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Mechanical and physical performance of filament wound kenaf/unsaturated polyester composites

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ABSTRACT

This study introduces the advantage of using kenaf fiber as a composite to replace the present material such as synthetic fiber, in order to achieve environmental friendly and biodegradable materials. The physical properties such as moisture content (MC) and water absorption (WA) of the single yarn fibers were determined. Composite specimens were fabricated using filament winding technique. The experimental tensile test was investigated on/with the effect of winding angle on a filament wound kenaf yarn fiber-reinforced with an unsaturated polyester composite.

Keywords: *filament winding; kenaf; unsaturated polyester; winding angles.*

1. INTRODUCTION

Natural fibers such coir, sisal, hemp, jute and flax have attracted the attention of many researchers to develop environmentally friendly and sustainable ‘green’ composites based on plant fibers (Habiba et al., 2015, Satyanarayana 2015, Faris 2015). These materials have good mechanical properties such as high tensile strength for low density, low environmental impact, renewability, recyclability and low cost (Dario et al., 2015). The recent research processing the natural fibers a filler of polymer based composite materials. This reinforcement of those natural fibers can improve the mechanical properties of natural fibercomposites for the manufacture in the composites industry (Arifuzzaman et al., 2015), which produces potential to substitute synthetic fibers (Boon et al., 2015). These materials have found use in lower end applications such as furniture and automotive dash board.

Kenaf is a cheaper source and can be harvested in 4–5 months and consists of a core (65%) and bast fibers (35%) (Saba et al., 2015). The long bast fibers are being used in many applications including paper products, building materials, absorbents, livestock feed, protective packaging for fruits and vegetables, composite board and textiles and the filters. There are many benefits for using kenaf fibers, such as their minimal abrasive wear to machinery, low density, low production costs, high specific strength, good damage resistance (Ratna Prasad and Mohana Rao 2011, Faris 2015(2)) and extensive availability compared to other natural fibers (Salman et al., 2015). The researchers reported that kenaf fibers are suitable for reinforcement, as the fibers have strong interfacial adhesion with polymer resins (Umar et al., 2015). Noor conducted a study on the kenaf fiber reinforcement concrete, which presents kenaf fibre concrete enhanced more toughness and ductility behaviour compared with the conventional concrete (Noor et al., 2015). It shows the kenaf fiber composites are good in increasing the specific mechanical properties of the composite. The polyester resins are used in this study because they are cheaper than the epoxy resin.

Kenaf *(Hibiscus Cannabinus, L)* is an annual fiber crop that is related to cotton and okra. Presently, kenaf has been cultivated in Africa for its use in ropes and animal consumption (Kwon et al., 2014).

Martin et al. (2013) studied the influence of retting on the properties of measuring the degree of retting of single flax fiber/polypropylene composites, in order to optimize the reinforcement quality for composites.

A lot of studies on kenaf composites were conducted toward the improvement of the properties of the fibers and composites. The Kenaf has the potential to be used as reinforcement fiber in thermosets and thermoplastics composites. It is reported that the treatment by alkalization treatment has improved significantly the tensile properties of the short kenaf fibers, as compared to untreated short kenaf fibers (Meona et al.,2012). Hafizah et al. (2014) presented the experimental results of a series of tensile tests conducted on continuous kenaf fibers produced with different types of thermoset resin (epoxy, polyester, and vinyl ester), arranged longitudinally. They conclude that all the composites were brittle materials. Hayamet al. (2014) reported the different percentages of kenaf and polyester fibers in the yarn have some effects on the yarn quality, in terms of yarn strength and imperfections. Saiman et al. (2014) studied the effect of selected weave design has increased the tensile strength of the woven kenaf reinforced unsaturated polyester composite.

