber orientation, polyester composites, runner foot prosthesis, bending strength
1. Introduction
Carbon fiber has been widely applied in various fields. One application is the use of carbon fiber in a runner’s foot prosthesis. The main reason for using carbon fiber as a reinforced composite, due to its high strength and modulus. The price of imported runner foot prosthesis is quite expensive, because the main material for making a runner’s foot prosthesis is made entirely of carbon fiber. An alternative way can be done to reduce the price of the runner’s prosthesis by substituting some carbon fiber lamina with a glass fiber. The reason of glass fiber was chosen as a carbon fiber substitution because the price is cheap [1,2]. The other reason is the glass fiber strength is relatively close to carbon fiber [3,4].

The alternative way that can improve the strength of composites is by modifying the direction of fiber orientation. The mechanical coupling effect is the main factor which affects the composite strength. In some directions, the orientation of certain fibers is able to transfer the distributed fiber load through the matrix optimally [5,6]. As in the research conducted by Fatemi et al [7], it was shown that the highest tensile strength occurred in glass fiber reinforced composites with short orientation direction fibers of 45° with thermoplastics resin types. On composites with 45° of fiber orientation direction provided better mechanical coupling compared to the composites with 0° (longitudinal) and 90° (transverse) orientation.

The load received by the runner’s feet when used in the field is a bending load. Making foot prosthesis for runners must pay attention to the maximum compressive load that can be received. In order the design of foot prosthesis for runners is safe to use, it is important to test the flexural strength of runner foot prosthesis products [8,9]. Based on the description above, the study of the orientation direction of hybrid composite fibers reinforced with palm sugar and E Glass fibers for the application of runner foot prosthesis is need to be done.

2. Materials and methods

2.1 Materials
The fibers used as composite reinforcement in this study are carbon fiber and E Glass fiber. The independent variables in this study are the direction of fiber orientation and fiber volume fraction. The control variables in this study are carbon fiber, E Glass fiber and unsaturated polyester yukalac® 157 BQTN-EX with a density of 1.12 g cm^{-3}. Polyester composite are reinforced with carbon fiber and E Glass fiber with varying fiber orientation. Each composite was reinforced carbon fiber with orientation 0°, Glass fiber with orientation 90°, Carbon fiber with orientation 45°, Glass fiber with orientation 0°/90°/0° and carbon fiber with orientation 90°/0°/90°. The method of manufacturing composites is vacuum Assisted Resin Infusion (VARI) technique. Vacuum pressure for composite manufacturing is 1 Pa. Manufacturing bending test specimens by using a grinding machine. The curing process is carried out before bending test. The curing process is carried out at 62°C for 45 minutes. The curing process is carried out to increase the strength of the ester reaction in polyester composites. To find out the fault mechanism, then the scanning Electron Microscopy (SEM) test is performed on the fault area.

2.2 Mechanical testing
Flexural test was conducted by using 3-point loading using TORSEE universal testing machine according to the ASTM D 790 – 02 [10]. For each test, three samples were tested at room temperature. The machine will show the value of given force during measurement, which later will be used for analyzing the flexural strength. In addition to the bending strength, deflection is also known. The flexural strength was calculated by using equation 1.
where:
- $\sigma_b =$ flexural strength (N mm$^{-2}$)
- $P =$ Given force (N)
- $L =$ distance between axis point (mm)
- $b =$ sample width (mm)
- $d =$ sample thickness (mm)

3. Results and Discussions

3.1 Effect of fiber orientation on the flexural properties of the reinforced carbon-glass fiber composites

The result of the test is shown in Table 1. The test gave force data, and then we analyses it using Equation 1 to get the value of flexural strength. The bending test results as shown in Figure 1 above explains that the average bending strength of a composite reinforced with carbon-glass fibers with a fiber orientation of 0°, 45°, 90°, 0°/90°/0° and 90°/0°/90° are 1.32 MPa, 1.65 MPa, 0.93 MPa, 1.25 MPa, and 4.46 MPa respectively. The maximum flexural strength was obtained when the carbon glass fibers were arranged with 90°/0°/90° fiber orientation direction (4.46 MPa). Meanwhile, the lowest bending strength is obtained when the direction of carbon-glass is 90° (0.93 MPa). This was also reinforced by deflection for the orientation of the fiber 0°, 45°, 90°, 0°/90°/0° and 90°/0°/90° are 9.65 mm, 8.7 mm, 13.45 mm, 10.59 mm and 3.83 mm respectively. The relationship between fiber orientation and deflection are shown in Figure 2.

| Fiber orientation (°) | Maximum load (N) | Flexural strength (MPa) | Deflection (mm) |
|-----------------------|------------------|------------------------|-----------------|
| 0                     | 165.67           | 1.32                   | 9.65            |
| 45                    | 206.67           | 1.65                   | 8.7             |
| 90                    | 116.67           | 0.93                   | 13.45           |
| 0/90/0                | 157              | 1.25                   | 10.59           |
| 90/0/90              | 560              | 4.46                   | 3.83            |

