Investigation of Fracture Behavior on Glass & Natural Fibre Reinforced Epoxy Composites

Jegan. M. M [a], Sathishkumar. T P [b], Anand. V [c], Arun Ganesh. R [c], Logesh Raja. C [c], Mohanraj. K [c]
[A,b] Assistant Professor,
[C] UG Students
Mechanical Engineering, Nandha College of Technology, Erode-52, Tamil Nadu

***Abstract*:- The Jute fiber woven and glass fiber random mat reinforced epoxy composites were prepared with different orientation of jute fiber mat. The effect of jute fiber mat orientation and number of stacking layers on the fracture properties are investigated experimentally and then the compared with pure glass and jute fiber reinforced epoxy composites. The top and bottom layers are made up of glass fiber mat and the jute fiber mat is placed in between the glass fiber mat during the composite preparation. The epoxy and hardener are mixed by mechanical stirrer and the poured on the mould with fiber mats. The solidified composite plate is taken from the mould and then fracture samples are cut according to ASTM standard. The fracture behaviours are analyzed by Mode-I fracture with compact tension (CT) and single-edge notching bending (SENB) testing method. The tensile mode is used to analyze the fracture behaviours of CT samples and the three pint bending mode is used to analyze the fracture behaviours of SENB samples. From the results, the fracture load is gradually increased with crack opening displacement of all composites. The highest fracture toughness is obtained for pure glass fiber composites.**

Keywords: Fracture toughness, Natural fibers, Glass fibers, Epoxy resin.

1. INTRODUCTION

1.1. Composite materials

Composites are one of the most advanced and adaptable engineering materials. Progresses in the field of materials science and technology have given birth to these fascinating and wonderful materials. Composites are heterogeneous in nature, created by the assembly of two or more components with fillers or reinforcing fibres and a compactable matrix. The matrix may be metallic, ceramic or polymeric in origin. It gives to the composite shape, surface appearance, environmental tolerance and overall durability while the fibrous reinforcement carries most of the structural loads thus giving macroscopic stiffness and strength. A composite material can provide superior and unique mechanical and physical properties because it combines the most desirable properties of its constituents while suppressing their least desirable properties. At present composite materials play a key role in aerospace industry, automobile industry and other engineering applications as they exhibit outstanding strength to weight and modulus to weight ratio. High performance rigid composites made from glass, graphite, Kevlar, boron or silicon carbide fibres in polymeric matrices have been studied extensively because of their application in aerospace and space vehicle technology.

1.2. Classification of composites

The classifications of composites are of four types namely,

- Particulate reinforced composites
- Fibre reinforced composites
- Laminate reinforced composites
- Hybrid reinforced composites

1.3. According to type of matrix materials

The composite is classified based on type of material,

- Metal Matrix Composites (MMC)
- Polymer Matrix Composites (PMC)
- Ceramic Matrix Composites (CMC)

1.3.1. Metal matrix composites

Higher strength, fracture toughness and stiffness are offered by metal matrices. Metal matrix can withstand elevated temperature in corrosive environment than polymer composites. Titanium, aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

1.3.2. Ceramic matrix composites

One of the main objectives in producing ceramic matrix composites is to increase the toughness. Naturally it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of ceramic matrix composites.

1.3.3. Polymer matrix composites

Most commonly used matrix materials are polymeric. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn‟t require high temperature. Also equipment‟s required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications.

Two types of polymer composites are:

- Fibre reinforced polymer (FRP)
- Particle reinforced polymer (PRP)

1.3.3.1. Fibre reinforced polymer

Common fibre reinforced composites are composed of fibres and a matrix. Fibres are the reinforcement and the main source of strength while matrix glues all the fibres together in shape and transfers stresses between the reinforcing fibres. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or reduce the product cost.

1.3.3.2. Particle reinforced polymer

Particles used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials, including polymers and carbon black. Particles are used to increase the modules of the matrix and to decrease the ductility of the matrix.

