Mechanical Characterization of Coir Epoxy Composites and Effect of Processing Methods on Mechanical Properties

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Abstract

Composite materials have now attracted wide acceptance in product development and manufacture especially in automotive and aerospace applications where weight reduction and low fuel consumption are critical product performance metrics. In most applications, glass and carbon fibre composites are used. However, natural fibre composites also offer attractive properties. They are competitive especially in terms of price and density when compared to glass and carbon fibre composites while providing similar mechanical properties. Commonly available natural fibres include coir and sisal. Resin transfer moulding (RTM) process is also an established technique for manufacturing composites as it offers good surface finish and dimensional control. The aim of this paper is to investigate the effect of resin transfer rate on the performance of the product. Coir fibre / epoxy resin composites are prepared using RTM for differing resin transfer rates and fibre fraction for treated and untreated fibres. The results obtained indicate a slight reduction in performance with reduction in resin transfer rate. However, stiffness remained unaffected. Improvement in stiffness and strength with increasing volume fraction was reported which was in agreement with literature. However, the data exhibited an optimum fibre volume fraction of 30% beyond which performance deteriorated. This investigation indicates that further work is required to optimise the production of natural fibre composites using RTM.

Keywords

Coir epoxy composites, Mechanical performance, Natural fibres, Resin transfer moulding

1 INTRODUCTION

When a material contains more than one phase that is artificially blended together, it is then considered to be a composite material. Most commercial composites are made by using fibers to reinforce a matrix. The matrix can have fillers added to modify behavior such as improving fracture toughness [1]. A typical example of a commonly used composite is carbon fiber composite in which carbon fibers are used to reinforce a polymeric matrix, typically epoxy resin. The fibers in the composite can be short or continuous, multidirectional or unidirectional, woven or non-woven. A matrix alone excluding fillers is three-dimensionally continuous (isotropic). This means that directional properties are the same in all directions. Once fillers have been implemented into the matrix they can either be continuous or non-continuous depending on the intentions of the designer [2].

Natural fiber composites are becoming more popular today than ever before. With the increase in environmental costs of producing synthetic fibers, natural fibres have now become a necessity. Furthermore, natural fibers are renewable and can also be extracted from freely growing plants [3]. The advantages of natural fibers are therefore being exploited more and more in automotive and aerospace fields. However, they have largely been restricted to non-critical applications such as interior panels. They are also being applied in other fields as well, as they provide ideal strength at almost 50% of the weight. The main advantages of natural fiber as compared to glass fiber composites include lower density, lower toxicity, lower cost and biodegradability [4]. Stiffness, impact strength, flexibility as well as modulus are other properties that are favorable amongst natural fibers [5].

However, there are slight drawbacks to the use of natural fibers as opposed to synthetic fibers. These include water absorption, low working temperatures and the poor compatibility between the synthetic polymers and the natural fibers [6].

There exist several manufacturing methods for processing composites. The hand laminating or hand lay-up (HL) is the cheapest option [7]. In this case fibers are hand laid in a mold and the resin is applied by hand typically using a hand brush. The main challenge with had lay-up is air entrapment which results is air bubbles and defects in the component. Vacuum bagging combines the hand lay-up together with vacuum bagging to reduce air entrapment. Unfortunately, dimensional control remains a challenge with these techniques. Resin transfer molding (RTM) uses vacuum injection for both molding and air removal leading to better dimensional control and less defects [8]. Pultrusion is a process where the resin granules are impregnated with the fibres and are pulled through a die. This is the most expensive technique and is therefore rarely used [9].

Given this background, there is need to assess the effectiveness of using the RTM method as a production technique for coir fiber–epoxy resin composite components. The hand lay-up and the RTM process offer the best option for low cost production. The aim of this investigation is to therefore two pronged: (1) to determine whether a coir epoxy composite is a suitable replacement material for synthetic fiber composites with specific focus on glass and carbon fiber composites which are currently being used in the University of Johannesburg solar car project and (2) to compare the effect of hand lay-up and RTM processes on the mechanical performance of the resulting components.

2 EXPERIMENTAL PROCEDURE

2.1 Aim

The aim of the experiments was to determine the mechanical properties of components produced using the hand lay-up and RTM processes for varying fiber fractions.

2.2 Materials

Coir fiber used in this investigation was supplied by the Coir Institute of South Africa. Coir fiber is 100% natural and originates in the outer husks of coconuts. It is part of the seedpod of the coconut palm. Ampreg 21, a two part clear epoxy resin that cures at room temperature was used as the matrix. This resin was supplied by AMT Composites. Ampreg 21 is a UV resistant clear liquid epoxy. It has a specific gravity of 1.09, Shore D hardness of 75, mixed viscosity of 100 cps, pot life of 45 minutes and has a curing time of 16 hours.

