

INVESTIGATION OF FRACTURE TOUGHNESS OF BIDIRECTIONAL JUTE / EPOXY COMPOSITE AND ANALYSIS BY USING FEA

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ABSTRACT

Since past few years, the use of natural fibers as reinforcement in polymers has increased drastically. These natural fibers are strong, light as well as biodegradable. In this research work, an investigation has been carried out to make use of jute fiber, a natural fiber abundantly available in India. This present work is based on the development of a new composite involving woven jute fiber sheet as reinforcement and epoxy resin as matrix material. This composite is developed by hand lay-up technique and jute-epoxy layers are aligned so as to get the best mechanical properties. Experiments are carried out to find fracture parameters like fracture toughness and stress intensity factor of jute/epoxy composite. Then Analysis of the same specimens is done using ANSYS.

In this work, effort has been to find the fracture toughness of jute fiber reinforced epoxy composite. For this purpose six woven jute/epoxy SENB test specimens are prepared and three-point bend test is performed on them individually and results are drawn. Then the analysis result is compared with experimental results. The computational results show a good agreement with the experiments.

KEYWORDS: Jute/Epoxy Composite, SENB & Fracture Toughness

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1. INTRODUCTION

The development of composites and enhancement in their design and manufacturing techniques is a crucial turning point in the long history of engineering materials. Composites are the material used in various fields having exclusive mechanical and physical properties and are developed for the particular application. These materials have a wide range of advantages over the conventional materials with respect to properties such as tensile strength, impact strength, flexural strengths, stiffness, and fatigue. Because of their numerous advantages they are widely used in the aerospace industry, commercial mechanical engineering applications, like machine components, (like drive shafts, tanks, brakes, pressure vessels, and flywheels,) automobiles, combustion engines, aircraft structures etc. When two or more materials with different properties are combined together, they form a composite material. Composites basically consist of two types of materials 1) high strength load carrying material known as “reinforcement” and 2) “matrix”- a weak material in which the reinforcement is embedded and whose primary purpose is to hold the layers of reinforcement together. Also, the matrix functions as a medium to transfer stresses between the reinforcing fibers and to protect them from mechanical and environmental damage. The

presence of fibers in the composite materials as reinforcement helps in improving properties like tensile, shear and bending.

There are many materials that can be used as reinforcements in composites but out of all of them natural fibers have gained popularity because of their easy availability, low cost, and biodegradable nature. Apart from these the natural fibers have advantages such as they are renewable, environmentally friendly, they have low density, high specific properties, good thermal properties, and energy recovery. These are also non-abrasive in nature. A lot of studies have been conducted previously to find out which natural fibers can be a potential reinforcement in the composites. Out many natural fibers available, fibers of jute, bamboo, hemp, sisal, coir were found to have good properties. The speciality of natural fibers is their non-uniform cross-sections which results in unique structures much different from man-made synthetic fibres such as glass fibres, carbon fibres etc. As most of the natural fibers possess good properties (tensile and % elongation) than some of the metals and due to their low densities these can be used as reinforcements that are embedded in polymer matrix to produce composites with superior properties. One such combination of reinforcement and polymer matrix is jute/epoxy and determination of fracture toughness for this composite is the purpose of this research and to use it in a potential application.

2. LITERATURE SURVEY

P. J. ROE, M. P. ANSELL [1] have written a paper on Jute reinforced polyester composites in which they found out the tensile strength and Young's modulus, impact strength and inter-laminar shear strength have been measured as a function of fiber volume fraction. Vivek Mishra, Sandhyarani Biswas [2] Department have done work on physical and mechanical properties of bi-directional jute fiber epoxy Composites. Results of this paper suggest that the hardness, tensile properties and impact strength of the jute-epoxy composites increase with the increase in fiber loading. The properties like flexural strength and inter-laminar shear strength are greatly influenced by the void content of the composites. Asheesh Kumar and Anshuman Srivastava [3] have worked on preparation and mechanical properties of jute fiber reinforced epoxy composites. In this research, an Epoxy piece and Jute fiber-epoxy composite are prepared using hand lay-up technique. For this purpose, an open type mold made of mild steel plate has been used. It is revealed that the jute epoxy composite exhibited better tensile and compressive strength. Bundle strength of fibers decreases with increase in a number of fibers in a Bundle. Tensile and compressive strength increases with Jute fiber reinforcement. Prabhakar Kaushik, Jaivir, and Kapil Mittal[4]conducted experiments to find the flexural and impact strength of jute reinforced epoxy and polyester composites for different fibre loadings. The following conclusions could be obtained from their experimental results. The flexural and impact properties of jute fiber reinforced epoxy and polyester composite have been considerably enhanced with the various fiber volume fractions. It was found that with the increase in the fiber volume fraction, flexural strength also increases.

