The Effect of Lamina Intraply Hybrid Composites on the Tensile Properties of Various Weave Designs

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Abstract. The topic of natural fiber is one of the most active areas in thermoset composite research today. This paper will focuses on the effect of weave designs on the mechanical behaviour of lamina intraply hybrid composites. Twelve specimens were used and they were made of kenaf fibre and glass fibre as a reinforcement and unsaturated polyester resin as a matrix in various weave designs which were plain, twill, satin, basket, mock leno, and leno weave. Vacuum infusion technique was used due to its superior advantages over hand lay-up. The specimens were produced in two types which were kenaf fibre in warp direction interlace with glass fibre in weft direction (WK–WG) and glass fibre in warp direction interlace with kenaf fibre in weft direction (WG–WK). Various weave designs were found to affect the tensile properties. Glass fibre in warp direction has a greater effect on tensile strength compared to kenaf fibre in warp direction. Mock leno weave exhibited better mechanical properties for WK–WG and WG–WK, about 54.74 MPa and 99.46 MPa respectively.

Keywords: A. Fabric/textile; A. Lamina/ply; B. Strength; E. Vacuum infusion.

1. Introduction

According to Yadav et al. [1] a composite is a mixture of two or more distinct constituents or phases. Both constituents should be presented in reasonable ratios in which it should be greater than five percent. Both major constituents are the reinforcement and the matrix. The main advantages of composite materials are their high strength and stiffness along with low density as compared to bulk materials [2]. It produces lightweight finished parts [3]. The reinforcing phase which is stronger and stiffer than the matrix can provide strength and stiffness for the composite materials. Composite materials are also susceptible to intraply and interply [4].

Nowadays, researchers have shown an increased interest in possibility of replacing synthetic fibres. Natural fibres, one of the fibres that have great potential, can be used in producing composite materials due to its characteristics; environmentally friendly, low cost, available in abundance, and lightweight [5], [6], [7], [8], and [9]. Natural fibres are remove from various parts of plant (stem, leaf, and bark) and they are classified accordingly. The most used plant fibres include banana, sisal, kenaf, coir, etc.; but this research only focuses on kenaf fibre. However, natural fibre has some drawbacks in composite materials such as lower modulus, poor moisture resistance to absorption, and low strength compared to synthetic fibre such as carbon fibre and glass fibre [10]. Surface treatment is one of the methods that has been widely used by researchers in improving the mechanical properties of natural fibre. However, the use of fibre surface treatment can make the fibres become expensive to the point that they become...
unattractive materials [11]. On the other hand, several authors reported that hybridizing natural fibre with high strength synthetic fibre can improve mechanical properties of natural fiber. Hybridizing offers the design manufacturer the flexibility to tailor the material properties as indicated by the requirements, which is one of the real positive aspects of the composites. Many studies of hybrid composites also points towards environmental advantages of these materials. The finding is consistent with findings of past studies by Jayabal et al. [12] which found that they were significantly improved by glass hybridization; and in terms of stacking sequence, the two layers of woven glass at the extreme plies and coir mat demonstrated higher value of mechanical properties.

In addition, Sanjay et al. [13] have done a comprehensive review of the mechanical properties of natural–glass fibre reinforced polymer hybrid composites. They concluded that the incorporation of natural fibre into glass fibre reinforced polymer can improve the properties and it can also be used as an alternative to glass fibre reinforced polymer composites. Salleh et al. [14] showed that crack resistance of natural fibre composites can be further enhanced by hybridizing it with synthetic fibres. Meanwhile, Kumar et al. [15] studied the effects of layering pattern on vibrational behaviour of coconut sheath/banana fibre hybrid composites. They found a significant influence on natural frequency in both types of hybrid composites due to the changes in stiffness brought by the various layering patterns.

More recent studies have confirmed that hybrid composite have better performance in composites application. However, by using different weave designs and different materials in warp and weft direction significantly affected the tensile strength. A study by Shibata et al. [16] showed that the strength of woven fibre composites depends on the weave style, fibre orientation, and the bonding between the fibre and matrix. Another study by Khan et al. [17] showed that the woven structure exhibited excellent mechanical behaviour under tensile flexural and impact loading compared to non-woven composites. Recently, many researchers, [18], [19], [20], [21], [22] and [23], have reported that using woven structure as a composite reinforcement can produce better mechanical properties and it is easy to handle during fabrication process [24]. The fibres in woven fabrics are subjected to additional mechanical handling during the weaving process. Since it tends to reduce their tensile strength, it becomes one of the factors that need to be considered [25]. Woven fabric composites are frequently used in order to obtain superior dimensional stability and shapeability as well as balanced in-plane properties [26].