2.3 Pre-fabrication Preparations

2.3.1 *Specimen Geometry*

The experimental tests were conducted in accordance to ASTM 3039. The tensile test specimen selected was a flat plate specimen of dimensions 250 × 25 × 2.5 mm.

2.3.2 *Coir Fiber Treatment*

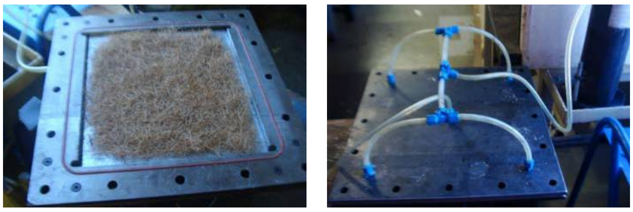
Fiber-matrix adhesion is key to the performance of a composite components. Special care was taken to prepare the fibers. After cleaning and cutting, the coir fibers were treated with a 2% solution of sodium sulphite and sonicated in an ultrasonic apparatus for approximately 2 hours. After the sonication the coir fibers were washed with deionized water and dried at room temperature for 2-3 days. This is called sulphite treatment. Once the treatment was complete the fabrication of the epoxy composite process began.

2.3.3 *Processing Techniques*

The two methods used for the fabrication of the epoxy composite were the Hand Lay-up (HL) and the Resin Transfer Molding (RTM) techniques.

2.3.4 *Resin Transfer Molding*

The first step before using the resin transfer mould is the coating of release agent. The coating method includes applying a single coat and letting it set for approximately 5 minutes before applying another coat and leaving it to set before use. The coir fiber was then placed into the mould. The fiber was measured to a specific mass to provide the right volume fraction in relation to the volume of the mould. Fiber volume fractions used were 4%, 6%, 8% and 10%. The fibers were fairly loose and so to produce an almost mat like feature, the fibers were randomly distributed and then compressed in the mold using weights. The setting up of the resin transfer mould was then carried out. However, prior to the run time, the resin and the hardener must be mixed to form the polymerized epoxy resin. The resin to hardener ratio used was standard AMT 100:38. Figure 1(a) shows the fiber in the mold and Figure 1(b) shows the RTM setup. The vacuum pressure was adjusted to vary the resin transfer rate.



(a) (b)

Figure 1 - RTM process configuration

2.3.5 *Hand Lay-up Technique*

The hand lay-up process was slightly simpler and less tedious than the RTM process. The fiber preparation followed the same approach used in the RTM process. Once the release agent was dry, the chopped fibers were placed in a container with required volume fraction. The resin to hardener ratio used for the hand lay-up process was 100:20. This was meant to increase curing time to improve handling due to the slower process. The mixture was then carefully laid in the mold which was then closed, locked with bolts and left to cure. The process is shown in Figure 2.

Figure 2 - Hand lay-up a)fibre distribution and b) resin distribution

Produced specimen were then cut into test specimen using band saw and polished using a grinder. Samples of the produced specimen are shown in Figure 3.

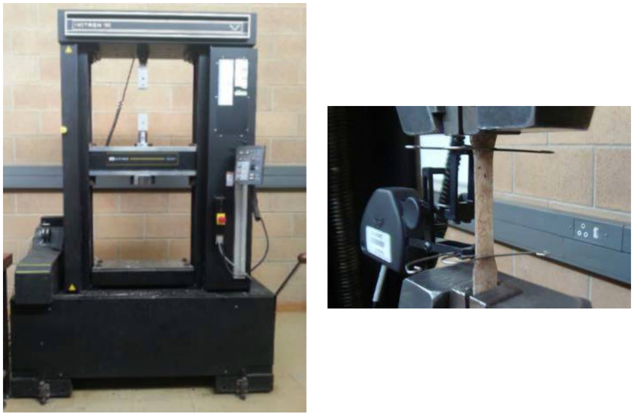
(a) (b)

Figure 3 - Specimen with different fiber volume fraction (a) 4% (b) 6%

2.4 Equipment

2.4.1 *Tensile testing*

Tensile tests were conducted on an Instron 1195 tensile testing machine controlled by Bluehill 2 software. This is a screw type machine which was used with a 100 kN load cell, see Figure 4(a). Figure 4(b) shows the mounting of the specimen in the testing machine grips showing extensometer mounting configuration.