S. S. Tripathy L. Di Landro D. Fontanelli A. Marchetti G. Levita [5] have worked on jute fibers and interface strength with an epoxy resin. In this work, they have taken four different forms of jute fibers, namely Untreated Jute Filament (UJF), Sliver Jute Filament (SJF), Bleached Jute Filament (BJF), and Mercerized Jute Filament (MJF), have been subjected to tensile strength analysis following Weibull's theory. Janaki Dehury [6] attempts have been made to study the effect of fiber loading and orientation on the physical, mechanical and water absorption behavior of jute/glass fiber reinforced epoxy based hybrid composites. Composites of various compositions with three different fibre loading (30wt%, 40wt%, and 50wt%) and three different fiber orientation (0°, 30° and 60°) are fabricated using simple hand lay-up technique. It has been observed that there is a significant effect of fiber loading and orientation on the performance of

jute/glass fiber reinforced epoxy based hybrid composites. TOPSIS a multi-criteria decision-making approach is also used to select the best alternative from a set of alternatives. Finally, the morphology of fractured surfaces is examined using scanning electron microscopy.

José Martins, Ferreira Carlos Capelaa Joao Manaia, José Domingos Costa[7] have aimed at establishing a link between the mats grammage and the mechanical properties of the epoxy/jute fibers laminates. Composites reinforced by coarse, medium and fine mats were processed by vacuum bagging. Immersion in water causes a marked loss of mechanical properties in the first days of immersion, especially for thinner fiber grammage composites. A strong influence of the mats grammage on the impact response was observed. Increasing mats grammage promotes a strong increase in peak load, restored energy and impact energy for perforation and also a marked reduction of the deformation. Sudeep Deshpande, T Rangaswamy[8] have fabricated E-Glass/Jute Fibre Reinforced Epoxy by hand lay-up technique and the mechanical properties such as ultimate tensile strength, flexural strength, interlaminar shear strength, tensile modulus, impact strength and hardness of the fabricated composites were tested. The test results of these were compared with unfilled HFRP composites. From the results, it was found that the mechanical properties of the composites increased with the increase in filler content. Composites filled with 15% volume coconut shell powder exhibited maximum flexural strength, interlaminar shear strength, tensile modulus, and hardness. Maximum impact strength was achieved by the addition of filler (15% Vol.) of bone powder.

T D Jagannatha and G Harish [9], have written that hybrid polymer composite material offers the designer to obtain the required properties in a controlled considerable extent by the choice of fibers and matrix. The properties are tailored in the material by selecting different kinds of fibre incorporated in the same resin matrix. In their investigation, the mechanical properties of carbon and glass fibers reinforced epoxy hybrid composite were studied. The vacuum bagging technique was adopted for the fabrication of hybrid composite materials. The mechanical properties such as hardness, tensile strength, tensile modulus, ductility, and peak load of the hybrid composites were determined as per ASTM standards. The mechanical properties were improved as the fibers reinforcement content increased in the matrix material. Ad Bakkar [10] has done a study on the elastic-plastic analysis of a Single Edge Notched Bend (SENB) specimen, a specimen commonly used for the determination of the fracture toughness of a material. First, a two-dimensional convergence study is described to investigate the influence of mesh size on the global response of the specimen and the fracture mechanics parameters J and COD. Then a three-dimensional analysis is compared with experimental results. The three-dimensional computational results show a good agreement with the experiments, except for the load region where the global deformations were dominated by the Lueders zone in the material stress-strain curve. S. Cicero[11] study applies a methodology that allows the fracture toughness of a given material to be estimated by testing notched fracture toughness specimens and applying the Theory of Critical Distances, which requires the elastic stress field at the notch tip to be determined by finite element simulation. This methodology, which is not intended to substitute any standardized fracture characterization procedure, constitutes an alternative in those situations where pre-cracking processes. Ch. V. Sushma [12] has done the investigation of fracture parameters like J-integral of compact tension specimen by using finite element analysis software which plays a key role to estimate fracture toughness of materials. Controlled displacement loading is applied on the CT specimen and the results compared with ASTM standards. The J-Integral values for 5mm pre-cracked compact tension specimen is measured by controlled displacement loading technique. The J-Integral values obtained by ANSYS are compared with ASTM values are found to be very close to each other and are satisfactory.

