Mechanical Properties of Hybrid FRP Arrangement of Glass and Kenaf fibres

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Abstract. The study discussed the mechanical properties of hybrid arrangement of glass and Kenaf fibre reinforced plastic (FRP). There are two types of hybrid arrangements compared with one controlled arrangement of 100% Kenaf fibre. The glass fibre types used in the study are chopped, woven and 3-dimensional. The FRP was fabricated via hand lay-up method using the two types of matrix namely epoxy 1,2 and polyester resins. Parameters evaluated were fibre hybrid FRP arrangement and fibre orientation for the two types of composite with two different matrix resins. The mechanical properties evaluated on the hybrid FRP arrangement are tensile strength, elastic modulus, elongation at break and water absorption. The mechanical properties of 36 composite samples were conducted by Instrons Machine 3382 according to ASTM D638-10a. The physical property of nine samples was performed using water absorption according to ASTM D 570-99. These tests were carried out to determine the effect of mechanical behaviour for all hybrid FRP arrangements. It was found that hybrid FRP arrangement #1 with layers of fibreglass 3D-woven-chopped-woven-3D give the outstanding properties both in polyester and epoxy matrices. However, adding Kenaf reduce the mechanical properties and increase water absorption.

1. Introduction

Composite is composed of two main components that are the fibre as reinforcement and the matrix as glue that hold fibres together. The combination of fibre and matrix makes a new material tougher than the individual materials. The most highly demand composites are fibre reinforced plastic (FRP) due its economical and low density.

Composites are strongly depends on the reinforcement materials which can either be synthetic fibre or natural fibre. Recently, most composites is focusing on natural fibre composites as it gives biodegradability.

Synthetic fibre composites namely glass fibre, carbon fibre generally have mechanical high stiffness to weight ratio and strength to weight ratio, advanced fatigue and corrosion resistances. The issues to glass fibre reinforced plastic (GFRP) is its application at high temperature. Yunfu Ou et. al [1] studied the tensile properties of GFRP under effect of various temperature and it was found that the tensile properties of GFRP depends on the glass temperature ($T_g$) of the matrix. The trend in both synthetic FRP composite and natural FRP are similar in terms of its high specific strength, low weight, low cost, good mechanical properties, and non-abrasive and corrosion resistance. The synthetic FRP
usually possess better physical and mechanical properties than the natural fibre but the set back is their higher cost [2].

Natural fibres are subdivided based on their origins, for example vegetable/plants, animals, or minerals. Many studies were conducted on natural FRP recently due to its cost effective as well as availability issues. A study comparing the mechanical properties of various natural fibres such as banana, coconut sheath and jute with epoxy resin composites was conducted recently where the usage of these natural fibres reduce energy and cost [3].

Another study on sisal fibre by Saranya et. al. was found that the addition of nano sisal fibre increase tensile properties higher than that of GFRP [4]. Another study comparing the coir/epoxy composite and glass/epoxy and the results shows coir can be used as a potential reinforcing material for making low load bearing thermoplastic composites [5].

Natural pineapple fibre was also investigated and it was found that all mechanical properties decrease with increase in fibre loading [6]. Pineapple leaf fibre FRP was investigated for construction application and it was found to reach its optimum properties at 30 wt% of fibre loading [7]. Other than vegetable/plants, mineral was also investigated as natural fibre. Basalt is used in FRP composite and it was found that the water intake of this composites is significantly reduced [8]. The Kenaf whole stalk and outer fibres have many potential specific uses, including as paper, textile, and composite. The use of Kenaf fibres is also of particular significance from the standpoint of environmental friendliness. Recently, various new applications for Kenaf products are emerging, including those for paper products, building materials, absorbents, feed, and bedding for livestock [9].

Kenaf natural FRP are light and easy to process. They can be used to replace glass-reinforced plastics in many cases. Kenaf compound panels have the mechanical and strength characteristics of glass–filled plastics. Besides, they are less expensive, non-toxic with low density [10]. They can be used in the automotive industry, construction, housing, and food package industry.

In FRP, the combination of various types of fibre can be applied to enhance its mechanical properties. The arrangement of these various types of fibre also influenced the performance of FRP mechanical properties. A study of various type of glass fibre such as chopped, woven and 3-dimensional and it was found that different arrangement of layers of fibre give different strength and stiffness evaluation [11].