(a) (b)

Figure 4 - Tensile testing set-up (a) Machine (b) Specimen mounting with extensometer

3 RESULTS

3.1 Fracture Analysis

Figure 5 shows the fractured specimens with 4 % fiber volume fraction. Fracture for three of the four specimens occured in the gauge section which is consistent with expectation. For one specimen fracture occurred outside the gauge section. This may been due to one or two reasons; either the jaws were not alighed and tightened properly or the sample was not cut to consistent ASTM dimensions due to human error as this was a manual process. However, specimens with 6% and 8% and 10% fiber volume fractions exhibited consistent fracture patterns.

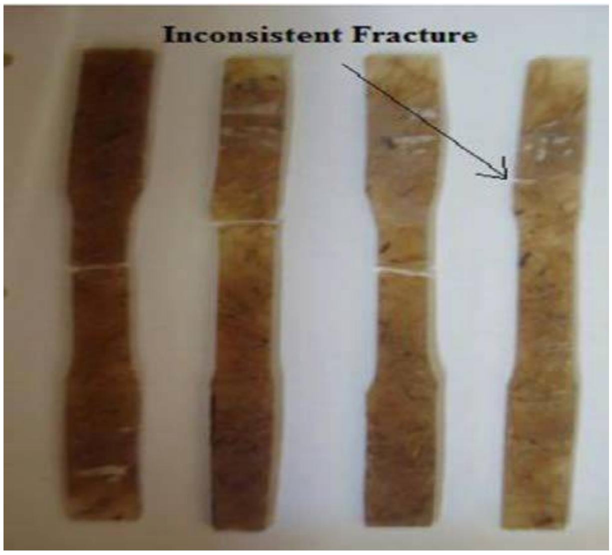
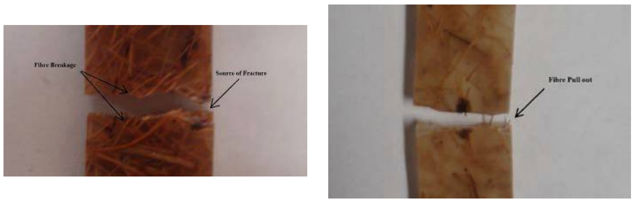


Figure 5 - Fractured specimens 4% vol

Almost all specimens indicated horizontal fracture. Horizontal fracture is an indication of brittle fracture. Brittle fracture is predominantly stress droven and the fracture direction is perpendicular to the direction of applied tensile stress. There was also no signs of plastic deformation by the naked eye and this further supports the brittle fracture observation. This is shown in Figure 6 (a).



(a) (b)

Figure 6 - Sample fractured specimens (a) Flat (b) Fiber pull out

Figure 6 (b) also shows fiber pull out observed in some of the specimens. Fiber pull out is an indication of poor adhesion between the matrix and the fibre while fiber breakage is an indication of good adhesion between matrix and fibre. Fibre pull out may be due to fibre length not meeting the critical fibre length requirement. Another possibility could be the effect of fiber orientation. The direction of the force is vertical whereas orientation is random. A fixed orientation provides a better adhesion between fibre and matrix and hence more predictable load carrying cappacity. Another factor that contributes to fracture is volume consistency of the matrix. Volume of the matrix can be altered due to voids and bubbles. These surface voids can be the source of fracture.

A sample of the close up of the fractured surface is shown in Figure 7 exhibiting the appearance of the fibre pull out feature.

Figure 7 - Sample fractured specimen showing fiber pull out feature

3.2 Tensile Test Results

Figure 8 shows the typical stress strain response obtained for specimen with 8 % fiber volume fractions. The graphs are for four different specimens. The variance between the specimens acceptable. The stress strain response confirms the brittle fracture observed on the fractured specimens.

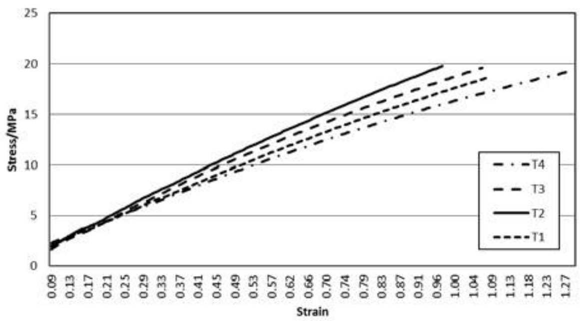


Figure 8 - Stress vs strain at 8 % fiber fraction

The effect of fiber fraction on composite mechanial properties for specimen produced using the RTM process is shown in Figure 9. It is clear that the volume fraction affects the mechanical properties of the composite. This is more pronounced for elastic modulus and less pronounced for tensile strength. The results seem to suggest the existence of an optimum volume fraction around 8%. This needs further work to confirm.

