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Thermal Characterization and Fracture Toughness of Sisal Fiber Reinforced Polymer Composite

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Abstract Interest in natural fiber polymer composite has increased worldwide due to their low cost, low density and good thermal resistivity. Sisal fiber is used as reinforced in mat form and epoxy as matrix in this composite. In present work, thermogravimetric analysis and fracture behavior of composites were studied. The percentage mass loss and physical changes of composite was observed through furnace pyrolysis. The improved value of fracture toughness and energy release rate were found 6.63 MPa.m$^{1/2}$ and 21.13 k J/m^2 respectively of composite at 30 wt. % fibers loading. The result from the TGA shows that the addition of sisal fibres up to 30 wt. % into the polymer slightly improves the thermal stability of the composite.

Key word: Sisal mat, epoxy, fracture toughness and TGA.

I. Introduction

Fibre reinforced polymer composite is a relatively new material in the construction industry as compared to steel and concrete. The commonly used synthetic fibres are glass, aramid and carbon [1]. The concept of green-building, the idea of introducing natural fibres in polymer composites has been introduced. The advantages of natural fibres over its synthetic counterparts include low weight, low cost, low density, biodegradable, availability from renewable resources, and good thermal and acoustic insulation properties [2-4]. Also, they are non-abrasive on processing equipment and provide safer and healthier working environment [5]. However, this very attraction also imposes a great drawback on its durability. The disadvantages of natural fibre include low moisture resistance, inferior fire resistance, limited processing temperature, lower durability, and variation in quality and price [2, 4]. Presence of hydroxyl groups in natural fibres makes them hydrophilic in nature and this generates high moisture absorption that causes composites to fail in wet condition through fibre swelling and delamination [6-9]. In terms of exposure to high temperature, majority of natural fibres have low degradation temperatures which are inadequate for processing with thermoplastics with processing temperatures higher than 200˚C [10].

Nomenclature

SM 1 10 wt. % sisal fiber reinforced polymer composite

SM 2 20 wt. % sisal fiber reinforced polymer composite

SM 3 30 wt. % sisal fiber reinforced polymer composite

II. Material and Methodology

2. Materials

Sisal mat supplied from Women Development Organization Board from Dehradun and Epoxy and Hardener were purchased from Universal Enterprise (Polymer Division) Kanpur. The properties of sisal fibers are given in Table 1[11].

TABLE I

Mechanical and Chemical Properties of Sisal Fibers

Mechanical Properties		Chemical Properties	
Density (Kg/m³)	1450	Cellulose %	65
Flexural modulus (GPa)	12.5-17.5	Hemicelluloses %	12
Tensile strength(MPa)	68	Lignin %	9.9
Young's modulus (GPa)	3.774	Microfibrillar angle	20^0

2.1 Fabrication of composites

For preparing composites the Epoxy resin AY-105 and the Hardener HY-951 were mixed in ratio of 10:1 by weight. A thin layer of epoxy is applied on Teflon sheet. After that fibers were laid uniformly over the mould. By ensuring that the fibers are uniformly distributed in mold then mixture of epoxy and hardener poured over the fiber and it was cured under 50 kg loads at 24 hours. After completing curing process composites were cut as ASTM standard by diamond cutter.

2.2. Mechanical Testing

Mechanical testing reveals the elastic and inelastic behavior of a material when force is applied. A mechanical test shows whether a material or part is suitable for its intended mechanical applications by measuring elasticity, tensile strength, elongation, hardness, fracture toughness, impact resistance, stress rupture, and fatigue limit. For fracture test 5 samples were cut from SM 1, SM 2 and SM 3 composition and average value is taken out from testing results.

2.2.1 Fracture toughness and Energy Release Rate:

The test performed on Universal Testing Machine with crosshead speed of 2 mm/min and the composite samples were cut as per standard of ASTM D5045. There dimensions are 56mm x 13mm x 3mm which is in rectangular shape having notch at depth of 1.26 mm with 45˚. The fracture toughness was calculated by given formula.

$$K_Q = \frac{P_Q}{BW^{\frac{1}{2}}} f(x)$$

Where (0<x<1), K_Q *is* fracture toughness, P_Q is maximum load which is obtained from load displacement curve and B , W is thickness and width respectively.

The Energy Release Rate was calculated by given formula.

$$G_{1C} = \frac{U}{BW\varphi}$$

Where U is calculated by given formula.

$$U = P_Q (U_Q - U_I)$$

Where U_Q is average displacement of un-notched sample, U_i is average displacement of notched sample and φ is taken from chart which is given in ASTM D 5045

2.3. Thermo gravity analysis (TGA):

Thermogravimetric analysis was conducted by using TGA Q500 machine.