Srikanth Rao [13] evaluated the fracture toughness of glass fiber/ Epoxy Composites. Mode I fracture test was conducted as per ASTM D5528 Standards. Samples with varying fiber and epoxy % compositions are studied. It was found that the sample with higher fiber composition has higher fracture toughness thus, concluding that the fracture toughness increases with increase in fibre composition. It also indicates that the material is behaving more like a ductile material as the fiber content is increasing, thus crack propagation decreases with the increase of fracture toughness. In the fracture test, the sample bears maximum stress up to some limit and then it starts decreasing before it gets failed. K. R. Harikrishnan [14] has studied the effect of volume fraction on Mode I fracture toughness of Jute/Glass composite by experimental compact tension and also by Finite element analysis using ANSYS software. It is found that hybrid composites with 75% glass & 25% jute and 50%glass and 50% jute shows fracture toughness values close to that of glass fiber composite. The finite element analysis results indicate that there is very less discrepancy between experimental and FE results. Thus valuable time and money can be saved by conducting the finite element analysis instead of experimentation processes. Failure incidents can also be avoided.

3. EXPERIMENTATION

3.1 Test Specimen Material

As we are analyzing the fracture toughness of jute-epoxy based composite the woven jute fiber is selected as fiber material (commonly used as rice bag material in India) and epoxy resin (EP-306 grade epoxy resin & EH-758grade hardener) is selected as a matrix.

3.2 Preparation of Test Specimen

Initially, a test specimen of about 55cm × 36cm × 1.2cm is prepared using 9 layers of woven jute epoxy material matrix. First, a steel mold of size 60cm x 37cm is taken and wax is applied all over it in order to clean the surface and avoid sticking of epoxy resin to the mold surface. After application of the wax a layer of jute is placed on the mold and epoxy resin is applied onto it, then another layer of jute is placed on top of it and again epoxy is applied. This process is continued for a total of 9 layers of jute, and a thickness of approximately 12 cm is obtained. This process of preparation of this specimen by application of epoxy onto the jute layers should be done at a faster rate in order to avoid the resin from getting heated up. Next, the upper half of the mold is placed on the top layer of the jute -epoxy composite and it is riveted with the lower half of the mold. Sufficient load is placed on top of the mold to maintain a good level of compactness. All of this process of preparation should be performed at a temperature of 20-25°C and the prepared mould with the layers of jute epoxy should be allowed to cure for about 24hours. Then the specimen is removed from the mold carefully and any cutting process that has to do, should be done after a gap of about one week. This specimen is then cut into 6 identical specimens with dimensions 116 x 24 x 12mm³ giving tolerances of ± 0.2mm. This cutting process was done by us on a surface grinding machine available at our institution. A notch is then made on each specimen as per the dimensions specified by ASTM D-5045.