As aforementioned, hybrid composites in woven fabric is interesting and thus worth to be explored. Therefore, this research aims to study the potential of kenaf yarns and glass fibre yarns in various weave designs in terms of intraply performance when it is hybridized with woven fabric.

2. Materials and Methods
The kenaf fibre yarn as shown in Fig. 1(a) was supplied by KIRD Enterprise (M), while the E-glass fibre 600g/m² as shown in Fig. 1(b) was purchased from My Tech Solution Enterprise with the both fibre are from Malaysia resource. The thickness of the kenaf fibre yarns was 1.05 (± 0.05) mm each. In this research, unsaturated polyester resin with the brand Norsodyne 3317 AW which was manufactured by Cray Valley Resins (M) Sdn. Bhd. was used. For material preparation, the resin was measured with a digital scale. 40% of the total weight fraction of the composite were mixed with one percent of methyl ethyl ketone peroxide (MEKP) catalyst which was manufactured by P.T. Kawaguchi Kimia Indonesia.
In particular, six types of weave designs for lamina composite were obtained (plain, twill, basket, satin, leno and mock leno weaves) as shown in Table 1. In this research, 12 specimens were fabricated as every specimen produced two types of designs; kenaf fibre in warp direction interlace with glass fibre in weft direction (WK–WG) and glass fibre in warp direction interlace with kenaf fibre in weft direction (WG–WK).

Table 1: Design of intraply lamina composite

| Weave type | Weave pattern | Description |
|------------|---------------|-------------|
| 1. Plain   |               | The plain weave were the simplest of the weaves and the most common. It consisted of interlacing warp and weft yarns in a pattern of over one and under one. |

Fig. 1. Fiber yarn (a) Kenaf and (b) Glass.
2. Twill

Twill weave pattern, one or more warp fibres alternately weave over and under two or more weft fibres in a regular repeated manner. In a twill weave, each weft or filling yarn floats the warp yarns in a progression of interlacings to the right or left, forming a distinct diagonal line. This diagonal line was also known as a wale. A float was the portion of a yarn that crosses over two or more yarns from the opposite direction.

3. Basket

Basket weave were fundamentally the same as plain weave except that two or more warp fibres alternately interlace with two or more weft fibres. An arrangement of two warps crossing two wefts was designated 2 x 2 basket, but the arrangement of fibre need not be symmetrical. Therefore it is possible to have 8 x 2, 5 x 4, etc.

4. Satin

Satin weaves are fundamentally twill weaves modified to produce fewer intersections of warp and weft. The ‘harness’ number used in the designation (typically 4, 5 and 8) were the total number of fibres crossed and passed under, before the fibre repeated the pattern.

5. Leno

Leno weave pattern, leno weave improved the stability in ‘open’ fabrics which had a low fibre count. A form of plain weave in which adjacent warp fibres were twisted around consecutive weft fibres to form a spiral pair, effectively ‘locking’ each weft in place.
Mock leno weave pattern, a version of plain weave in which occasional warp fibres, at regular intervals but usually several fibres apart, deviate from the alternate under-over interlacing and instead interlace every two or more fibres.

The weaving process was fabricated manually in order to obtain the weave pattern designs required. The specimen was designed into a dimension of 300 mm × 220 mm and implemented vacuum infusion technique to embedded resin into fibres. After the infusion process, the specimens were kept at room temperature for two days or 48 hours of curing process. The purpose of this process was to stabilize the specimen besides making sure the specimen was 100% cured and to reduce the internal stress caused by the process.

The specimen was cut using a laser cutting machine (as shown in Fig. 2) into a rectangular shape with a dimension of 250 mm (length) × 25 mm (width) based on the recommendation of ASTM D3039. The laser cutting machine used to cut the specimens was Helius – 2513 with a maximum capacity of 3 kW, tension of 400 V 50 Hz, and power of 77 kW. The reason for using a laser cutting machine was to get a specimen with more accurate measurement for mechanical and physical tests.

