Chapter 18
Filament Winding Process for Kenaf Fibre Reinforced Polymer Composites

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Abstract In this chapter, a study on filament winding process for kenaf fibre reinforced polymer composite manufacture is presented. Filament winding process for conventional fibre composites is discussed. Advantages and disadvantages of filament winding process are also briefly covered. A review on filament winding from various research is also performed. Brief review of filament winding of natural fibre composites is provided. The chapter also describes work on improvement of existing filament winding process and fabrication of hollow shaft made from kenaf fibre reinforced composites. The main contribution was the use of drum-type resin bath and surfacing veil, and these had facilitated ease of fabrication of kenaf yarn fibre reinforced unsaturated polyester composite hollow shafts.

Keywords Filament winding • Natural fibre composites • Kenaf • Biocomposites • Hollow shafts

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18.1 Introduction

Advances and innovation in composite material have made it a very important class of material, and it has been accepted as a major material in many industries such as in aerospace, automotive, oil and gas, marine, telecommunication, furniture, sport and leisure and construction industries. The advantages from using this material are enormous such as light weight, corrosion resistance, part integration, aesthetically pleasing and comparable strength and stiffness properties (Sapuan and Abdalla 1998; Davoodi et al. 2008; Hambali et al. 2009; Sapuan et al. 2002, 2005). Nowadays, composite technology has gone beyond conventional glass and fibre reinforced polymer composites. The development of ceramic matrix composites (CMC) and metal matrix composites (MMC) has now reached the commercialization stage. Nanocomposites (including carbon nanotubes, halloysite nanotubes and graphene-based composites), biomimetics, biocomposites, functionally graded materials and smart materials have become new important elements in composite technology, and they can be regarded as tomorrow's materials.

In the recent years, there is a growing interest in using natural fibres as reinforcements or filler materials for polymer-based composites due to many advantages that they offer such as abundance, environmentally friendly, low cost, low density, renewable, recyclable, low energy consumption, biodegradable, posing no harmful effect to the health and having comparable specific strength and stiffness properties (El-Shekeil et al. 2012; Anwar et al. 2009; Sastra et al. 2006; Yusoff et al. 2010; Ishak et al. 2010, 2012; Davoodi et al. 2011).

Nowadays, natural fibre reinforced polymer composites have been used to make numerous consumer and engineering products, and their applications are mainly restricted to semi- or nonstructural components. Examples of their use include furniture, food packaging, mulch film, drain cover, door or window panels for houses and offices, boat, automotive door panel, household appliances and food containers. Polymer system can be in the form of synthetic (thermoplastic and thermosetting polymers) or biopolymers (commercially available or in-house made). Among the natural fibres that are normally used as reinforcements for polymer composites include kenaf (Fig. 18.1), oil palm, sugar palm, cocoa pod, betel nut, pineapple leaf, sugarcane, abaca, banana stem, jute, sisal, hemp, Roselle and coconut. Manufacturing processes associated with natural fibre composites are normally the same processes used to produce components from traditional glass and carbon fibre composites such as injection moulding, pultrusion, vacuum bagging, hand lay-up, resin transfer moulding and filament winding. In this chapter, the manufacturing process of natural fibre composite products is presented and discussed.

Fig. 18.1 Kenaf plants

18.2 Filament Winding Process

Filament winding is a manufacturing process for fabrication of fibre reinforced composite components. Peters and Humphrey (1987) reported that the filament winding method was first presented in the form of patent since 1963. In 1964, a monograph describing the filament winding process was published. An automated filament placement technology was introduced in 1990 (Anon 2011). The filament winding process involves drawing continuous fibres through a container of resin mixture or bath and winding the continuous resin impregnated fibres around a rotating mandrel to achieve the desired shape (Fig. 18.2). The fibres are placed on the rotating mandrel by means of a horizontal carrier. The fibre orientation is controlled by adjusting the speed of the carrier. Mandrel can be removable, can be sacrificial or can form as part of the component. Thereafter, the component is cured in an oven for a certain period of time at a suitable temperature.

