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Effect of Stitching Patterns on Tensile Strength of Kenaf Woven Fabric Composites

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Abstract: In the past years, the natural fibre had attracted much attention by many researchers as an alternative fibre to replace synthetic fibre composite materials today. An experimental study was conducted to explore the effect of stitching on woven kenaf fabric. The hand lay-up and vacuum bagging technique were used. The composites were made of woven kenaf fabric as a reinforcement and epoxy resin as a matrix. The composites were made in different patterns of stitches that split into two categories which were basic pattern that was stitched by the single cross which includes Vertical, Horizontal, Tilt 30˚and Tilt 60˚. The other one was complex pattern, stitched by the double cross which includes Box, Tilt 45˚/90˚, Tilt 30˚/30˚and Tilt 60˚/60˚. It was found that the increasing specific strength for single stitch composite of the V, T60, and T30 patterns were 14.51 %, 1.49 % and 0.64 % respectively, compared to the unstitched composite. The specific strength produced by V stitch which was about 9.53 MPa/g, was higher than other stitch patterns. The results also showed that the specific strength for all the double stitch patterns were gradually increased compared to the unstitched ones. T60/60 exhibited the highest specific strength which increased about 53.17 % compared to the unstitched composite. The evidence from this study suggested that the double stitch composite gave better performance in specific strength, while stitching patterns and stitching angle gave significant effect to the performance of woven stitch kenaf composite compared to the unstitched ones. Implications of the results and future research direction were also presented.

Keywords: stitching patterns, woven kenaf fabric, tensile properties, composite

1. Introduction

In the recent decades, natural fibre has become one of the major interesting research subjects due to its lightweight, tool wear reduction, thermal isolation properties, renewable and has suitable specific mechanical properties [1], [2]. Natural fibres are commonly used in non-structural and non-load bearing components applications by using non-woven

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or random fibre orientation, such as car door map pocket [3], door panels [4], [5] and spare tyre cover [6]. These natural fibres include sisal, pineapple, jute, banana, oil palm, kenaf and coir fibres [7].

In recent years, there has been an increasing amount of literature on kenaf fibre. Kenaf fibre is a type of natural fibres which brings many advantages and has high potential as reinforcement in composite material fields because each component of the plant is usable such as stalks, leaves, and seeds. Moreover, it can be easily harvested in 5 – 7 months. Kenaf-fibre reinforcement has become the common natural fibre used in various application such as automotive, construction, electrical, marine, aircraft, and transportation [3][8]. Author in Ref. [9] also agreed with this statement because kenaf is a fast-growing property as it is able to produce a large volume of raw material within a short period of time. It has become a high demand for many industrial sectors due to its high environmental sustainable which is able to reduce the use of fossil fuels, low density, cost effective, and great performance in terms of physical and mechanical. Therefore, kenaf fibre is chosen as the reinforcement for this research instead of other natural fibre.