![Mock leno weave pattern](image)

Fig. 2. Preparation of specimen (a) cutting via laser cutting machine; and (b) rectangular shape for tensile test.
3. Results and Discussion

3.1 Weight fraction of specimen
As shown in Fig. 3, the results showed that most of the weights were in the range of 42g - 70g in dry condition while in wet condition, most of the weight were in the range of 88g - 138g. The graph shows that the highest and the lowest weights of the specimens in dry condition were basket weave and leno weave, 70g and 42g respectively. Meanwhile, the highest and the lowest weights in wet condition were basket weave and leno weave, 138g and 82g respectively. This is due to the number of fibre yarns used in the basket and leno weave. The graph shows that the weights of the specimens in dry condition for plain weave, twill weave, satin weave, and mock leno weave were slightly different, 49g, 62g, 59g, and 55g respectively. Meanwhile, the weights of the specimens in wet condition for plain weave, twill weave, satin weave, and mock leno weave were also slightly different, 88g, 137g, 118g, and 103g respectively.

In addition, Fig. 3 shows that most of the fibre contents for WK–WG after the infusion process were in the range of 45.2% - 55.7%. It can be concluded that the fibre content of the specimen was 50% and the resin content of the specimen was 50%. Irrespective of the weave designs, it can be clearly seen that the kenaf fibre yarns in warp direction and glass fibre yarns in weft direction managed to balance the composition of the specimen to become 50% fibre content and 50% resin content respectively. By adding the glass fibre yarns in weft direction, the permeability of the specimens was reduced. This is because glass fibre yarns have lower permeability compared to glass fibre yarns. Rodriguez et al. [27] studied the permeability–porosity relationship in resin transfer moulding (RTM) for different fibreglass and natural reinforcements. They found that the permeability of natural fibre mats higher than glass fibre mats.

3.2 Weight fraction for WG–WK
As shown in Fig. 4, the results showed that most of the weights were in the range of 33g - 53g in dry condition while in wet condition, the range was 70g - 87g. The graph shows that the highest and the
lowest weights of the specimens in dry condition were basket weave and leno weave which were 53g and 33g respectively. While, the highest and the lowest weights in wet condition were twill weave and leno weave which were 87g and 70g respectively. The graph shows that the weights of the specimens in dry condition for twill weave, satin weave, basket weave, and mock leno weave were almost similar which were 49 g, 49 g, 53g, and 47g respectively. Meanwhile, the weights in wet condition for satin weave, basket weave, and mock leno weave were exactly similar, 83 g. For plain weave design, the weights of the specimens in dry and wet condition were 44g and 82g respectively.

In addition, Fig. 4 shows that most of the fibre contents for WG–WK after the infusion process were in the range of 47.1% - 63.8%. It can be concluded that the fibre content of the specimen was 60% and the resin content of the specimen was 40%. Irrespective of the weave designs, it can be clearly seen that the resin content in the specimen was only 40%. This is because glass fibre yarns have lower permeability compared to kenaf fibre yarns. The hybridization of high-permeability kenaf fibre yarns improves the low permeability of glass fibre yarns. This is one of the efficient ways that have been widely used for synthetic fibres [28] and [29]. Moreover, by comparing the results of WK–WG and WG–WK, WG–WK is shown to be lighter than WK–WG and it can be concluded that the kenaf fibre in warp direction affects the weight fraction. This is because kenaf fibre yarns are able to absorb more resin due to its high permeability and high cellulose content compared to glass fibre yarns. More recent studies have confirmed that [18], [30], [31], and [32] reported that kenaf fibre consists of cellulose (56% - 64%). On the other hand, kenaf fibre has higher cellulose content ranging up to 69.2% compared to core fibres and other abundantly natural fibres [33] and [34]. Lai and Mariatti [35] have studied the morphological, physical, and mechanical properties of natural fibres and resulting woven composites. They found that kenaf fibre exhibited better tensile properties than betel palm fibres due to their higher cellulose content. The high cellulose content in the kenaf fibre yarns causes permeability or wettability of the fibre.

3.3 Effect of weave designs on the tensile strength of WK – WG

The tensile properties of a composite material mainly depend on the fibre strength, modulus, filler, fibre length and orientation, fibre/matrix interfacial bonding, and fibre content [16] and [36]. The tensile strength of the specimens was measured by using Instron 5969 universal testing machine. This
test was conducted as per ASTM D3039 specification. The average value of five (5) specimens was reported. As shown in Fig. 5, mock leno weave produced the highest tensile strength; about 54.74 MPa. By hybridizing the fibre with the specimen (glass fibre) in weft direction, it is interesting to notice that the structure of mock leno weave is better than other weaves structure in which the structure and adhesion between the kenaf and fibre may have a greater effect on the tensile strength. Perhaps the fibre in weft direction can cause morphological changes in adhesion and thus leads to a better bonding between the fibres and matrix. Moreover, the plain weave also produced one of the highest tensile strength. This is due to the uniform distribution of stress transfer with the application of tensile load. Generally, in plain weave design, the fibres interlace one another both in warp and weft directions; whereas, there is no such interlacing of fibres in the weft direction [37].