Defects are normally found in products made from filament winding process such as in the forms of voids, fibre wrinkles and delaminations (Mallick 2008). There are three common types of winding patterns of filament winding process, namely, hoop (circumferential), helical and polar. Typical products that are normally made from filament winding process include drive shafts, pipes, rods, hollow and solid tubes, space frames, tanks, gas cylinders, water filters, aerospace components, lamp posts, fishing rods and high-pressure vessels (Meijer and Ellyin 2008;

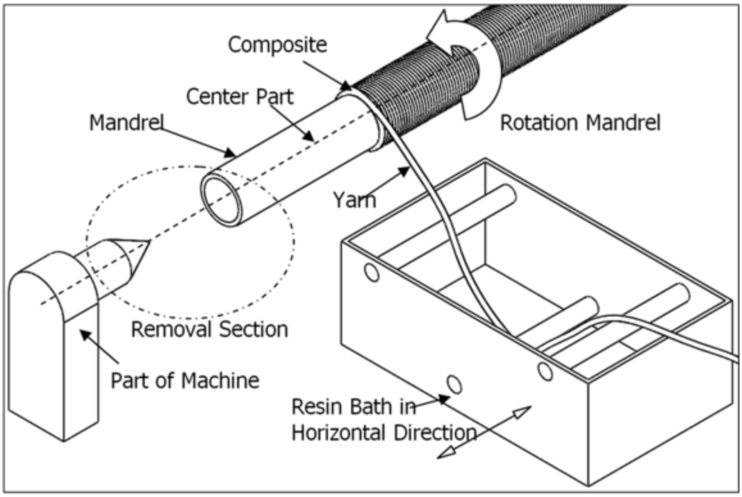

Fig. 18.2 3D schematic diagram of filament winding process

Fig. 18.3 Shaft made from filament winding process

Shaw-Stewart 1985). Figure 18.3 shows an example of a drive shaft made from filament winding method.

The polymer matrices used for filament winding process are mainly thermosetting polymers such as epoxy and unsaturated polyesters. The synthetic fibres such as glass, aramid and carbon fibres are the main reinforcing fibres used in the filament winding process, and so far, research and development work on filament winding process employing natural fibre composites is very limited. Advantages and disadvantages of filament winding process are presented in Table 18.1.

Table 18.1 Advantages and disadvantages of filament winding process (Zu 2012; Krishnamurthy and Idkan 2014; Buragohain and Velmurugan 2011)

Advantages	Disadvantages
1. Winding time is short because of simplified tooling concept 2. Mandrel preparation time is short 3. Availability of raw materials 4. Relatively low cost of raw materials (matrices and reinforcements) 5. Relatively low tooling costs 6. Polymers can easily be formulated, and the formulation can easily be changed according to individuals' needs 7. The process is reproducible or repetitive 8. Continuous fibres can be used for the entire components 9. High fibre volume is achievable 10. Fibres can be oriented in the loading direction 11. There is no need to use autoclave 12. Part size is not limited by the size of oven 13. Process can be automated and cost savings can be achieved 14. Limited use of capital equipment	1. Component must facilitate removal of mandrel 2. High cost of mandrel and may be complex 3. Winding reverse curvature is not possible 4. Problem in placing fibres parallel to the mandrel axis 5. The need for external mandrel surface treatment for surface evenness

18.3 Review of Filament Winding Process

A review of filament winding process based on published literature is presented in this section. Gemi et al. (2009) had carried out an experimental work on fatigue analysis of filament wound fibre reinforced polymer composites. The fibre used in the study was glass and the matrix used was epoxy. The hoop winding pattern was employed. In this study, composite pipe was subjected to internal pressures at different fibre loadings. Modes of failures at low and high fibre loadings were found to be different. Mutasher et al. (2012) had reported their work on the fabrication of a small filament winding machine used for fabrication of polymer composite parts for the purposes of teaching and research at Swinburne University, Malaysia branch. Mechanical, electrical and electronic control system was designed in an integrated manner to facilitate ease of use. Winding angles of 40–80° were achievable using this control system.

Wang et al. (2004) developed an improvement method during curing process in filament winding process. A model called 'helical tow model' was used to improve curing of the composites. Numerical problem was solved using finite volume method. The work was performed using computer code development and was used to investigate on-line thermal curing. Akkus et al. (2008) developed a control system that can optimize the pulling force of the resin impregnated fibre reinforcement. The mechatronics-based pretensioning system for filament winding process can be used for any types of fibres such as carbon, Kevlar and glass fibres, and it can ensure constant pulling force is achieved. This in turn can enhance the quality of finished filament wound composite parts.

