Pertanika J. Sci. & Technol. 24 (2): 475 - 482 (2016)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Split-Disk Properties of Kenaf Yarn Fibre-Reinforced Unsaturated Polyester Composites using Filament Winding Method

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ABSTRACT

There are many contributions from synthetic fibres in the world of industrial composites over the years. However, they contain hazardous properties to humans causing irritation when exposed to the skin and eye. Inhalation of fibrous synthetic can cause lung cancer with its deadly effects. There have been studies and researches conducted on natural fibres to replace synthetic fibres as it is believed the latter are more environmental-friendly and pose less health risks to humans. The aim of this study was to investigate hoop tensile properties of the composite hollow shaft for different winding angles and PVC reinforcement produced via the filament winding technique. For this purpose, split-disk tests (according to ASTM D-2290 standard) were performed for the specimens produced with two different winding angles such as 45^o and 90^o winding angle. By determining the hoop tensile strength and modulus of these specimens, the effects of filament-winding processing parameter in winding angle were evaluated. Experiments successfully showed that the mechanical properties such as tensile properties of kenaf yarn fibre reinforced unsaturated polyester hollow tube at 90° and 45° winding angle with and without PVC. The value was 15% for the different winding angles and 25% for the different winding angles with and without PVC. The results indicate that 90° fibre winding angle kenaf yarn fibre unsaturated polyester with PVC has the highest hoop tensile strength compared with other composite specimens. The experiments concluded that the orientation on fibre angle has a significant impact on the hoop tensile strain, hoop tensile modulus and hoop tensile strength properties.

Keywords: Split-disk tests, filament winding, composite tube, hoop tensile strength, hoop modulus of elasticity

Article history:
Received: 17 February 2016
Accepted: 22 April 2016

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ISSN: 0128-7680

INTRODUCTION

In the world of composites, there are many natural fibres that have not yet been explored for the sake of commercial purposes . Synthetic fibre composites have many bad side effects on human health and the environment. As a result, many researchers have studied natural fibre composites with the hope that natural fibre composites may reduce the usage of synthetic fibre in composite. Before discussing further on how natural fibres can contribute to the world of composite, below is a brief overview of bio-composites. What is a bio-composite? Bio-composites or natural fibres are made up of resin and reinforced by natural fibres. Natural fibres can be categorised into three different types: = bast fibre, leaf fibre, and seed fibre (Suddel, 2008).

Kenaf is categorised as bast fibre in natural fibre. There are many studies that have been conducted on kenaf and its composites (Alkbir et al., 2014; Misri et al., 2015;). Kenaf is a fibre plant which has been grown for several thousand years for its food and fibre sources, especially in east-central Africa. It is also a common wild plant in Asia. Kenaf has been a source of textile fibre to produce products such as rope, twine, bag and rugs. Kenaf is a promising source of raw material fibre for pulp, paper and other fibre products, and has been introduced since World War II (WWII) in China, USSR, Thailand, South Africa, Egypt, Mexico and Cuba.

Lehtiniemi et al., (2011) studied the use of natural fibre yarn reinforcement composites such as flax fibre made from filament winding process. Filament winding process of fibre reinforced thermosetting resin and can used to make simple components such as pipes, tubes and rods such as those found in sailboard masts, lamp posts, and fishing rods or high tech components such as high pressure vessels, and aerospace components (Hernández-Moreno et al., 2008; Abdalla et al., 2007; Zhou et al., 2009). Shaw-Stewart (1985) reported that complicated tubes can be made from a series of joined filament wound tubes to develop a space frame. Synthetic fibres such as glass and carbon are the main fibres used for filament winding process. Studies on the winding process employing natural fibre composites however, are very limited.

