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A Comprehensive Study on Fracture of Natural Fibre Composites

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ABSTRACT

Fracture toughness of natural jute fibre composite is almost similar to the glass fibre reinforced polymers (synthetic fibre). The fracture toughness (Kic) of composite sample is determined. The fractural behaviour of the surfaces is observed by SEM (Scanning Electron Microscopy) and it is observed that the prime factors of failure are fibre pull out, matrix de-bonding, fibre breakage and matrix cracking. In this paper, the author has studied about the fracture of natural fibre composites.

Keywords: fracture, natural fibre, composites, materials, jute, SEM.

INTRODUCTION

Natural fibre is the material which can be obtained from the plants, animals and mineral resources, for example, cotton, flex, hemp, sisal, silk, and wool. Natural fibre has valuable mechanical properties which are widely used in the industry. Researchers are conducting research to replace synthetic fibre with natural fibre. Engineers are always being challenged to go for environmental friendly process. Natural fibres are used as reinforcement materials which are made up of synthetic resin matrix, derived from natural resources such as plants, animals. They are originated from the natural renewable resources and their disposal becomes very easy, after usage. Natural fibre composites are environment friendly material, so they can be a good option to replace the glass fibres reinforced plastics. The price of synthetic fibre, as the reinforced material, is rising and at the same time their disposal is threat to the nature, so, researchers are finding the ability of natural fibre composites to replace synthetic fibres as reinforced materials. Most of the researches have been done to study the mechanical properties of natural fibre composites.

Motivation

The current global warming crisis has impacted researches all over the world to find suitable eco-friendly alternatives to synthetic fibres. This is one of the primary motivations for this project. Furthermore,

- There is increased demand for jute based composites.
- There is insufficient information about the microscopic fractural behaviour of jute/epoxy composites.
- Obtaining information on jute based composites will help with future simulations for designed based on these materials.

LITERATURE SURVEY

Natural fibres are fibres obtained from plants and animals but the fibres obtained from plants is to be studied as jute fibre (mat) is going to be used in this study for the experiments. These are fibres with lignocelluloses compounds. Lignocelluloses are a plants dry mass and are the most abundant raw material in the world. These fibres are ecofriendly, bio-degradable and abundant. These properties make them extremely desirable to manufacturers and scientists all over the world. A concern over the human influenced climate change has motivated research into natural fibre composites.

Technological advancements in manufacturing the bio-composites has made producing bio-composites easier. One of the issues is the material availability and the ever-growing customer demand. This has made these materials an efficient alternative to the existing synthetic composites. The petroleum crisis has accelerated the research on natural alternatives and the demand for it has grown significantly. Despite effective alternatives, the research for natural fibres keeps growing due to pressure from the global market. This sort of demand ensures continuous research into effective bio-fillers.

The global market for bio-composites annually increases by 38%. This growth rate has been consistent between 2003-07 (Fowler et al. 2006). The growth rate was 48% during the same period in Europe alone (Fowler et al. 2006). This increase is due to the growing awareness about the declining resources for non-renewable materials. Hence, renewable fibres are the most demanded alternatives. The primary source for renewable materials is from plants.

The plants that produce fibre are classified as primary and secondary fibre sources. Primary plants are those that are primary grown for their fibre content. Some examples of primary fibre plants are jute, hemp and kenaf. Secondary fibre plants are those which produce fibre as a by-product. Examples of secondary plants are coir and pineapple. Table 1 shows the various fibre sources and their global production in tons (Staiger & Tucker 2008).

As it can be seen in table 1, Sugarcane bagasse is the highest produced fibre then Jute, bamboo, kenaf, flax and many more. Currently, jute production is growing at an increasing rate and their use in the composite industry is still widely being researched.

Table 1 Commercially major fibre sources (Staiger & Tucker 2008)

Fiber source	World production (10^3 ton)
Bamboo	30,000
Jute	2300
Kenaf	970
Flax	830
Sisal	378
Hemp	214
Coir	100
Ramie	100
Abaca	70
Sugar cane bagasse	75,000
Grass	700

Jute is a fibre that is produced from the plants that belong to the genus Corchorus. This genus includes about 100 plant species (Faruk et al. 2012). It is one of the most affordable fibres second to cotton. It is collected from the phloem of plants or sometimes known as the skin. Hence, it comes under the category of bast fibres. It is mainly composed of lignin and cellulose which are bio-degradable. Owing to its cheap production cost, bio-degradability, and abundance it can be considered as an appropriate alternative to synthetic fibres.

Treatment Methods

The major problem with natural fibres is the moisture absorbability (Faruk et al. 2012). The hydrophilic nature of fibres increases moisture absorption misaligning the fibres which affects properties such as tensile, toughness and other mechanical properties. This mainly occurs due to the influence of hemicellulose and lignin in these fibres. As mentioned earlier, removing hemicellulose and lignin allows the fibrils to orient themselves and gradually decreases micro voids. The fig below shows a SEM image of micro voids and misaligned fibrils.

