The Effect of Various Weave Designs on Mechanical Behavior of Lamina Intraply Composite Made from Kenaf Fiber Yarn

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Abstract. The development of lamina intraply composite is a novel approach that can be adopted to address the challenges of balance mechanical properties of polymer composite. This research will focuses on the effects of weave designs on the mechanical behavior of a single ply or also known as lamina intraply composite. The six (6) specimens of lamina intraply composites were made by kenaf fiber 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. The vacuum infusion technique was adopted due to advantages over hand lay-up. It was found that the plain, twill and satin weave exhibited better mechanical properties on tensile strength. The fiber content of the specimen was 40% and the result of the resin content of the specimen was 60% due to the higher permeability of natural fiber.

Keywords: weave designs, mechanical behavior, lamina, intraply, kenaf fiber yarn

1. Introduction

Recently, researches have shown an increased interest in natural fibers and their feasibility as the reinforcement in the polymer matrix. Natural fibers are proposed to substitute synthetic fiber due to several advantages such as environmentally friendly, low cost, abundant, renewability, and good weight – strength property [1-7]. Natural fibers are extracted from various parts of a plant (stem, leaf and bark) and classified accordingly. The most widely used plant fibers include banana, sisal, kenaf, coir and so on but this research will focus on kenaf fiber only.

In the recent decade, European automobile have shown interest in natural fiber reinforced polymer composites, especially in the manufacturing of door panels [2], backseat, headliners, package trays [3], dashboard [4] and trunk liner [5]. This trend has spread to other parts of the world such as United States and Asian region [6]. In Malaysian context, since there are abundantly available natural fibers (Kenaf fiber) in Malaysia that can be economically processed into natural fiber polymer composites, excess fiber from kenaf plant has become the top national commodity crops under the organization of Malaysian National Kenaf and Tobacco Board. This may be because of kenaf fiber composite has better ductility, toughness and can increase tensile as well as flexural and impact strength significantly [7].
Furthermore, the comprehensive study by Manap et al. [8] on the tensile and compressive properties of glass reinforcement in kenaf reinforced epoxy composite, they presumed that the direction of kenaf fiber in longitudinal heading indicated higher strength compared to the transverse kenaf direction. Theoretically, arrangement of fiber in longitudinal direction is more superior compared to the arrangement in transverse direction in tensile properties evaluation [9]. The research study by Mahjoub et al. [10] also found that the kenaf fibers fabricated in unidirectional were almost broken in the fracture plane due to the strong bonding between kenaf and matrix.

On the other hand, a woven fabric increasingly appealing to composite researchers and considered as an alternative of conventional laminated composites. Woven fabric is a textile formed by weaving and made of many yarns woven on a warp (0°) and a weft (90°) direction. The strength of woven fabric depends on the weaving patterns [11-12]. Depending on the weave patterns, woven fabric are categorized into plain weave, twill weave, satin weave [13]. Previous studies by Baghaei and Skrifvars on characterization of polylactic acid biocomposites made from prepregs composed of woven polylactic acid/hemp-lyocell hybrid yarn fabric have reported that the satin weave composites leading to a tensile strength of 101.2 Mpa, Young’s modulus of 11.4 GPa, flexural strength of 158.2 MPa, flexural modulus of 9.7 GPa and impact strength of 47.4 KJ/m². It has also been observed that woven fabric show higher mechanical strength compare to nonwoven fabric [14].

Furthermore, Nassif [15] stated that the different weft densities in plain weave, twill and satin weave patterns will be affected the physical and mechanical properties in woven fabric. The author also observed that plain weave are more superior compare to other weave structures in breaking load, breaking elongation and stiffness. While, satin weaves have higher air permeability and twill weave have higher crease recovery. Besides that, Chu and Chen [16] also reported that basket weave are more pliable and stronger but less stable than plain weave.

Among the various parameters influencing the mechanical properties of fabric, weaving structure is identified as one of the main factors influencing the mechanical performance for high strength application [12][17]. In particular, the woven fabric composites provide more balance in strength, toughness and stiffness compare to nonwoven fabrics. Previous studies conducted on nonwoven fiber composites mainly focused on adhesion of matrix and fiber, arranged in different direction to offer a good mechanical properties in each ply, with less emphasis on achieving high strength in single ply. This reason leads to development of intraply woven fabric to improve the mechanical properties in polymer composites.