Development in polymer technology had also improved the performance of filament winding process. New epoxy matrices were used with carbon fibres in filament winding process as reported by Chen et al. (2007). These new matrices had demonstrated good interfacial bonding with carbon fibres. Results of scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR) and atomic force microscopy (AFM) revealed that these new epoxy matrices are superior to conventional epoxy matrices. Another development in composite materials for filament winding was the use of metal prepreg as reinforcement (Gordon 2006). It is a form of MMC. The performance of this MMC-based filament wound composites is comparable with polymer-based filament wound composites. In tensile properties (transverse direction), non-linear effects were detected, and these made the metal composites (MC) to be different from polymer-based composites.

Velosa et al. (2009) had developed new pressure vessels from filament wound glass fibre reinforced polymer composites. The liner was made from high-density polypropylene (HDPE), and the polymer matrix used in the composites was unsaturated polyester resin. The fibres used in this research were continuous E-glass rovings. Design analysis was conducted using a commercial finite element analysis software (Abaqus). The major parameter being studied was mainly internal burst pressure. The results of the study on internal burst pressures from finite element analysis and experimental work were compared and they have shown good agreement.

Hernández-Moreno et al. (2008) had carried out a study on the effect of winding pattern and architecture of impregnated glass fibres on mechanical properties of filament wound polymer composites. Winding pattern that was chosen for the research is helical winding. Detailed work on buckling characteristics at different winding patterns (e.g., one- and five-unit cell patterns) was carried out. Implosion pressure tests were carried out on the specimens. Results of implosion pressure tests and buckling analysis revealed that two different winding patterns did not significantly influence the implosion pressure and buckling behaviour of the polymer composites. Similar work on winding pattern issues in filament winding was presented by Park et al. (2002). The focus was on the study of through thickness direction. Helical winding was considered in this study. Winding angle and winding thickness were two major parameters being investigated in detail. The work on water pressure test was performed both numerically and experimentally for comparison purposes, and they have shown good agreement. A commercial finite element analysis software package (Abaqus) was used in the study. Ha and Jeong (2005) also perform similar work, but the component being studied was composite rings.

Morozov (2006) had carried out a research work on the influence of winding pattern on the mechanical properties of filament wound polymer composite products. The winding pattern that was considered in this study is called mosaic pattern. The products being investigated were thin-walled shells. The investigation was done with numerical analysis software (MSC Nastran). Different mosaic patterns had given different values of mechanical properties. Buragohain and Velmurugan (2011) had carried a study to determine the performance of filament wound polymer composite structures. The structures being investigated were in cylindrical form. The structures were stiffened by means of few ribs. The cylindrical structures were fabricated from filament winding process. Experimental study on compression and the finite element analysis were performed and their results were compared and discussed in details.

18.4 Filament Winding with Natural Fibre Composites: A Short Review

Very limited number of literature had reported on the use of filament winding of natural fibre composites. There is still a large scope of research in this topic.

Lehtiniemi et al. (2011) had studied the mechanical properties of flax fibre yarn-reinforced polymer composite tubes, and they had compared the results with the properties of glass fibre reinforced polymer composite tubes. Composites were produced using the filament winding process. The major problems associated with filament wound composites made from flax fibres and polymer matrix are poor interfacial bonding between fibres and matrix. Mahdi et al. (2002) had used filament winding process to fabricate polymer composite specimens from oil palm frond fibre reinforced epoxy composites. The composite products were circular, cylindrical and conical shells. Static crushing tests and crushing energy absorption tests were performed. The results were compared with polymer composites made from glass and carbon fibres.

Misri et al. (2014) had reported their work on fabrication of kenaf yarn fibre (Fig. 18.4) reinforced unsaturated polyester hollow tube composites using filament winding technique. Split-disk tests were performed for the specimens being wound with two different winding angles: 45° and 90°. The effect of filament wound processing parameter, namely, winding angle, was evaluated by determining the tensile properties of the composites using split-disk method (see Fig. 18.5). A recent work by the authors was concerned with the study of torsional behaviour of kenaf fibre reinforced polymer composite hollow shafts fabricated using filament winding process (Misri et al. 2015). The resin used was unsaturated polyester. Experimental work was conducted to study the torsional properties of the polymer composites. Figure 18.6 shows a kenaf fibre reinforced polymer composite specimen tested for torsion. The experimental work was compared with finite element analysis (Abaqus). Torsional properties of kenaf composites (with and without aluminium mandrels) at two different winding angles (45° and 90°) were determined. There was a good agreement between both sets of results. Nadia and Ishak (2014) had carried out a study on various aspects of kenaf fibre hollow composite shaft. They reported that changing the orientation angle would change the fatigue life of the filament wound composites. They concluded the kenaf composites can be used for light-weight and low-cost engineering application.