METHODOLOGY

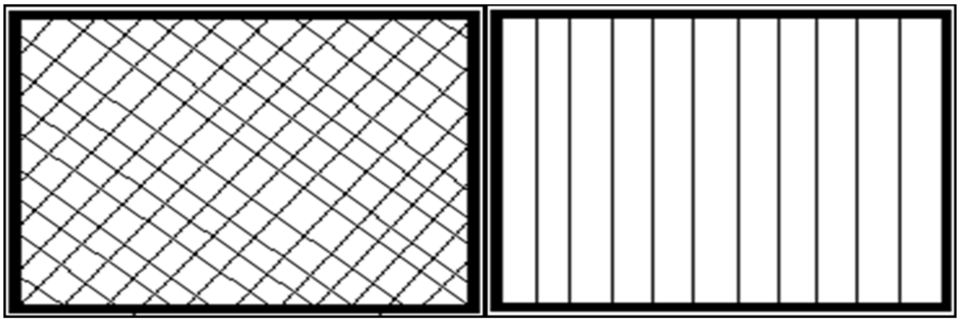
Materials

There are four types of fabricated specimens. The first specimen is ±45° kenaf yarn fibre reinforced unsaturated polyester (UP) composite without PVC. The second specimen was 90° kenaf unsaturated polyester (UP) composite without PVC. The third specimen consists of ±45° kenaf unsaturated polyester (UP) composite with PVC while the fourth specimen consists of 90° kenaf unsaturated polyester (UP) composite with PVC.

Fabrication

An advanced composite material is made up of a fibrous material embedded in a resin matrix and usually laminated with fibres oriented in alternating directions to give the material strength and stiffness. The strength and stiffness of a composite build-up depend on the orientation sequence of the plies. A proper selection of ply orientation in advanced composite materials is necessary to provide a structurally efficient design. The part may require 90° plies to react to the axial loads, ±45° plies to react to the shear loads and 90° plies to react to the side loads.

In filament winding, a bundle of continuous filaments is wound on mandrel. For hoop winding and polar winding filaments, they are wound together in one direction. For helical winding filaments, they are wound together in two directions. The directions are determined by given winding angles in Figure 1 (a) and Figure 1 (b).



(a) (b)

Figure 1. (a) ±45° Winding Angle, and (b) 90° Winding Angle

Split Disk Method

The current experimental test to study the mechanical properties of kenaf yarn fibre reinforced unsaturated polyester hollow tubes uses 4 sets of specimens. The orientation at 90° and 45° winding angle with and without PVC were done according to ASTM D2290 standard. The ASTM D2290 standard determines the comparative apparent tensile strength of most plastic products using a split disk test fixture tested under defined conditions and test machine speed. Extruded and moulded thermoplastic piping is also covered in this test. Data from this test are useful for research and development, quality control specification and design. This test method covers the determination of the comparative apparent tensile strength of most plastic products utilising a split disk test fixture when tested under defined conditions of pre-treatment, temperature, humidity and test machine speed. In a split-disk tensile test, tension forces are applied as shown by the arrow in Figure 2. The internal diameter of the kenaf yarn fibre hollow composite was 90 mm and the length was 35 mm. The thickness of kenaf yarn fibre hollow composite was 4.5–5.5 mm. The mandrel was a PVC cylinder with a diameter of 90 mm.

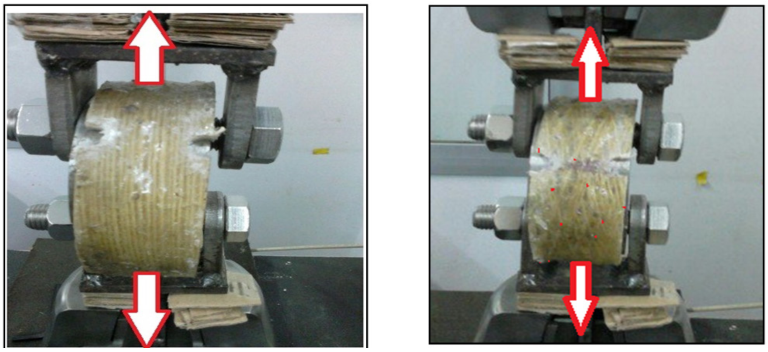


Figure 2. 90° and ±45° Fibre winding angle kenaf with PVC when given load (direction of load)

Equation for Hoop Tensile Strength and Hoop Tensile Modulus

The hoop tensile strength of the specimens was calculated using the following equation:

$$\sigma_{hts} = \frac{P_m}{2.A_m} \quad [1]$$

where:

σ_{hts} : Hoop tensile strength, MPa

P_m : Maximum load, N

A_m : Cross-sectional area of crack composite sections, mm^2

Obtained strain and calculated stress data were then used to plot hoop tensile of stress-strain curve for kenaf yarn hollow tube composites. The plotted curves were analysed to obtain the hoop tensile modulus elasticity of the kenaf yarn hollow tube composites specimens. Then, the slopes of the linear portion of the curve were determined. After that, fitting a straight line to the linear portion of the curve and the least square method was done. Therefore:

$$E_{htm} = \frac{d\sigma}{d\varepsilon} \quad [2]$$

where:

E_{htm} : Hoop tensile modulus of elasticity, GPa.

$d\sigma/ d\varepsilon$: Slope of the linear portion of the stress – strain curve from kenaf composite analysis.

RESULTS AND DISCUSSION

By conducting the tensile test experiment, it can determine the stress-strain curve. From the stress-strain graph, it can be examined whether the material is brittle or ductile. The hoop tensile properties such as hoop tensile strength, hoop tensile modulus and hoop tensile strain could be determined from the stress-strain graph. This experiment was conducted to investigate the hoop tensile strength, hoop tensile modulus and hoop tensile strain of the specimen and to differentiate the tensile properties between kenaf reinforced unsaturated polyester with and without PVC as a composite material with different 90° and ±45° fibre winding angle. Figure 3 shows the tensile stress-strain behaviour of kenaf reinforced hollow tube in filament winding technique.

From the graph, it can be observed that composite materials with 90° kenaf fibre winding angle have the highest hoop tensile strength compared with the other specimens. It clearly shows that at 90° orientation of kenaf fibre winding angle with PVC, the hoop tensile strength value has increased. This was followed by ±45° kenaf fibre winding angle with PVC (142.79 MPa), pure kenaf 90° winding angle (119.72 MPa), ±45° kenaf fibre winding angle (98.13 MPa) and PVC of 59.67 Mpa. Emrah (2004) compared the hoop tensile strengths of specimens having different winding angle hollow fibre composite. The result shows the 90º winding angle has the highest hoop tensile strength compared with the lower winding angle. It shows a similar trend with the current study where lower winding angle gives lower hoop tensile properties. This is because the failure fibre direction for 90º winding angle is parallel to the direction of loading. The lowest strength values were obtained for the fibre direction in 90º winding angle where the failure fibre direction is perpendicular to the direction of loading.

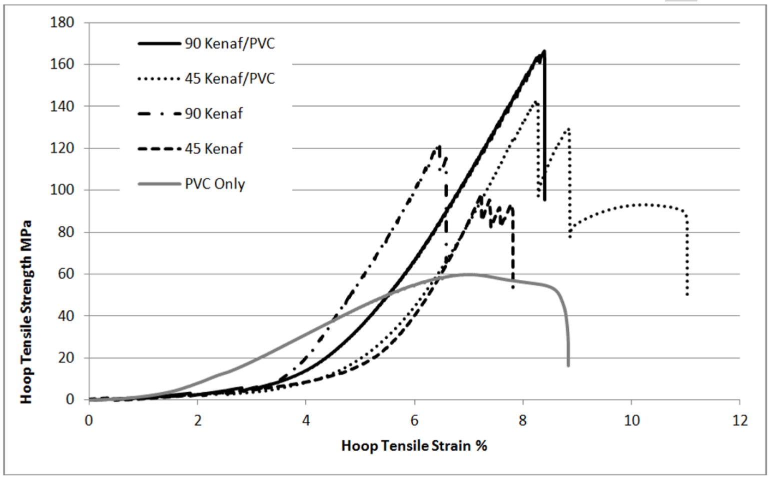


Figure 3. Hoop tensile of stress-strain curve for kenaf yarn hollow tube composites

The hoop tensile strength of the kenaf fibre composite with different type of winding angle and specimens are shown in Figure 4. The highest hoop tensile strength values were obtained for the specimens having the 90º winding angle with PVC due to the fact that they have two layers. The first layer is kenaf yarn composite and the second layer is the PVC hollow tube. Reinforcing it with PVC increases the strength of structure fibre hollow tube composite. The lowest strength values were obtained for the specimens having only PVC. The results for the specimens having ±45º winding angles show decreased ability of the kenaf fibre to absorb stress from the matrix during failure. Thus, as shown in Figure 4, when the winding angle decreases, the values of hoop tensile strength specimens also decrease.