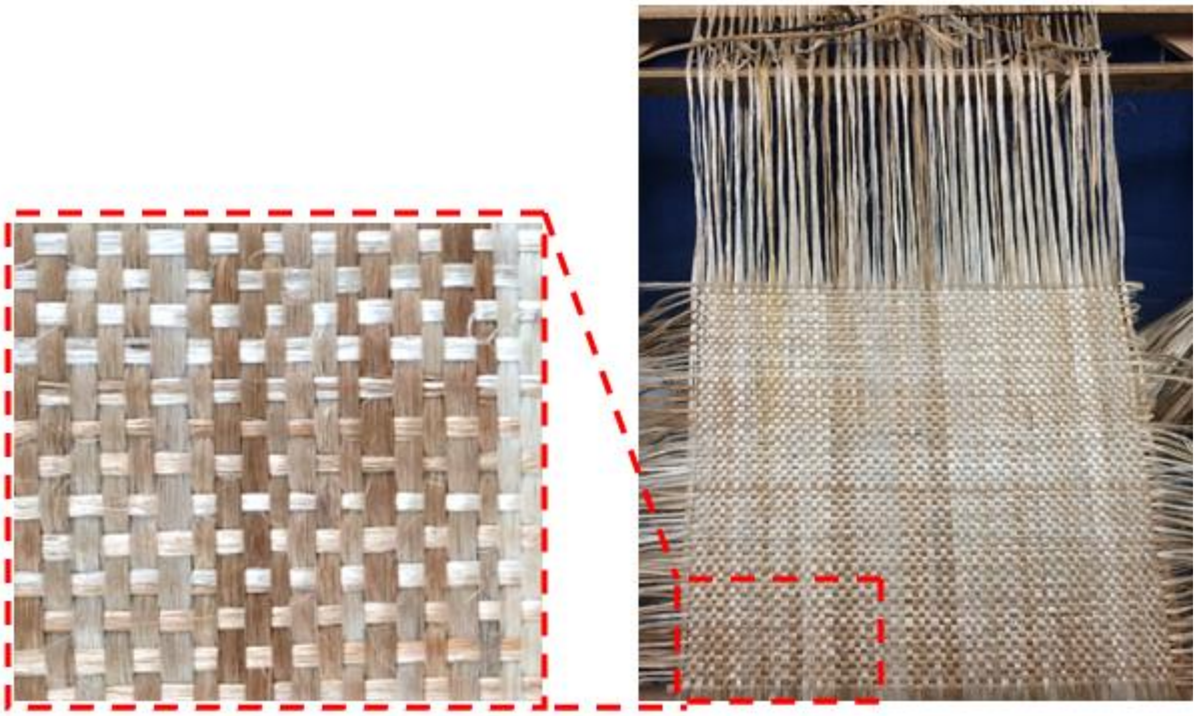
Stitching is a process to bind two components together by using thread and needle. In the past thousand years, they are made by hand work over the woven threads on clothing by using natural fibre or animal fur. The first sewing machine was invented in 1790 by Thomas Saint to sew leather, canvas and boots [10]. Conventional stitching uses yarn of carbon, glass or other good performance fibres to be applied into the composite performed by using one or double-sided machine. In the modern technology, advanced stitching can be performed with sewing machine. Lock stitch, modified lock stitch and chain stitch are the common stitching types used by many researchers on the composite material. The use of stitching in the composite is to join the composite structure to improve through-thickness strength, interlaminar fracture toughness and impact damage tolerance [11]. Previous studies have reported that the stitched composite can enhance the toughness properties of the composite material compared to the unstitched composite. Bhudolia *et al*. (2018) found that stitched ply carbon fibre epoxy composite gave better performance in fracture toughness which when it was tested, it can achieved 37 % of high energy absorption and 23 % of high peak load [12]. Yang *et al*. (2013) found that the stitched network increased the delamination toughness and healing of the delamination and matrix crack in composite T-joint utilizing mendable polymer fibre stitching. Moreover, they also investigated the effect of stitching on the healing efficiency and mechanical properties of mendable carbon-epoxy composites. Through the studies, the size or density of mendable stitches affects the delamination toughness, healing and mechanical properties of the composite. The size of mendable stitches reduced the mechanical properties but it increased the delamination toughness and healing. The toughness of composite material can be improved with stitching with delamination as the healing function [13]. In another studies, Ahmad *et al*. (2008) compared the stitches of different fabric system pattern with the unstitched fabric system by using ballistic limit test and found that the stitched fabric system had the highest trend revealing the higher energy absorption by the fabric [14]. It was also noticed that the stitching would increase the absorption of impact energy in the soft composite fabric depending on their pattern. According to Author in Ref. [15], stitching will cause fibre breakage in the composite. They highlighted that stitching on the mendable composite reduced the mechanical properties due to the increasing of areal density or the stitch sizes. Furthermore, the stitch density and the stitch size will influence the performance of the composite. Suhaimi *et al*. (2018) also agreed with this claim. The stitch density with different stitching pattern contributes different strengths on the composite. They had investigated that diagonal stitch can withstand high load compared to other stitching pattern [16].

Next, the textile structures such as woven, knitted or braided are usually used for reinforcement in fibre-reinforced polymer composite. Woven fabric will be studied further in this research. This is because woven fabric provides high stiffness, strength and stability. Warp yarn and weft yarn interlace together to form weaving direction on the woven fabric. Knitted reinforcement provides better impact strength but poor in tensile properties while woven reinforcement gives a higher modulus value [17]. Alavudeen *et al*. (2015) has studied the mechanical properties of banana and kenaf fibre-reinforced composite with the effect of weaving pattern and random orientation [18]. They found that plain woven hybrid composite gave higher mechanical strength compared to the random orientation composite. This shows that the mechanical properties of the composite are also affected by the woven structure. They also studied the sodium hydroxide (NaOH) and sodium lauryl sulphate (SLS) treatments being applied to the natural fibre. Furthermore, they indicated that the alkali tends to improve the mechanical strength of the reinforced composite through the interfacial bonding between the fibre and the matrix due to better absorption of the fibre and hence, enable the matrix to ebb together.