In addition, the graph shows the leno weave design produced the lowest tensile strength, about 53.2% lower than mock leno weave. This is due to the weave structure and the low number of fibres contained in the specimen. As shown in Fig. 5, it can be concluded that the plain weave and mock leno weave exhibited better mechanical properties (tensile strength) for WK–WG. Moreover, by hybridizing the fibre with the specimen which the glass fibre was added in weft direction, it was observed that the tensile strength produced by the twill and satin weave designs were not significantly different compared to kenaf fibre in weft direction.

3.4 Effect of weave designs on the tensile strength of WG–WK

Fig. 6 shows the effect of weave designs on the tensile strength of WG–WK. As shown in Fig. 6, the tensile strength produced by mock leno weave (about 99.46 MPa) was higher than other weave designs. It was also observed that the twill and satin weave designs were not significantly different in which they only managed to decrease by 5.6% and 2.1% respectively, compared to mock leno weave. This is because there are more balance and symmetry during the tensile stress compared to other designs [38]. Generally, mock leno is another version of plain weave in which occasional warp fibres, at regular intervals but usually several fibres apart, deviate from the alternate under-over interlacing and interlace every two (2) or more fibres instead. This happens with similar frequency in the fill direction, and as a whole, the thickness of the fabric increases and the surface becomes rougher. Mock leno weave is not widely used but it is popular due to their strength and appearance.

In addition, Fig. 6 shows that the tensile strength of plain weave and basket weave was almost similar in which it decreased 23.2% and 22.9% respectively compared to mock leno weave. Basket weave is fundamentally the same as plain weave except that it has two or more warp fibres that
alternately interlace with two or more weft fibres. As shown in Fig. 6, leno weave design exhibited the lowest tensile strength, about 71% lower than mock leno weave. This is due to the structure and the low number of fibres in the specimen.

On the other hand, by hybridizing the fibre in the specimen in which the glass fibre was added in warp direction, WG–WK in all types of weave designs was found to increase significantly compared to WK–WG. According to Saiman et al. [39], natural fibres have some drawbacks such as low tensile strength, modulus, and flexural strength compared to industrial synthetic fibres.

In addition, Fig. 8 shows that the tensile strength of WG–WK was higher than WK–WG irrespective of the weaving designs. Based on the graph, it can be observed that WG–WK showed a significant increase in tensile strength compared to WK–WG. This could be due to the glass fibre in warp direction had a good tensile strength than kenaf fibre in warp direction. Baghaei and Skrifvars [5] have studied the tensile properties of PLA composites reinforced with hemp, Lyocell, and glass fibre. They reported that glass fibre composites were superior to hemp fibre composites irrespective of fibre orientation, and the tensile strength in particular was higher for glass fibre composites. Banghaei et al. [41] studied the characterization of thermoplastic natural fibre composites made from woven hybrid yarn prepregs with different weave patterns. They reported that the types of weave produced materials with good processability, high stiffness, and strength in warp direction. Moreover, the mechanical properties of the hybrid composites were improved by adding glass fibre content [10], [41] and [42]. As shown in Fig. 6, it can be concluded that hybridizing the fibre with the glass fibre in warp direction gives greater effect on tensile strength compared to kenaf in warp direction.

Fig. 6. Effect of weave designs on tensile strength of WG – WK.

3.5 Effect of thickness on the tensile strength of WK–WG
The thickness of material is one of the factors that affect the strength of material. The actual thickness of the specimens was recorded after the infusion process. The thickness of the specimens was measured using a digital Vernier calliper and the average value of the five (5) specimens recorded.

Fig. 7 shows the effect of thickness on the tensile strength of WK–WG. The results showed that increasing the thickness of the specimen did not affect the tensile strength, without considering the specimen with leno weave design. This is due to the weave structure and the better bonding between the fibre and matrix in which it may have a greater effect on the tensile strength compared to the thickness of the specimen. Without considering the specimen with leno weave design, it can be
observed that the specimen with plain weave and mock leno weave designs decreased the thickness and thus increased the tensile strength compared to basket weave.

However, the specimen with basket weave design showed the highest thickness, about 2.62 mm, but low in tensile strength. This is due to the interlacement between the fibres in the basket weave in which it generates a big gap without any reinforcement [39] and it affects the tensile strength and the thickness of the specimen as shown in Fig. 8 (a) and Fig. 8(b).