Samples were subjected to pyrolysis in nitrogen environment to a maximum temperature of 700˚C at a heating rate of 10˚C/min. The weight loss was recorded in response to increasing temperature, with final residue yield on set of degradation temperature and number of degradation steps reported.

III. Results and Discussions

3. Fracture Toughness: The fracture toughness of sisal reinforced epoxy composites of SM 1, SM 2 and SM 3 are shown in fig 1. It is observed from results that fracture toughness increases of SM 3 due to better fiber and matrix adhesion and low percentages of voids than other wt. % of composition. Fracture toughness is 6.63 MPa.$m^{1/2}$ of SM 3 which is 72% and 61% better than SM 2 and SM 1 respectively.

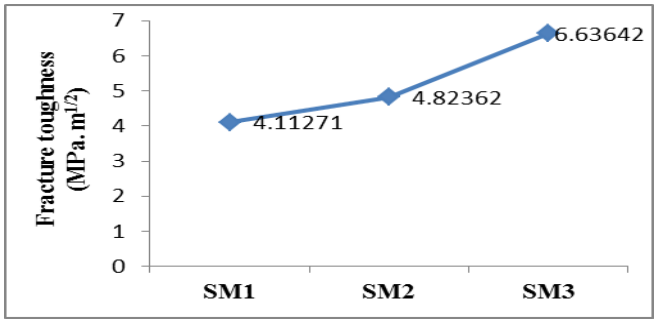

Fig.1 Fracture toughness of composites

3.1 Energy Release Rate G_{1c}:

The energy release rate of sisal reinforced epoxy composites of SM 1, SM 2 and SM 3 are shown in fig 2. The energy release rate improves as fibre content increases. This could be due to at lower fibre weight fraction; crack growth rate is locally accelerated due to relatively low polymer tenacity. With increment in fibre loading, crack is deflected and pinned by reinforcing obstacles, thus slowing down the propagated velocity, causing an indirect crack path.

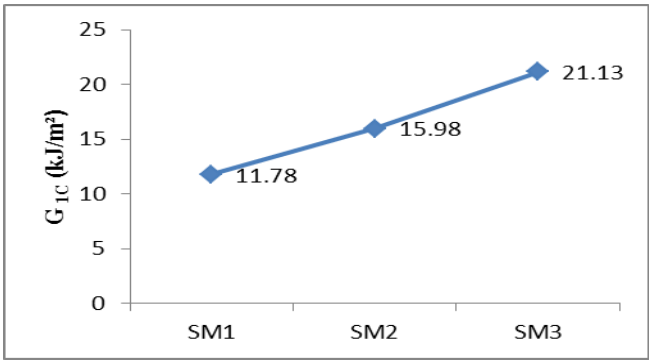

Fig.2 Energy Release Rate of composites

3.2 Thermogravimetric analysis (TGA):

Figure 3 shows the TGA curve of SM 1, SM 2 and SM 3. It can be seen that SM 1 starts to lose mass earlier than the other samples. This may be attributed to the higher moisture content of untreated fibres whereby, the presence of hemicelluloses has caused higher moisture absorption of the composite [13].

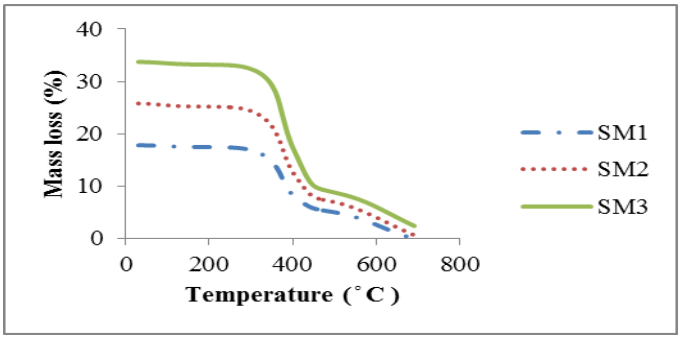

Fig 3 Effect of the Fiber Loading On Thermal Properties of Composites

From TGA curve it is described that first weight loss of sample occurs at 60-100˚C due to presence of moisture. Second weight loss occurs at 325-360˚C due to thermally depolymerisation of hemicellulose and third weight loss occurs near 425-460˚C due to sample failure at this temperature product phase change occurs due to phase change.

IV. Conclusions

The objective of this study was to define the benefits of reinforcing sisal fiber in the mat form with epoxy. Fracture toughness and energy release rate of SM 3 are found 6.63 $MPa.m^{1/2}$ and 21.13 k J/m^2 respectively. The result from the TGA shows that SM 3 has better thermal stability due to high fiber content. At higher temperature, duration of exposure has little influence on the mass loss.

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