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EVALUATION OF STRESS INTENSITY FACTOR FOR GFRP LAMINATES USING DIC TECHNIQUE

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Abstract

Polymer composites have emerged as important structural engineering materials in automotive, marine, aerospace, transportation, infrastructure applications, because of their high strength to weight ratio. GFRP is widely used for boats, airplane, sports goods etc. because of its high specific strength and modulus. There are several fracture modes in polymer composites such as delamination or interlaminar fracture, matrix cracking or interlaminar fracture, matrix-fiber debonding, fiber breaking, fiber pullout, etc., In this study, the Mode I test is considered for DCB (Double Cantilever Beam) specimen. Displacement images at the crack tip region were simultaneously recorded during the tests. In addition, digital image correlation (DIC) technique was successfully employed to obtain full field measurement of displacements and strains in the vicinity of the crack tip. The mode-I stress intensity factor has been calculated from the crack surface displacements obtained experimentally from DIC measurements and the results were verified by empirical formulae.

Keywords*:* Glass/Epoxy Composite, Digital Image Correlation (DIC), Stress Intensity Factor, Double Cantilever Beam (DCB).

1. INTRODUCTION

Advanced composite materials have been widely used due to their lightweight and high corrosion resistance. The composite structures are used in the various applications namely aerospace, automobiles, architecture, marine etc. GFRP is widely used for boats, airplane, sports goods etc. because of its high specific strength and modulus. There are several fracture modes in polymer composites such as delamination or interlaminar fracture, matrix cracking or interlaminar fracture, matrix-fiber debonding, fiber breaking, fiber pullout, etc., Stress Intensity factor (SIF) is a commonly used parameter characterizing fracture and is used for the safe design of structures. The stress state in the vicinity of the crack tip and the failure of the cracked material are determined by the SIF, which depends on the loading condition, crack length and the geometry of the material. When the SIF reaches the critical value (fracture toughness) at a certain loading condition, the initial crack propagates and failure occurs. In this study, Double Cantilever Beam (DCB) Specimen is tested to obtain the Stress Intensity Factor of Glass Fiber Reinforced Polymer (GFRP) Composites under Mode I loading condition. DIC method is employed to obtain the displacement and strain field near the crack tip. Under load, the stress intensity factor (SIF) calculated according to linear elastic fracture mechanics formulae and using the deformation fields obtained by DIC and the results are compared.

2. FABRICATION AND TESTING

A. *Material Fabrication*

Glass Fiber Reinforced Polymer (GFRP) laminates has fabricated by hand lay-up process. In this fabrication E-Glass fibers were reinforced with the matrix. The matrix phase is epoxy resin LY556 with hardener HY951. The resin and hardener are taken in the ratio of 10:1 and mixed thoroughly to avoid bubble formation. Solidification of mixture may happen if it mixed for a longer period of time. The initial crack has been made by introducing a thin Teflon film during stacking procedure. Initially the upper and lower mould surfaces are cleaned to remove the dirt present. Once the dirt is being removed, wax is applied on both the surfaces. Mylar sheets were used to get better surface finish and ease in releasing the plate. Certain amount of resin-hardener mixture is poured over the Mylar sheet and spread over by using brush. Then, First layer of Glass Fiber is placed over the mould in proper direction and squeezed with Teflon roller in to remove the excess resin. Successive layers of Glass fiber is placed and mixture is poured and squeezed to get the required thickness of laminates. The laminates contain five laminas to have the Teflon insert at the center. A layer of Mylar sheet is placed on top of the laminates and squeezed with roller to remove the entrapped air and achieve the void free smooth surface. Then, the laminate is allowed to cure in the mould for about 1 day at room temperature. After curing Mylar film is removed from both sides of the laminate and it is removed from the mould as shown in Fig. 1. Then, the inserted Teflon sheet has removed to form the initial crack

Fig. 1. Prepared GFRP Laminate with Initial Crack

B. *Specimen Preparation*

As per ASTM standard (D5528), the DCB specimen of GFRP material is prepared and shown in Fig. 2. The optimum length of the DCB specimen should be at least 125mm, the width of the specimen should be around 20 to 25mm, and the thickness can be between 3–5mm.

