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RESEARCH ARTICLE

Determination of Stress Intensity Factor of Banana Fibre Reinforced Hybrid Polymer Matrix Composite Using Finite Element Method

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Abstract

In the current scene on material field, designers are focusing on the development of lightweight, high strength, recyclable and environment friendly materials. Due to increasing environmental admiration, ecological concerns and new statutory laws, natural fibre reinforced polymer matrix composites have found increasing attention from the recent decades. Past studies show that synthetic and natural fibres such as glass, carbon, jute, coir etc., have been used in fibre reinforced polymer matrix composite. In this work, banana fibre is used as reinforcement. An investigation is carried out to make use of banana fibre made hybrid polymer matrix composite. Biodegradable polymer like Cashew Nut Shell Liquid (CNSL) in different percentage is used with General Purpose (GP) resin to make a hybrid polymer matrix. This work intends to study the fracture analysis of composite by using experimental and Finite Element methods. The critical stress intensity factor (KIC or critical SIF) has been evaluated and validated.

Keywords

banana fibre, Cashew Nut Shell Liquid (CNSL) resin, Stress Intensity Factor (SIF or KIC), fibre discontinuity, hybrid polymer matrix fracture

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1 Introduction

The interest in using natural fibres, such as different wood and plant fibres as reinforcement in plastics, has increased during the last decades. With consideration to the environmental side, it would be very interesting if natural fibres could be used instead of glass fibres in some structural applications. Reis studied that natural fibres have many advantages like low density, biodegradable and recyclable as compared to glass fibres. Also, they have relatively high stiffness and density and are renewable as raw materials. The low-density values allow producing composites that have low specific mass. Banana fibre is a waste product of banana cultivation and without any additional input cost, banana fibres can be used for industrial and general purposes. Banana fibre is found to be a good reinforcement in polyester resin [1]. Piyush and Shaikh concluded that fibrous materials have different values of mechanical properties in different directions [2]. Venkateshwaran et al. investigated that natural fibres are hydrophilic in nature and good adhesion between fibre and matrix does not exist which affects the material properties. To improve fibre matrix adhesion and compatibility, coupling agents can be used [3]. These coupling agents can reduce hydrophilic nature which is studied by Oksman et al. [4]. Kulkarni et al. investigated the mechanical behavior of banana fibre. They found that during tension test banana fibre fails due to pull out microfibrils by tearing of the cell walls [5].

Problem of non-biodegradability also exists with synthetic polymers. This disadvantage leads to expand research on natural polyester resins. One of such matrix material is cashew nut shell liquid (CNSL) resin. CNSL resin has many applications in polymer based industries like rubber compounding resins, friction linings, cashew cements, paints and varnishes laminating resins, foundry chemicals, aerospace and automobile industry, surfactants and intermediates for the chemical industry. The natural matrix material provides good performance, environmental friendliness and having less cost than synthetic matrix. Natural plant based resins such as CNSL are suitable for the manufacturing of natural fibre reinforced composites with required engineering properties. Shariffah and Ansell observed that alkalized and long fibre kenaf-CNSL composite gives higher flexural strength and flexural modulus and analogous with low work of fracture [6]. Also, Vishnu Prasad et al. investigated the tensile strength of banana fibre reinforced hybrid polymer matrix composite [7]. Bakare et al. found that the properties of unidirectional fibre-reinforced composites gave good thermal and mechanical properties [8].

Fracture toughness is defined as the amount of energy required to form new surfaces. Prasad et al. studied that fracture mechanics is divided into two theories which are Linear Elastic Fracture Mechanics for brittle material and Elastic Plastic Fracture Mechanics for ductile material [9]. Knott et al. introduced a concept in 1973. A crack tip locates in the material and it seems like a line running from one location of the component to another location. The high stress is concentrated at the crack tip. That's why; a crack tip analysis is useful for getting the stress field and displacement. To make the problem simpler these two variables are converted into one variable known as Stress Intensity Factor.

In this paper, fracture behaviour of Banana fibre reinforced hybrid polymer matrix composite is studied. The analysis is carried out by FEA and is validated with experimental results. Here, determination of Stress Intensity Factor (KIC) of banana fibre reinforced hybrid polymer matrix composites is carried out by varying three parameters such as CNSL percentage in hybrid polymer, fibre volume and fibre discontinuity.

2 Experimental analysis

2.1 Materials

Materials used to prepare composite are as follows,

Reinforcement: Banana Fibre

Matrix: Hybrid polymer – Mixture of General Purpose polyester (GP) resin and Cashew Nut Shell Liquid (CNSL).