Fig. 18.4 Kenaf yarn fibre

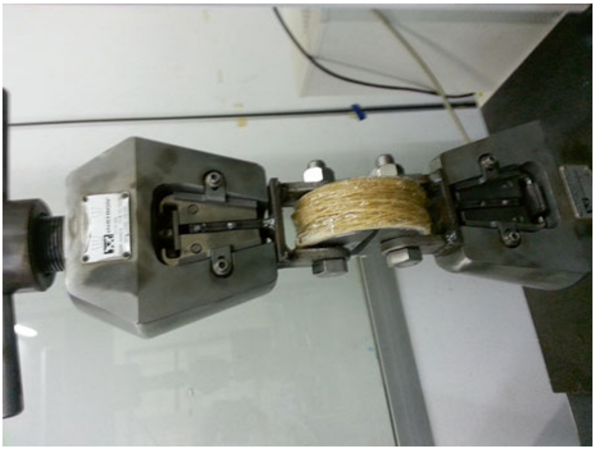

Fig. 18.5 Split-disk test for a filament wound kenaf composite specimen

Fig. 18.6 Kenaf composite specimen in torsion test

18.5 Improvement of Filament Winding Machine

In this section, improvement of filament winding machine was made. The existing machine (Abdalla et al. 2007) was a lathe machine, and improvements were made to cater for the use in kenaf fibre reinforced polymer composite part development.

18.5.1 Innovation in Rotating Drum Design

Figure 18.7 shows the schematic diagram of the concept of fibre-dip type of resin bath, and the concept follows the work of Mutasher et al. (2007). This was the resin bath normally used for winding carbon and glass fibre rovings. In this process, excessive pulling force caused the fibres such as kenaf fibres to break as the fibres demonstrate lower tensile strength compared to glass and carbon fibres. To solve the problem of excessive pulling force, drum-type resin bath was proposed by Misri et al. (2014) as shown in Fig. 18.8. Three-dimensional representations of the resin bath are shown in Figs. 18.9 (schematic) and 18.10 (photo). A servomotor with the capacity of 12 V 20 A was attached at the drum. The drum rotating at the speed of 95 rpm was covered with surfacing veil made of polyester mat. The resin bath provided the impregnation mechanism for the fibre by wetting both the soaked drum surface and the static polyester mat (attached at the guide rollers) when the drum rotated. The impregnated yarn fibres were then passed through a guide roller to wipe off the excess resin before winding them over the rotating mandrel. The innovative rotating drum design helped to eliminate yarn fibre breakage by decreasing the excessive pulling load from the rotating mandrel during the manufacturing.

Hoop winding took place when the mandrel and fibre yarn were in perpendicular direction, while the helical winding took place when the mandrel and fibre yarn

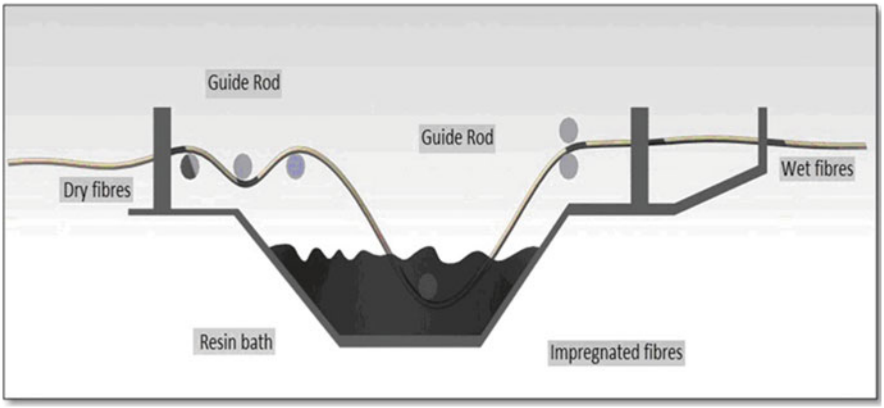

Fig. 18.7 The existing concept of resin bath (fibre-dip type)

