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# Effect of Fabric Count and Weave Design on the Properties of Hybrid Fabric Kenaf-Carbon Reinforced Laminated Epoxy Composites

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## ABSTRACT

Hybrid woven kenaf-carbon composite were fabricated in this study using epoxy resin as matrix. Effects of different fabric material namely weave designs (plain and satin) and fabric counts (5×5 and 6×6) on the properties of laminated woven kenaf polymer composite were evaluated. This study evaluates the mechanical and morphological properties of hybrid fabric kenaf-carbon from kenaf yarn of 500tex. Kenaf and carbon fabrics were used in this work, where vacuum infusion technique was selected to prepare the composite and epoxy resin was used as a matrix. The fibre weight content is 30% and four specimens were prepared for each samples and tested for their tensile, flexural, and impact strengths. The morphological properties of composites were analysed through the scanning electron microscope (SEM). The results revealed that plain woven fabric is favourable in terms of tensile and impact strengths compared to satin woven fabric. Meanwhile, 5×5 of fabric count gives better flexural modulus than composite fabricated with 6×6 fabric count. The morphologies of the fractured surface investigated by SEM demonstrated better adhesion properties and less fibre pull-out on plain woven fabric.

**Keywords**: Fabric; kenaf; plain; satin; woven composite; epoxy.

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## INTRODUCTION

Composite materials reinforced with natural fibres are becoming increasingly prevalent in many applications such as semi-structural building component, automotive, furniture, and many other applications owing to its renewability, bio-degradability, light weight, good mechanical properties, and having low density with good strength. On the other hand, substitution of conventional material with natural fibres textile as reinforcement agent prevails all over the world as they offer several advantages including high strength and stiffness, durable and superior design flexibility [1]. Many researchers studied the utilisation of natural fibres as a textile reinforcement with polymer matrix such as those from hemp [2-3], jute [4-7], flax [8-9] and kenaf [10-12]. Over the years, kenaf fibre has been utilised extensively as a reinforcement agent in many productions of polymer composites. Low density and high specific mechanical properties of kenaf has become a pulling factor for kenaf as a preferred natural reinforcement fibre in biocomposite industry. Akil et al. [13] stated that kenaf fibre reinforced polymer composite has good potential among other natural fibres due to its excellent properties.

Woven fabric are formed by interlacing vertical yarn (warp) and horizontal yarn (weft) to form a fabric. Performance of woven composite is governed mainly by the textile/fabric properties. According to Das [14], the main elements and critical factors that control the fabric properties are yarn properties, fabric count and weave design. The manipulation of these elements would produce fabric with different physical and mechanical properties. For instance, Alavudeen et al. [15] found that plain fabric made of banana/kenaf reinforced polyester composite showed improved tensile properties compared to the twill fabric weave design. A study by Wahab and co-workers [16] on woven composite revealed that the performance of woven kenaf composite were affected by yarn size and weave design that determine the woven fabric porosity and crimp percentage. These factors was found to be the main factor that control the mechanical properties of the composite. Furthermore, the addition of woven material improves the fracture toughness of the flax composites as reported by Liu and Hughes [17].

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In order to optimize the performance of the woven composite, hybridization synthetic fibre with natural fibre is believe to be able to improve the plant-based material for composite fabrication. According to Jambari et al. [18], hybridization in composite area is the method of the combination of different resources and processes with different properties for the improvement of existing material. Several studies have been carried out on utilising kenaf yarn for fabric composite production [14,15, 19, 20]. However, the idea of hybrid woven between synthetic fibres and kenaf fibres is highly recommended to compensate the dramatic loss of strength [21]. One study found that pure kenaf woven and pure Kevlar woven epoxy composite has tensile value of 16MPa and more than 250MPa, respectively. The hybridisation affected the intermediate mechanical properties compared to the highest Kelvar/epoxy properties and lowest properties of kenaf/epoxy composite [22].

This study aims to evaluate the effects of different fabric types particularly weave designs, in two different type of kenaf/carbon fibre hybrid woven composite by using Vacuum Infusion Process (VIP). The mechanical properties of composite (tensile, flexural, and impact strengths) were evaluated.

## METHODOLOGY

### Materials

Kenaf yarn with 500 tex were weaved into fabric which is used in combination with carbon fibre in hybrid woven composite fabrication. Carbon fibre in a fabric form with a plain woven structure (SPN.B 200.P) was supplied by Spinteks Tekstil Ins. The density of the carbon fibre was 1.78g/m$^3$ and the thickness was 0.20mm, with tensile strength of 3800MPa/240GPa. The matrix used to fabricate the samples was EPIKOTE Resin 240, industrial liquid epoxy resin with a density of 1.12g/cm$^3$ and hardener EPIKURE Curing Agent 3090 supplied by Chemrex Corporation Sdn. Bhd.

### Methods

*Weaving Process*

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Plain and satin fabric structure was fabricated using weaving loom machine. The plain structure is the simplest weave where the yarn interlace in alternate order. In this study, satin structure is weaved by four of weft yarns floating over a warp yarn or four warp yarns floating over a single weft yarn. Two different fabric counts were selected which were 5×5 and 6×6 fabric (number of warp yarn × number of weft yarn) with a size of 350×350 $mm^2$. The compositions of laminated composites are shown in Table 1.

**Table 1. Composition of woven fabric and carbon fabric composite.**

| Code | Fabric Count | Weave Design |
|---|---|---|
| **P5** | 5 × 5 | Plain |
| **P6** | 6 × 6 | Plain |
| **S5** | 5 × 5 | Satin |
| **S6** | 6 × 6 | Satin |

*Fabrication of Hybrid Woven Kenaf-Carbon Composite*

The composite was prepared using VIP to pull the epoxy resin into the layer of kenaf and carbon fabrics to remove the air from the system. Each composite consists of single ply kenaf fabric as the reinforcement at centre and carbon fibers at the upper and lower layers. The ratio of kenaf-carbon fabric and epoxy resin was 30:70 by mass. The samples were prepared by hand lay-up method followed by vacuum bagging. The release agent was applied to the surface of glass mould to ease the sample removal once cured. Then, the vacuum pump was switched on until the infused materials are compact. The epoxy was infused from the resin tank until excess resin flow into the resin trap vessel. The resin was then allowed to flow for few minutes to ensure the resin penetrated all the layers. Finally, the infused fabric composite was left to cure for 24 hr at room temperature. The carbon fabric epoxy specimens were also prepared as the control sample.

*Evaluation of Composite Properties*

All samples were tested for physical (fibre volume fraction, density, and void contents) and mechanical properties (tensile test, flexural test, and impact test) according to the ASTM Standard. The morphological feature of the composites were also examined under the scanning electron microscope (SEM).

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*Composite Physical Properties Test*

The density of the kenaf fabric, carbon fibers and hybrid woven composite was measured based on ASTM D3800-99. The samples of were conditioned for 24 h, and the density of both fibers were measured using the Mettler Toledo (XS205) density kit. The average density of kenaf fabric *(kf)*, carbon fibre (*cf)* and composite of ten specimens were taken and recorded.