Thus, many research mainly studied the properties of the natural fibre reinforced composite and hybrid reinforced composite. However, there is a few amounts of study on the effect of stitching on other material but not for kenaf woven fabric embedded with epoxy in intraply composite. The epoxy resin embedded to woven kenaf fibre was expected to enhance the properties of the composite. There are only a few types of stitching that had been used in previous studies which are lock and chain stitch. Consequently, the types of stitching with different patterns will be further explored in this study.

2. Materials and methods

The natural fibre used in this study was kenaf fibre as the reinforcement and epoxy auto-fix 1345-A and auto-fix 1345-B as the matrix. The epoxy auto-fix 1345-A and auto-fix 1345-B were obtained from Chemibond Enterprise Sdn. Bhd while kenaf fibre was purchased from Lembaga Kenaf dan Tembakau Negara, Malaysia (LKTN). Before the weaving process, kenaf fibre was cleaned and divided according to the size of 4 to 5 mm (±0.1). There are many designs of weave pattern that have been used and studied from previous researchers. These designs included plain, basket, twill, leno, satin and mock-leno weave. Plain weave design is the most basic weave type which is strong enough among others. The kenaf fibre was aligned in the weft and wrap directions. However, plain weave design was selected to be carried out as experimental testing in this research. A plain weave design kenaf was shown in Fig. 1 (a). The weaving process was done manually as shown in Fig. 1 (b). After that, kenaf fibre was stitched by using sewing machine brand SINGER, model 8280 with capacity of machine of 240 V, 50 Hz and 85 W. There were eight types of stitching patterns that had been applied on the woven kenaf fabric. The stitch patterns were the main point of this study. These patterns split into two categories which were basic pattern and complex pattern. The basic pattern was stitched by single cross which include Vertical, Horizontal, Tilt 30˚and Tilt 60˚. While complex pattern was stitched by double cross which include Box, Tilt 45˚/90˚, Tilt 30˚/30˚ and Tilt 60˚/60˚as shown in Fig. 2 and Table 1. All of these design were stitched on the woven kenaf fabric with distance of 5 mm between each stitch.



(a) (b)

Fig. 1 - (a) woven kenaf fabric; (b) weaving process.

Table 1 - Types of single and double stitch patterns.

Single stitch		Double stitch	
Composite samples	Types of stitching patterns	Composite samples	Types of stitching patterns
O	Unstitch	O	Unstitch
V	Vertical	Box	Box
T60	Tilt 60°	T45/90	Tilt 45°/90°
T30	Tilt 30°	T30/30	Tilt 30°/30°
H	Horizontal	T60/60	Tilt 60°/60°

Stitching is a process that use stitches to fasten or gather two objects by using needle and thread. The structure of modified lock stitch was used in this study as shown in Fig. 3. Fig. 4 shows the example of stitched Tilt 60°/60° on woven kenaf fabric. The stitching parameter such as stitch density and stitch orientation will be taken into consideration. This is because it might influence the performance of the composite. Cotton fibre is a natural material which is produced from a cotton plant. It is chosen as the thread for stitching process based on ASTM D1441 standards which make it easy to bind the woven kenaf fibre with stitches due to its strength and elongation. Specification of cotton fibre was shown in Table 2.