2.2 Geometry

Sample geometry selected according to the ASTM D5045 standard of dimension 96.8mm × 22mm × 5.5mm, is shown in Fig. 1. The banana fibre used in this work has a diameter (d) of 1 mm with a length of 96.8 mm.

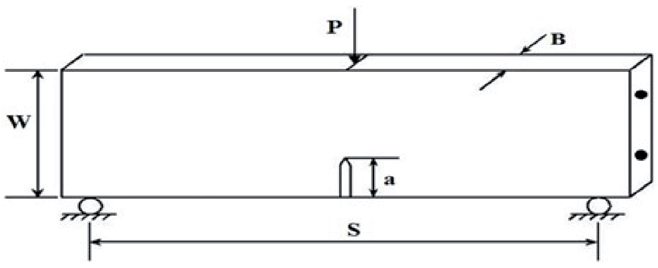


Fig. 1 Geometry of standard specimen

2.3 Composite preparation

The samples are prepared in different combination of varying parameters such as CNSL percentage in hybrid polymer, fibre volume in percentage and number of fibre discontinuity. The CNSL %: GP % ratio's used in this work are 25:75, 5:95 and 15:85. The fibre volumes in percentage are calculated by adopting unit cell concept. Three different fibre volumes are considered in this work. Fibre discontinuity means divided the total length of a fibre into 2 equal parts (1 discontinuity), 3 equal parts (2 discontinuities). Table 1 gives the different parameters considered along with their levels. Also, the Taguchi L9 array is used to achieve different combinations which are shown in Table 2.

Table 1 Manufacturing Parameters

Parameters	Number of Fibre Discontinuity (A)			Fibre Volume in % (B)			CNSL Percentage (C)		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
	0	1	2	1.3	2.6	3.9	25	5	15

Table 2 Taguchi L9 Array of Manufacturing parameters

Sample No.	1	2	3	4	5	6	7	8	9
Number of fibre discontinuity	A1	A1	A1	A2	A2	A2	A3	A3	A3
Fibre Volume in %	B1	B2	B3	B1	B2	B3	B1	B2	B3
CNSL %	C1	C2	C3	C2	C3	C1	C3	C1	C2

Hand Lay-Up method is used to prepare samples. GP resin and CNSL are mixed in different ratio's to get the hybrid polymer and used as a matrix material. Methyl ethyl ketone peroxide and cobalt naphthanate are used as catalyst and hardener respectively. The fiber volume in composite is increased by increasing the fibre content while keeping the volume of the composite as constant. Two single continuous fibres are used in each row which are arranged parallel to each other and horizontal to mold. For getting the three fibre volume percentages such as 1.3 %, 2.6 % and 3.9 %, the rows of fiber followed are 1, 2 and 3 respectively. The ends of each fiber are fixed stiffer in the plastic mold and ensured that the fibres are straight. Then the prepared hybrid polymer, after adding proper ratio of catalyst and hardener, is poured into the mold. Curing is carried out in the room temperature for 48-72 hrs. Figure 2 shows the prepared samples with no fibre discontinuity.

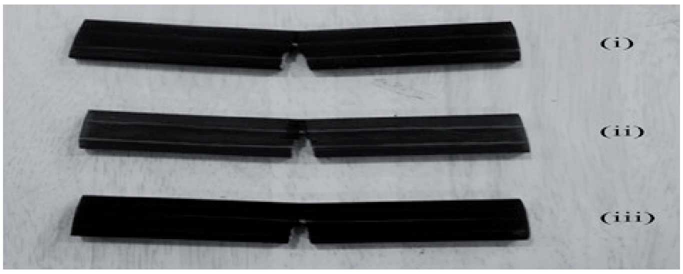


Fig. 2 Composite samples with no fibre discontinuity: (i) A1B1C1, (ii) A1B2C2, (iii) A1B3C3

For the fracture testing, single edge notch is produced by machining process and then a pre crack is made. Testing is carried out using Universal Testing Machine (i.e Instron 8801) along with three point fixture.

3 Finite element analysis

The three dimensional models are created in Solid Works 10 for various combinations mentioned in Table 2. Figure 3 presents the modelled image of the specimen A1B3C3 with loading and support solid cylinders of 25mm diameter. Finite Element modelling and analysis is carried out using Ansys 14.5. Solid 186 and solid 187 elements are used as element type. The total Numbers of nodes and elements are 291628 and 116578 respectively. The properties of hybrid polymer and banana fiber are taken from the Vishnu Prasad et al. and Kulkarni et al. respectively. Table 3 shows the properties like Young's modulus, Poisson's ratio and Density of hybrid polymer and banana fibre.