A study on renewable resource of natural fiber composite such as kenaf and reinforcement in polymer composite can increase the potential properties for application. (Nadia et al., 2014). Mansor et al. (2014) reported that the natural fiber, such as kenaf fiber polymer composites has potential into the component design and to apply it on automotive parking brake lever, using the integration of the Theory of Inventive Problem Solving (TRIZ), morphological chart and Analytic Hierarchy Process (AHP) methods. The aim is to generate and select the best concept design of the component based on the product design specifications with special attention to incorporate the use of natural fiber polymer composites into the component design. El-shekeil et al. (2013) studied the effect of kenaf bast fiber composites to optimize the processing parameters of processing temperature, time and speed and it showed that the processing temperature was the most significant parameter affecting the production of kenaf-bast-fiber, that reinforced the thermoplastic polyurethane composites.The researcher studied the optimization of the manufacturing process parameters of kenaf fiber reinforced the vinyl ester composites during the pultrusion process to define the best combination parameter and the most contributed parameter in the process through the analysis of variance “ANOVA”(Fairuz et al., 2015).

The effect for different winding angles in 45° and 90° wound of kenaf fiber composites, in experimental and simulation studies, is to investigate the behavior of composite hollow shafts, with a specific focus on the maximum torsion capacity of the composite hollow shaft (Misri(a) et al., 2015). They investigated the effect of filament winding angles on the crushing behavior of hollow kenaf fiber yarn reinforced unsaturated polyester composites produced by the filament winding technique. It is also found that it is very sensitive to the change in different winding angles between ± 45° and ± 90° in analyze the static crushing behavior of the structural hollow composite (Misri(b) et al., 2015).

The current product such as glass fiber can harm people and cause skin irritation. Furthermore, the cost for this man-made fiber is expensive in comparison to the natural fiber. Kenaf fiber got a great attention because of its advantage in lightweight, fast growing plant, and low cost production. This makes it suitable to become an alternative to building materials that are non-biodegradable (Subasinghe and Bhattacharyya, 2014).

Since the 1990s, natural fiber composites are emerging as realistic alternatives to glass-reinforced composites in many applications (Sallih et al., 2014). Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP), and china reed fiber-PP are particularly attractive in automotive applications because of lower cost and lower density. Glass fibers used for composites have density of 2.6 g/cm³ and cost between US $1.30 and US $2.00/kg. In comparison, flax fibers have a density of 1.5 g/cm³ and cost between US $0.22 and US $1.10/kg (Joshi et al., 2004).

In Polymer Matrix Composite (PMC), kenaf has good mechanical properties and can grow quickly. It can grow in height 4-5 m within 3-4 months. This means kenaf fiber composite can bring the same result in producing products same as wood. This can bring less deforestation of cutting timbers (Hashim et al., 2012).

Filament winding is a fabrication technique for forming reinforced plastic part of high strength and lightweight. Filament winding is the used of circumferential wrapping to increase the bursting strength. In the filament winding, the basic process is precision in high-speed positioning of continuous fiber in a pre-determined pattern. The process involves winding filament under varying amounts of tension over a mandrel. In this process, the method of winding can be divided into two, that is circumferential winding and the helical winding. The filament winding process can improve the production speed, volume, size and shape of the product (Lethiniemi et al., 2011). The product produced can be applied in storage tank, railway tank car, pipe, and also in aerospace. A study on the improvement of filament winding machine to be used with kenaf fiber composites was carried out. The major improvement was made on the use of fiber drum type of resin bath in place of an existing fiber dip type of resin bath, to utilize kenaf fiber yarn and unsaturated polyester (UPE) matrix to make a composite rod in hoop direction (Misri et al., 2013). In this study, the use of the filament winding machine was designed and developed by Abdalla et al. (2007). It is for the fabrication of pipes and round shape specimens (Abdalla et al., 2007).

This study is carried out because there are still lacks of research in kenaf fiber, including the strength of materials, and the suitable orientation during fabrication. Many kenaf composite researches have been carried out, but not the kenaf composite vessel. This is a preliminary study on the material’s properties of kenaf fiber hollow composite, especially on the tensile properties, that helps in understanding the strength of the material.

2. EXPERIMENTAL SECTION

2.1. Materials.

Figure 1. Single yarn kenaf fibers.

In this study, the polyester resin was mixed with catalyst MEKP (hardener) in the ratio of 10:1(Srivastava and Maurya, 2015). The fiber used was kenaf yarn supplied by Innovative Pultrusion Sdn. Bhd., Seremban, Malaysia. Figure 1shows the single yarn kenaf fibers.