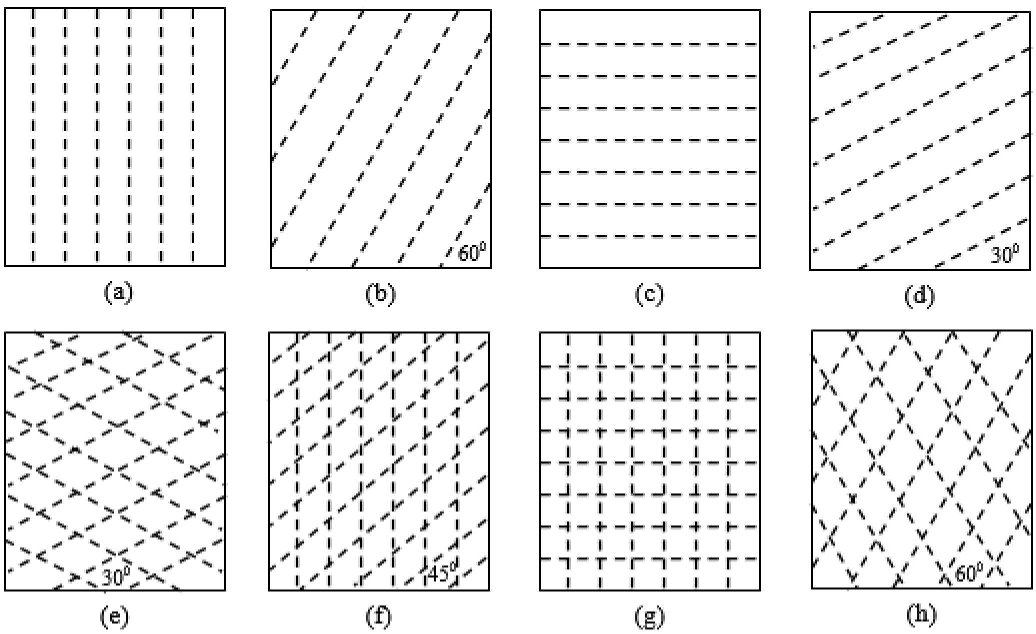


Fig. 2 - Types of stitching patterns (a) Vertical; (b) Tilt 60°; (c) Horizontal; (d) Tilt 30°; (e) Tilt 30°/30°; (f) Tilt 45°/90°; (g) Box; (h) Tilt 60°/60°.

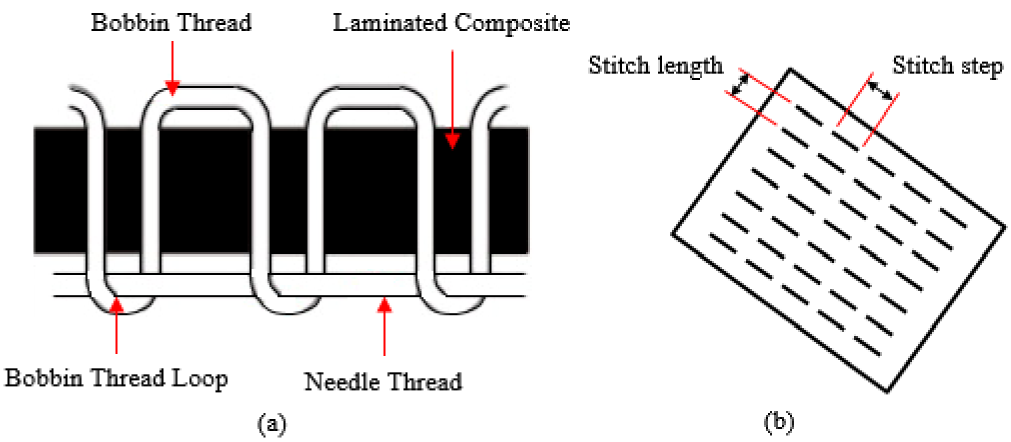


Fig. 3 - Schematic view of (a) modified lock stitch (b) on woven fibre composite, with permission [19][20].

Fig. 4 - Example of stitched Tilt 60°/60° on woven kenaf fabric.

Table 2 - Specification of cotton fibre [21].

Parameters	Cotton
Elongation (%)	6.6
Short fibre index	33.4
Moisture (%)	8.5
Micronaire	4.6
Strength (gm/tex)	35.6
Water absorption capacity	>24 grams per gram of fibre

Hand lay-up and vacuum bagging technique was used to produce the composite. Before that, stitch woven kenaf fabric were dried in the oven at 50 ˚C for 24 hours to absorb the moisture, avoid voids formation and to improve fibre-matrix adhesion. The stitch woven kenaf fabric (Fig. 4) with the dimension 300 mm x 220 mm was prepared and then followed by the vacuum bagging technique. After the vacuum bagging process was done, the samples were kept at room temperature for 48 hours of curing process to stabilize the samples and ensure it was 100 % being cured. Next, the samples were cut according to ASTM D3039 standard by using laser cutting machine with a dimension 250 mm (length) x 25 mm (width) for tensile test. Fig. 5 shows schematic diagram of vacuum bagging arrangement used for fabricating composite.