Table 3 Properties of banana fiber and hybrid matrix

Material Property	Banana Fiber	Hybrid polymer		
		5 % CNSL	15 % CNSL	25 % CNSL
Density (ρ), kg/m3	1300	9132.8	9106.5	9080.5
Young's Modulus (E), MPa	976	151.06	55.9	24.195
Poisson's Ratio (υ)	0.30	0.35	0.35	0.35

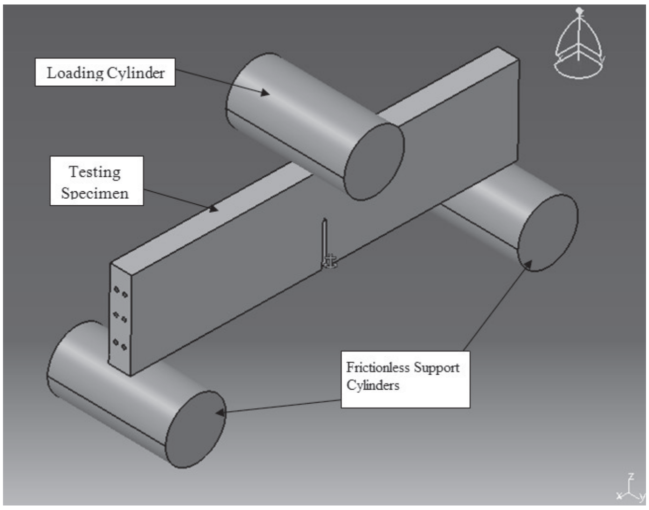


Fig. 3 Modelling image of A1B3C3 Specimen with roller

4 Results and discussions

In pure matrix material, the stress required to start the crack propagation is maximum stress, which is located at the crack tip. But in this study, maximum stress is observed on the fibre which is higher than pure matrix material. Also, stress intensity factor is maximum at the point where stress is maximum. The Stress intensity factor is shown in Fig. 4.

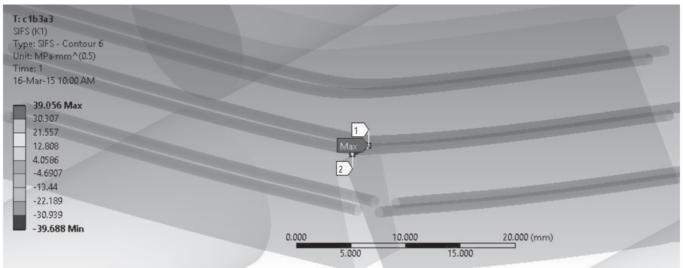


Fig. 4 Stress Intensity Factor (KIC)

FEA results of nine specimens and their comparison with experimental result are shown in Table 4 and 5 respectively.

Table 4 Results of Finite Element Analysis

Sample no.	Max. Equivalent (Von- Mises) Stress (MPa)	Max. Equivalent Elastic Strain	Stress Intensity Factor (KIC) (MPa-m$^{1/2}$)
1	56.997	0.754	1.0364
2	89.188	0.7018	2.8749
3	211.98	0.58714	2.3544
4	89.585	0.77092	1.2792
5	26.137	0.63259	0.3696
6	14.141	0.79075	0.19999
7	59.646	0.74046	0.902
8	51.251	0.67371	0.4117
9	283.78	0.7321	2.6889

Maximum SIF is obtained for sample no. 2 which has low CNSL content with no fibre discontinuity. Minimum SIF is obtained for sample no. 6 which has high CNSL content and one discontinuity. Table 5 presents the percentage of deviation between FEA and experimental results.

Table 5 Comparison of results

Sample No.		1	3
Stress Intensity Factor (MPa-m$^{1/2}$)	Experimental	1.1209	2.6289
	FEA	1.0364	2.3544
Deviation in %		8.15	11.66

Regression is a powerful tool which is used to find whether variables have relations with response or not. ANOVA technique is employed using Minitab software to get regression equation, surface plots and main effect plot. The regression equation is given in Eq. (1).

$$\mathrm{SIF}(\mathrm{KIC}) = 2.36 - 0.377\mathrm{A} + 0.260\mathrm{B} - 0.0866\mathrm{C} \quad (1)$$

Where A – Fibre discontinuity,

B – Fibre volume in %,

C – CNSL %

Main effect plot displays relation of mean response to one or more process parameters which is shown in Fig. 5. As the number of discontinuity increases the stress intensity factor decreases up to one discontinuity and then increases. As fibre volume percentage goes on increasing the fracture toughness increases, but it decreases with increase in CNSL percentage.