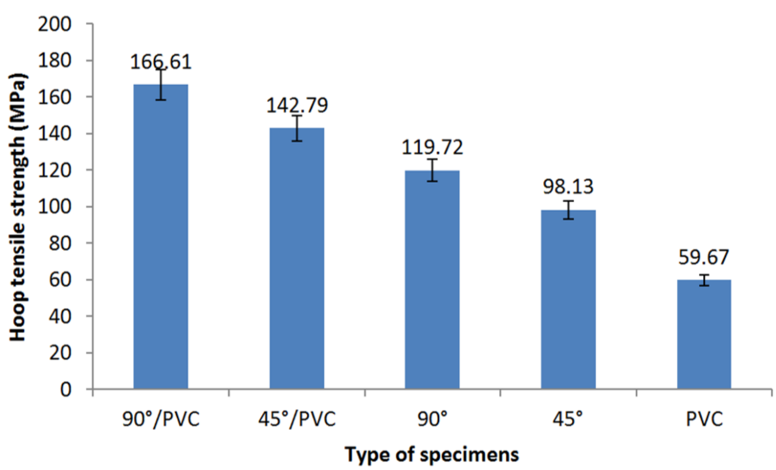


Figure 4. Hoop tensile strength graph of kenaf yarn filament wound hollow tube

Another substantial property that can be extracted from the tensile stress-strain behaviour is hoop tensile modulus. The hoop tensile modulus is the capability of a material to persist deformation in tension. Theoretically, the higher the hoop tensile modulus is, the stiffer the materials. It means that the tensile modulus affects the stiffness property of the material (Ishak, 2009). Figure 5 shows the results of tensile modulus kenaf yarn fibre reinforced unsaturated polyester hollow composite with different fibre winding angle, with PVC and without PVC. The results shown in Figure 5 clearly indicate that ±45º kenaf reinforced unsaturated polyester without PVC has the higher hoop tensile modulus compared with other composite samples whereas PVC has the lowest hoop tensile modulus. The ±45º was increased and so, the composite becomes stiffer compared with 90º winding angle of composite. Thus, it is clear that different winding angle has a different effect on the mechanical properties of composites.

The fractured kenaf yarn fibre in this hollow composite was observed to exhibit brittle fracture as well, suggesting that the arrangement of the 90º winding angle kenaf fibre has decreased the ability of the kenaf fibre to absorb stress from the matrix during failure and contributed to the decreasing hoop tensile modulus and hoop tensile strain failure of the composites. At the ±45º winding angle kenaf yarn fibre hollow composite, only a few fibre de-bonding occurred during the failure of the unsaturated polyester composites.