A combination of glass and stainless steel fibre was investigated with different orientation of glass fibre varies from 0° to 45° and it is found that the hybrid composites presented improve energy dissipation, tensile strength and stiffness [12]. There are many studies on natural fibre hybrid composites such as kenaf, flex, hemp, jute, sisal and banana fibres was investigated [13].

In this study, the variation of fibre arrangement and types of fibre were investigated in terms of their mechanical properties.

2. Methodology

2.1. Materials

The main ingredients for composite are reinforcement and matrix. The reinforcement in the study are various types of fibre either synthetic or natural fibre. Synthetic fibre used are glass fibre with few variations i.e. chopped, woven and 3-dimensional (3D). Chopped fibreglass is loose strand of glass fibre being chopped at standard length as shown in Figure 1(a). Woven glass fibre comes in rolled. It is a weave fibreglass in a mat-like condition (Figure 1(b)). The 3D glass fibre is a weave mat-like glass fibre with cross-linked fibre between the two layers of the weave mat as in Figure 1(c).
Natural fibre used in the study is Kenaf fibre (Figure 2). Kenaf fibre was first treated with chemical for 24 hours. Then it is dried at room temperature. After it was dried, it was chopped to an average of 300 µm length.

There are two types of matrix used in the study. The polymer matrix are 1,2 epoxy resin and unsaturated polyester resin. These two resins are well known for their good mechanical properties.

2.2. Hybrid Arrangement of Fibre.
There were two (2) hybrid arrangement of fibre investigated. The fibre volume fraction was kept constant at 0.3 for every layers. The arrangement of fibre was identified by varying layer of different type of glass fibre or Kenaf fibre and one reference of 100% natural Kenaf fibre in each layer as shown in Table 1.

| Arrangement # | Layer1 | Layer2 | Layer3 | Layer4 | Layer5 |
|---------------|--------|--------|--------|--------|--------|
| #1            | A      | B      | C      | B      | A      |
| #2            | A      | K      | K      | K      | B      |
| #3            | K      | K      | K      | K      | K      |

*3D (A), woven (B), chopped (C) and Kenaf (K).

2.3. Hand Lay-Up.
Composite was fabricate via hand lay-up method. It is a simple and cost effective process. An open mould of aluminium alloy frame with outer dimension of 18 x 24 x 1 mm and inner dimension of15.5 x 21.5 x 1 mm was fabricated by CNC machine (CNC 10-HVA).

Both glass fibres with natural fibre was weight and cut according to the volume fraction required each layer. Similarly with epoxy and polyester resins. They were weighed accordingly to its respective
volume fraction and portion of hardener added. The polyester and epoxy resin were mixed well with hardener to ensure it will cure perfectly. It is important that the mixing was done slowly and gently as to avoid formation of air bubbles trapped within the resin. The air bubbles trapped in matrix resin may cause defect in the FRP.

Then, glass fibre or Kenaf fibre was placed in the mould according to the hybrid FRP arrangement in the Table 1 followed by matrix resin. This process was repeated until the layers were completed (Figure 3). Each layer was properly rolled to ensure no air was entrapped within the layer and then cold pressed for 24 hours.

![Figure 3: Open mould filled up with fibre in hand lay-up process.](image)

2.4. Tensile Test.
The FRP was taken out from open mould and were cut into dumbbell tensile specimen by using a standard cutter. The FRP sheet after cutting is shown in Figure 4.

![Figure 4: FRP sheet after cutting into dumbbell shape specimen](image)

Tensile testing was conducted using Introns machine 3382 with maximum load of 100kN. Crosshead speed was set to 5 mm/min and data was processed in computerized Blue Hill 3 software. There were 36 dumbbell shaped samples produced for the tensile testing in accordance to the ASTM D-638-10a as shown in Figure 5. Each test was repeated three (3) times.
2.5. Water Absorption Test.
The test was conducted according to ASTM D 570-99. The hybrid FRP was cut into three rectangular shaped specimens with a dimension of 20 × 20 × 5 mm. The samples were soaked for 24 hours and then dried at 150°C to reach the constant weight. The weight before and after drying was recorded.