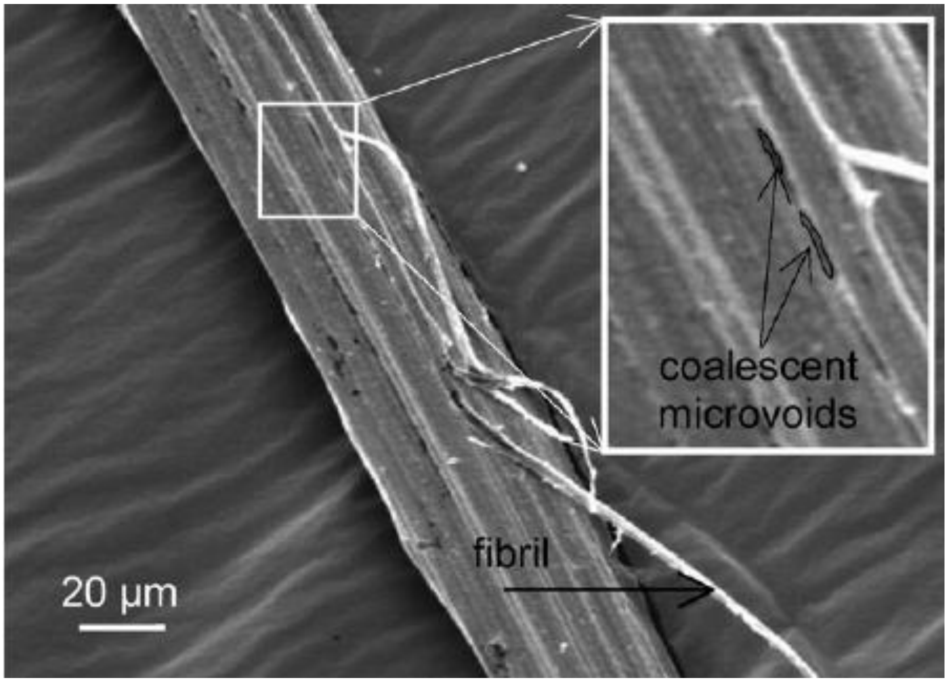

Figure 1: SEM image of micro-voids and misaligned fibrils (Cayer-Barrioz et al. 2004)

Micro void elimination increase inter fibre alignment and therefore increases mechanical properties of the fibre (Gassan & Bledzki 1999). The treatment methods are classified primarily into physical and chemical methods. Physical methods are methods that use physical techniques to modify the morphology of the fibre. Chemical methods use different chemicals to do the same.

METHODOLOGICAL STUDY

The aim of the study is to determine the fracture performance of the jute fibre composites, which is a natural fibre. This section provides the methodology that will be used to determine the performance of the jute fibre during the process of fracturing. The section provides information on the material selection and the experimental procedure that will be used to study the fracture performance of the natural jute fibre composites. In the world today, the technological advancements besides the consumer's increasing demands linked to the material availability and environmental sustainability require the exploitation of the earth's natural resources to ensure low energy consumption to avoid increasing global warming.

Natural fibre composites are some of the earth's resources capable of low energy consumption and supporting the decrease in global warming processes. Some of the natural fibres have been adopted in the automotive industry among others such as door panels, dashboards and headliners among many other uses. Thus, the section presents an outline on material selection and preparation to understand the performance of the jute natural fibre composites. That is; the section will conduct mechanical experiments to determine the fracture performance of the jute fibre composites, which will present how it can be mechanically improved to enable the extended use of the fibres in many industries.

Material Selection and Preparation

The Jute Fibre is a natural fibre that was selected for the fracture performance study. The Jute fibre does not require complex planning and preparation to make it ready to be used in the fracture study process. Additionally, the jute fibre is used in many industries today, which stipulates that studying it fracture performance was beneficial in showing the additional areas it could be used. It was selected for these process based on many more applications issues named in the literature review. Through reinforcing it with the epoxy resin will brand it effective for application in many other areas, since the fracture performance of the material will stipulate the maximum load the material can bear prior to fracturing (Grcaeraj & Venkatachalam, 2015).

The experimental procedure to determine the fracture performance of the jute fibre composites demonstrates the dependence of the mechanical properties on the mechanisms natural fibre composite failure, while determining the possible ways to improve such properties. Jute fibre is a long, shiny and soft vegetable that is coarsened into strong threads (Pickering, 2008).The experimental process of composite materials is an evolving one demanding high loading structures among other mechanical testing procedures. The inherent properties of the fibres such as mechanical properties, physical and geometrical properties of the fibre demand new and different testing methods to determine their fracture performance (Zhou, et al., 2013).

Table 2: physical properties of jute fibre (Zhou, et al., 2013)

PHYSICAL PROPERTIES OF JUTE FIBRE	
Properties	
Density (g/cm3)	1.4 to 1.8
Young Modulus (GPa)	30
Tensile strength (MPa)	700 - 800
Tensile Elongation (%)	1.1 -1.7
Cellulose content (%)	51% to 58%
Lignin content	8% to 10%

Tensile testing machine

The mechanical experimental tests to perform to determine the fracture performance of the material include the shear experimental test, flexural, compressive and tensile testing. These tests are effective in determining the fracture performance of a material based on the load they can handle. The mechanical tensile testing of the jute fibre has been conducted using the MTS universal tensile testing machine which is located in lab P11 of University of Southern Queensland under the supervision of Mr. Wayne Crowell (Assistant Manager, structural testing services). Risk management and standard work procedures were completed before the commencement of lab work and shown in APPENDIX below.