2.2. Physical properties of single kenaf yarn fibers.

The chosen physical properties to be determined were water absorption and moisture content.

Water absorption,

$$\text{WA}\ (\%) = \frac{m_{c2} - m_{c1}}{m_{c1}} \times 100 \text{ (Equation 1)}$$

where, m_{c1} = Mass of fiber before soaking in water (g), m_{c2} = Mass of water swollen fiberafter soaking in water (g).

Moisture content,

$$\text{MC}\ (\%) = \frac{m_{ca} - m_{c0}}{m_{c0}} \times 100 \text{ (Equation 2)}$$

where, m_{ca} = mass of air dry fiber(g), m_{c0} = mass of oven dry fiber(g).

Water absorption (WA) of the fibers was determined by immersing the fibers in distilled water, placed in small glass vessels, maintained at 23℃ and left for 24 hours. At the end of the

24 hour period, the fibers were taken out from the distilled water and wiped off by using dried cloth. The fibers were then weighed immediately by using an analytical balance. For the determination of moisture content (MC), the fibers were dried in the oven for 24 hours at a constant temperature of 80℃. After 24 hours, the fibers were taken out from the oven and weighed using an analytical balance.

2.3. Tensile properties of single kenaf yarn fiber.

For the determination of tensile properties of single kenaf yarn fiber, a simple tensile test was carried out using a Universal Testing Machine (UTM) Instron model, with the load capacity of 5 kN as shown in Figure 2.

Figure 2. The single fiber was pulled in UTM foe tensile testing.

This machine is available in the Strength of Materials Laboratory, Department of Mechanical, Faculty of Engineering, University Putra Malaysia. The fibers were prepared with 10 mm gauge length and attached it to sand paper as shown in Figure 3, in order to avoid slip during testing. The fibers were tested with a speed rate of 0.3 mm/min.

Figure 3. Fiber sample for tensile test.

2.4. Filament winding process of kenaf yarn fiber composites.

A modification in the existing lathe machine was used to do the filament winding. The same machine was used to determine the torsional properties of the currently investigated composite materials. The hoop and helical winding were performed, whereby the unsaturated polyester (UP) impregnated yarn fibres was wounded on the rotation mandrel. The mandrel is made of a wooden plate as shown in Figure 4. Once the kenaf yarn fibre reinforced unsaturated polyester has been fabricated, it was cured in an oven at temperature of 80 ºC for 1 h. A mandrel is often used in fabricating industrial composite and natural fiber composite (kenaf) by using a filament winding process.

Figure 4. Filament winding of kenaf yarn fiber composite.

2.5. Tensile tests of filament wound kenaf yarn fiber composites.

Figure 5. UTM, Instron 3382 for tensile testing of kenaf composite.

Figure 6. 90° and ±45° specimens of kenaf yarn fiber composite when Given Load (Direction of load).

The procedure is based on the kenaf yarn fiber that was impregnated with resin prior to the winding around the mandrel surface, in order to produce a composite component. The mandrel was removed when the part have been cured. A new type of mandrel also has been invented to overcome the difficulty in removing the mandrel once the parts have been cured. This was achieved by creating a mandrel with an ability to change its shape.

For example, the mandrel become elastic when exposed to heat at a certain temperature and it becomes rigid after the cooling process. The shape of the mandrel can be reconstructed into the desired shape during heating to accommodate the removal of the mandrel from the composite parts. The control of speed of the moving carriage for the resin bath is necessary in fabricating the composite. Increasing the speed of the moving carriage can cause angle of yarn that was wound on the mandrel to decrease and the process as shown in Figure 4. The tensile test was conducted by using a universal testing machine, Instron 3382. Tensile test samples were cut in dimension gauge length of 50 mm and width of 25 mm on a vertical saw. The specimens were positioned vertically in the grips of the testing machine as shown in Figure 5. The direction of load of 90° and ±45° specimens of kenaf yarn fiber composite are shown in Figure 6. The grips were then tightened evenly and firmly to prevent any slippage. Tests were carried out at room temperature and each test was performed until tensile specimen failed. Samples of ±45^o and 90^o specimens were tested and the value was tabulated.