2. MATERIALS

2.1 Synthetic fibres

2.1.1 Glass fibre

Glass fibre is the best known reinforcement in high performance composite applications due to its appealing combination of good properties and low cost. The major ingredient of glass fibre is silica which is mixed with varying amounts of other oxides. The different types of glass fibres commercially available are E and S glass. The letter „E‟ stands for electrical as the composition has a high electrical resistance and „S‟ stands for strength. Glass fibres are used successfully for reinforcing the plastics and therefore, the suitability of this fibre as a reinforcing material for rubbers has been studied. High initial aspect ratio can be obtained with glass fibres, but brittleness causes breakage of fibres during processing.

2.1.2 Carbon fibres

Carbon fibre is the one of the important high performance fibre used in short fibre-polymer composite. They are commercially manufactured from three different precursors rayon, polyacrylonitrile (PAN) and petroleum pitch. They are mainly used in aerospace industry due to its outstanding mechanical properties combined with low weight. Though carbon fibres are extensively used in polymer composites, its application in rubber matrices is limited to specific end use, mainly in electrically Conductive composite

2.1.3 Aramid fibres

Aramid is a generic term for aromatic polyamide fibres. The first commercial p- Aramid fibre (Kevlar) was introduced in 1971. Several aspects of aramid fibre reinforcement of elastomeric matrices and thermoplastic elastomers were discussed by various authors. Sunan et al compared the reinforcing effect of as received and hydrolysed Kevlar fibre reinforced thermoplastic elastomers (Santoprene) composites.

2.2 Natural fiber (Jute fiber)

Jute is one type of natural fiber which is one of the cheapest fiber and is second only to cotton in amount produced and variety of uses. Jute fibers are composed primarily of the plant materials cellulose, lignin, and pectin. Both fiber and plant from which it comes are called jute.

3. EXPERIMENTAL

3.1 Fabrication of composites

While fabricating composite products with reinforcing fibers (in form of mats or fabric)are placed layer-by-layer over the surface, to ensure appropriate stacking sequence, as well as requisite thickness of the final product. Once a particular layer of fiber is placed, it is coated with a layer of resin through a brush. Care is taken to ensure that resin is

For this, serrated rollers devoid of air bubbles, as it is applied to reinforcing fibers. may be used, which help remove air bubbles, as well as ensure increased wetting of fibers. This manual method of layup may also be used for short fiber composites.

3.2 Selection of molding process

The bidirectional woven fabric made of jute fibers gives the bidirectional orthotropic behaviours. A long woven mat was cut into different angles of laminas such as (0/90)°, (30/120)°, (45/135)°, (60/150)° and (75/165)° respectively and the size of the laminas are 75 mm × 75 mm. Prior composite processing, the mats were dried at temperature of 33°C with the relative humidity of 65% for at least 24 hours. Epoxy and hardener were mixed in the ratio of 10:1 (by weight) by the help of mechanical stirrer. The mixing was done about 4 minutes for degasing. A layer of resin applied on the mold and then the mats were laid one-by-one, the layers glued with help of resin. The spring roller was rolled over the each layer to remove the air bubbles and distribute the resin uniformly. Finally, the mold was kept closed and kept in compression moulding machine under
5 bar pressure for 4 hours. Hereafter, the solidified laminated composites plates was taken from the mould and then machined for studying the fracture behaviours.

3.3 Fracture

A fracture is the separation of an object or material into two or more pieces under the action of stress. Crack propagation in the composites is an important reason for structure failure. The fracture of a

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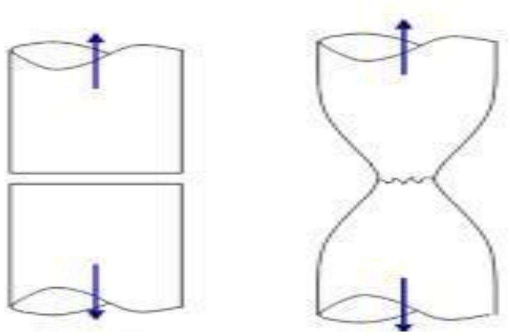
composite usually occurs due to the development of certain displacement discontinuity surfaces within the composite. If a displacement develops perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack. If a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation. Fracture strength or breaking strength is the stress when a specimen fails or fractures.

