A Comparative Study on Mechanical Properties of Kenaf Fiber-Reinforced Polyester Composites Prepared by VARI, RTM and CM Techniques

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Abstract. This work aims at comparing the mechanical properties of composite laminate fabricated by three different fabrication processes. Kenaf fiber polyester composite laminates were fabricated by compression moulding technique, Vacuum assisted resin infusion process (VARI) and Resin transfer moulding process (RTM). Vacuum assisted resin infusion (VARI) process bridges the gap between labour intensive compression moulding process and capital intensive Resin transfer moulding (RTM) process. The mechanical properties such as tensile, flexural and impact behaviour were studied. Vacuum assisted resin infusion process showed improved tensile and flexural strength as compared to resin transfer moulding process and compression moulding (CM) process. On the other hand, impact strength of VARI composites is slightly lower than that of RTM and CM composites. From the study, it was found that mechanical properties increase with increase in fiber content and uniform distribution of resin in the matrix. The void content and water absorption properties were evaluated and found to be maximum for the compression moulded composites.

Keywords: Compression moulding (CM), Kenaf fiber, Polyester, Resin transfer moulding process (RTM), Vacuum assisted resin infusion process (VARI).

1. Introduction

Traditional fibers (carbon, glass, aramid) are harmful to the environment, so there is an urge to develop new environment friendly fibers. Researchers are very keen to develop the alternative fibers to replace traditional synthetic fibers. Few bio-based fibers have similar mechanical properties, high strength to weight ratio, low material density, low cost, ease of processing, obtained from renewable resources, biodegradable and environment friendly. These are the desirable properties, which makes lot of researchers to shift their focus towards natural fibers. Recently several authors reviewed the advances in natural fibers such as flax, kenaf, hemp, straw, coir, etc. Li et al (2008) conducted a research on interfacial performance of the hydrophilic natural fiber and hydrophobic polymer matrix. For improving the interfacial bonding between natural fiber and polymer matrix, he used two types of surface treatment on the natural fibers such as chemical bonding and oxidization. The results show that the single fiber pull out test surface treatment improves the interfacial bonding between natural fiber and polymer matrix. Based on the results obtained from the tests, surface treatment method tends to improve the interfacial bonding between natural fiber and polymer matrix. Akil et al (2011) conducted a research on kenaf fiber and polymeric composites. The result of the experiment shows that kenaf fiber and polymeric composites have similar mechanical properties when compared to glass fiber. Marsh et al (2003) states that because of the excellent mechanical properties and low density, these kenaf fiber and polymeric composites have possibilities to serve as the materials for the automotive applications. Most of the investigation shows that composites are being manufactured by hand-layup and compression moulding (CM) techniques. Recent researchers focus on the composites being produced by resin transfer moulding and vacuum assisted resin infusion process, because of the excellent surface finish and uniform distribution of resin throughout the fiber material.
Compression moulding technique is widely popular due to possibility of high fiber content and good surface finish. High fiber content in composite material offers high strength. The production process is also cheap. Advanced fabrication process such as Resin transfer moulding (RTM) and vacuum infusion process are now a days widely popular due to the minimum requirement of labour, good surface finish, desired process control, required dimensional tolerances, lower cost when compared to other processes, minimum waste, high fiber and low void content. Sreekumar et al (2007) conducted a research to compare the laminate made by RTM process and compression moulding process. The results show that laminates made by RTM offer high strength and have low water absorption characteristics. In addition, RTM process have the opportunity to alter many processing parameters such as pressure and temperature before, during, and after injection of the resin in the fiber content and this process controls the laminate's quality. Many researchers now a days perform research on RTM process because of these exceptional characteristics.

Resin transfer moulding process (RTM) is mainly for the production of high strength composite materials. In this process, resin and additives are stored in separate container, they are mixed in the pre-polymeric state (by adjusting percentage of additives mixed to the resin) and poured to the natural fiber material, which is placed in the mould cavity. During penetration, vacuum is created throughout the mould cavity by using vacuum pump at the vent position. Due to negative pressure created on the mould cavity, resin evenly spread it self throughout the mould cavity, thereby impregnating the fibers. It is then allowed to cure. Emission of volatile component in the resin is low, because of closed mould process. The major lead of the RTM process are; the product obtained will have good surface finish, low void content, good dimensional tolerances, nominal tooling cost and good range of available resin system.