3. RESULTS SECTION

3.1. Physical, tensile and thermal properties of single kenaf yarn fiber.

Physical and mechanical properties of single yarn kenaf fiber are shown in Tables 1 and 2 respectively. The physical properties of the studied kenaf yarn fiber are moisture content (MC) and water absorption (WA) and for the mechanical properties, tensile strength, modulus and elongation at break were determined.

Table 1. Physical properties of single yarn kenaf fiber.

Physical property	Value
Moisture content (MC, %)	5.51~5.71
Water absorption (WA, %)	100.51~110.05

Table 2. Mechanical properties of single yarn kenaf fiber.

Mechanical property	Value
Tensile strength (MPa)	100.0~109.91
Tensile modulus (GPa)	20.50~30.71
Elongation at break (%)	0.95~1.8

Thermo gravimetrical analysis (TGA) gives the evidence that molecules were grafted onto the fibers at the optimal condition for kenaf fiber/unsaturated polyester composite, polyester composite and kenaf fiber. The obtained thermographs allow the evaluation of the mass changes that occur at different temperatures, indicating the transformations taking place at all times.

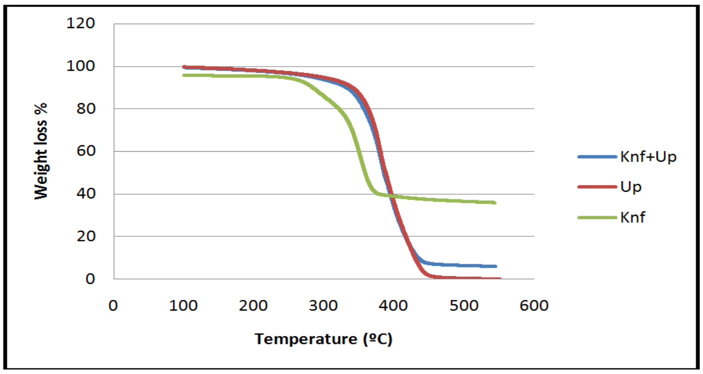

Figure 7. TGA of the kenaf fiber, polyester composite (UP) and kenaf fiber reinforced unsaturated polyester composite.

Figure 7 shows the weight loss as a function of temperature. Degradation of kenaf fiber/unsaturated polyester composite and polyester composite (UP) can be observed at 350 °C whereas kenaf fiber degrades at approximately 300 °C.

3.2. Effect winding angles on tensile properties of kenaf yarn fiber composites.

This section explained the effect of winding angle on the tensile testing of kenaf composites with two different winding angles (±45^o and 90^o). These are composites of filament wound kenaf yarn fiber with unsaturated polyester reinforced for ±45^o and 90^o winding angle.

Two specimens with different winding angles (±45^o and 90^o) were set to tensile test. Representative results for the kenaf yarn fiber-reinforced unsaturated polyester composite are presented and discussed in the following section. The stress-strain curve of two composites with different winding angles is shown in Figure 8.

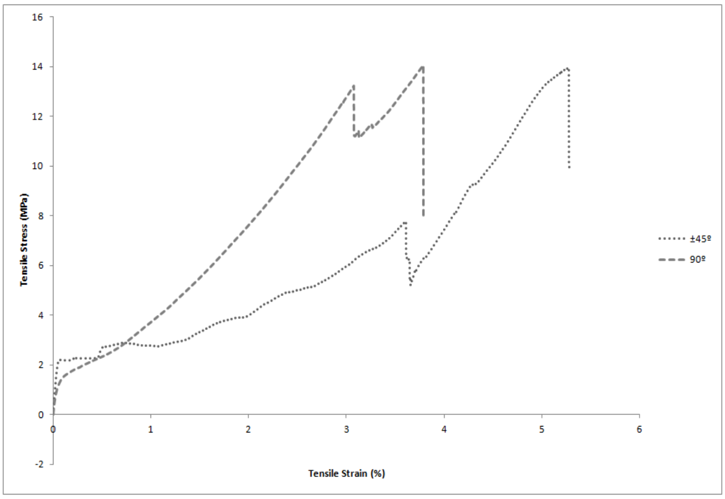

Figure 8. Tensile stress- strain curves for ±45° and 90° winding angles.