2.6. Sample Orientation.
The orientation of the specimen was taken from the longitudinal FRP sheet as reference of 90°. Theoretically, the orientation of fibre plays an important factor to determine mechanical properties of the composites. In this study, three (3) orientations of sample were used that is 0°, 45° and 90°.

![Figure 6: Illustration of sample orientation as referred to the open mould/ FRP sheet](image)

Each hybrid FRP was cut into three (3) variation of sample orientation as illustrated in Figure 6 above and was tabulated in Table 2. Each orientation is duplicated three (3) times.

| Arrangement # | Orientation | Layer1 | Layer2 | Layer3 | Layer4 | Layer5 |
|---------------|-------------|--------|--------|--------|--------|--------|
| #1            | 0°          | A      | B      | C      | B      | A      |
|               | 45°         |        |        |        |        |        |
|               | 90°         |        |        |        |        |        |
| #2            | 0°          | A      | K      | K      | K      | B      |
|               | 45°         |        |        |        |        |        |
|               | 90°         |        |        |        |        |        |
| #3            | 0°          | K      | K      | K      | K      | K      |
|               | 45°         |        |        |        |        |        |
|               | 90°         |        |        |        |        |        |

*3D (A), woven (B), chopped (C) and Kenaf (K)

3. Results and Discussions
The result will discuss on the mechanical properties of the composites on the effect of hybrid FRP arrangement, fibre orientation, and water absorption behaviour.
3.1. Effect of Hybrid FRP Arrangement

The mechanical properties of variation of hybrid FRP arrangement of fibres was investigated. The variation of FRP arrangement is notated as #1 for GFRP with three (3) types of fibreglass. Arrangement #2 is a combination of 2 types of fibreglass and Kenaf fibre and arrangement #3 is for controlled specimen of 100% Kenaf fibre as shown in Table 1. The cross-section area of hybrid FRP arrangement #1, #2 and #3 are shown in Figure 7. Arrangement #1 contains voids between layer due to the 3D fibreglass that is meant for high strength to weight ratio. The arrangement #2 showed the top layer of 3D fibreglass, woven fibreglass at the bottom layer and Kenaf fibre in between.

Figure 7: Hybrid structure between layers for fibre arrangement (a) #1 (b) #2 (c) #3.

The mechanical properties such as tensile strength, elastic modulus and elongation at break are compared and discussed for each hybrid FRP arrangement. The tensile strength of the FRPs are shown in Figure 8. In general, the polyester matrix FRP performed better than those of epoxy matrix. This is because the tensile strength of polyester matrix is in the range of 41.4-89.7 MPa whereas the epoxy matrix is in range of 27.6-90.0 MPa [14]. Without the reinforcement of fibre, the polyester matrix has higher strength than the epoxy. The natural Kenaf fibre was found the lowest value as expected from the literature where the GFRP will out perform the natural fibre [10]. The hybrid FRP arrangement #1 showed far better strength than arrangement #2 since arrangement #1 has 2 layers of 3D fibreglass and woven fibreglass. The tensile strength for E-glass-epoxy composite is 1020 MPa whereas FRP arrangement #1 (epoxy) was slightly higher at 1031.2 MPa[14].

Figure 8: The effect of FRP hybrid arrangement on tensile strength

The elastic modulus properties of all hybrid FRP arrangements are shown in Figure 9. In general, the trend of all three (3) elastic modulus are similar to those of the tensile strength. Based on the elastic...
modulus data for polyester matrix in the range of 2.06-4.41 GPa whereas the epoxy matrix is 2.41 GPa, thus the polyester has higher range than the epoxy [14]. The elastic modulus for both hybrid FRP #1 (epoxy) is 1.1 GPa was lower by almost 50 times than the E-glass-epoxy composite at 45 GPa [14]. The huge drop in elastic modulus for arrangement #1 must be due to its rigid fibreglass structures of 3D-woven-chopped-woven-3D that make it more brittle.