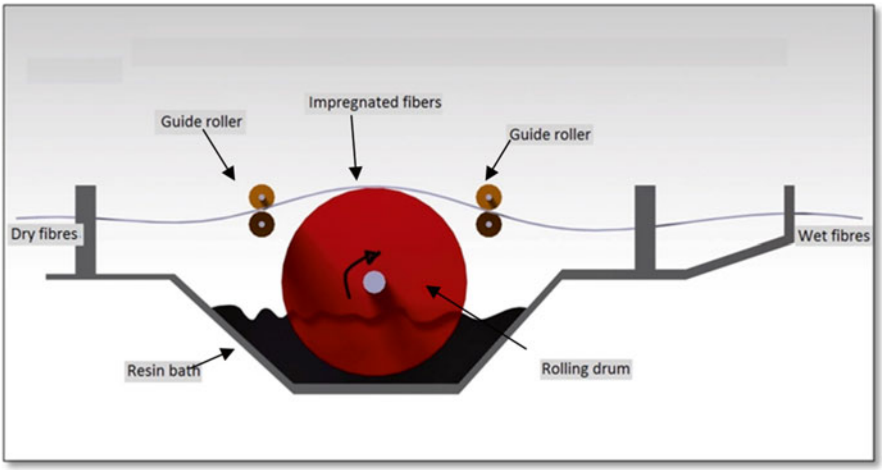

Fig. 18.8 The improved concept of resin bath (drum type)

were at certain angles lower than 90° (e.g., 45°) to each other. In this experiment, kenaf yarns were wound at 90° and 45° fibre angle orientations. It means that the kenaf yarn underwent the helical and hoop winding processes. The yarns were wound onto the rotation mandrel, which was made of hollow circular aluminium rod and PVC, and they covered all the mandrel surfaces. The filament winding process was performed by pulling the kenaf fibres through a resin bath.

Once the kenaf fibre reinforced unsaturated polyester composite hollow shafts were fabricated, it was cured in an oven at a temperature of 80 °C for 5 h. The surface of composite shaft was surface finished using a lathe machine as shown in Fig. 18.11. In this process, vernier caliper was used to control their thickness with tolerance of ±0.02 mm.

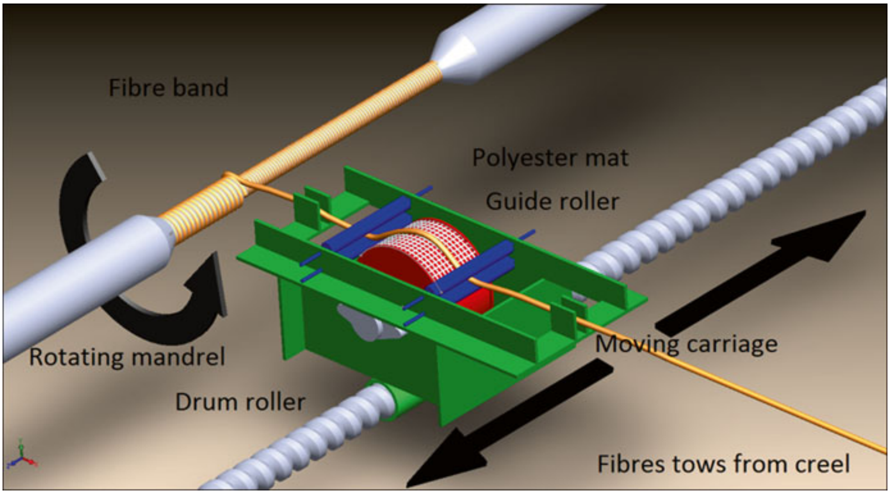

Fig. 18.9 A three-dimensional representation of the resin bath (drum type)