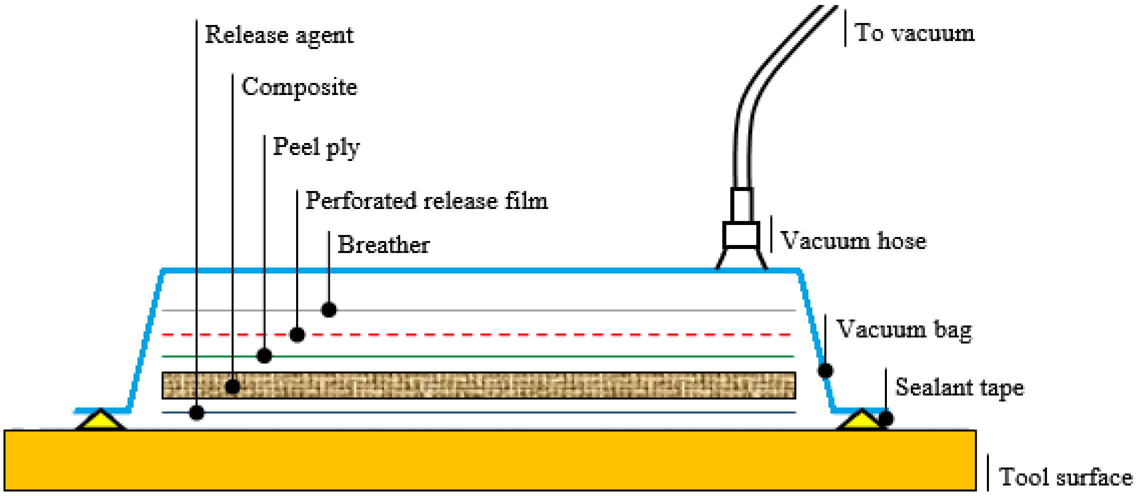


Fig. 5 - Schematic diagram of vacuum bagging arrangement

3. Results and discussion

3.1 Tensile properties of single stitch

For the tensile test, the composite samples were cut according to ASTM D3039 standard and the average of 5 samples was recorded. The samples were measured by using Instron 5969 universal testing machine. Tensile properties of single stitched and unstitched woven kenaf composite were stated in Table 3. The average tensile strength of composites samples, O, V, T60, T30 and H were 28.31 MPa, 45.86 MPa, 33.59 MPa, 39.97 MPa, and 37. 82 MPa respectively. Fig. 6 shows the specific strength of single stitch and unstitched composite. Specific strength is defined as the strength-to-weight ratio. The specific strength can be defined as follow;

$$Specific\ strength = \frac{\sigma}{m} \tag{1}$$

Where σ is maximum tensile strength and m is mass of composite.

Table 3 - Properties of single stitch and unstitch composite.

Patterns	Tensile strength (MPa)	Mass (g)	Specific strength (MPa/g)	Young's modulus (MPa)
O	28.31	3.40	8.33	1.76
V	45.86	4.81	9.53	2.29
T60	33.59	3.98	8.45	2.23
T30	39.97	4.77	8.38	1.99
H	37.82	4.60	8.22	1.64

Fig. 6 demonstrated that the specific strength of single stitch and unstitched woven kenaf composites were O, V, T60, T30 and H were 8.33 MPa/g, 9.53 MPa/g, 8.45 MPa/g, 8.38 MPa/g and 8.22 MPa/g respectively. Among five samples, H exhibited the lowest specific strength. In assessment to the unstitched sample, the specific strength of H was lowered by 1.26 %. This was due to the effect of stitches in the horizontal line (Fig. 2 (c)) which it couldn't withstand when the load was applied. It was also observed that the failure of mechanism occurred in the stitch line, as clearly shown in Fig. 7. As shown in Fig. 7, it has loose region and tight region. In the tight region, the matrix couldn't penetrate well in the fibre and this inversely affected the resin permeability through the fibre preform. These factors would defect the voids, matrix micro-cracking and porosity. On the other hand, other stitched samples (V, T60, and T30) actually exhibited better specific strength performance than their unstitched sample. The specific strength increased of the V, T60, and T30 patterns were 14.51 %, 1.49 % and 0.64 % respectively, compared to unstitched composite. As shown in Fig. 6, the specific strength produced by V stitch, about 9.53 MPa/g was higher than other stitch patterns. This is due to the vertical stitched pattern was parallel with the load direction testing and make it tend to withstand at several load compare to others stitch patterns. Although the specific strength increase may be deliberate small due to below 20 %. However, it is still improved the performance compare to unstitched composite. The finding is consistent with findings of past studies by Author in [22], which found that stitch fabric having more strength compare to unstitch fabric composites.