The volume fractions of composite ($V_f$) was calculated by using Equation 1. The fibre volume fraction for kenaf fabric *(kf)* and carbon fabric *(cf)* were calculated based on Equation 2 and 3, respectively.

$$V_f = (W/\rho)_{fibre} / [(W/\rho)_{fibre} + (W/\rho)_{epoxy}] \quad \text{(Eq 1)}$$

$$V_{kf} = (W/\rho)_{kenaf} / [(W/\rho)_{kenaf} + (W/\rho)_{carbon} + (W/\rho)_{epoxy} \quad \text{(Eq 2)}$$

$$V_{cf} = (W/\rho)_{carbon} / [(W/\rho)_{carbon} + (W/\rho)_{kenaf} + (W/\rho)_{epoxy} \quad \text{(Eq 3)}$$

Where, (W/ρ) are the known weights and density of kenaf fabric, carbon fibre and epoxy resin, respectively. Based on the determined volume fraction of composite, kenaf fabric, carbon fabric and matrix, voids ($V_v$) in the composites were calculated according to Equation 4.

$$V_v = 1 - (V_{kf} + V_{cf} + V_e) \quad \text{(Eq 4)}$$

*Composite Mechanical Properties Test*

Tensile specimens were cut into 250 × 25 mm × actual thickness with gage length of 170 mm. The test was conducted based on ASTM D3039 using a universal testing machine (Instron P5567) at the crosshead speed of 2 mm/min. For each sample, 10 specimens were tested from each sample and average values were obtained. The rectangular specimens with dimension of 100 × 20 mm were cut and flexural test was conducted by three-point loading using universal testing machine (Instron P5567) according to ASTM D790 at the crosshead displacement rate of 5 mm/min. Ten specimens were tested for

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each sample and average values were recorded. The impact strength was measured using Charpy impact test machine (Instron Ceast 9050) according to the ASTM D6110. Ten specimens for each composite sample were cut into dimension of 127 × 12.7 mm X actual thickness for the striking hammer energy of 5 J.

*Morphological Observation*

Hitachi 3400 SEM was used to observe the tensile fracture surfaces of the woven fabric laminated composite. The fractured part of the samples were cut and the SEM micrographs were taken to investigate the fracture mechanisms and interface adhesion of the composites. All samples had been sputter-coated with gold with the acceleration voltage at 15 kV to avoid charging.

*Data Analysis*

The data were statistically analysed using statistical analysis system (SAS) software by using analysis of variance (ANOVA) and least significant difference (LSD) method for mean separation to evaluate the effect of types of fabric count and weave design on the panel properties. LSD method calculates the least difference that must occur between two means and compare them at $p \leq 0.05$. Means that differ more than the value is considered significantly different with each other and is ranked as a, b, c, d, e. According to this method, means having the same letters are not significantly different from each other at $p \leq 0.05$.

## RESULTS AND DISCUSSION

### Volumetric Composition of Kenaf/Carbon Fibre Hybrid Woven Composite

Table 2 shows the results for the density, fibre volume fraction and void content of the composite as a function of fabric count and weave design. It can be seen that, the density of the composites varies between different samples. CP5 (composite with plain fabric and 5x5 fabric count) showed the lowest density value of 0.98g/cm$^3$, while CS6 (composite with satin fabric and 6x6 fabric count) shows the highest density value of 1.24g/cm$^3$, which was about 26.5 % denser than CP5. Obviously, the high variation in the density of the three-layered kenaf/carbon fibre hybrid woven composite is attributed to the fabric areal

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density. Satin fabric has higher areal density and thickness than plain fabric due to its design structure and fabric arrangement. In addition, fabric count also contributed to the increase in weight and the density increase consequently. For instance, fabric having fabric count 6x6 has higher density than those made with 5x5 since it contains more fibres i.e 6 yarns in warp and weft directions, as compared to 5 yarns in warp and weft directions.

**Table 2. Fibre density and volumetric composition of kenaf/carbon fibre hybrid woven composite.**
**Note : C=composite. P and S refer to types of fabric and fabric count in the composite; P5=Plain,5x5; P6=Plain,6x6; S5=Satin,5x5; S6=Satin,6x6.**

| Type of Composite | Density ($g/cm^3$) | Kenaf Fabric | | Carbon Fabric | | Total Fibre Vol. Frac. $V_f$ (%) | Void Vol. Frac. (%) |
|---|---|---|---|---|---|---|---|
| | | Wt. Frac. $W_{kf}$ (%) | Vol. Frac. $V_{kf}$ (%) | Wt. Frac. $W_{cf}$ (%) | Vol. Frac. $V_{cf}$ (%) | | |
| **CP5** | 0.98 | 20.37 | 17.45 | 11.27 | 12.27 | 28.62 | 0.32 |
| **CP6** | 1.19 | 20.95 | 16.33 | 11.33 | 12.31 | 29.74 | 0.38 |
| **CS5** | 1.11 | 21.98 | 20.14 | 11.45 | 12.23 | 31.11 | 0.62 |
| **CS6** | 1.24 | 22.60 | 18.89 | 11.85 | 12.25 | 32.33 | 0.75 |

The fibre volume fractions of kenaf fabric ($V_{kf}$) are found to be higher than that of the carbon fabric ($V_{cf}$). Fibre volume fraction is the ratio of fibre volume by composite volume and mostly depends on the density of materials used in composite production [23]. Composites made from kenaf fabric significantly increased its weight fraction and volume fraction as different weave design and different fabric count are used. On the other hand, carbon fibre maintained its weight fraction (11.27-12.0%) and volume fraction (12.23-12.31%) irrespective of weave design or fabric count used.

Table 2 also shows that the kenaf fabric significantly affected the total fibre volume fraction of composite ($V_f$) meanwhile the $V_{cf}$ are almost same. Kenaf fabrics with satin design are higher in volume fraction ($V_{kf}$) compared to plain design, which is important in the determination of tensile properties. According to Yahaya et al. [22], volume percentage of kenaf was highly related to tensile strength and tensile modulus; high volume percentage of kenaf fabric decrease the tensile strength about 50% of woven kenaf/Kevlar epoxy composite. Composite at 6x6 of fabric count found to have higher value in $V_f$ than those of 5x5. The introduction of fabric count of 6x6 increase the $V_{kf}$ by 8 to 10%, which implies

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that $V_f$ governed by kenaf fabric than carbon fabric.

The void content of the composite of different types is shown in Table 2. Apparently, S6 (Satin, 6x6 fabric count) gives the highest void content despite having the highest density and $V_f$. Two plausible explanation for this are: (1) satin fabric has loose structure compared to plain fabric, thus resulted in higher void content, and (2) 6x6 fabric count structure was very tight, thus the flow of the resin is less efficient and subsequently creating voids and delaminations between the fibres. According to Goodwin et al. [24], in the satin fabric laminates composites, the number of voids is higher than in plain fabric laminates composites and reflected in the reduction on shear strength value. They found that higher numbers of cracks formed in the satin composites as a result of higher void content. It can be concluded that, weave design and fabric count of kenaf fabric had influenced the $V_f$ and void contents which can lead to different performance in composite properties, specifically tensile.

**Mechanical Properties of kenaf/carbon fibre hybrid woven composite.**

The results of the ANOVA conducted on the effect of the fabric count and weave design and their interaction on the mechanical properties are presented in Table 3. The ANOVA results suggest that there is no interaction effect between both fabric count and weave design on all the properties except for flexural strength which is also very low ($p \leq 0.10$). Examination on the main effects suggest that only weave design has some influences on the strength properties of the composite. Both tensile modulus and flexural strength were not affected by any factors. Very high significance were detected for the effects of weave design on tensile strength ($p \leq 0.01$), flexural modulus, impact strength and impact energy all at $p \leq 0.05$. Hence the following discussions are based on factors that have significant effects on the mechanical properties of kenaf/carbon fibre hybrid woven composites.

