Effect of fibre sequence on the mechanical properties of woven fan palm/glass fabric reinforced polymer hybrid composites

H Hestiawan¹², Jamasri², Kusmono²
¹ Department of Mechanical Engineering, Faculty of Engineering, Universitas Bengkulu, Jln. WR. Supratman, Kandang Limun, Bengkulu 38122, Indonesia
² Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jln. Grafika No. 2, Yogyakarta 55281, Indonesia
hestiawan1@yahoo.com

Abstract. The aim of this research is to investigate the influence of fibre sequence on the mechanical properties of woven fan palm/glass fabric reinforced polymer hybrid composites. Research specimens were varied in fibre sequence between woven fan palm and glass fabric. Vacuum bagging method was used to manufacture the specimens (at pressure of -70 cmHg). The results of tensile, bending, and impact tests show that the addition of glass fabric can increase the mechanical properties of the hybrid composite. Based on the fibre sequence, the glass fabrics on surface of the hybrid composite have the best mechanical properties.

1. Introduction
In the last decade, the development trend of composite materials has changed in the use of natural fibres as a substitute for synthetic fibres. These are supported by several advantages possessed by natural fibres, such as light weight, high flexibility, and reduced engine usage during processing, recyclable and biodegradable. They are also renewable and have relatively high strength and stiffness and cause no skin irritations. On the other hand, natural fibres also have limitations, such as moisture uptake, quality variations as well as poor moisture resistance when compared to synthetic fibres [1-4].

One way to improve the mechanical properties of composites can be done by reinforcing using two or more variations of fibres in the same matrix material so as to take the best advantage of the properties of both fibres. This results in a hybrid composite and having increased mechanical properties than natural fibre composite. Tensile, bending and impact strength increases with increasing amounts of fibres up to 30%. There are a significant decrease in mechanical strength if the number of fibres is added [5]. Synthetic fibres can be used as a reinforcement together with natural fibre. Synthetic fibre commonly used in industry is glass fibre because it is light and strong. Although the strength of glass fibre is lower and more brittle than carbon fibre, but glass fibre is relatively cheaper [6].

The mechanical properties of the woven hybrid composite are better than the woven composite due to the different structures of the cross section. The hybrid composite shows a significant increase in tensile strength over the pure woven banana and knead fibre reinforced polyester composites [7]. The hybrid composites with glass fabric have better strength, toughness, and out-of-plane stiffness, as well as easier handling in production than unidirectional composites [8]. Glass fabrics offer superiority in
terms of good dimensional stability and high packaging density. Mechanical properties of woven coir-glass fabrics/polyester composites [9] and woven jute-glass fabric/polyester composites [10] were evaluated with the effect of woven fabric reinforcement, which was observed to improve mechanical properties of hybrid composites. By varying the stacking sequences of reinforcing layers in the composites, higher mechanical properties of hybrid composites can be achieved [11].

However, there are few studies have been done on the woven natural fibres. John and Naidu [12] reported that the addition of 25, 50 and 75% glass fibres on sisal fibre reinforced composites increased their tensile strength and strain respectively by 28% and 26%. In the present study, woven fan palm and glass fabric composites were chosen due to its ability to be produced in a continuous form, hence easier in producing a woven mat fabric. The fibre sequences are varied from 1 to 4 glass fibres and their effects on tensile, flexural, and impact properties are examined.

2. Experimental method

2.1. Materials

The following materials are used for hybrid composite including woven fan palm (WFP), E-glass fabric 200 g/m², unsaturated polyester BQTN 157, and methyl ethyl ketone peroxide (MEKP) as catalyst. Hestiawan et al. [13] describe the extraction of fan palm fiber from the young leaves of gebang plant (Figure 1). Prior to form FPF, the fibers were soaked in fresh water for 24 hours. Then they were rinsed and followed by drying at room temperature for 2 days. The Fan palm fibers were made by traditional weaving machine and formed WFP as shown in Figure 2. The weight of the woven FPF was approximately 140 g/m². WFP was supplied by Jogijavanesia Handicraft, Indonesia. Unsaturated polyester and MEKP catalyst were provided from by Justus Kimiaraya, Indonesia.