Figure 2: Tensile testing machine

Figure 3: Tensile testing of specimen

The specimen (Jute Fibre), used for the experiment has a gauge length of 200mm, which is used to determine the tensile strength and modulus of the material. The material is placed in between the grips, and as the stress is applied, the strain processes will occur. At a certain point when the stress is more than the material can handle, it will reach the breaking point, which stipulates the fracture performance of the material (Zhou, et al., 2013). The jute fibre tensile testing followed the standard dimensions for all tensile tests, which are 200 * 30 * 3mm. When the break point of the material is attained, the ultimate tensile strength of the material is given as wellas the tensile stress and strain curves.

NUMERICALLY CALCULATION OF FRACTURE TOUGHNESS (KIC)

The fracture toughness (Kic) was determined for all the four samples using the equation mentioned in methodology which is according to the ASTM D5045. These fracture toughness (Kic) values has been compare with the previous result of glass fibre composites in which different lengths of fibre have been used.

$$Kic = \frac{P}{B\sqrt{W}} f\left(\frac{a}{W}\right)$$

Where $f(x)$ can be calculated from ASTM D5045 and x =$\frac{a}{W}$

$$f(x) = \frac{(2+x)(.886 + 4.64x - 13.32x^2 + 14.72x^3 - 5.6x^4)}{(1-x)^{\frac{3}{2}}}$$

We know that,

Width (W) = 15 mm Notch (a) = 5 mm

So after putting known values we get,

$$\boldsymbol{f(x) = 6.10271}$$

After performing experiments we got following results:

Table 3: Dimensions and peak load of fracture samples.

Specimens	Width (W) in mm	Thickness B in mm	Peak load P in N
1	15	2.80	119
2	15	2.96	99
3	15	2.73	111
4	15	2.77	111
Mean	15	2.82	110

For first sample $Kic = \frac{119}{2.80 \times \sqrt{15}} f(\frac{5}{15})$

On solving this equation, **Kic = 2.07 Mpa** $\boldsymbol{m^{\frac{1}{2}}}$

Similarly, Kic values have been determined which is shown in table below.

Comparison of Fracture Results

The fracture toughness (Kic) is calculated for jute fibre composites and now the results have been compared with the glass fibre composites made of different fibre lengths. The maximum value of the fracture toughness (Kic) for the jute fibre composites is calculated as **2.07** Mpa m^1/2 which is little less than the glass fibre composites. The results have been compared with GFRP of different fibre lengths in which the fracture toughness of jute fibre epoxy composites is greater than the GFRP made from 10 mm fibre lengths but little less from GFRP made of 15 mm fibre length. The comparison between the results is shown below with the help of bar graph.

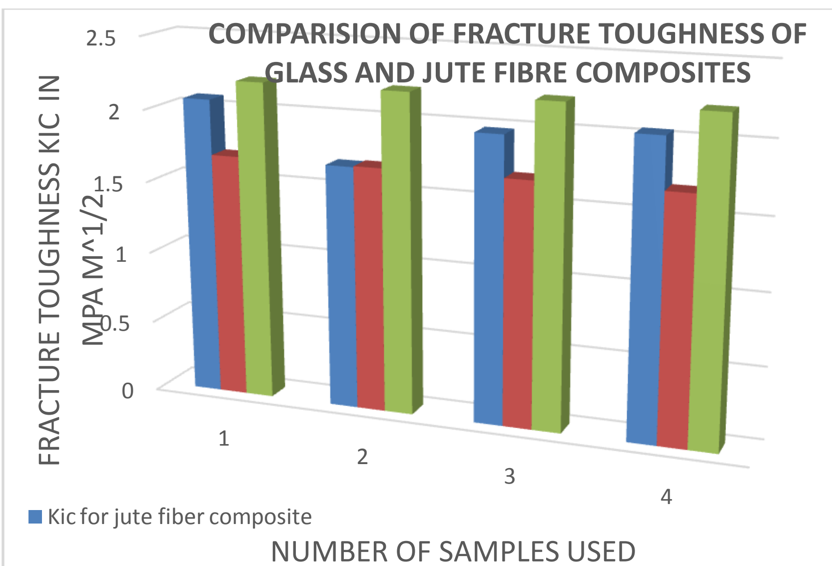

Figure 2: Comparison of fracture toughness values with GFRP made of 30 % volume fraction and different fibre lengths.

CONCLUSIONS

To conclude the fracture mechanism, during the SEM study of fractured surfaces of jute fibre reinforced epoxy composites matrix cracking, fibre pull out, de-bonding and fibre breakage are the various types of failures that have been observed. In this paper, it is studied that fracture toughness of jute fibre composite (natural fibre) is almost similar to the glass fibre reinforced polymers (synthetic fibre). The fracture toughness (Kic) of composite sample is determined.

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