**Table 3. Summary of ANOVA on the mechanical properties of kenaf/carbon fibre hybrid woven composite.**

| Variables | df | p-value | | | | | |
|---|---|---|---|---|---|---|---|
| | | Tensile Strength | Tensile Modulus | Flexural Strength | Flexural Modulus | Impact Strength | Impact Energy |

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| | | (MPa) | (GPa) | (MPa) | (GPa) | (kJ/m$^2$) | (J) |
|---|---|---|---|---|---|---|---|
| **Fabric Count (FC)** | 2 | n.s | n.s | n.s | n.s | n.s | n.s |
| **Weave Design (WD)** | 2 | *** | n.s | n.s | ** | ** | ** |
| **Interaction (FC x WD)** | 4 | n.s | n.s | * | n.s | n.s | n.s |

Note : *** : Significantly different at p≤ 0.01, ** : Significantly different at p≤ 0.05,
* : Significantly different at p≤ 0.10, ns : not significant

### Tensile Strength

Tensile strength is related to the ability of the sample to resist deformation in tension while the tensile modulus measures the capacity of stress uptake in the composite. This properties depends mainly on the weaving factors such as yarn linear density, weave design, fabric density or yarn spacing, fabric crimp. It also influenced on the lamination structures (fibre/fabric orientations, fibre volume fraction) as well as the inherent properties of the materials, i.e. fibres and matrix. [22, 25, 26]. As shown in Table 4, tensile strength is significantly affected by different weave design used. Composites made from satin-designed kenaf fabric had significantly lower tensile strength and modulus than those made with plain-designed kenaf fabric, where reduction of 14.76% and 8.42%, respectively were observed. This finding was supported by Chow et al. [27] who found that plain woven composite leads to an improvement in tensile strength and modulus, contributed from the minimum force development caused by the distribution of load transfer along the fibre direction. Furthermore, plain fabric has higher fabric strength and modulus than satin fabric, thus are able to withstand higher tensile load.

**Table 4. Effect of kenaf weave design on the tensile strength of kenaf/carbon fibre hybrid woven composite.**

| Weave Design | Tensile Strength (MPa) | Tensile Modulus (GPa) |
|---|---|---|
| **Plain** | 122.04$^a$ | 7.97$^a$ |
| **Satin** | 104.96$^b$ | 7.30$^b$ |
| **LSD** | 8.3841 | 1.157 |

Note : Means are average of ten specimens.

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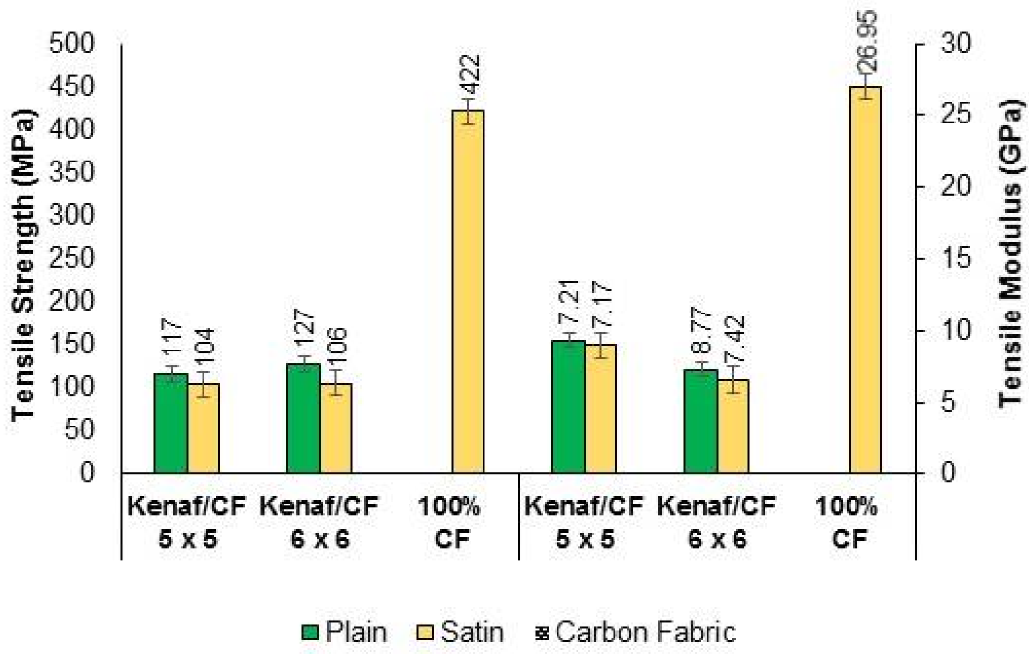


**Figure 1. Tensile strength and tensile modulus of kenaf/carbon fibre hybrid woven composite**

Figure 1 shows the tensile strength values of all types of kenaf/carbon fibre hybrid woven composite and carbon fibre composite. In general, it can be seen that both tensile properties of the plain-designed composite were much higher than those of satin-design composite, irrespective of fabric count (5x5 or 6x6). This is in agreement with Salman et al. [28], who also highlighted that plain fabric composite resulted in better tensile properties. They attributed this strength to a more uniform distribution of tensile load transfer in both warp and weft direction in plain fabric than in satin fabric. The former contains symmetrical fabric structure and therefore able to provide a much more consistent transfer of stress from one layer to another fibre layer.

When loaded in tension, i.e. tensile test, the composite experienced fractures in the transverse direction which normally associated with extensive longitudinal splitting or failure of the specimens as shown in Figure 2. Morphological analysis on damaged areas suggests that the transversal cracks are apparently developed perpendicularly to the loading direction i.e. in the transverse direction [29-30]. The crack promotes further

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delamination and failure of the specimens. Rios-soberanis et al. [29] explained that transversal cracks would usually lead to small delamination in the interlacement interface area between yarns. They also identified that the interlacement of warp-weft yarn is the origin of the cracks that occurred due to high stress concentrations hence acting as crack-initiation points.

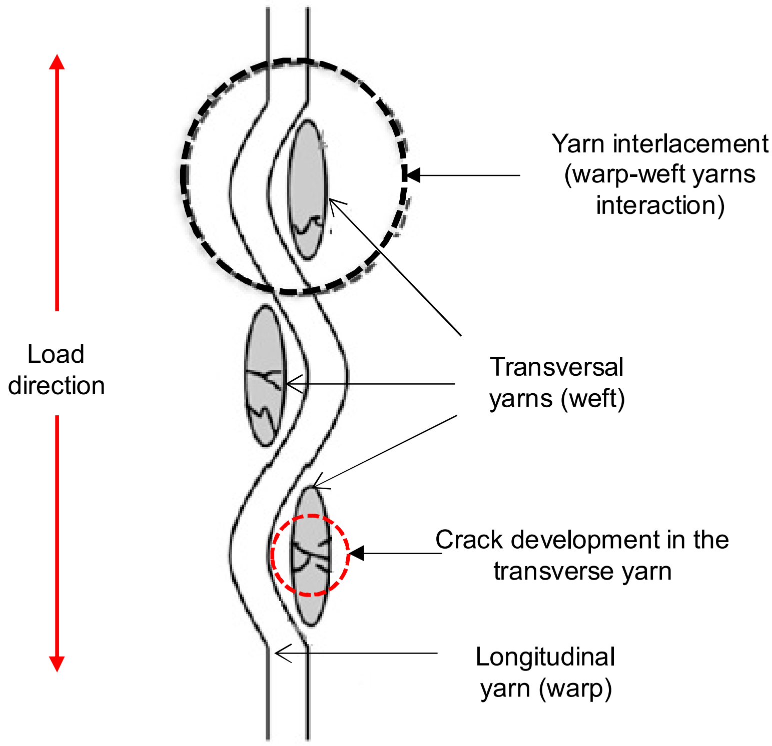


**Figure 2. Development of failure perpendicular to the loading direction i.e. in transverse direction [29].**

This is in agreement with the findings of Salman et al. [28], who found that higher tensile strength and tensile modulus of j plain fabric is associated to the differences in the load-distribution properties of the yarns along the longitudinal and transverse directions, which resulted in higher stress uptake capacity. Furthermore, the yarn orientation in the plain fabric, i.e. criss-cross arrangement and interlocking structure, decelerates the initiation and propagation of microscopic cracks through the matrix, and leads to higher tensile

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strength [31]. In other study conducted by McDaniels et al. [32], tensile loading in fabrics induce transverse loads at warp-weft yarn overlap section (yarn interlacement) as crimped yarns tend to straighten. This reduces the translation of fibre strength to fabric strength and decreases long-term fatigue and creep rupture performance.