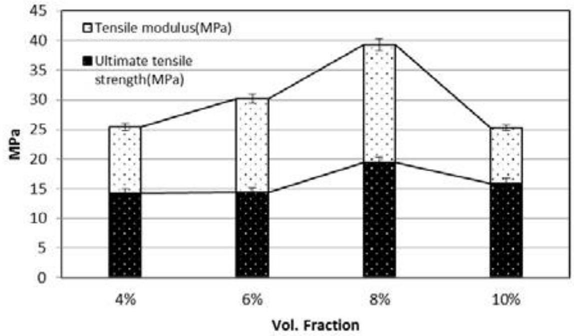


Figure 9 - Effect of fiber volume fraction on mechanical properties

A comparison of the mechanical properties for the high and low rate of resin transfer in the RTM specimens is presented in Figure 10. The results show better performance of the high rate (HR) of resin transfer compared with the low rate (LR) specimens. This is more pronounced for tensile strength and less so for elastic modulus. The average LR tensile strength was found to be 29.6 % lower than that for the HR process. Resin transfer rate therefore affects the mechanical performance of the composite.

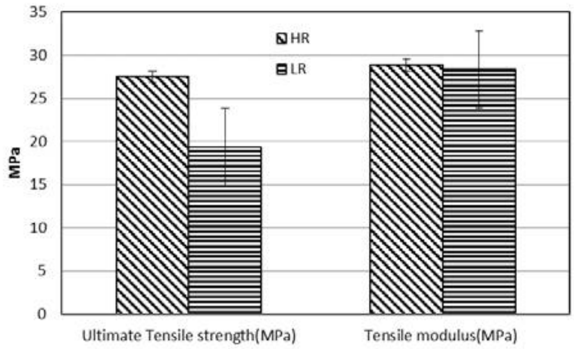


Figure 10 - Effect of resin transfer rate

3.3 Micro hardness

Micro hardness tests were conducted on all the specimens to determine the effect of loading on the softening of the specimen. Measurements were made for varying distance from the fracture surface. No consistent pattern was observed which shows that the loading did not have an effect on the hardness of the composite.

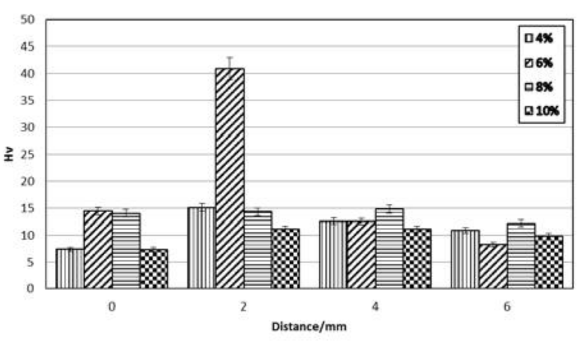


Figure 11 - Microhardness of fraction percentages

4 COMPARISON RTM AND HAND LAY-UP

On average the RTM process produced better performing specimens in terms of mechanical properties. The difference was more pronounced for tensile strength and less so for elastic modulus. This is summarized in Table 1 for the specimen with 4 % fiber volume fraction. However, the RTM process is more time consuming that the manual lay-up due to suction pressure adjustments required to achieve optimum resin flow rate. Moreover, mechanical properties are affected by the resin flow rate.

Extraction rate	**UTS (MPa)**	**Tensile modulus (MPa)**
RTM	28.61	31.25
MANUL	18.35	29.25

Table 1 - Comparison of RTM and hand lay-up for specimen with 4% fiber volume fraction

5 CONCLUSION

Coir fiber-epoxy resin composites were successfully made using the resin transfer molding (RTM) and the manual hand lay-up processes for varying fiber volume fraction. The specimen prepared were then characterized for mechanical performance. Based on the results obtained, the following conclusions can be made:

1. Coir fibers can be successfully used to strengthen epoxy resins to form a natural fiber composite
2. The strength of the composite produced is significantly dependent on the volume fraction of the fiber used
3. The RTM process produced specimen with superior mechanical performance compared to hand lay-up
4. The tensile strength of RTM specimen was about 29.6 % higher than that of hand lay-up and elastic modulus was not significantly affected
5. The RTM produced specimen whose quality is dependent on the rate of resin transfer that has to be determined by trial and error prior to making final components
6. RTM process is recommended due to its favorable geometrical control
7. Results seem to suggest the existence of an optimum fiber volume fraction of about 8% which produces maximum tensile strength

Further work is recommended to determine optimum resin transfer rate, the optimum fiber volume fraction and the optimum fiber diameter and length.

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7 BIOGRAPHY

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