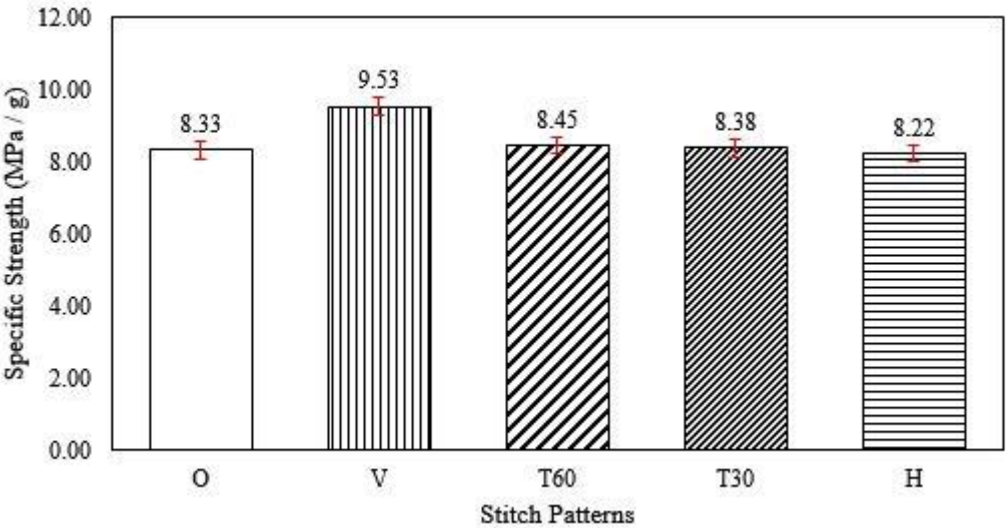


Fig. 6 - Specific strength of single stitch and unstitch composite

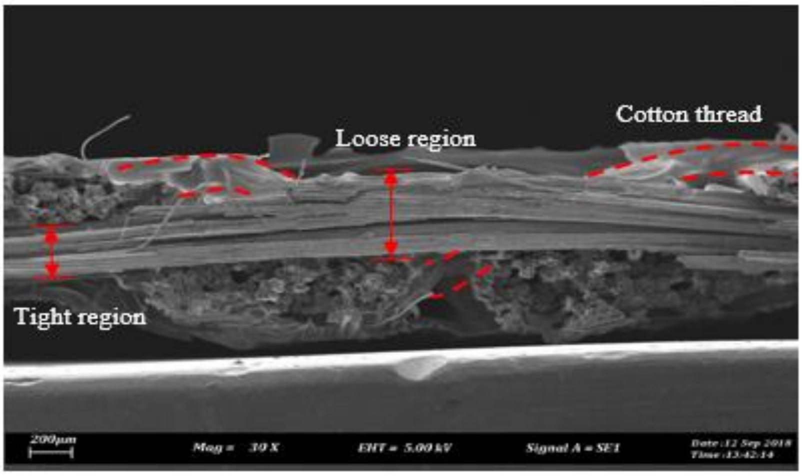


Fig. 7 - Scanning electron magnification of horizontal stitch.

3.2 Tensile properties of double stitch

Tensile properties of double stitched and unstitched woven kenaf composite were given in Table 4. The average tensile strength of composites samples, O, box, T30/30, T45/90, and T60 were 28.31 MPa, 40.58 MPa, 53.43 MPa, 46.81 MPa, and 45.02 MPa respectively. Fig. 8 presents the specific strength of double stitch and unstitched woven kenaf composites which is O, box, T30/30, T45/90, and T60/60 were 8.33 MPa/g, 9.44 MPa/g, 10.21 MPa/g, 11.41 MPa/g and 12.75 MPa/g respectively. The interesting thing in this data is that the specific strength of box, T30/30, T45/90, and T60/60 exhibited better specific strength performance than their unstitched sample. The specific strength increase of box, T30/30, T45/90, and T60/60 composite samples were 13.34 %, 22.58 %, 37.02 % and 53.17 % respectively.