Table 3. Tensile behavior of ±45° and 90° winding angles.

Specimen	Tensile Strength (MPa)	Tensile Strain (mm)	Young's Modulus (GPa)	Toughness (MJ/m^3)
±45°	13.95	5.28	5.99	38.61
90°	14.04	3.79	4.03	27.80

Figure 8 shows the tensile stress-strain behavior for unsaturated polyester composite samples. At the elastic region of the curve, the ±45^o winding angle trend is steeper than the 90^o winding angle composite. This shows that ±45^o winding angle has higher modulus of elasticity than the 90^o winding angle specimen due to the effect of different winding angle. The same analysis of the effect of angle wound fiber composite reported by Lethtiniemi that the angles of ±45° filament winding should obtain the highest value (Lehtiniemi et al., 2011).

The differences in curve size of the two specimens can be clearly seen from the tensile stress-strain. The differences are due to the toughness of the composite, showing that composite has higher value of toughness and has bigger size of tensile stress-strain curve. Figure 9 shows the tensile strength of each specimen. In general, it clearly indicates that the 90^o winding angle composite (14.04MPa) has higher value of tensile strength than the ±45^{o}winding angle composite (13.95 MPa).

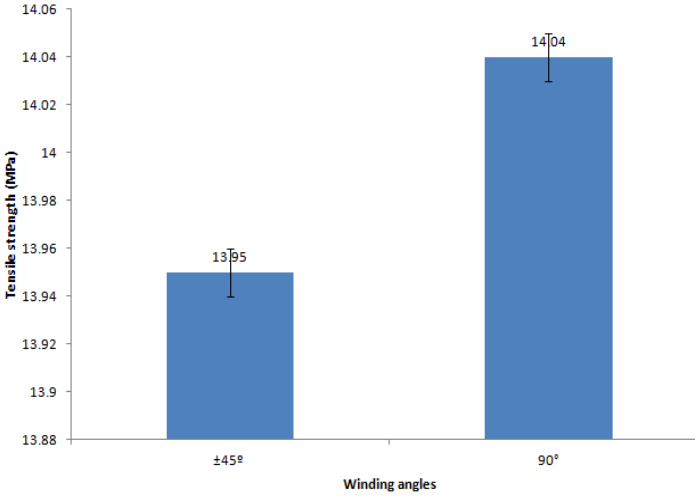

Figure 9. Tensile strength of ±45° and 90° winding angles.

Figure 10 shows the different values of tensile strain that were obtained from tensile stress-strain curve of specimens of ±45^o and 90^{o}winding angle kenaf yarn fiber composite. It is shown that the ±45° winding angles has higher tensile strain (5.28 %) than the 90^{o}winding angle (3.79 %), this is due to the difference in winding angle; the ±45^o angle makes the specimen bear more load before breaking.

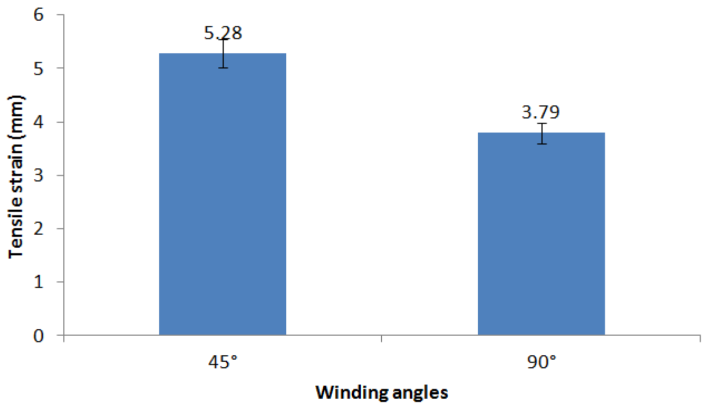

Figure 10. Tensile strain of ±45° and 90° composites.