Figure 3 and 4 show the cross section view of (a) warp direction and (b) weft view of laminated woven composite from plain fabric and satin fabric, respectively under optical microscope. The frequency of yarn interlacing and the linearity of the yarn segments distinguish both fabrics. The plain weave has the highest frequency of yarn interlacing, whereas the satin weave has the least number of yarn interlacing. Due to more consistent and higher amount of yarn-to-yarn interlacement in plain-designed composite, the applied stress are distributed uniformly and the cracks ran transversally in all direction, perpendicular to the loading direction due to isotropic woven packing. This type of composite has high number of yarn interlacement thus can withstand greater tension that hold to each other, stress transfer gradually to the adjacent yarn and resulted in less slippage in the structure. Nonetheless, in the satin-designed composite, there is anisotropic arrangement of yarns in the packing structure, thus lacks uniform distribution of force along the applied stress to support the transference of load. Hence, cracks and damages are easily formed due to insufficient of test sample to support the tension load. In addition, there are higher number of floating yarn in satin arrangement cooperate with loose satin structure, led to stress transfer intermittently to neighboured yarn and consequently reducing the strength because the failure are easily occur at this zone and disseminate to the adjacent yarns.

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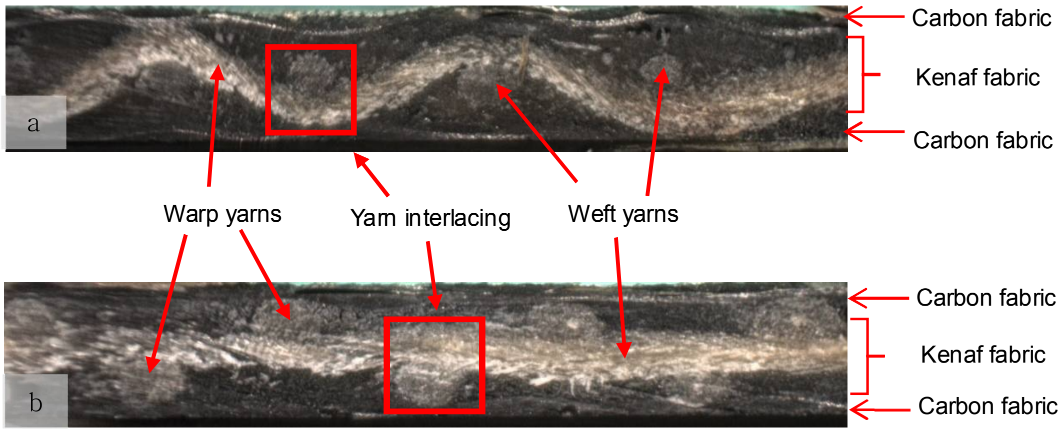


**Figure 3. Cross section view of (a) warp direction and (b) weft view of laminated woven composite from plain fabric under optical microscope.**

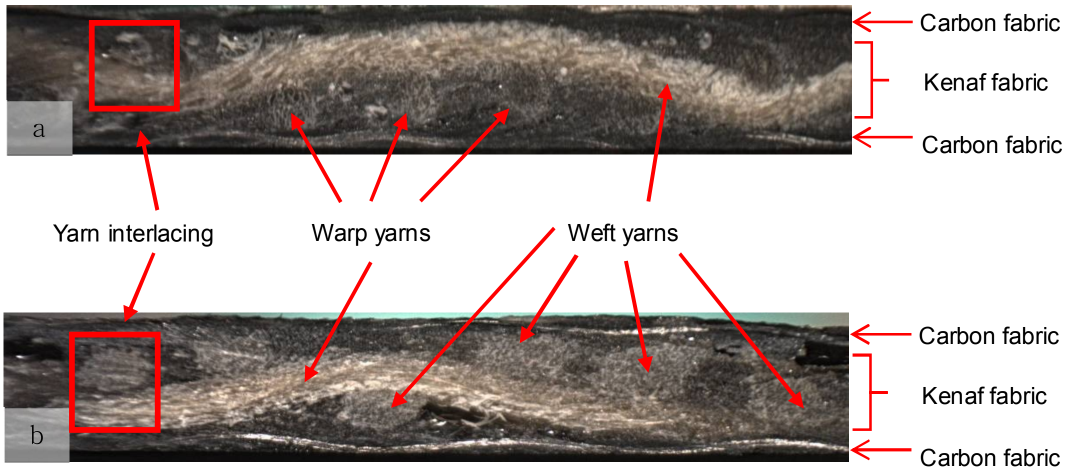


**Figure 4. Cross section view of (a) warp direction and (b) weft view of laminated woven composite from satin fabric under optical microscope.**

The morphology of the tensile tested composites of the kenaf/carbon fibre hybrid woven composite for plain and satin fabric are shown in Figure 5. Figures 5a and 5b show the cross-sectional view at the fracture surface of tensile failure test for plain and satin woven composite, respectively. More severe broken yarns are observed on the failed specimens of satin-designed composite compared to those of plain-designed composite. The latter appears to have better bonding (Figure 5c) as shown by the presence of most parts of the failed fibres are still in the form of aggregates except for a small number of individual pull-out fibres. Satin-designed composite seems to experience serious interfacial debonding particularly at the fibre bundles of the kenaf yarns (Figure 5d). It is noted that

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empty fibres regions (i.e. voids) are also present which was caused by the tensile force under tension loading. High magnification of SEM images of the failure fracture surface confirmed that the mode of failure was due to either fiber fracture, pull-out fibers and voids and their combinations which resulted from different fibre structure in the core layer of the kenaf/carbon fibre hybrid woven composite (Figures 5e and 5f) According to Zhou et al. [33], the interfacial debonding and matrix failure are closely associated to the interlaced constitution of the woven fabrics. Additionally, the tensile stresses from tensile load shifting from matrix to yarns up to optimum stresses that can overcome the friction resistance. The weak bonding strength of epoxy-yarn make the fibre bundles break and pulled out from the matrix.

Several researchers highlighted that the fibre volume fraction and void content of composite influenced the mechanical properties particularly tensile properties [26, 34,35]. Junior et al. [36] found that tensile behaviour of ramie/cotton polyester composite was governed mainly by volume fraction, rather than yarn size and fabric compactness. On the other hand, Zhu et al. [37] reported that tensile strength of carbon-epoxy laminated composite reduced as the void content increased because of the void introduce initiation and formation of the cracks in composite structure. Hernandez et al. [38] found the increasing in void content was related to the result of air trap and wrinkles created during lay-up process. In addition, they also mentioned that voids are oriented parallel to the fibers and concentrated along the laminate as a result of the inhomogeneous process of consolidation and resin flow along the fibers. In this study, all composites made using plain woven kenaf fabric in the core have relatively higher tensile strength and tensile modulus than those made using satin woven kenaf fabric. Apparently, the trend in tensile properties was affected more by the weave design instead of fabric count for the case of fibre volume fraction. Higher fibre volume fraction significantly increased the tensile strength. As shown in Table 2, the total volume fraction (Vf) of composite made with plain woven kenaf fabric in the core is markedly higher than that of with satin.