Figure 1: JUTE



Figure 2: JUTE+EPOXY

Dimensions of test specimens obtained after cutting:

Table 1: Dimensions of the SENB Specimens

| Specimen | Length in mm | Width in mm | Thickness in mm |
|----------|--------------|-------------|-----------------|
| JP1 | 116.08 | 24.17 | 11.93 |
| JP2 | 116.01 | 24.05 | 12.20 |
| JP3 | 116.17 | 24.10 | 11.95 |
| JP4 | 115.97 | 23.95 | 12.10 |
| JP5 | 116.03 | 24.04 | 12.15 |
| JP6 | 115.96 | 23.99 | 12.05 |

3.3 Test Method

The procedure followed as per **ASTM D-5045**. This test method establishes a procedure for characterizing the toughness of the resin system materials. As per the test standard single edge notch bending geometry of the specimen is used to find out the critical stress intensity factor K_{Ic} and critical strain energy release rate G_{Ic} at the initiation of the crack. This particular test assumes the linear elastic behavior of the specimen under testing hence there are corresponding restrictions on the load-displacement diagram obtained.

3.4 Test Machine

The test machine used was a simple UTM available at our institution. The load is applied to the test specimen by the screw driven mechanism of the UTM machine. Initially, the specimen is placed on two roller supports, taking care of the distance of the rollers from each end. Then load is applied exactly above the notch in the vertical direction, gradually. Suitable extensometer associated with the UTM helps to plot the load v/s displacement curve which is seen on the computer. Care should be taken that the roller diameter should not exceed the overall thickness of the specimen.

3.5 Point Bend Test

3 point bend test was performed to calculate the mode I fracture toughness. This test method is used to define the toughness of plastics in terms of critical stress intensity factor. In this test, a specimen with an already created notch is loaded i. e., a compressive load applied due to which the crack (which is created to make a notch) propagates. The test was performed according to ASTM D-5045 test standard using a universal testing machine (UTM) at CBIT. Special 3 point bending test fixtures are used to fix the specimen. The machine can be used for the maximum load of 25KN and can bear the maximum weight of 160 kg. A gradual load is applied(at a rate of 5 mm per minute) on the test specimen and the load at which the crack propagates is noted with the help of a computer attached to the UTM. After the test, the data excel sheet obtained from the computer is used to plot the LOAD v/s Displacement and STRESS v/s STRAIN Graph and repeated for other six.

3.6 Testing

The notched test specimen is loaded at a rate of about 5mm per minute. At the end of the experiment, we obtain the load v/s displacement curve of the specimen. In an ideal case, there is an abrupt drop of load to zero at the initiation of the crack. When this happens we can calculate the values of K_Q and Q_{Ic} directly at the maximum load. But initially, before the occurrence of fracture, there is no linear behavior between load and displacement hence the final load at which the specimen fails should be taken at a deviation of about 2.5% on the load v/s displacement curve. After breaking, the interface should appear smooth and glossy.

3.7 Calculations from the Graph

Load the specimen and obtain a P (load) versus u (displacement) plot (see Figure 3). In order to determine the initial compliance, we have to draw a best straight line (AB) that passes through maximum interpolating points. The reciprocal of the slope of this line gives the initial compliance. Another line (AB') is drawn with a compliance 5% greater than that of the line (AB). If the maximum load that the specimen is able to withstand that is P_{max} , falls within lines (AB) and (AB') we can use this P_{max} value to calculate K_Q . If the value P_{max} falls outside the line (AB) and (AB'), then use the point of intersection of the curve and line (AB') as the load PQ. Further, if $P_{max}/PQ < 1.1$, use the calculation of K_Q . However, if $P_{max}/PQ > 1.1$, the test is invalid. Calculate K_Q in accordance with the procedure for single edge notch bending in For this calculation, a value of a, which is the total crack length after both notching and pre-cracking, but before fracture, is best determined from the fracture surface after testing. An average value is used, but the difference between the shortest and longest length should not exceed 10 %. We have to see that it is the original crack that is being observed because slow growth can occur prior to catastrophic failure. The general formula for KQ calculation is given by

$KQ = (P Q/BW^{1/2}) f(x)$;where $(0 < x < 1)$: $f(x) = 6x^{1/2} (1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2)) / (1 + 2x) (1 - x)^{3/2}$ and: PQ = load as determined in kN, B = specimen thickness, cm, W = specimen depth (width), cm, a = crack length, cm and $x = a/W$.