Vacuum assisted resin infusion (VARI) is a process, which has only bottom mould. Top mould is covered by polyethylene bag. Resin and additives are mixed in the same container. By using vacuum pump at the vent position, the resin is sucked and evenly spread throughout the fiber material. Voids present in a porous natural fiber material are filled with a liquid resin. When the resin solidifies, it tightly binds with the fiber material. Finally, the desired composite laminates are obtained. Main objective of this process is the evacuation or removal of air from the porous natural fiber before impregnation of the resin. This process gives better results when compared to other processes such as compression moulding and RTM process. Due to this low void content and high strength to weight ratio, these process allow typical inorganic fibers such as glass and carbon fibers and allow organic natural fibers such as flax, hemp, balsa wood, kenaf, etc. In resins, mostly thermosetting types are preferred, but thermoplastic resins can also be used for infusion.

2. Materials Selection
Kenaf fiber in mat form was used. Unsaturated isophthalic polyester resin, Methyl ethyl ketone peroxide (curing agent) and cobalt naphthenate (accelerator) were also used and they were of commercial grade. The mechanical properties of fibers are given in tables 1 and 2.

| Table 1. Properties of kenaf fiber |
|-----------------------------------|
| Cellulose wt%        | 45 – 57 |
| Hemicellulose wt%    | 21.5    |
| Lignin wt%           | 8 – 13  |
| Pectin wt%           | 3 – 5   |
| Density(g/cm<sup>3</sup>) | 1.4     |
| Tensile strength(MPa) | 223 – 930|
| Young modulus(GPa)   | 14.5 – 53|
| Elongation at break(%) | 1.5 – 2.7|
Table 2. Properties of isophthalic polyester resin

| Property            | Value     |
|---------------------|-----------|
| Appearance          | Pale yellow colour |
| Viscosity           | 650       |
| Density             | 1.14      |
| Elongation          | 4.7       |
| Tensile strength    | 41 ± 1.6  |
| Young’s modulus     | 967 ± 4.07|
| Flexural strength   | 61 ± 2.25 |
| Flexural modulus    | 2461 ± 2.21|

3. Composite fabrication

3.1 Compression moulding

1) In this process kenaf mat 5 layers (5*18=90g) were arranged layer by layer. In between the kenaf mat, polyester resin were poured manually & distributed in it.
2) This kenaf preform was kept in hot press at 80 bar pressure, 100 °C for 1 hour and 80 bar pressure, 150 °C for 1 hour. Figure 1 shows compression moulding set up.

![Figure 1. Compression moulding set up](image)

3.2 Resin transfer moulding

1) In this process also, kenaf mat 5 layers (5*18=90g) were arranged layer by layer in between the two fixed moulds.
2) By using external pressure, resins were supplied into the mould cavity.
3) Mould cavity is cured for 24 hours. Figure 2 shows resin transfer moulding set up.
3.3 Vacuum assisted resin infusion process

1) Kenaf mat 5 layers (5*18=90g) were arranged layer by layer in this process, in the fixed glass mould.
2) Peel ply and wire mesh were placed above on it for uniform distribution of resin over the fiber.
3) By using vacuum pump, negative pressure was created over the mould and resin was sucked.
4) Mould cavity was cured for 24 hours. Figure 3 shows set up of Vacuum assisted resin infusion process.

4. Mechanical Testing

Tensile characteristics of the kenaf fiber reinforced polyester composites laminate was found by universal testing machine based on ASTM D638 standard. Flexural characteristics were found out using ASTM D790 standard. Izod impact test on unnotched specimen was carried out by using 25 J impact testing machine as per ASTM B 557 M standard. Five replicates were tested and average value was taken.

5. Water absorption tests
The kenaf fiber reinforced polyester composite laminates with a dimension of 100*25*5 mm thickness were taken for thickness swelling and water absorption characteristics. Five samples were taken from each fabrication process. Based on ASTM D1037 standard, water submersion tests for 24 hours period were taken.

6. Results and Discussion

6.1 Tensile results

The tensile test results are shown in the Table 3.