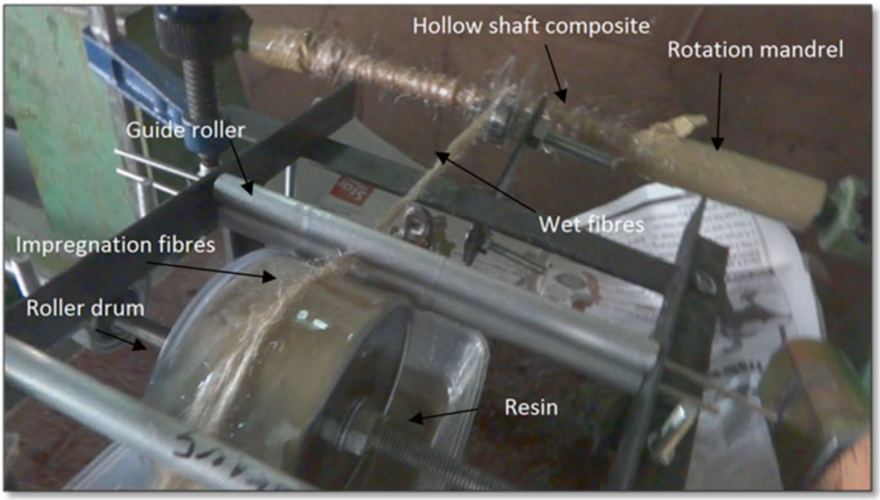

Fig. 18.10 Innovative rotating drum

18.5.2 Fabrication of Kenaf Composite Hollow Shaft Using Improved Method

Figure 18.12 shows the composite hollow shafts made by different types of raw materials (carbon, glass and kenaf fibres) that were fabricated by filament winding method. It shows the carbon and glass composite shafts were fabricated using the

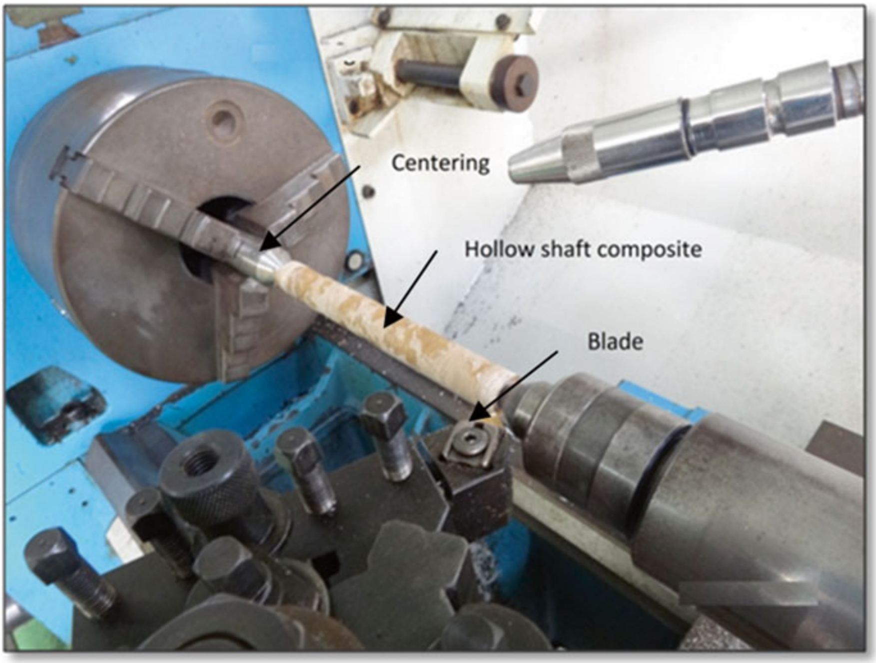

Fig. 18.11 Finishing process

Fig. 18.12 Carbon, glass and kenaf fibre hollow shaft composites

Fig. 18.13 Kenaf fibre composite hollow shafts fabricated using the improved method

regular method of resin bath fibre-dip type (as shown in Fig. 18.7), while the kenaf hollow shaft (Fig. 18.13) was fabricated using the improved method (resin bath drum type) (as shown in Fig. 18.8).

18.6 Conclusions

In this chapter, a review of filament winding process with conventional and natural fibre composites was presented. From the review, it is concluded that there is a huge scope of research and development in the area of natural fibre reinforced polymer composites using filament winding method. The emphasis of this study is on kenaf fibre composites. Various work on kenaf composites such as torsion and split-disk test are reported. Improvement in the existing fabrication process using filament winding had produced good kenaf composite specimens and parts. Drum type of resin bath and with the use of surfacing veil has helped in the fabrication and the study of kenaf fibre reinforced unsaturated polyester composite hollow shafts.

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