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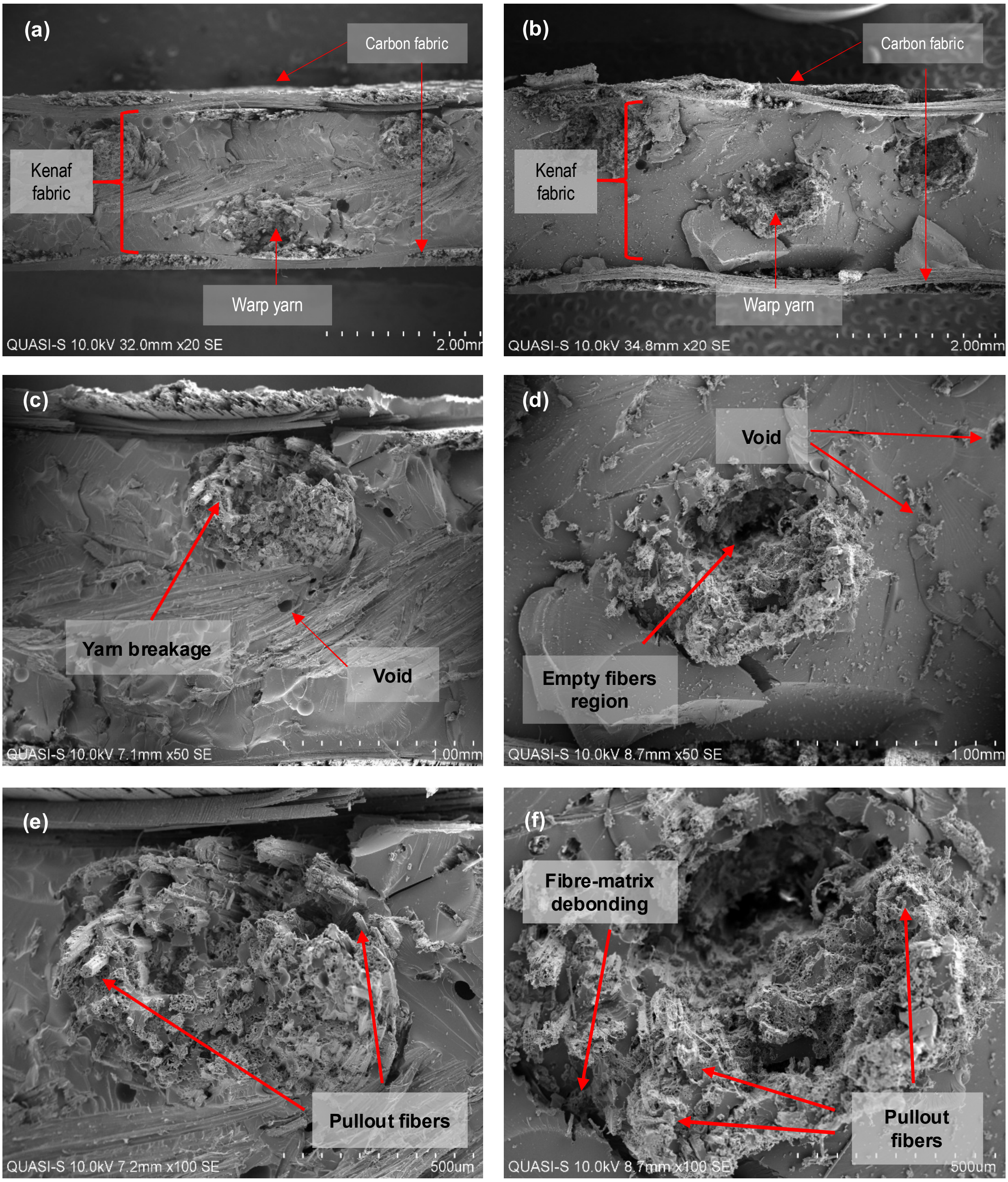


**Figure 5. The SEM micrograph of tensile fracture surface of laminated woven kenaf composite. (a) fracture surface at low magnification of plain-designed composite and (b) satin-designed composite; (c) yarn fracture in plain-designed composite and (d) yarn fracture in satin-designed composite; (e) fibre pullout in plain-designed composite at 100X magnification and (f) fibre-matrix debonding and pullout in satin-designed composite at 100X magnification.**

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**Flexural Strength**

Flexural strength of composite determine the capability of materials to withstand the bending before breaking and normally it's depend on types of polymer and the fibre orientation. On the other hand, flexural modulus or bend modulus is a measure of materials stiffness and resistance to deformation of the composite in bending. Flexural properties also integrated with the interfacial bonding between matrix and polymeric resin. From ANOVA table in Table 3, only weave design have significant effects on flexural modulus of the composite. The flexural strength of the hybrid woven composite was not significantly influenced by both the fabric count (5x5 or 6x6) and weave design (plain or satin fabric). However, the flexural modulus was significantly affected by the weave design of the kenaf fabric used in the core layer of the composite. For instance, by changing the fabric type from satin to plain the flexural modulus improved from 16.28 to 17.74 GPa or 9% improvement. Table 5 shows the main effect of weave design on flexural modulus.

**Table 5. Flexural properties of composite at different weave design**

| Weave Design | Flexural Modulus (GPa) |
|---|---|
| **Plain** | 17.74$^{a}$ |
| **Satin** | 16.28$^{b}$ |
| **LSD** | 1.209 |

Comparison of the composite flexural properties as affected by different combination of fabric count and weave design are shown in Figure 6. From the figure, CP5 exhibited the highest flexural strength (224.33 MPa) and CP6 exhibited the highest flexural modulus (17.79 GPa), while CS6 showed the lowest value of flexural strength (185.04 MPa) and CS5 showed lowest value of flexural modulus (16.17 GPa).

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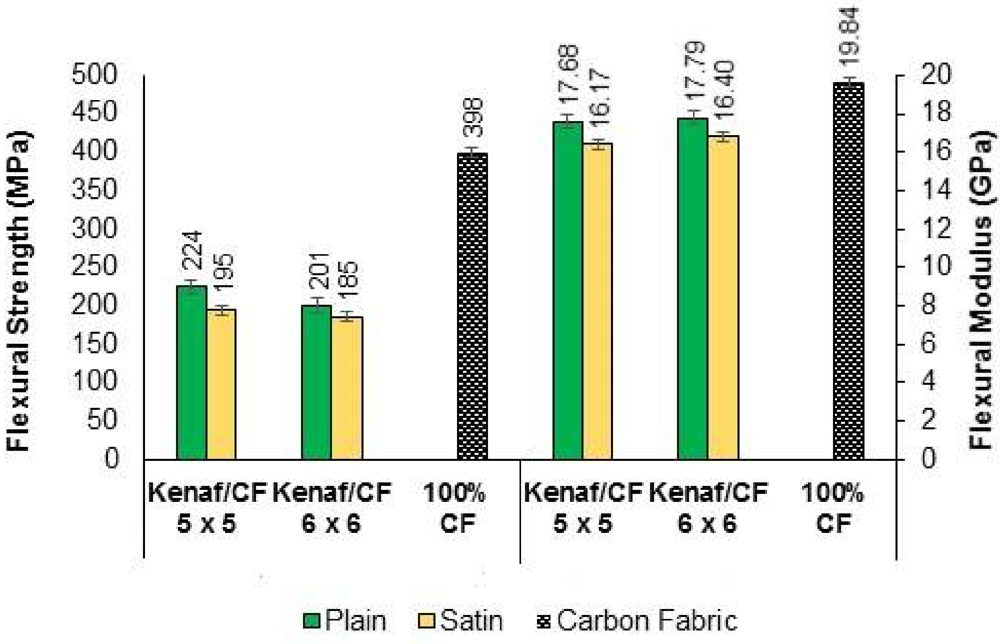