Table 4 - Properties of double stitch and unstitch composite.

Patterns	Tensile strength (MPa)	Mass (g)	Specific strength (MPa/g)	Young's modulus (MPa)
O	28.31	3.40	8.33	1.76
box	40.58	4.30	9.44	1.76
T30/30	53.43	5.24	10.21	2.97
T45/90	46.81	4.10	11.41	2.23
T60/60	45.02	3.53	12.75	2.81

From the data in Fig. 8, it is apparent that T60/60 exhibited the highest specific strength. In comparison to the unstitched sample, the specific strength of T60/60 improved about 53.17 %. As clearly shown in Fig. 9, the fibre of stitched T60/60 is more consistent and stable to withstand load compared to the other stitch patterns. However, the failure of T60/60 occurred due to porosity, clearly shown in Fig. 9 where the line of failure has more porosity but it still can withstand load compared to the other stitch patterns. On the other hand, it can be noted that, as the angle of stitch increased from 30^0 45^0 and 60^0 respectively, the specific strength gradually increased.

The comparison between single stitched and double stitched were highligted in Fig. 10. From the data in Fig. 10, it is apparent that the double stitched composite gave better performance in specific strength. This indicated that the stitching patterns and stitching angle gave significant effect to the performance of woven stitch kenaf composite compared to the unstitched. However, as stated in Ref. [23], they mentioned that stitching architectural irregularities, such as fibre compaction (Fig. 7), fibre waviness, stitch debonding, fibre breakage and resin-rich region. These irregularities, which are presented during fabrication process (processing defects), may act as a damage initiator or induce a rapid growth of damage. They also mentioned another concern which is the effect of stitching on the in-plane mechanical properties as well as the damage mechanism in composites under fatigue loading is not known in details. Yudhanto et al, (2015) also raised several concern about the use of stitching technique. They suggested that the use of stitching technique must be based on this following consideration, which is out of-plane performance of composite must be significantly improve and the in-plane properties should be at least maintained [24].