Fig. 2. Prepared DCB Specimen of GFRP Material

C. Speckle Pattern Preparation

The speckle pattern is essential to get accurate results in Digital Image Correlation. The ideal pattern is a quantity of black speckle with different shape and size. It can be applied by painting the surface with a thin layer of white paint and then applying black paint to create the black speckles. Figure-3 shows the prepared speckle pattern.

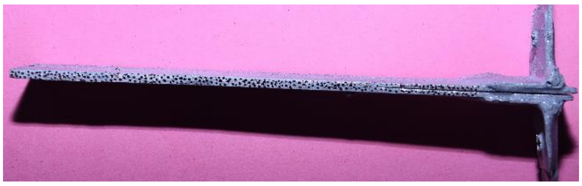


Fig. 3. Speckle Pattern of DCB Specimen

D. Mode I Fracture Test

The prepared DCB specimen is loaded in Universal Testing Machine to carry Mode I fracture test. Displacement of the specimen while loading is recorded by using a Digital Camera. The failure behavior of the material can be study from the testing response. Applied load values are noted from the dial and the stress intensity factor of the specimen can be obtain by the theoretical formulae. Captured successive images near the vicinity of the crack tip as shown in Figure-4 are used for image analysis to compute the strain values.

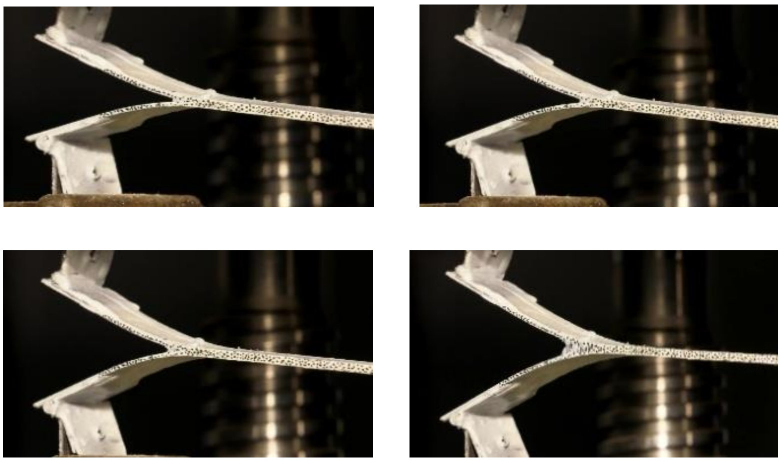


Fig. 4. Captured Images in Sequential Order

For DCB specimen, stress intensity factor can be estimated by the following formula

$$K_I = \frac{2\sqrt{3}}{h\sqrt{h}} \times \frac{P\times a}{B}$$

K_I - Stress Intensity Factor in MPa$\sqrt{m}$
a – Crack length in m
B – Width of the Specimen in m
2h – Thickness of the Specimen in m
P – Applied Load in MN