**Figure 6. Flexural strength and flexural modulus of kenaf/carbon fibre hybrid woven composite**

All the hybrid composites have significantly lower flexural strength than the 100% carbon fibre laminates. This is expected as carbon fibre can transfer and withstand flexural load more efficiently owing to the strength and rigidity of a carbon fiber component is created by positioning fabrics in a specific way. The relatively higher flexural strength for composite made from plain fabric was largely attributed to the interlocking structure of plain fabric. In plain fabric, the warp and weft yarn are aligned and formed a criss-cross arrangement. This type of yarn arrangement prevent any extension of the yarn along the load directions, which increase the bending load capacity and resulted in better composite strength properties. The effect of fibre orientation on the flexural modulus have been reported by many studies [13, 28, 39, 40]. Fibre orientation affects the flexural properties by influencing the whole yarn structure, yielding an improved in fabric orientation. This better fabric arrangement can explain the increased in flexural strength of woven composite made with plain-weave fabric.

Furthermore, in satin-weave fabric, there is a complex arrangement of warp and weft yarns, which allows longer float yarns across the warp/weft yarns. The less stable

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arrangement in satin fabric obstructed distribution of this load, giving low flexural strength, as shown by the fibre breakage and pull-outs, indicating there is a disorder arrangement of fiber as observed on the SEM images of the tested specimens shown in Figure 7. In addition, plain weave fabric has better wetting properties since it contains large amount of fibres and higher kinetics rate of water absorption [41, 42]. The good wetting properties give rise to resin penetration and subsequently produced composite with better strength properties. According to Salman et al. [28], flexural properties of composites also influenced by the adhesion and interfacial bonding between matrix and reinforcement materials.

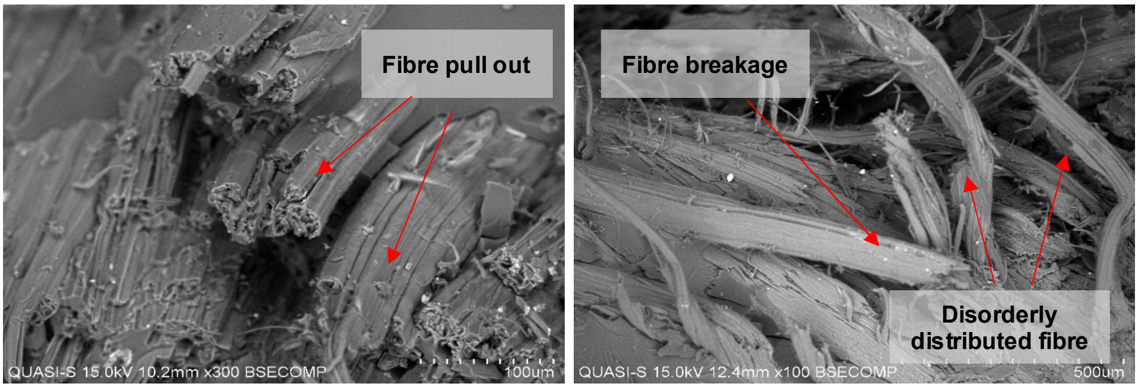


**Figure 7. SEM micrograph images of the flexural failure surfaces of kenaf/carbon fibre hybrid woven composite.**

In the case of flexural modulus, the values obtained from samples with 100% carbon fibre is higher than that obtained with the samples of hybrid with kenaf fibre. However, it was observed that kenaf/carbon fibre hybrid woven composite have comparable flexural modulus values when compared to pure carbon fibre composite. A significant increase of flexural modulus in kenaf fabric of 6x6 fabric count are used, both for composites with plain and satin design, is observed when compared to composite with 5x5 of fabric count. In the three-point flexural test, a vertical load is applied, the compression load associated with the deformation is generated on that upper side, whereas on the opposite side, a tensile load is generated, leading to a tensile deformation of test specimens. Since the sample experiences both the compressive and tensile forces during a flexural test, this may explain the greater sensitivity of the flexural data to this phenomenon.

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According to Dhakal et al. (2013), in the flexural test, surface of the composite is subjects to higher compression stress that the core part, thus the flexural modulus is controlled by the strength of the intense reinforcement, i.e the kenaf fabric in this study [43]. The kenaf fabric stiffness is apparently dependent on fabric arrangements, such increment of the modulus with the fabric sturcture implied a good dispersion of the reinforcements. The function of kenaf fibers as a rigid filler was assumed to enhance the stiffness of polymer matrix and its strong interaction with epoxy matrix [44]. This implies that the stronger carbon fibers in the outer layers might have influenced the flexural strength of hybrid woven composites, meanwhile kenaf fibers play a major role in increasing the stiffness of hybrid woven composites by offset the low elongation of kenaf fabric. A similar finding was found, where hybridisation of woven flax with carbon fibre has beneficial effect on flexural strength, modulus and elongation of hybrid composite [43]. On the other hand, Lee et al. [45] also concluded that flexural modulus is dominantly affected by the effectiveness of epoxy resin with the reinforcement materials.

Even though fabric count has no significant effects on both flexural strength and flexural modulus, it is interesting to note that fabric count of 5x5 consistently produced higher flexural strength and modulus. This may be due to the effectiveness of epoxy resin in 5x5 fabric to spread into kenaf and carbon fabric, hence enhancing kenaf-carbon bonding adhesion. In 5x5 fabric, less fabric tightness was found than in 6x6 fabric due to less yarn numbers, hence higher mobility and wetting properties within the fabric structure. It appears that higher porosity in the 5x5 fabric provides better penetration of epoxy resin. Conversely, the higher tightness in the 6x6 fabric provide poor resin penetration resulting in composites of low in flexural strength due to the presence of ‘resin-rich-area’ as more resin being accumulated on the surface instead of penetrating into the next layer. This area influenced the composite properties as it is the weakest point where poor bonding between fabric and epoxy that creates crack propagating through the epoxy matrix (Figure 8) reaches a kenaf fiber causing decohesion and separation of fibrils and consequently reduced its strength.

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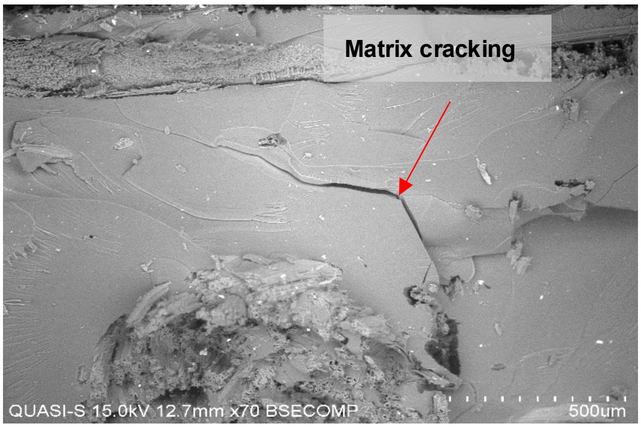


**Figure 8. Matrix cracking is observed at resin rich area in 6x6 fabric.**

**Impact Strength**

Impact strength of composite determine the total impact energy needed to fracture the specimen, how resistance of a material to fracture under a sudden impact and reflect to energy absorption capability of the composite. It is a measure of the toughness of the material. Joseph et al. [46] mentioned that, the impact strength of composite is driven by several factors, include the types of polymers, fibre-matrix interface, structure and arrangement of materials used for composite. On the other hand, energy absorbed is a total energy being absorbed by the material in a complete penetration.