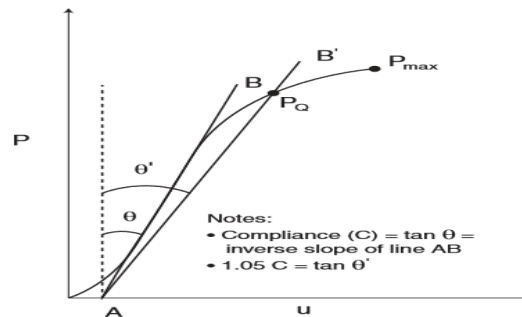


Figure 3: Compliance from ASTM D-5045

3.7.1 Test Specimen Jp1 Dimensions

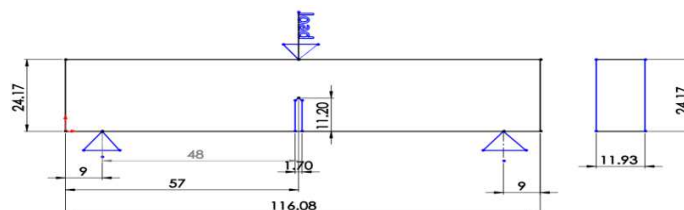


Figure 4: Test Specimen JP1 dimensions

From fig: Total length of the specimen=116.80mm, Roller distance from the ends =9mm, Width W=24.17mm, Thickness B=11.93mm.

3.8 Results Obtained when Test Specimen Jp1 Is Subjected to Test

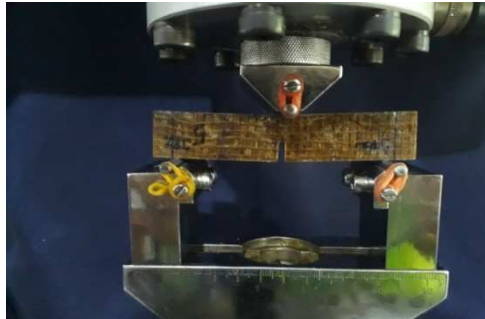


Figure 5: Specimen at the Beginning of the Experiment

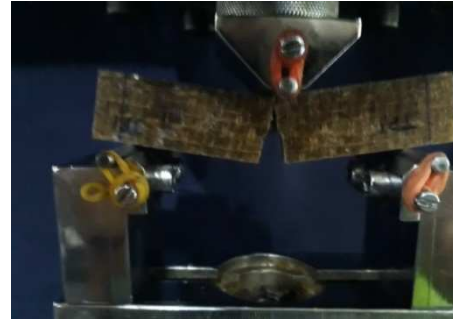


Figure 6: Failure of the Test Specimen

3.8.1 Graph Obtained

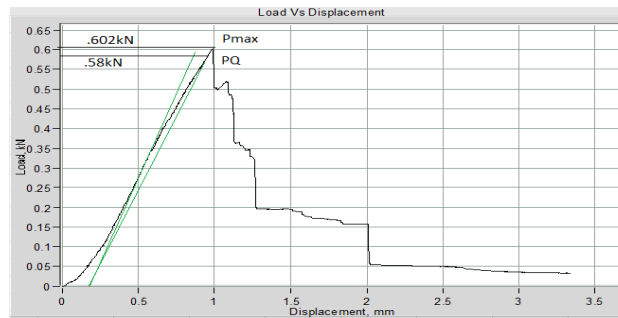


Figure 7: Estimation of P_Q for Specimen JP1

Upon calculations the following results were obtained

Table 2: Obtained P_{max} and P_Q Values upon Experimentation

| Specimen | P_{max} in N | P_Q in N | K_Q in $MPa\ mm^{1/2}$ |
|----------|----------------|------------|--------------------------|
| JP1 | 602 | 580 | 92.970 |
| JP2 | 611 | 591 | 94.805 |
| JP3 | 607 | 575 | 92.243 |
| JP4 | 620 | 585 | 93.856 |
| JP5 | 607 | 565 | 90.630 |
| JP6 | 615 | 577 | 92.559 |