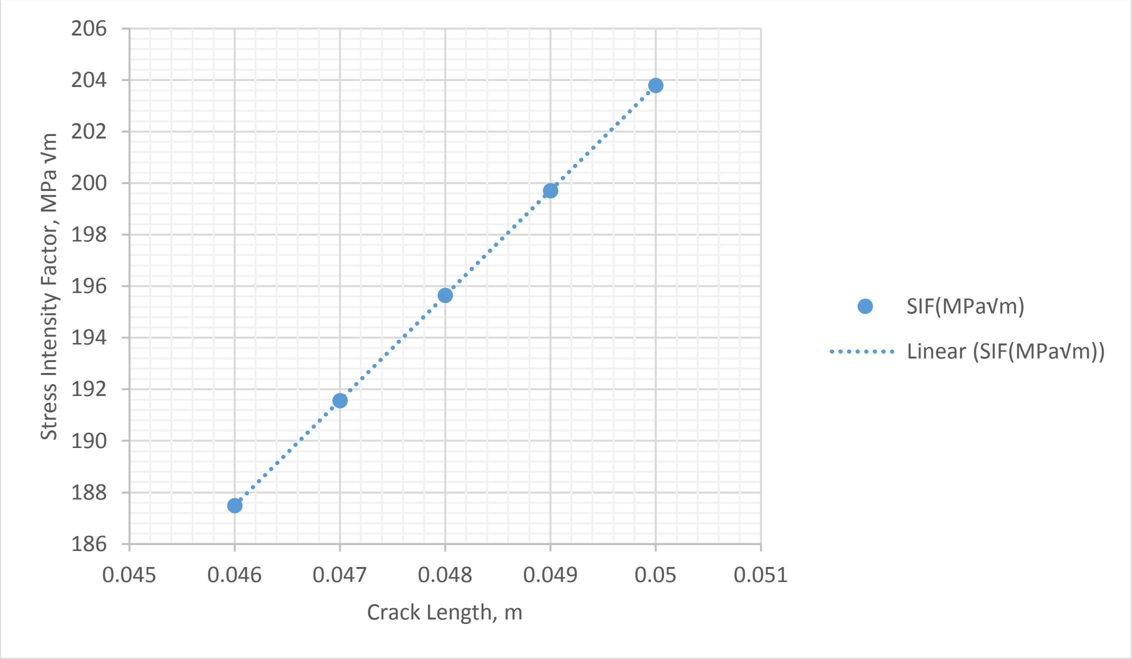


Fig. 5. SIF Values for Various Crack Length

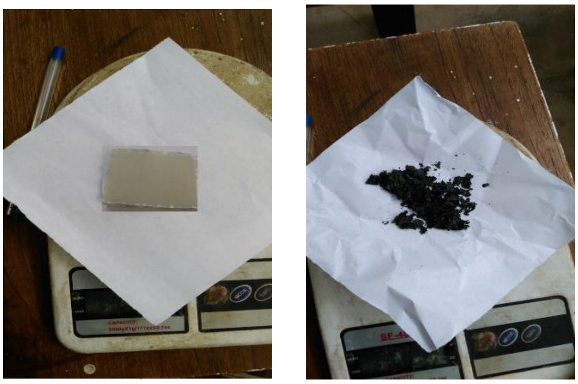
E. Burnout Test

Weight of the composite is equal to the sum of the weight of the fiber and weight of the matrix. Burnout test has carried to estimate the weight fraction of the fabricated composite laminates.

$$w_c = w_f + w_m$$

TABLE I: BURNOUT TEST RESULT

Weight of the Composite in gms		Weight of the Fiber in gms	Weight Fraction (from the test)	Weight Fraction (calculated)
Before the Test	After the Test			
4	2	2	0.5:0.5	0.5:0.5



(a) Before the Test (b) After the Test

Fig. 6. Weighing of Composite.

F. Digital Image Correlation

DIC is based on the relation between the consecutive images of the material after deformation. The main principle is the comparison of the digital images at different deformation stages. The displacement of the surface determines the deformation and strain fields by tracking each pixels. The displacement near the vicinity of the crack tip is recorded by using Digital Camera. The captured sequential images are utilized for the process of correlation to compute the strain values from the deformed images.