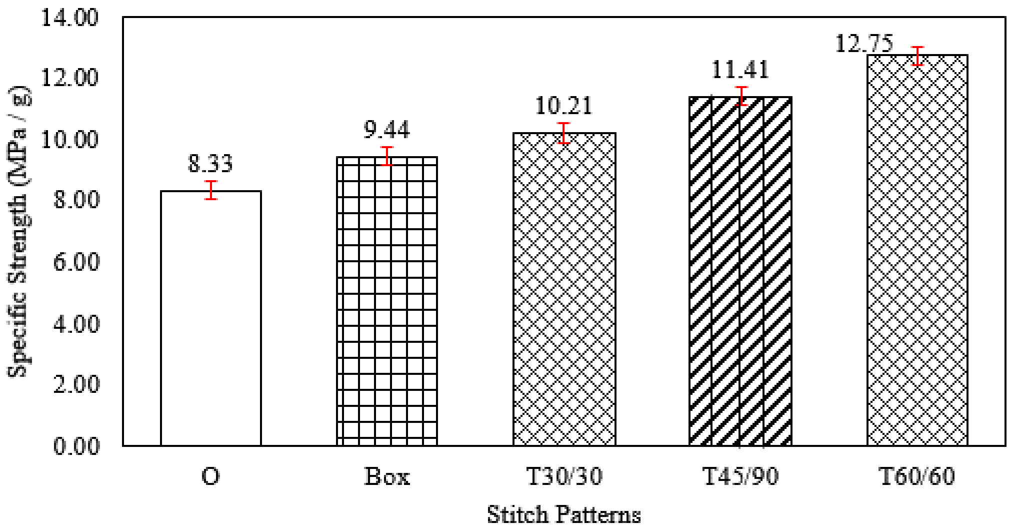


Fig. 8 - Specific strength of double stitch and unstitch composite

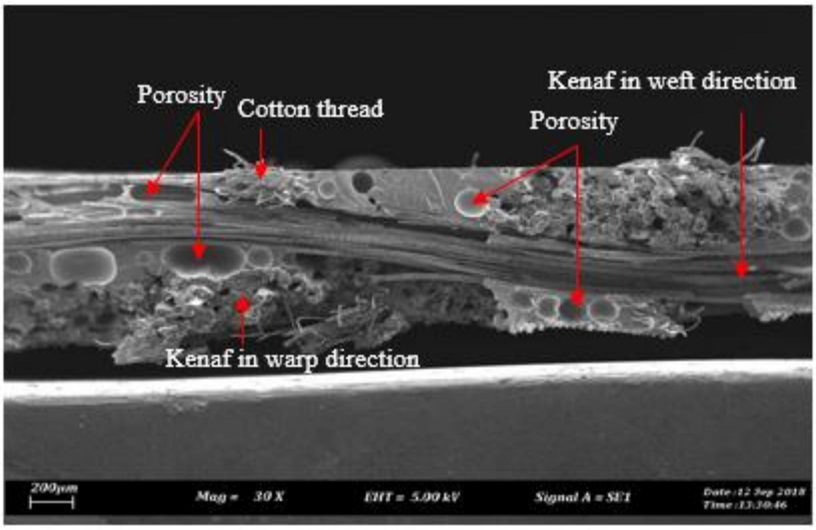


Fig. 9 - Scanning electron magnification of horizontal stitch.

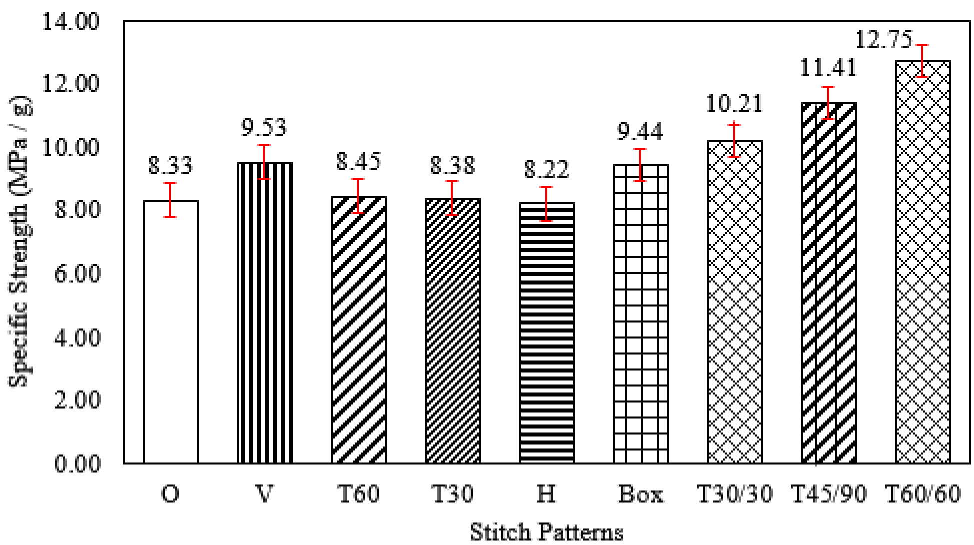


Fig. 10 - Comparison of single stitch and double stitch composite

4. Conclusion

The present study was designed to determine the effect of stitching pattern on woven kenaf fabric. The results of this investigation showed that the increasing specific strength for single stitch composite of the V, T60, and T30 patterns were 14.51 %, 1.49 % and 0.64 % respectively, compared to the unstitched composite. The specific strength produced by V stitch, about 9.53 MPa/g was higher than the other stitch patterns. It was also shown that the specific strength for all the double stitch patterns was gradually increased. T60/60 exhibited the highest specific strength which increased about 53.17 % compared to the unstitched composite. The findings from this study make several contributions to the current literature. Firstly, the double stitched composite gave better performance in specific strength. Secondly, stitching patterns and stitching angle gave significant effect to the performance of woven stitch kenaf composite compared to the unstitched ones. Further investigation and experimentation into woven stitch kenaf fabric is strongly recommended. A number of possible future studies using the same experimental set up are apparent. It would be interesting to assess the effects of laminated woven stitch kenaf fabric.

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