3.3.1 Types of fracture

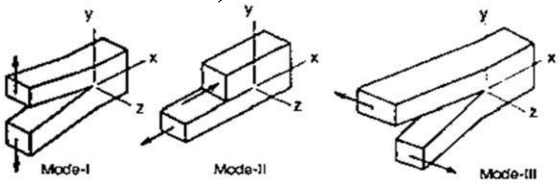
Brittle fracture   Ductile fracture



3.3.2 Modes of fracture

There are three different modes of fracture failures. They are,

- **Mode I crack** – Opening mode (a tensile stress normal to the plane of the crack)
- **Mode II crack** – Sliding mode (a shear stress acting parallel to the plane of the crack and perpendicular to the crack front)
- **Mode III crack** – Tearing mode (a shear stress acting parallel to the plane of the crack and parallel to the crack front)



Modes of fracture

Crack initiation and propagation accompany fracture. The manner through which the crack propagates through the material gives great insight into the mode of fracture. In ductile materials (ductile fracture), the crack moves slowly and is accompanied by a large amount of plastic deformation. The crack will usually not extend unless an increased stress is applied. The cracks that propagate in a brittle material will continue to grow and increase in magnitude once they are initiated. Another important mannerism of crack propagation is the way in which the advancing crack travels through the material. A crack that passes through the grains within the material is undergoing transgranular fracture. However, a crack that propagates along the grain boundaries is termed an intergranular fracture.

4. MODE- I FRACTURE TESTING OF COMPOSITE MATERIAL

Fracture toughness is to measure the resistance of a material to the presence of a flaw in terms of the load required to cause brittle or ductile crack extension in a specimen containing a pre-crack.

There are two types of test:

- Compact Tension
- Single-Edged Notched Bend

4.1. Compact Tension

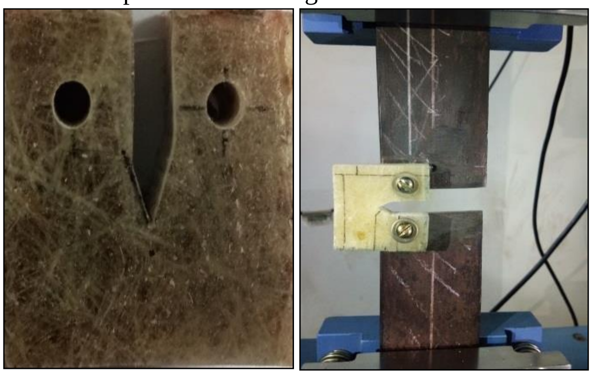
The plane-strain fracture toughness test was conducted by the help of Universal Testing System according to ASTM E D5045-99 with test configurations of Compact-tension (CT) specimen method and Single-edge notch-bend specimens (SENB) using three-point bending mode, at room temperature. The fracture tests were conducted by mode I fracture behaviour

a) CT testing specimen b) Experimental setup for CT test

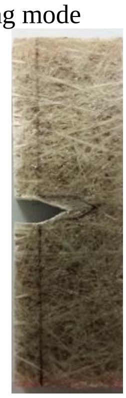
The stress intensity factor at the crack tip of a compact tension specimen is calculated.