The main aim of the present study is to investigate the mechanical properties of kenaf yarn in various weaving designs in terms of intraply performance when it is 100% natural fiber. The selection of kenaf fiber as a reinforcement was based on its good mechanical properties and availability. Likewise, the selection of polyester as a matrix based on good curing and low cost compare to epoxy matrix. The vacuum infusion technique was choose due to less manpower, lower void content and higher fiber volume fraction compare to hand lay-up.

2. Materials and Methods
The kenaf fiber yarns were supplied by KIRD Enterprise (M) in Nilai Negeri Sembilan (Malaysia) and the price was MYR300 per 10 kg per roll as shown in Figure 1. The thickness of the kenaf fiber yarns was 1.05 (± 0.05) mm each. In this research, polyester with brand Norsodyne 3317 AW manufactured by the Cray Valley Resins (M) Sdn. Bhd. was used. The price for this unsaturated polyester resin was MYR20.00 per liter. For the material preparation, the resin was measured with the digital scale as 40% of the total weight fraction of the composite with the addition of one percent of a methyl ethyl ketone peroxide (MEKP) catalyst which was manufactured by P.T. Kawaguchi Kimia Indonesia.

![Figure 1. Kenaf fiber yarns.](image)
In particular, six (6) types of lamina composite weave designs obtained were plain, twill, basket, satin, leno and mock leno weave as shown in Table 1.

**Table 1: Design of intraply lamina composite**

| Weave type | Weave pattern | Description |
|------------|---------------|-------------|
| 1. Plain   | ![Plain Weave Image] | 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. |
| 2. Twill   | ![Twill Weave Image] | 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 interlacing 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 Image] | 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.

6. Mock Leno

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 weaving pattern designs required. The specimen was designed into the dimension of 300 mm x 220 mm and Figure 2 shows the weaving process. This research implemented the vacuum infusion technique as shown in Figure 3. After the infusion process, the specimen was kept at room temperature for two days or 48 hours of the curing process. The purpose of this process was to stabilize the specimen in turn of making sure the specimen was 100% cured and reduce internal stress due to process.
The specimen was cut using a laser cutting machine into a rectangular shape with a dimension of 250 mm length x 25 mm width based on the recommendation of ASTM D3039 as shown in Figure 4. The laser cutting machine type was Helius – 2513 with a maximum capacity of 3 kW, tension 400 V 50 Hz and power 77 kW was used for cutting the specimens. The purpose of using the laser cutting machine is to get a more accurate specimen measurement for the mechanical and physical test.

Figure 2: Weaving process

Figure 3: Vacuum infusion process

Figure 4. Laser cutting process (a) laser cutting machine, (b) cutting the specimen and (c) rectangular shape for the tensile test.
Tensile properties of a composite material mainly depend on the fiber strength, modulus, filler, fiber length and orientation, fiber/matrix interfacial bonding, and fiber content [18 - 19]. The tensile strength of the specimen was measured by using an instron 5969 Universal Testing Machine. This test was conducted as per ASTM D3039 specification. The average value of five (5) specimens was reported.

3. Results and Discussion
Some weave designs and fiber directions by different materials have a significant influence on the mechanical and physical properties of the lamina composite. Below are the relationships between the weave design, fiber directions by different materials, and the mechanical and physical properties.

![Figure 5: Specimen weight of specimen](image)

3.1 Weight fraction of specimen
Figure 5 shows that most of the fiber contents after infusion process were between the ranges of 37% to 40%. It can be concluded that the fiber content of specimen was 40% and the result of the specimen resin content was 60%. Irrespective of the weave designs, it clearly shows that the resin content in the specimen was higher. This was caused by the kenaf yarn fiber (natural fiber) which absorbed more resin due to high permeability. Liu and Dai [20] studied the impregnation of a jute mat by a thermoplastic resin. They found that natural fiber had higher permeability compared to the glass fiber mat.