The modulus of elasticity is one of the most important properties that can derive from tensile stress-strain curve. It is defined as the ability of the material to resist deformation in tension. The higher the modulus of elasticity is, the stiffer the materials are. The modulus of elasticity applies specifically to the situation of a component being stretched with a tensile force. The result of the modulus elasticity is shown in Figure 11, which is specimen of ±45^{o}that has higher tensile modulus than the specimen of 90^o. Theoretically, the tensile modulus or elasticity modulus is found to be increasing as the material gets stronger. Based on the result, the specimen of ±45° has a tensile modulus of 5.99GPa, while the specimen of 90^{o}has a tensile modulus of 4.03GPa. These results satisfy the theoretical result.

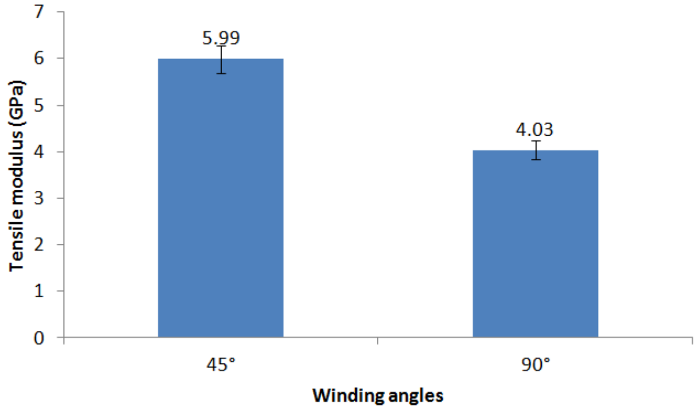

Figure 11. Tensile modulus of ±45° and 90° composites.

The toughness of the composites can be calculated based on the area under the graph. The equation is used to calculate the area under the graph for each specimen. This shows that composite ±45^o has 38.61 MJ/m³ while composite 90^o has 27.80 MJ/m³value of toughness (Figure 12).

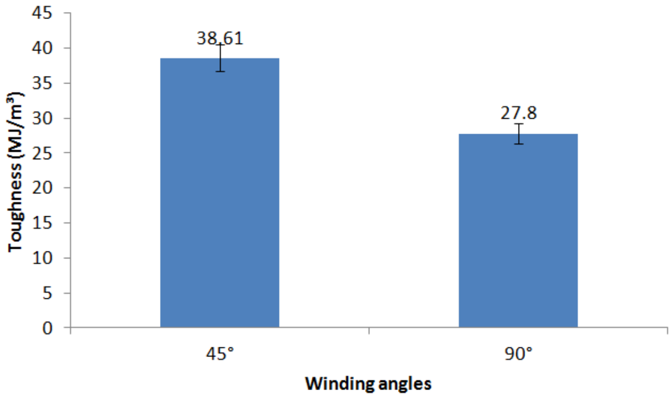

Figure 12. Toughness of 45° and 90° composites**.**

3.3. SEM micrographs.

Figure 13 shows the micrographs of the fracture surfaces of tensile kenaf yarn fiber composites specimens. The SEM micrograph shows the specimens of ±45° wound winding angle of kenaf yarn fiber UP composites. It shows that the fiber pull-outs are much longer and only few fiber debondings occurred during the fiber pull-outs of the matrix with the natural fiber of ±45° wound winding angle of the kenaf yarn fiber composite. The composite fracture surface show several toughening mechanisms such as fibrillated fiber upon fracturing of the fiber and massive step mark structures. The step mark structures are branches of new surfaces formed when the matrix absorbed the fracture energy from the applied stress during fracturing of the composites (Wouterson et al., 2007).