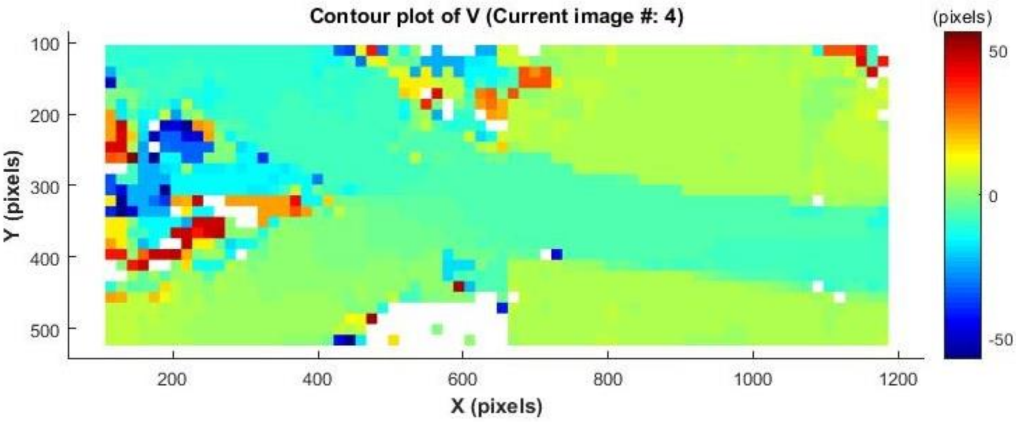


Fig. 7. Contour Plot of Deformed Image

In this work, MATLAB R2016a is used for the processing of images. From the obtained strain values, the Stress Intensity Factor values are determined and compared with the values obtained from empirical formulae. DIC involves number of steps to be run for getting the deformation results. Grid formation over the crack tip area of the specimen is carried for correlation process. Figure-8 shows the contour plot of deformed image from which the strain values are computed.

TABLE II: COMPARISON OF RESULTS

CRACK LENGTH (m)	STRESS INTENSITY FACTOR, K_I $(MPa\sqrt{m})$		DEVIATION (%)
	BY EXPERIMENTAL	BY DIC	
0.046	187.49	194.97	3.83
0.047	191.56	199.6	4.02
0.048	195.64	204.1	4.14
0.049	199.7	208.01	3.9
0.050	203.79	211.8	3.78

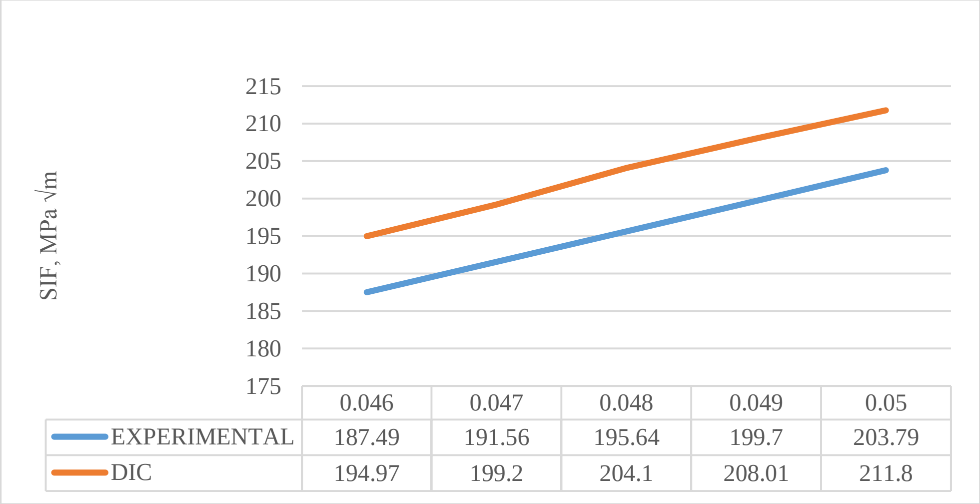


Fig. 8. Comparison of SIF Values

CONCLUSION

In this work, Experimental Mode I fracture test has carried for the prepared Glass Fiber Reinforced Polymer composite material. From the obtained result values Stress Intensity Factor computed for various crack lengths. The speckle pattern of Double Cantilever Beam specimen is used for the testing and the deformation near the vicinity of the crack tip is recorded by using digital camera. Digital Image Correlation (DIC) method has been implemented to calculate the fracture parameter of the material by obtaining the strain values from the correlated images. These results obtained from DIC were validated by theoretical value. It is found that the DIC results has good agreement with theoretical value.

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