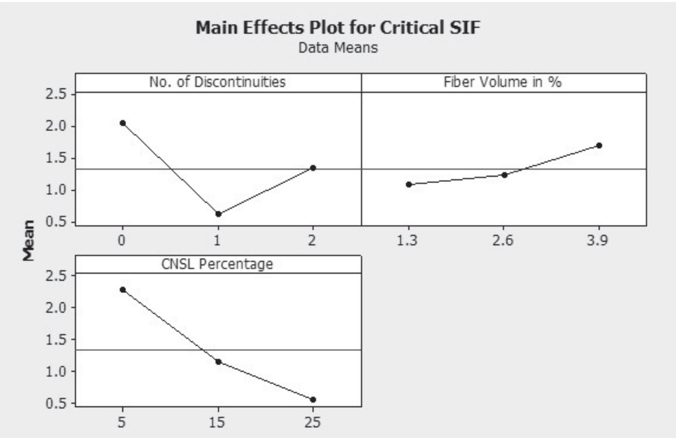


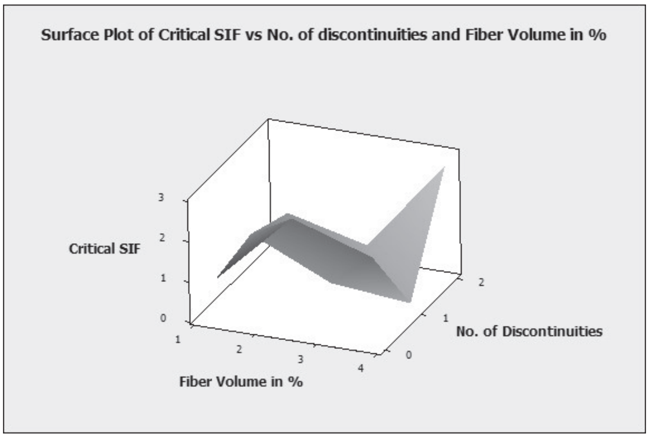
Fig. 5 Main effect of Critical SIF (KIC)

The potential relation between three parameters is explored by the three dimensional graph called 3D Surface plot. In surface plot, there must be 2 input variables and one output variable. Here the critical stress intensity factor is response and other three parameters are taken in three different cases which are shown in Figs. 6(a) – 6(c).

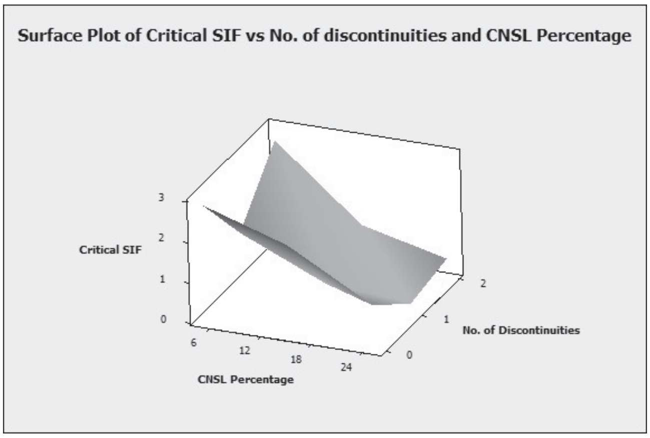
5 Conclusion

An attempt is made in this work to investigate the fracture toughness of banana fibre reinforced hybrid polymer matrix composite using finite element analysis (FEA). FEA results are verified by experimental analysis for two samples. Increase in amount of CNSL in the matrix reduces fracture toughness. If the fibre discontinuity is located exactly above the pre-crack, then stress intensity factor decreases, which conclude that SIF depends on location of fibre discontinuity. Due to this, one discontinuity specimen shows less SIF than two and without discontinuity materials. In this study, no discontinuity 4 fibre 5 % CNSL resin material is an optimum combination and corresponding stress intensity factor is 2.8749 MPa-m$^{1/2}$.

a



b



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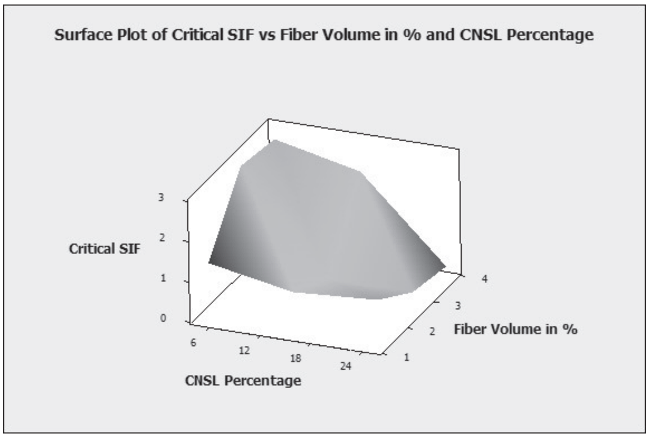

Fig. 6 Surface Plots of SIF

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