The highest deflection is obtained on the composite in the direction of orientation 90° of 13.45 mm, while the lowest deflection occurs in carbon-glass fiber reinforced composites with fiber orientation 90°/0°/90° of 3.83 mm. In carbon-glass fiber reinforced composites with 90° orientation of the fibers the load received is parallel to the orientation of the fiber so that the ability of fibers to withstand bending loads is much smaller than composites that are fiber-reinforced in the direction of perpendicular orientation to bending loads. Whereas in carbon-glass fiber reinforced composites with orientation of 90°/0°/90° there is a combination of uniform distribution of load between lamina so the ability of composites to withstand bending loads is much better than composite lamina with the orientation of the fiber parallel to the bending load.
Figure 1. Flexural properties of hybrid composites

Figure 2. The relationship between fiber orientation and deflection

3.2 Analysis photograph of composite failure mechanism

The macro photograph shows the type of fracture obtained from the test. Composite reinforced carbon glass fibers occur perpendicular to the bending load direction so proving that composites in the direction of orientation of fiber $0^\circ$ have the ability to withstand bending loads. Failure begins on the surface to experience delamination and then some fibers are pulled out of the matrix (fiber pull out). Composite reinforced carbon-glass fiber with the orientation of the $45^0$ fiber there was a crack forming a pattern with an angle of $45^\circ$. This proves that the load received by the composite is continued with the burden passed on thoroughly to the fiber so the failure pattern shows cracks.
in the direction of orientation of the fiber [11]. Composite failure begins at the edge and continues at the center until failure occurs on the entire composite surface.

Composite reinforced carbon-glass fiber with the orientation of the 90°, fractures occurs parallel to the direction of the bending load. This proves that composites in the fiber orientation of 90° have the ability to withstand the smallest bending loads. Ability to withstand a smaller bending load caused neither fiber nor matrix is able to resist bending loads optimally. Composite reinforced carbon-glass fiber with orientation of 0°/90°/0°, cracking begins with delamination at the edges then followed by several fibers breaking up until the composite breaks (failure). Figure 4.1.d, it is clear that delamination occurs on the surface. This strengthens the analysis that the load is not evenly distributed to the underlying lamina (lamina with an orientation of 90°). Composite reinforced carbon-glass fiber with fiber orientation of 90°/0°/90°, cracks occur in the lamina with the orientation of fiber 90° (parallel to the direction of bending load). The direction of the crack in the upper lamina is held by the lower lamina with the orientation of the fiber 0° (perpendicular to the direction of the bending load. Bending load is retained in the lamina with the orientation of the fiber 0° followed by delamination in the lower lamina (fiber orientation 90°).

3.3 SEM analysis
The composite reinforced carbon-glass fiber with orientation of the 0° shows the visible cracking on its matrix surface. This shows that the failure of the composite begins with fiber breakdown and then forwarded to the matrix. The direction of bending load perpendicular to the direction of orientation of the fiber causes the bending load to be distributed across the fiber and matrix. Because the bending load is so large, it causes the matrix occurs cracking [12].

The composite reinforced carbon-glass fiber with orientation of 45° has almost the same fracture surface conditions. The mechanism of composite failure begins with fiber breaking followed by failure on the matrix. The composite reinforced carbon-glass fiber with orientation of 90° indicates that the composite failure occurs due to the delamination (release of bonds between the fiber and the matrix). This shows that both carbon fiber and glass fiber are not able to
withstand the bending load parallel to the bending load due to the weak bond between the fiber and the matrix. Composite reinforced carbon-glass fiber with orientation of $0^\circ/90^\circ/0^\circ$ shows a fracture combination between delamination and pull out fiber. Delamination occurs on the surface then followed by the breaking up of some fibers in the lamina below (in the orientation of the fiber $90^\circ$).

![SEM photos](image)

**Figure 4.** SEM photo of tested samples with the orientation of (a) $0^\circ$, (b) $45^\circ$, (c) $90^\circ$, (d) $0^\circ/90^\circ/0^\circ$, and (e) $90^\circ/0^\circ/90^\circ$

Flexural properties are a key for material designing of running prosthetic, as the material used should be strong, elastic, and able to receive dynamic load [13-15]. Therefore, a deep analysis should be done in the next study. The composite reinforced carbon-glass fiber with orientation of $90^\circ/0^\circ/90^\circ$ has shown a mixed fracture in the form of delamination and fiber pull out. In certain parts it appears that there is a breakdown in the matrix area which is quite broad. In the broken part, the bending load is evenly distributed, which is marked by the shape of the fracture in a uniform fiber.

4. **Conclusion**

Bending strength of carbon-glass fiber reinforced composites with orientation $0^\circ$, $45^\circ$, $90^\circ$, $0^\circ/90^\circ/0^\circ$ and $90^\circ/0^\circ/90^\circ$ are 1.32 MPa, 1.65 MPa, 0.93 MPa, 1.25 MPa and 4.46 MPa, respectively. The highest bending strength was obtained in carbon-glass fiber reinforced polyester composites with fiber orientation of $90^\circ/0^\circ/90^\circ$ at 4.46 MPa, while the lowest bending strength was obtained in carbon-glass fiber composites with fiber orientation direction of 0.93 MPa. The results of the macro photo of cross section fracture of polyester fiber reinforced carbon-glass fiber due to failure caused by fiber pull out and delamination.
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6. References
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