3.2 Effect of weave designs on the tensile strength
Figure 6 shows the effect of weave designs on the tensile strength (MPa) of 100% kenaf. The results show that the satin weaving design had the highest tensile strength, about 48.43 MPa compared to other weave designs. However, the tensile strength of plain weave and twill weave was almost similar with the satin weave which was only 2.1% and 0.1% respectively lower than the satin weave. The basket weave and mock leno weave had 19.1% and 16.4% respectively lower than the satin weave. Besides that, the leno weave design had the lowest tensile strength, about 60% lower than the satin weave. This was due to the weave structure and lower number of fiber contained in the specimen.

As indicated in Figure 6, it was observed that the satin and twill weave had the highest tensile strength, about 48.43 MPa and 48.4 MPa respectively. This was due to the weave structure of satin and twill weaves that are able to withstand the loads before the failure occurred. Banghaei et al. [21] studied the characterization of thermoplastic natural fiber composite made from woven hybrid yarn prepregs with different weaving patterns. They reported that the composite made of the satin weave is of high quality, because of its lower porosity. Meanwhile, Siengchin and Wongmanee [22] studied the
mechanical and impact properties of PLA/2 x 2 twill and 4 x 4 hopsack weave flax textile composites produced by the interval hot pressing technique. They found that the tensile strength and stiffness of the PLA/flax composites were also markedly higher than those of PLA and reflected the effect of their structures. From the results in Figure 7, it can be concluded that the weave designs which were plain, twill and satin weaves exhibited the better mechanical properties on the tensile strength.

![Figure 6. Effects of weave designs on tensile strength of 100% kenaf.](image)

3.3 Effects of thickness on the tensile strength
The thickness of a material is one of the factors that affect the strength of the materials. The actual thickness of specimen was recorded after the infusion process. The thickness of specimens was measured by using digital vernier calipers and the average value of five (5) specimens was reported as shown in Table 2.

| Weave Designs | Thickness (mm) |
|---------------|----------------|
| Plain         | 2.32           |
| Twill         | 2.46           |
| Satin         | 2.28           |
| Basket        | 2.71           |
| Leno          | 1.87           |
| Mock Leno     | 2.55           |

As indicated in Figure 7, it was clearly shown that by increasing the thickness in the specimen, it did not affect the tensile strength. It could be seen that the basket and mock leno weaves had the higher thickness, about 2.71 mm and 2.55 mm respectively compared to other weave designs but it was lower in the tensile strength compared to the plain, twill and satin weaves. This was due to the weave structure and better bonding between fiber and matrix that may have a greater effect on the tensile strength compared to the thickness of the specimen. However, it is theoretically said that by increasing the thickness and proper bonding between the fiber and matrix would increase the tensile properties. A comprehensive study by Abdellaou et al. [23] on fabrication, characterization and
modeling of laminated composites was based on the woven jute fiber reinforced epoxy resin. They found that the mechanical properties increased with the increasing number of layers (thickness). Thus, this result was based on one ply or lamina composite only.

In addition, weaving structure may have a greater effect on the tensile strength compared to the thickness of the specimen. It can be seen that the plain, twill and satin weaves had less thickness compared to the basket and mock leno weaves. However, it was higher in the tensile strength, about 47.4 MPa, 48.4 MPa and 48.43 MPa respectively. Irrespective of the leno weave design, it can be concluded that the decrease of thickness increased the tensile strength of lamina or one ply composite due to the fact that there was a weaving structure that had better interlocking between the fiber and sufficient resin to wet all the specimens in the lamina composites.

![Tensile strength and thickness graph](image)

**Figure 7.** Effects of the thickness on tensile strength of 100% kenaf.

4. Conclusions
The mechanical properties of lamina intraply composite made from kenaf fiber yarn have been studied and analyzed with respect to polyester resin. The fabrication process adopted was vacuum infusion technique due to its advantages, such as low void content, high fiber volume fraction and strong interfacial bonding. The fiber content of the specimen was 40% and the result of the resin content of the specimen was 60% due to the higher permeability of natural fiber. Plain, twill and satin weaves exhibited better mechanical properties on the tensile strength. The thickness of specimen was found that the decrease of thickness increased the tensile strength of lamina or one ply composite due to the fact that there was a weaving structure that had better interlocking between the fiber and sufficient resin to wet all the specimens in the lamina composites.

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