4. FINITE ELEMENT ANALYSIS

Finite element analysis is done in ANSYS 18.1. In this first, a three-dimensional finite element model is created in Mechanical APDL Product Launcher. Pre-processor: The element type used here is shell 281 (8 nodes). The material type chosen here is structural & orthotropic material. The properties are as listed below:

Table 3: Properties of Jute Epoxy

| | |
|----------|---------|
| E_1 | 14030.3 |
| E_2 | 14030.3 |
| E_3 | 8909.25 |
| V_{12} | 0.241 |
| V_{23} | 0.431 |
| V_{31} | 0.431 |
| G_{12} | 3198.9 |
| G_{23} | 3123.7 |
| G_{31} | 3123.7 |

Then 9 equal sections (layers) are created to get a thickness of 11.93mm. After this key points are created which are then joined by lines. Here only half sectional view is created then symmetry boundary conditions are applied while applying the load. Two separate areas are created instead of one, on either side of the line at the support. To these created areas free mesh is applied by using some appropriate size controls. After meshing is done loads are defined

4.1 Solution

Loads are then defined in such a way that the node which is to have roller support is restricted to all degrees of freedom except rotation in Z. Then load is applied in the negative Y direction at the top node above the notch. The value of the load is equal to P_{max} obtained from compliance.

4.2 Calculation of J Integral

J-integral is estimated by following procedure [12].

4.3 Results Obtained when Specimen JP1 is Analysed

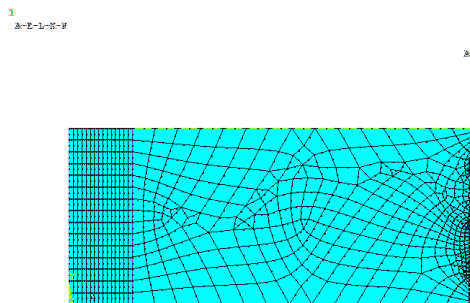


Figure 8: Element Plot for SENB Specimen JP1

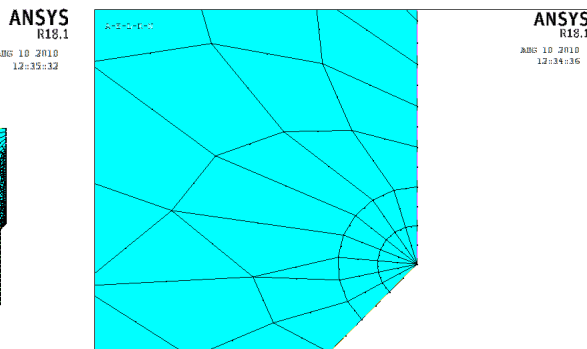


Figure 9: Element Plot in the Vicinity of Crack

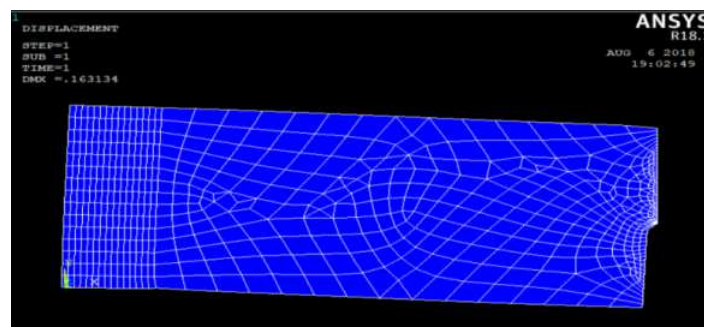


Figure 10: Deformed Shape of the Specimen Under Load

After we get the deformed shaped K_Q value is obtained by typing a series of code in the command prompt that includes the calculation of J integral