![Figure 1. Gebang plant.](image)

2.2. Fabrication of composites

Prior to fabricating the composite laminates, the WFP was placed in an oven at 105 °C for 1 hour in order to remove the moisture contents of fibres. Nine different kinds of laminates were prepared 22 mm x 22 mm size with total seven plies maintains. The sample designation were summarized in Table 1. Five specimens were fabricated for each group used the vacuum bagging technique as shown in Figure 3. The vacuum bagging technique provides a number of improvements over traditional methods such as better fibre-to-resin ratio, very consistent resin usage, and unlimited set up time, and it is cleaner. The process of making specimens is carried out at a pressure of -70 cmHg for 2 hours. Comparison of
hardener and polyester resins was 1: 100 (v/v). Demoulding the specimens was done after curing at room temperature for 2 hours, then the specimens were stored on a flat surface under room conditions. The next step the specimen is cut and formed into a tensile, flexural, and impact test specimen according to ASTM standard.

![Figure 2. Woven fan palm (WFP).](image)

| Composite sample code | Number of WFP | Number of glass fabric | Fiber sequence |
|-----------------------|---------------|------------------------|----------------|
| F                     | 7             | 0                      | [F7]           |
| G1                    | 6             | 1                      | [F/G]S         |
| G2A                   | 5             | 2                      | [G/F/F/F]S     |
| G2B                   | 5             | 2                      | [F/G/F/F]S     |
| G3A                   | 4             | 3                      | [G/F/G/F]S     |
| G3B                   | 4             | 3                      | [F/G/G/F]S     |
| G4A                   | 3             | 4                      | [G/F/G/F/F]S   |
| G4B                   | 3             | 4                      | [G2/F/F/F]S    |
| G                     | 0             | 7                      | [G7]           |

| G : Glass fabric      | F : WFP       |

2.3. Mechanical properties of composites

The effect of fibre sequence on the mechanical properties of woven FPF/UPE composites was investigated in the materials laboratory of the Mechanical and Industry Engineering Department, Universitas Gadjah Mada, Indonesia. The tensile tests of hybrid composites were formed according to ASTM D 638 standard. Tests were conducted using Shimadzu testing machine at a cross-head speed of 5mm/min as per ASTM D 638 standard. All specimens were cut to the 165 mm x 20 mm x actual thickness and were finished by grinding machine (Figure 4). Five specimens with identical dimensions for each composite material were tested and average result was determined. The flexural tests were investigated using the three-point bending fixture according to the ASTM D790 standard, with a crosshead speed of 5 mm/min. The test was conducted using the Torslee’s Universal. The rectangular shape specimens were prepared with dimensions of 80 mm x 10 mm x actual thickness. For each case, five specimens were tested and the average values reported. The impact strength of the samples was measured using Charpy impact test machine, according to the ASTM 5942 standard. All impacted
specimens were un-notched. The standard specimen size was 75 mm x 10 mm x actual thickness. The average values of five specimens for each sample have been reported.

![Vacuum bagging technique](image1.png)

**Figure 3.** Vacuum bagging technique.

![Tensile specimen of hybrid composites](image2.png)

**Figure 4.** Tensile specimen of hybrid composites.

3. **Result and discussion**

3.1. **Tensile properties**

The effect of fibre sequence on the tensile properties of hybrid composites using are studied and shown in Figure 5. From Figure 5, it can be seen that the adding glass fabrics improve the tensile strength of hybrid composite. The highest tensile strength was obtained in the addition of four glass fabrics with sequential fibre arrangement (G4A) of 130 MPa, but still lower than pure glass fabric reinforced composites. It is attributed to the reason that glass fabrics are stronger than WFP.