Moreover, irrespective of leno weave design, it can be concluded that the decrease of thickness increased the tensile strength of the WK–WG lamina or one ply composite due to the fact that the weaving structure has better interlocking between the fibres and possesses sufficient resin to wet all the specimens in the lamina composites.

3.6 Effect of thickness on the tensile strength of WG–WK
Fig. 9 shows the effect of thickness on the tensile strength of WG–WK. Fig. 9 shows the comparison of three (3) weave designs; twill weave, satin weave, and mock leno weave. It can be seen that thickness has a significant influence on tensile strength. The tensile strength of twill weave, satin
weave, and mock leno weave increased as the thickness increased. This is because the weaving structure of the specimen is able to withstand higher stress when the specimens are stretched or pilled before failure occurs. However, the specimen with basket weave design showed the highest thickness (1.74 mm) but low in tensile strength. This is because the interlacement between the fibres in the basket weave generates a big gap without any reinforcement and the jammed structure has a great influence on the properties of dry fabric such as porosity because it affects the resin penetration between fibres.

As shown in Fig. 9, it can be concluded that increasing the thickness of WG–WK will increase the tensile strength of twill, satin, and mock leno weave designs. This is due to the weave structure and the better bonding between the fibre and matrix in which it may have a greater effect on the tensile strength compared to the thickness of the specimen. Moreover, by comparing the results in Fig. 7 and Fig. 9, it can be concluded that decreasing the thickness will increase the tensile strength. Banakar et al. [43] studied the influence of fibre orientation and thickness on the tensile properties of laminated polymer composites. They found that the laminated specimens with low thickness led to more ultimate strength irrespective of fibre orientation. Ahmed et al. [44] studied the effect of variation of thickness on the tensile properties of hybrid polymer composites (glassfibre–carbonfibre–graphite) and GFRP composites. When the comparison was carried out between the hybrid and GFRP composites with different thicknesses, they concluded that the difference between the tensile strengths of hybrid and GFRP composites of 4 mm thickness was less compared to 2 mm and 3 mm thickness. This shows the weak bond of 4 mm thickness hybrid composites lamina and this may be due to the starvation of resin or improper moulding of lamina.

3.7 Fracture analysis
The fractured surface of higher strength composites due to the tensile loading was selected as the representative sample for the interpretation of degree of interfacial adhesion. SEM images of twill weave, satin weave, and mock leno weave after it fractured under tensile loading are shown in Fig. 10. The mechanical performance of lamina composites depends not only on the properties of fibre constituents but also the interfacial interactions established between the reinforcing agent and the matrix material as well [45].

![Fig. 9. Effect of thickness on tensile strength of WG – WK.](image-url)
Moreover, the cracks propagated through the matrix of twill weave at the interface are clearly shown in Fig. 10(b). There were some hollow portions after the fracture, indicating that the phenomenon of fibre pull-out occurred to a large extent. Besides that, the failure of satin weave under the tensile mode is probably due to the complete removal of glass fibre along the warp direction of loading.

In addition, the mock leno weave shows a better bonding between the fibre and the matrix. The strength of the lamina intraply composites was governed by the initiation and propagation of microscopic cracks through the matrix, which depends on the weave and direction of the reinforcement. As a conclusion, twill, satin, and mock leno weave showed a better bonding between the fibre and the matrix and this makes the specimen can withstand higher loads before failure occurs.

4. Conclusions
The present study was designed to determine the effect of lamina intraply hybrid composites on the tensile properties of various weave designs. This study has shown that the fibre content of the specimen for WK–WG was 50% and the result of resin content of the specimen was 50%. The fibre
content of the specimen for WG–WK was 60% and the result of resin content of the specimen was 40%. It was also shown that various weave designs affect the tensile properties. These findings enhance our understanding of glass fibre in warp direction has a greater effect on the tensile strength compared to kenaf fibre in warp direction. Mock leno weave exhibited better mechanical properties for WK–WG and WG–WK, about 54.74 MPa and 99.46 MPa respectively. The decrease of thickness increase the tensile strength of lamina or one ply composite due to the fact that the weaving structure has better interlocking between the fibres and it has sufficient resin to wet all the specimens in the lamina composites. The fracture analysis for selected specimens (twill, satin, and mock leno weave) showed better bonding between the fibres and the matrix. This makes the specimen can withstand higher loads before failure occurs.

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