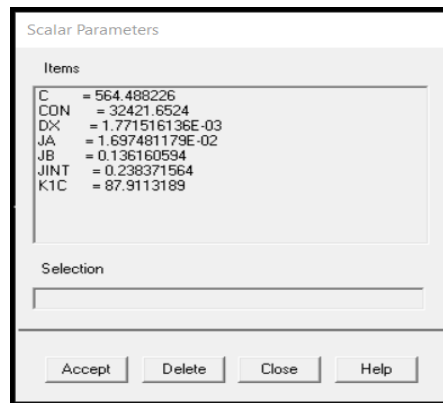


Figure 11: K_Q Value from ANSYS

5. RESULTS

Following table shows the values of K_Q obtained from ANSYS and Experimentation:

Table 4: Comparison of Stress Intensity Factor between Experiment and FEA

| Specimen | K_Q from ANSYS in MPa mm ^{1/2} | K_Q from Experimentation in MPa mm ^{1/2} | Percentage of Deviation (%) |
|----------|---|---|-----------------------------|
| JP1 | 87.911 | 92.970 | 5.5 |
| JP2 | 89.211 | 94.805 | 5.9 |
| JP3 | 87.278 | 92.243 | 5.4 |
| JP4 | 91.263 | 93.856 | 2.7 |
| JP5 | 86.330 | 90.630 | 4.8 |
| JP6 | 89.650 | 92.559 | 3.2 |

The following table shows the values of strain energy release rates from ANSYS and Experimentation:

Table 5: Comparison of Strain Energy Release Rate between Experiment and FEA

| Specimen | Strain Energy Release Rate G_{1c} (J/m ²) from ANSYS | Strain Energy Release Rate G_{1c} (J/m ²) from Experiments | Percentage of Deviation (%) |
|----------|--|--|-----------------------------|
| JP1 | 238 | 262 | 9.1 |
| JP2 | 259 | 277 | 6.5 |
| JP3 | 235 | 256 | 8.2 |
| JP4 | 257 | 271 | 5.1 |
| JP5 | 230 | 251 | 8.3 |
| JP6 | 248 | 259 | 6.0 |

From the above results, it is clear that the values obtained from ANSYS vary from that of the experimentation values. However, the variation is considerably less due to the method used for fabrication and different loading conditions during the compact tension test. It may also be due to the approximate values of orthotropic properties taken during estimation of stress intensity factor using command statements. The finite element simulation of practical problems is found very useful. Results of the finite element analysis are reliable as they are found to be reliable with the experimental results obtained.

6. CONCLUSIONS

Experimentation and Finite element analysis have been done and it has been observed that the values of fracture toughness obtained from experimentation are almost on par with the values obtained from ANSYS software. These obtained values are also observed to be closer to some of the ceramics like aluminum oxide, silicon carbide and better than those of polymers and few multi-fiber composites. Thus jute-epoxy composite can be used as a substitute in cases where the composite is proved to be better in the aspects of cost, availability and preparation method.