4.2. Single-Edged Notched Bend

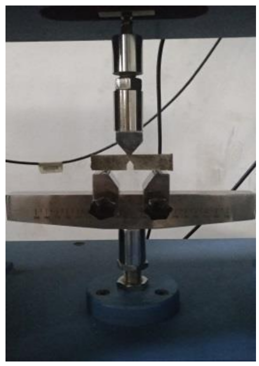
The plane strain-toughness value at slow



loading rate is calculated according to ASTM E D5045. The SENB fracture test is conducted by three-point bending mode



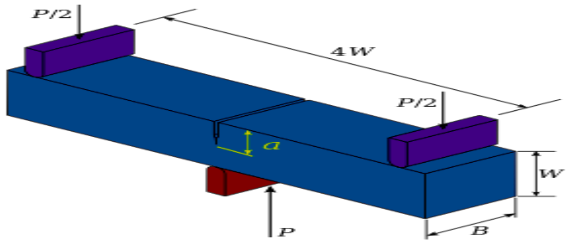
SENB testing specimen



Experimental setup for SENB test

The test method for conducting the test usually involves a specified test fixture on a universal testing machine. Details of the test preparation, conditioning, and conduct affect the test results. The sample is placed on two supporting pins a set distance apart.

Single-edge notch bending specimen (also called three-point bending specimen) for fracture toughness testing. The fracture toughness of a specimen can also be determined using a three-point flexural test. The stress intensity factor at the crack tip of a single edge notch bending specimen was calculated by equation



Schematic of the SENB fracture testing

Where is P the applied load, B is the thickness of the specimen, a is the crack length, and W is the width of the specimen. In a three-point bend test, a fatigue crack is created at the tip of the notch by cyclic loading. The length of the crack is measured. The specimen is then loaded monotonically. A plot of the load versus the crack opening displacement is used to determine the load at which the crack starts growing. This load is substituted into the above formula to find the fracture toughness equation

The ASTM E1290-08 Standard suggests the relation [12],

$$K_I = \frac{6P}{BW} a^{1/2} Y$$

Where,

$$Y = \frac{1.99 - a/W(1-a/W)(2.15 - 3.93a/W + 2.7(a/W)^2)}{(1+2a/W)(1-a/W)^{3/2}}.$$

The predicted values of K_I are nearly identical for the ASTM and Bower equations for crack lengths less than $0.6W$.

5. Result and conclusion

5.1. Fracture tests

The composites were prepared with 9 layers of jute fiber mats. It is clearly showed that the load versus displacement curves of all orientations is almost linear increased. This proves the linear elastic fracture mechanics (LEFM) approach because the non-linear failure is not exhibited. Once the fiber incorporated in the resin, a different behaviour has been found for Jute fiber reinforced epoxy laminated composites at various fiber orientations. By changing the jute fiber orientation, the fracture load is varying and the maximum fracture load is obtained for composite containing 30/120 9J compared to all other orientation. The propagation of rack along the 30°/120° fiber orientation resists during the experiments which results in maximum fracture load.

Incorporation of jute fiber mat in-between glass fiber random mat in the epoxy composites is increasing the fracture load absorption. Compared to jute and hybrid fiber epoxy composites, the pure glass fiber random mat epoxy composite is found highest fracture load. This is due the highest stiffness of the glass fiber compare to the jute fiber. The crack propagation is found to be linear and perpendicular to the loading direction. It is clear that the fracture behaviours obey the LEFM. The hybrid composites load is found to be higher than the pure jute fiber mat reinforced epoxy composites and it is increased to twice.

In this work, the effect of different orientation of Jute fibre on fracture behaviours of the epoxy composites was investigated. The jute fibre mat reinforced epoxy laminated composites were fabricated by compression moulding process. The fracture behaviour was studied according to ATSM standard. From the results and discussions the following conclusions were obtained based on the mode-I fracture behaviours of SENB and CT samples.

- The fracture is almost linear for all composites and propagation of crack was linear and perpendicular to the loading direction.
- Even different orientation of jute fiber mat presented in the composites, the propagation of crack was linear due to glass fiber random mats.
- Overall the fracture toughness was improved by introducing the jute fiber mat in the glass fiber mat epoxy composites

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