The ANOVA results in Table 3 suggest that weave design was significant effect on both impact strength and energy absorbed of the composite whilst fabric count has no marked influence on impact properties. Figure 9 presents the impact strength and energy absorbed of kenaf/carbon fibre hybrid woven composite. All of the hybrid composites CP5, CP6, CS5 and CS6 has low impact energy compared to 100% carbon fibre laminated composite, CF. In contrast, results for energy absorbed show that hybrid woven composite resulted in comparable values with carbon fibre laminated composite.

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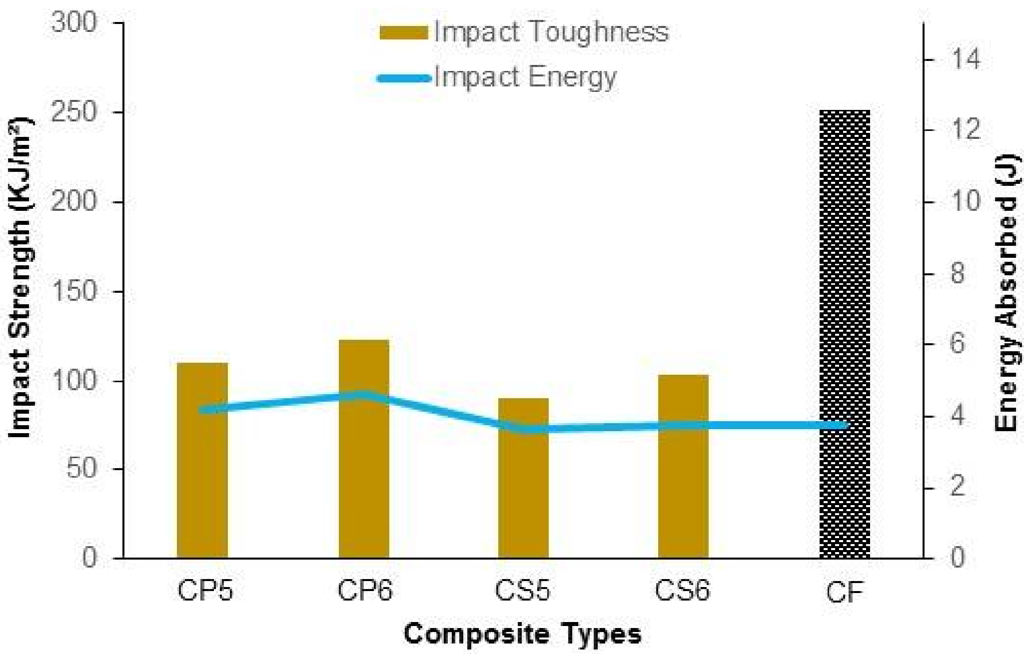


**Figure 9. Impact strength and total energy of kenaf/carbon fibre hybrid woven composite and carbon fibre composite**

Based on the results, the impact strength of sample CP6 was highest in impact strength and energy absorbed with the values of 123.07KJ/m² and 4.62J, respectively. As expected, the weave design is found to be the main factors contributing to the improvement of impact strength of specimen. This could be due to plain fabric in the composite has higher energy absorption capacity associated from its interlocking structure that contributed to composite strength [47]. In addition, plain fabric also has high elongation capabilities which lead to high impact strength compared to satin fabric. The tightening effect of plain fabric have increased the specimen stiffness, stiffer materials deform less and carry higher load and increased its ability to absorb impacts [48]. When the impact load is applied on the specimen, the upper layer is under compression stress while lower layer is under tension stress. The middle layer is put in a shear stress. The woven fabrics structure parameters in the middle layer effect on the resistance behavior during load. Throughout the impact load, cracks start at the impact side and spread into the loading direction, while Figure 10 shows the typical impact damage mode in composite laminate. The middle layer of shear strength help in absorbing a large amount

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of impact energy. The firm structure of plain fabric offers an obstacle to the spread of further crack by absorbing and disseminating the impact stress before failure. Conversely, satin fabric contains more floating yarn that can bring to the yarn slip phenomena [49]. This phenomena happens in satin fabric because of less number of interlacements between warp and weft yarn, thus some of yarns are not hold firmly and only few grips in the satin structure resulted in low absorbing impact energy. Fiber breakage and fiber pull out are occurred due to maximum energy absorption which leads to delamination.

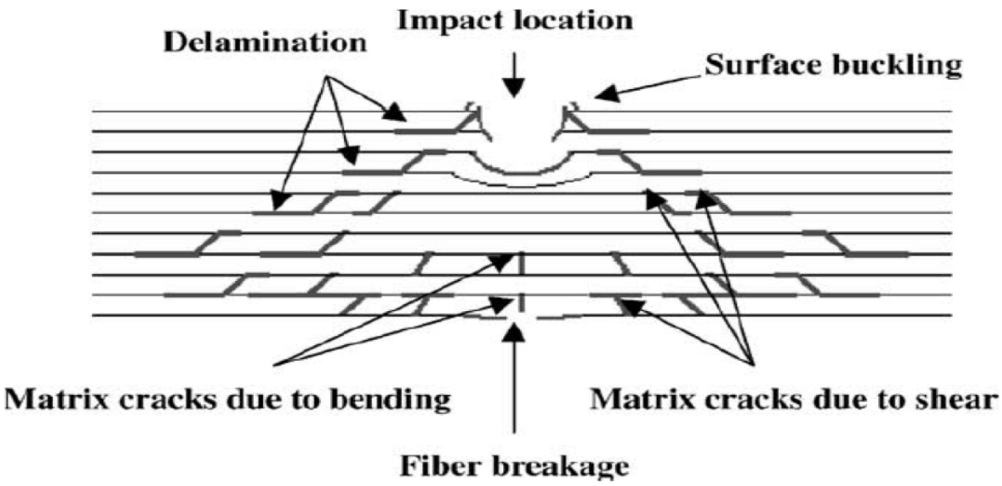


**Figure 10. Schematic representation showing a typical impact damage mode for a composite laminate [50].**

As noticed in Figure 9, hybrid composite with kenaf fabric resulted in better energy absorbed, particularly in the case of CP6 that shows significant increment (22.47%) when plain fabric with 6x6 of fabric count was used as core in the composite. It also found that hybrid with kenaf plain-designed composite perform better energy absorption than satin-designed composite, and slightly higher than carbon fibre composite (CCF). This finding is in agreement with research work done by Wambua et al. [51] that showed by incorporating natural fibres (flax, hemp and jute) in the woven form at the middle layer of natural fibres/mild steel hybrids composite, resulted in better energy absorption due to higher strain to failure properties of the hybrid composites. This is related to the unique energy absorption properties by natural fibres that acted as a stiff layer to deflect and

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absorb more impact energy, compared to carbon fibre that was more brittle. Furthermore, fibres derived from plants has low level of embodied energy than synthetic fibres and contain cellulose as their major structural component. High cellulose content and cellulose microfibrils aligned in the fibre direction give higher performance in energy absorbtion as well as the cellulose-based natural fibres having higher specific Young's modulus and tensile strengths than synthetic fibres [52]. This leads to the novel concept of using natural fibres in woven type to increase the inter yarn friction of the fabrics during impact.