The elongation at break of all hybrid FRP arrangement are shown in Figure 10. In general, hybrid FRP arrangement of epoxy shows higher elongation at break than the polyester FRP. This is due to the elongation at break of polyester matrix is less than 2.6% whereas the epoxy matrix is in the range of 3-6% [14]. Hence, both the hybrid FRP with arrangement #1 and #2 are found lower since they are brittle and rigid. This behaviour is supported by the elastic modulus in Figure 9. The elongation at break for E-glass-epoxy composite is 2.3% thus the hybrid FRP arrangement #1 and #2 are lower showed that they are more brittle or less elasticity [14].

In most cases the mechanical properties of the polyester FRP are higher than epoxy except for elongation at break. However, the polyester FRP at arrangement #2 is always lower than those of #1. This could be due to strong hydrophilic behaviour of polyester [14]. Hybrid FRP arrangement #2 contain Kenaf fibre, and Kenaf contains high moisture. This moisture repel the polyester from binding the fibre together. Thus, the interfacial bonding between the Kenaf and polyester matrix is low and consequently lower the mechanical properties obtained.
It is seen that hybrid FRP arrangement #1 with various types of fibre has dominant mechanical properties for both epoxy and polyester matrices. The woven fibreglass type is more compatible to use at the second and fourth of the layers because its thickness is thicker than the others. The chopped fibres at the middle layer strengthen the composite by fibre pull-out and its random orientation produces an anisotropic behaviour.

On the other hand, hybrid FRP arrangement #2 contained 3 layers of Kenaf fibre and supported with 3D and woven glass at both sides. The present of glass fibre enhanced the mechanical properties of Kenaf significantly as compared to the controlled hybrid FRP arrangement #3.

3.2. Effect of Fibre Orientation

Tensile strength of different sample orientation for hybrid FRP arrangement #1, #2 and #3 is shown in Figure 11 below.
In general, the trend of orientation effect on FRP arrangement #1 and #2 are similar. Polyester matrix composite shows higher values than epoxy. Both 0° and 90° orientation do not affect the strength significantly. This is due to the present of woven and 3D that is consistently aligned in these two (2) directions. On the other hand, at 45° orientation the fibre directions are not aligned thus it fail to strengthen the FRP in this direction.

As for FRP arrangement #3, the fibre are 100% Kenaf, thus the strength for both epoxy and polyester are the lowest. The trend is different from hybrid FRP arrangement #1 and #2 where the polyester matrix is strongly affected by the sample orientation as the orientation change from 0° to 90°. The epoxy matrix shows consistent strength or insignificant variation of strength at all sample orientation. hybrid FRP arrangement #3 is all Kenaf where they were chopped at 300 μm. There is possibility that for polyester matrix sample most of the Kenaf fibre was rolled and aligned to the longitudinal direction of the open mould. Therefore, the strength at 90° is enhanced whereas at 0° is at the weakest.

3.3. Water Absorption

One of the most important parameter effects on the mechanical properties and dimensional stability of the composites is the poor resistances of the fibres to water absorption. The data of water absorption for the three (3) arrangement is compare and shows in Figure 12.

![Figure 12: Water absorption property for varied FRP arrangement](image-url)
In general, the water absorption trend increases from hybrid FRP arrangement #1, #2 and #3. It is expected that #3 will absorb more water as it consist of 100% natural Kenaf fibre. Natural fibre tends to be hydrophilic property compare to synthetic fibre [8]. FRP arrangement #2 also contain 3 layers of Kenaf fibre thus it is expected that they have higher water absorption but the amount is controlled due to outer layer of fibreglass. Polyester is known for its hydrophobicity properties, it tends to repel water away [15]. Thus the water absorption for polyester matrix FRP is much lower than that of epoxy matrix FRP.

4. Conclusions
In conclusions, the mechanical properties of three hybrid FRP arrangement of polyester matrix showed better results than that of the epoxy. The hybrid FRP arrangement of five layers of various types of fibreglass namely 3D-woven-chopped-woven-3D shows the highest strength and modulus but lower elongation at break. The orientation of fibre do affect the mechanical properties especially at 45°. The 0° and 90° were not affected much for hybrid arrangement #1 and #2 due to the anisotropic behaviour from the woven and 3D fibres. The water absorption for polyester matrix is lower compared to the epoxy matrix with value as low as 2.40%.

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