Table 3. Tensile test results of kenaf fiber reinforced polyester composites.

| Fabrication types | Tensile strength (MPa) | Tensile modulus (MPa) | % Elongation |
|-------------------|------------------------|----------------------|-------------|
| CM                | 20.33                  | 965.32               | 2.25        |
| RTM               | 24.78                  | 980.32               | 2.35        |
| VARI              | 29.03                  | 1161.2               | 2.52        |

From the tensile result it is found that tensile stress of vaccum assisted resin infusion (VARI) fabrication process was higher when compared to RTM and CM process. This shows that tensile strength increases with respect to the fiber content present in the composite laminate. Tensile stress of VARI fabrication process is 17.15% higher than RTM and 42.79% higher than CM process. This shows composite laminates fabricated by VARI and RTM process have lower void content. In RTM process, resin is injected into the mould cavity through optimum pressure. If any air is present in the fiber, it is pushed out. In VARI process, by creating negative pressure, the air gap present in the natural fiber is removed and it reduces the void content present in the laminate. From the results, it can be concluded that reduction of void content is one of the main reason for improvement of mechanical properties in VARI process.

![Fractograph of tensile sample of CM Process](image)

a) Fractograph of tensile sample of CM Process
Figure 4. Scanning electron micrographs of the tensile fracture surfaces of the composite fabricated by (a) CM (b) RTM and (c) VARI process

Figure 4a, b and c shows the SEM analysis of tensile fiber pull-out of the composites laminates fabricated by CM, RTM and VARI techniques respectively. From the figures, CM fractured samples is shown to have fiber pull-out. That means fiber and matrix are not strongly bound in CM fabricated sample. RTM and VARI fabricated composites shows brittle fracture in the fractured laminate and hence it shows fiber/matrix interaction was firm in RTM and VARI fabricated composites.

6.2 Flexural Results

The results of flexural tests are summarised in Table 4.

| Fabrication types | Flexural stress (MPa) | Flexural modulus (MPa) | Yield displacement (mm) |
|-------------------|----------------------|-----------------------|------------------------|
| (CM)              | 24.20                | 3632.348              | 2.685                  |
| (RTM)             | 20.98                | 3413.165              | 1.882                  |
| (VARI)            | 66.78                | 6084.206              | 7.921                  |

VARI process gives very high flexural strength when compared to CM and RTM process. This result shows that fiber content is directly proportional to the flexural strength. In VARI, fabricated
Composites have high fiber loading 60-65% and lower void content. In CM process, it has 30-35% fiber content due to high void content present in the laminate. Therefore it offers lesser flexural strength.

6.3 Impact results
The impact results are shown in the fig 5.

![Figure 5. Impact strength of composites fabricated by CM, RTM and VARI process](image)

From the impact test results it is found that VARI fabrication process absorbs more energy when compared to RTM and CM process. Energy is dissipated in composite laminate due to fiber pull out from the laminate. When the stress level exceeds the fiber strength, fiber fracture occurs.

6.4 Water Absorption Test Results
Water absorption test of three differently fabricated composite laminates are shown in the Fig 6.

![Figure 6. Water absorption test of composites fabricated by CM, RTM and VARI process](image)

From the above results, it is clear that composite fabricated by VARI process absorbs less water when compared to RTM and CM process. Through mechanical tests and water absorption tests, vacuum assisted resin infusion (VARI) process gives better results when compared to all other fabrication techniques. It is because of increase in fiber content in the composite laminate. In VARI
process, fiber content can be reached up to 70% but in RTM and compression moulding process, it can be reached only 40%. It clearly shows that increase in fiber content in the kenaf fiber/polyester laminate increases the tensile strength, flexural strength and impact strength of the composites.

7. Conclusion
This study shows that the tensile strength, Young’s modulus, flexural strength and flexural modulus of VARI samples are higher than RTM and CM samples. The void content and water absorption property of composites prepared by VARI is lower as compared to RTM and CM due to good fibre/matrix interaction. It is also observed that mechanical properties increase with increase in fiber content. In VARI process, reach fiber content can reach upto 70% but in RTM and compression moulding process it can reach upto 40% only. In VARI process, thickness is controlled by fiber compaction under vacuum pressure. To summarize, VARI fabrication process is an excellent technique to fabricate kenaf fiber/polyester composites which have superior mechanical properties.

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