REFERENCES

1. P. J. ROE, M. P. ANSELL, *Jute-reinforced polyester composites*. University of Bath, UK. *Journal of Materials Science* November 1985, Volume 20, Issue 11, pp 4015–402
2. Vivek Mishra Sandhyarani Biswas, *Physical and Mechanical Properties of Bi-directional Jute Fiber Epoxy Composites*. *Procedia Engineering* Volume 51, 2013, Pages 561-566
3. Asheesh Kumar and Anshuman Srivastava, *Preparation and Mechanical Properties of Jute Fiber Reinforced Epoxy Composites*. *IndEng Manage* 2017, Vol 6(4): 234
4. Prabhakar Kaushik, Jaivir Jaivir, Kapil Mittal, *Analysis of mechanical properties of jute fiber strengthened epoxy/polyester composites*. ISSN 2291-8752 (Online) - ISSN 2291-8744 (Print) *Quarterly Publication* Volume 5 Issue 2 pp. 103-112, 2017
5. S. S. Tripathy L. Di Landro D. Fontanelli A. Marchetti G. Levita, *Mechanical properties of jute fibres and interface strength with an epoxy resin*. *Journal of applied polymers*; Volume 75, Issue 13 28 March 2000 Pages 1585-1596.
6. Janaki Dehury, *Processing and characterisation of jute/glass fibre reinforced epoxy based hybrid composite*. Project; National institute of technology (NIT) Rourkela.
7. José Martins Ferreira Carlos Capelaa João Manaia José Domingos Costa, *Mechanical Properties of Woven Mat Jute/Epoxy Composites*. *Mat. Res. vol.19 no.3 São Carlos May./June 2016*.
8. Sudeep Deshpande, T Rangaswamy "Effect of Fillers on E-Glass/Jute Fibre Reinforced Epoxy Composites ". *Int. Journal of Engineering Research and Applications* ISSN: 2248-9622, Vol. 4, Issue 8(Version 5), August 2014, pp.118-123
9. T D Jagannatha and G Harish, *MECHANICAL PROPERTIES OF CARBON/GLASS FIBER REINFORCED EPOXY HYBRID POLYMER COMPOSITES*. *International Journal of Mechanical Engineering and Robotics Research*, Vol.4, No. 2, pp. 131-137, April 2015.
10. Ad Bakker, *Elastic-plastic fracture mechanics analysis of an SENB specimen*. *International Journal of Pressure Vessels and Piping* Volume 10, Issue 6, November 1982, Pages 431-449
11. S. Cicero, V. Madrazo, and I. A. Carrascal, *Estimation of Fracture Toughness by Testing Notched Fracture Specimens and Applying the Theory of Critical Distances*. *Research article ;ISRN Materials Sciencem* Volume 2012, Article ID 689386, 8 pages
12. Ch. V. Sushma, Dr. P. Ravinder Reddy, P. Rama Lakshmi, *Investigation of Fracture Parameters of Compact Tension Specimen By FEA*, *IJERT*, Vol. 2, Issue 6, June-2013.
13. D. Srikanth Rao P. Ravinder Reddy Sriram Venkatesh, *Determination of Mode-I Fracture Toughness of Epoxy-Glass Fibre Composite Laminate*. *Procedia Engineering* Volume 173, 2017, Pages 1678-1683
14. Harikrishnan K. R, Dr. Deviprasad Varma P. R, E. Shivakumar, *Mode I Fracture Toughness of Jute/Glass Fibre Hybrid Composite –An experimental and Numerical Study*. *International Journal of Engineering Trends and Technology (IJETT) –*

Volume 28 Number 6 - October 2015

15. M Ramesh, K Palanikumar, *Mechanical property evaluation of Sisal-jute glass fiber reinforced polyester composites. Composite Part B: Engineering*, Vol. 48, May 2013.
16. Dr. Gujjala Raghavendra, *Jute fiber reinforced epoxy composites and comparison with the glass and neat epoxy composites: Journal of composite materials*, Aug 2013.
17. T. Prabeena, D. SrikanthRao, N. Gopikrishna, *Evaluation of Mode-I Fracture Toughness of Epoxy-Glass Fiber Composite Laminate, IJRSET Vol. 6, Issue 1, January 2017.*
18. Elgallad, E. A., Alkahtani, S. A., Doty, H. W., & Samuel, F. H. (2016). *On the mechanical properties and fracture characteristics of Al-2% Cu based cast alloys. International Journal of Materials Science and Engineering*, 6, 15-34.
19. "Fibre-Reinforced Epoxy-Hybrid Composites". *International Journal of Modern Engineering Research*, Vol.2(2), pp-471-474. *International Journal of Advanced Engineering Science and Technology*, 6(1), 97-104.
20. A. K. Rana A. Mandal B. C. Mitra R. Jacobson R. Rowell A. N. Banerjee, *Short jute fiber-reinforced polypropylene composites: Effect of compatibilizer. Article in Journal of Applied Polymer Science 69(2):329 - 338 · July 1998.*
21. Jochen Gassan & Andrzej K. Bledzki *Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres. Article in Composites Science and Technology 59(9):1303-1309 · July 1999*
22. Girisha. C, Sanjeevamurthy, Gunti Rangasrinivas, Manu. S, *Mechanical Performance Of Natural Fibre-Reinforced Epoxy Hybrid Composites. International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 5, September- October 2012, pp.615-619.*