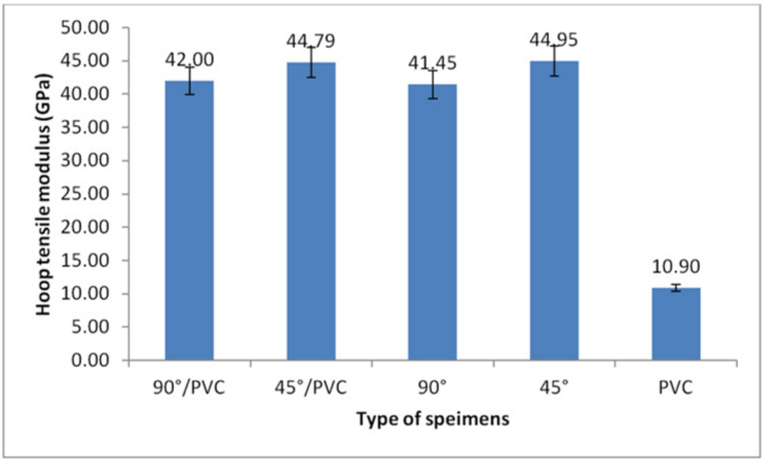


Figure 5. Hoop tensile modulus graph of kenaf filamen wound hollow tube

By studying the hoop tensile strain, the ductility of a material can be determined where a higher hoop tensile strain indicates a higher ductility of the material. The result of hoop tensile strain for 90º and ±45º winding angle kenaf yarn fibre reinforced unsaturated polyester with and without PVC are shown in Figure 6. It has been shown that ±45º kenaf yarn fibre composite with PVC has the highest value of hoop tensile strain compared with other samples. The Figure 6 below also show the same behaviour between two types of winding angles such as 90º and ±45º. The ±45º winding angle kenaf yarn composite was higher than the 90º winding angle; it has been shown that the ±45º winding angle improves the hoop tensile strain of kenaf yarn fibre composite. The effect of winding angles and the different layers are depicted in Figure 6. Generally, the in plane tensile modulus for winding angle 45° is higher than 90°. It is a well-known fact the maximum tensile strain occurs at 45° from hollow of loading. It means that it can withstand more tensile and this is clearly seen in Figure 6. These have been supported by Cho and Lee (1998) and in a large scale test of a hybrid aluminium/composite drive shaft for passenger car.

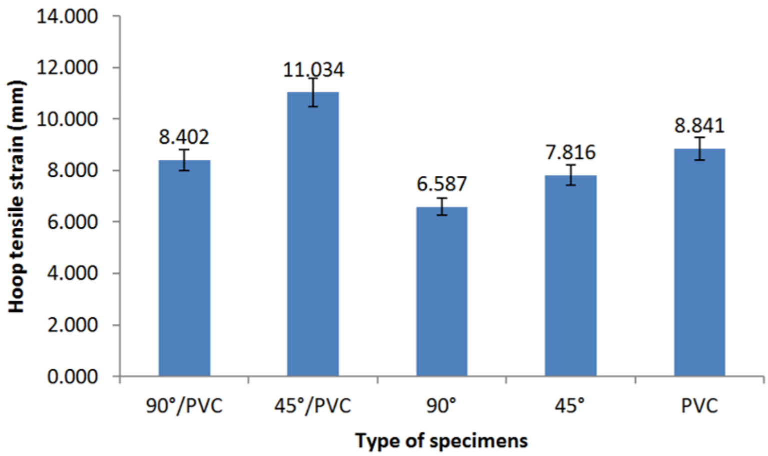


Figure 6. Hoop tensile strain graph of kenaf filamen wound hollow tube

The winding angle fibre composite plays a major role in determining the fibre strength. It is because the force is exerted by the composite and will be distributed to the fibre so the winding angle is very important for load distribution. In general, it is known that fibre winding angles are related to mechanical properties, especially in unidirectional fibrous composites (Baosheng et al., 2010).

CONCLUSION

From the experiments, the mechanical properties such as hoop tensile properties of 90° and ±45° winding angle kenaf yarn fibre reinforced unsaturated polyester hollow tube composites with and without PVC are successfully determined. The results of the experiments concluded that the winding angle fibre has a significant impact on the hoop tensile strain, hoop tensile modulus and hoop tensile strength. This is because they have different winding angle fibre and effect the mechanical properties of composites. When the loads were further increased in testing, the crack grew in the composite and penetrated the fibres at the interface, showing the brittle fracture perpendicular to the load direction in composite. This proves that winding angle fibre has a significant impact on improving the mechanical properties of the material. Adding a kenaf yarn fibre composite using the filament winding technique will increase the material structure. In this experiment, PVC is used as a mandrel for kenaf yarn fibre composite and also to improve the strength of the kenaf yarn fibre composite. The results showed that the 45°winding angle has a higher value for hoop tensile strain and hoop tensile modulus to crack the wound of winding single yarn kenaf fibre composite compared with 90º winding angle.

ACKNOWLEDGEMENTS

The authors wish to thank the Ministry of Education, Malaysia, for providing the scholarship MyPhD to the principal author. Thanks are also extended to Universiti Putra Malaysia for providing a research grant: Research Universiti Grant Scheme (RUGS) with vote number

9301200. The authors wish to thank Professor Y. Ando of Kyushu Institute of Technology Kyushu Institute of Technology for his contribution.

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