Based on the morphology of the impact fractured surface in Figure 11, it was observed that composites failed by a combination of intense fibre pull out, fibre breakage, delamination between layers and voids in the composite, with occurred more in the specimen with satin fabric compared with the specimen with plain fabric. Some of these failure modes were also observed on the plain fabric samples, but the extent of the failures differed from that of satin fabric sample. Many researchers [53-55] mentioned that weave design was responsible for determining the impact toughness of the composite. Carbon fiber and epoxy matrix are sheared and delaminated as shown in the Figure 11a. A crack through the woven carbon/kenaf and epoxy interface after the failure can be seen clearly, indicating that the phenomenon of fibre pull-out happened to a large degree (Figure 11 b and c). This failure mode is in agreement with Aly et al. [53] who studied the effect of different structure parameters such as weft yarn material, picks densities, as well as weaving structures on the impact properties of flax fibre reinforced epoxy composite. They concluded that the impact properties are strongly affected by woven fabric structure and the resin properties. The failure mechanisms described above were also observed in this study. Another factor that may be influence this result is related to the plain fabric's high cover factor and porosity values. Plain fabrics are better in interfacial adhesion due to its higher cover factor and porosity, which leads to good resin-fabrics penetration. Thus, the composites experienced less kenaf fibre pull out and void in the composite, resulting in high impact resistance. Pickering et al. [52] mentioned that the impact absorption capability of composite material depends upon the interfacial strength between the fibers and the matrix [52]. These findings also supported by Salman et al. [28], who stated that

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the plain fabric could add structural strength and leads to increase in the strength as well as energy absorption capacity of the composite.

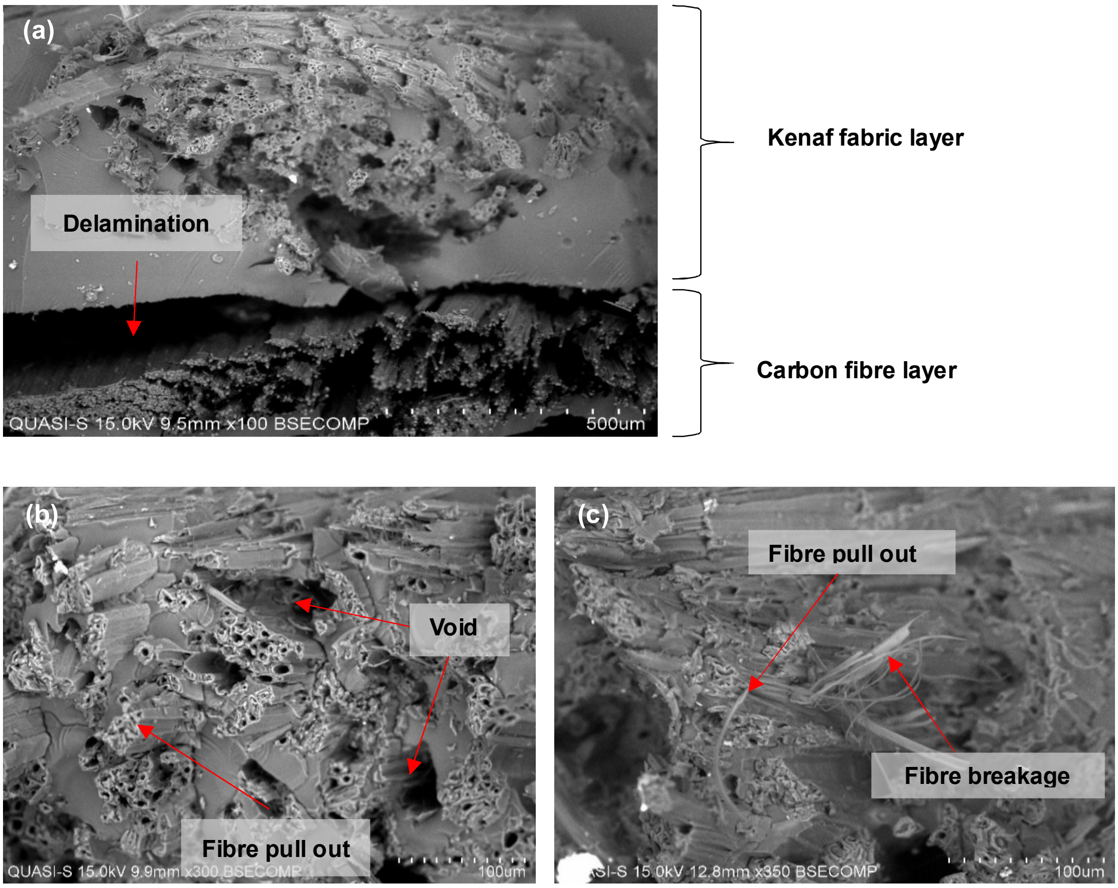


**Figure 11. The SEM micrograph of impact fracture surface of laminated satin woven kenaf composite. (a) Delamination between layers; (b and c) fibre pull out, breakage and voids can be observed at higher magnifications in satin-designed composite.**

It was particularly noticeable that the impact properties increased with an increasing in fabric count to 6x6. This indicates that the addition of fiber content in the composites has increased energy absorption capacity or makes the composite to be more resistance to impact stress. This can be interpreted that increasing the number of warp yarn leads to increasing the numbers of yarns bearing the impact load. This is an agreement with the study by Wong et al. [56] who found that increasing the fibre content in composite increased its strength properties due to impact stress can be distribute efficiently in the

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composite with higher amount of fibres and increase delaying delamination. Closer weave structure improves energy absorption because high fabric density slow down crack growth and resulted in a smaller damage length [57]. Moreover, woven composite with high fabric density have higher impact and damage tolerance due to reduced impact damage resulted from the higher number of yarn interlacement in a preform [58]. Hosur et al. [59] observed that the impact response of plain fabric composites reduced the delamination initiation due to fibre interlacement in their structure. They also indicated that bottom layer of the woven laminates did not split during impact loading. Plain fabric composite also have better impact resistance due to higher transverse strength in woven composites provided by the interlacement of the weft and warp yarns in the preform [60]. Furthermore, CP6 fabric and carbon fibre bond better with the epoxy resin, provide better adhesion between fabric and resin, thus less fibre pullout and created strong bonding. This bonding resulted in great amount of impact energy absorption and plain composite have a better impact strength than satin composite.

**Conclusion**

The mechanical properties of kenaf/carbon fibre hybrid woven composite were affected by the fabric count and weave design of fabric. Weave design was the more influential factor that affected most of the mechanical properties. The results showed the advantage of using plain fabric for tensile and impact strength compared to satin fabric, and using 5x5 of fabric count for flexural modulus compared with 6x6. The tensile and impact strength of the composite at fabric count of 6x6 was found to be higher than other composite indicated that composites strongly determined by the fabric structure, fabric strength and fibre content. While, plain fabric at 5x5 of fabric count showed higher flexural strength due to the better adhesion of kenaf fabric in the epoxy resin. SEM examinations of failure test specimens show that poor adhesion in the composite structure and failed by fibre pullout, fibre-resin debonding and some voids. The increment of fibre volume fraction and reduction of void content has increased the tensile strength of composite simultaneously.

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