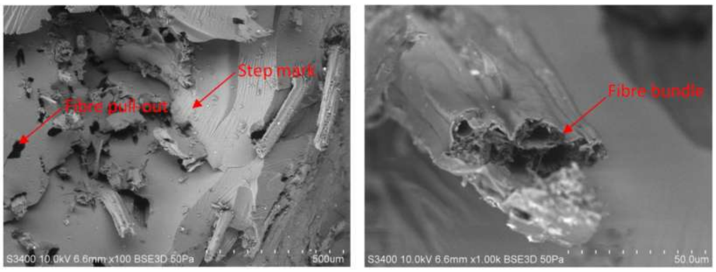

Figure 13. SEM micrographs of fractured specimens of kenaf yarn fibercomposites at ±45°wound of winding.

The fracture surface of the kenaf yarn fiber composites at 90° fiber wound winding angle in Figure 14 can be observed. The extensive fiber pull-out that was observed has clean fracture surface of the composites with no visible step marks. It was also observed from the SEM micrograph that the composite fracture surface shows a brittle fracture during the testing. The result of tensile strain and tensile modulus value of the composites of kenaf fiber at 90° wound winding angle lower than ±45 wound winding. This because a poor adhesion between the fibers and the matrix to absorb stress during failure. Thus, it is dependent upon the effect of the angles orientation fibre composites, which had also been reported by Karpuz. (2005) and Ramachandran. (2009).

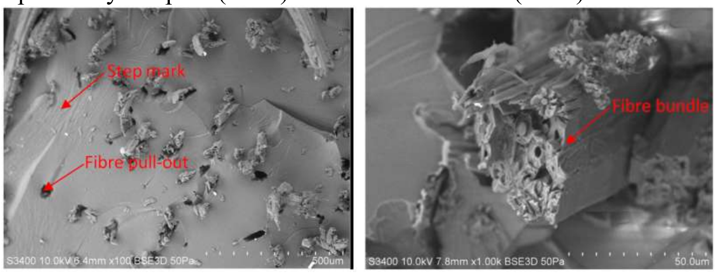

Figure 14. SEM micrographs of fractured specimens of kenaf yarn fiber composites at 90°wound of winding.

As a comparison, the kenaf fiber at ±45° wound winding angle in UP composites can be seen as an example for a good matrix/fiber that absorbed the fracture energy and has proven in SEM images the step marks implied good stress transfer that occurred between the fiber and the matrix and also resistance to crack propagation. It also shows good tensile properties. The kenaf fiber at ±45° wound winding angle has improved the composite to absorb more stress transferred from the matrix before fracture. The stress-strain graphs can be seen previously in Figure 8 and show the result in the tabulated data, accordingly to this study. In comparison to the layup method and filament winding method, the SEM micrograph surface fracture shows the similar result that the±45° angles fiber has good tensile properties.

Our previous study on tensile properties of hand laid-up kenaf composites (Misri et al., 2014) was performed at the same dimensions and orientation of the current study. Table 4 shows the tensile strength lay-up higher than the filament winding method, but for the tensile strain the filament winding method is the highest. In the filament winding method, the winding angle for 90° is similar to orientation fiber for 0°. The different behaviour between ±45° winding angles in the two type methods. The filament winding method show that the ±45º winding angle orientation fiber have good mechanical properties. But for the lay-up method show the ±45º orientation fiber have decrease the properties.

Table 4. Comparisons between lay-up and filament winding method.

	Filament winding method Winding angles		Hand lay-up method Orientation Fibers	
	±45°	90°	±45°	0°
Tensile strength (MPa)	13.95	14.04	27.69	29.08
Tensile strain (mm)	5.28	3.79	1.40	0.85
Tensile modulus (GPa)	5.99	4.03	5.15	10.61

4. CONCLUSIONS

A study on the physical and mechanical properties of the kenaf yarn fiber unsaturated polyester has been conducted. The physical properties of the kenaf fibers, such as moisture content (MC) and water absorption (WA) had been determined. The kenaf yarn fibers also were subjected to a tensile test, where its tensile strength (TS), tensile modulus (TM) and elongation at break (EB) has also been determined. From the experiment, the tensile properties of hollow kenaf yarn fiber composite unsaturated polyester between 90º and ±45º are successfully determined. The different wound of winding has effects on the mechanical properties. The results showed that the ±45° wound winding has the highest value for the tensile strain, the tensile modulus and the toughness to crack the wound of winding single kenaf yarn fiber composite.

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