In addition, the tensile strength of specimens increases due to fibre sequence in the hybrid composite. The G2A vs G2B, G3A vs G3B, and G4A vs G4B sample have different tensile strength approximately 9%, 14%, and 17% respectively. The glass fabric contained in the hybrid composite surface has a higher tensile strength than the glass fabric contained inside the hybrid composite. It is observed, in this study, that the effect of tensile strength not only the number of glass fabric but also fibre sequence in the hybrid composites. Tensile properties are higher in the composites that keep the glass fabrics as outer layers.
The similar behaviour was observed in previous work based on fibre sequence in hybrid composites [14, 15]. Fractures photos of the tensile test specimens are presented in Figure 6. The type of fibre fracture, both WFP and glass fabric composites is brittle fracture. The cross section of glass fabric looks sharper than WFP. This indicates that the glass fabric has a higher fibre tensile strength than WFP so that the strength of the hybrid composite is highly dependent on the presence of glass fabric.

Figure 5. Tensile strength of hybrid composites with different fibre sequences.

Figure 6. Fracture photograph of tensile test of (a) WFP composite (F); (b) Hybrid composites (G2B); (c) Hybrid composite (G4A); (d) Glass fabric composite (G).
3.2. Flexural strength

Figure 7 shows the flexural strength of hybrid composites with respect to fibre sequence. The flexural strength of the WFP reinforced composite is found to be 52 MPa. The addition of glass fabric enhances flexural strength. The flexural strengths of hybrid composites were obtained to be greater for fibre sequence with four glass fabric (G4A and G4B) having 168 MPa and 154 MPa, respectively. Although the flexural strength of hybrid composites still lower than that of pure glass fabric reinforced composites being 284 MPa. Previous reports also showed improvement of the flexural properties of composites due to incorporation of glass fabric [4, 16]. The same trend of data as like as tensile testing was observed for the case of flexural properties. The glass fabrics on the outside of the bamboo fibre on the hybrid composite have better flexural strength and modulus than the other fibre sequences [17].

![Figure 7. Flexural strength of woven hybrid composites with different fibre sequences.](image)

3.3. Impact properties

Unnotched specimens were not broken during Charpy tests. Figure 8 shows impact strength of hybrid composites with different fiber sequences. The increase in the impact strength by increasing the number of glass fabrics can be attributed to the higher energy dissipation at the fiber/matrix interfaces to release fibers from the matrix. The impact strengths of hybrid composites were found to be greater for fiber sequence with four glass fabric (G4A and G4B) having 49 kJ.m$^{-2}$ and 46 kJ.m$^{-2}$, accordingly. In this study it was found that, the impact strength of hybrid composites is in similar trend as the tensile and flexural properties. Similar results were obtained by Yahaya et al. [18] where the impact strength of hybrid composite was higher than that of woven kenaf composite. The specimen photos after impact test are shown in Figure 9. Delamination is not only occurred on WFP reinforced composites but also composite hybrids (9(a-c)). While the glass fabric reinforced composite, delamination was not observed so it has better impact strength (9(d)). It meant that there was a good interfacial adhesion between the unsaturated polyester matrix and glass fabric. On the other hand, poor interaction between the woven fan palm and the polyester resin can be observed in Figure 9(a-c) leading to delamination.
Figure 8. Flexural strength of woven hybrid composites with different fiber sequences.

Figure 9. Fracture photograph of impact test of (a) WFP composite (F); (b) Hybrid composites (G3B); (c) Hybrid composite (G4A); (d) Glass fabric composite (G).

4. Conclusion

Woven fan palm/glass fabric reinforced polymer hybrid composites were successfully prepared. It was found that that fibre sequence strongly influenced the mechanical properties of the hybrid composites. The mechanical properties increased with increasing glass fabric content in hybrid composites with the highest tensile, flexural, impact strength being 130 MPa, 168 MPa, and 49 kJ.m\(^2\), respectively for hybrid
composites reinforced with 4 glass fabrics. Based on the fibre sequence, the glass fabrics on surface of the hybrid composite have the best mechanical properties.

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