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Evaluation of Energy Release Rate of Particle Filled GFRP Composite Laminates

C.Panneerselvam[1], M.Gopala krishnan[2], S.Gaudham Babu[3]

[1] Assistant Professor, Department of Mechanical Engineering, VRS College of Engineering and technology, Tamilnadu, India
[2] Assistant Professor, Department of Mechanical Engineering, VRS College of Engineering and technology, Tamilnadu, India
[3] Assistant Professor, Department of Mechanical Engineering, VRS College of Engineering and technology, Tamilnadu, India

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Abstract - ***Study on delamination in composite material is used to express the fracture behavior of the composite material. Since the strength of resin is lower than the lamina strength, failure may be expected to start at interface. But it is hard to predict the failure of composite due to anisotropic nature. The Mode I failure behaviour influence the ensuring delamination propagation and mode II ensures the crack initiation. It is therefore important to analyze each mode separately. The main objective is to analyze the influence of alumina filler on energy release rate (G) of Chopped Strand Mat E-Glass FRP resin matrix composites. The alumina filled CSM E-Glass epoxy composite is fabricated by using hand layup process with an initial crack of 50 mm. The epoxy resin and hardener are mixed in the weight ratio of 10:1. Energy release rate is evaluated for four different proportions of alumina filler in CSM E-Glass epoxy composite. For each proportion three ENF specimens have been prepared. End notched flexure (ENF) specimen is used to evaluate Energy release rate under mode II according to ASTM D5528 standard. The compressive test has been carried out on the fabricated specimens and deflection values for the applied load are measured. The effect of alumina filler on energy release rate of CSM E-Glass epoxy composite is determined. The numerical analyses are done by using ANSYS 15.0 software based on cohesive zone modeling (CZM) technique. Cohesive zone modeling is used to predict the Mode-II delamination energy release rate in laminated composite. The numerical results are verified with the relevant experimental results.***

Key Words: *Chopped strand mat, Delamination, Energy release rate, ENF , Mode II.*

1. INTRODUCTION

The composite material exhibit extremely good strength to weight ratio, therefore the composite being used more in the construction of vehicles (helicopter, trucks, and racing cars) and equipment for the military, sport equipment (crash-helmets, pole vault, tennis rockets, bicycle frame works and wheels, buildings roofs, structure and bridges, air-space crafts, fuel tanks and pressure vessels).The favourable properties of composite materials such as high specific tensile, good electrical conductivity, good fatigue resistance, low coefficient of thermal expansion, compressive strength and suitability for the production of intricate shapes [1]. The main disadvantages of composite material system is their inability to resist blemish initiation and propagation is characterized by the fracture toughness of the materials [2].So many researchers have been investigating the fracture toughness behaviour in different continuous fiber reinforced composites. But there is a limited number of literatures available on fracture toughness behaviour of randomly oriented Chopped Strand Mat E-Glass FRP composites [3]. In this study, chopped strand mat is used because of their very good properties such as excellent coating performance, high strength, excellent flexibility, high dry and wet tensile strength, and good transparency for end product. The life expectancy of composite structure requires a clear understanding of the material's behaviour to the growth of interlaminar delamination under Mode I, Mode II, Mode III and Mixed Modes. Fracture testing of FRP matrix composites is an active area of research [4]. Delamination between layers or plies of a composite laminate is a major weakness in composite materials. Delamination may reduce the stiffness of components and cause a catastrophic failure. A source of delamination is a stress concentration, which usually appears at a geometric discontinuity, i.e. edges and ply drops. [13]

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1 Materials and composition

Chopped Strand Mat (CSM) E-Glass Fiber (Density 2.54 g/ and Modules 70GPa) having fiber thickness 0.35 to

0.40mm are used as the reinforcement material supplied by GVR Enterprises, Madurai, India. The Matrix material used is epoxy resin (LY556) and hardener (HY951) supplied by Ram Composites, Hyderabad India. They are mixed in 10:1 weight ratio. Filler material used is Alumina (Density $3.54g/m^3$ and Melting Point 2000) active neutral white odourless powder is supplied by Telco Scientific supplier, Tirunelveli, India. All materials used in this project work are fabricated by using hand layup technique. The detail of four different composition of composite are made is shown in Table 1 for End notched flexural test.

Table-1: Material Compositions

Sample No	Epoxy (Wt. %)	Glass Fiber (Wt. %)	Alumina (Wt. %)
1	40	60	0
2	38	60	2
3	36	60	4
4	34	60	6

1.2 Fabrication of the Specimen

The composite materials used in this work are manufactured by using hand layup technique with an initial crack of 50mm. Before layup, Mold release sheet is placed to the mold plate to insure that the part will not adhere to the mold. Resin and hardener are mixed in 10:1 in ratio of the Weight. Then, this mixture is mixed with the alumina and applied to the release sheet. Then, the CSM is place over the release sheet and the epoxy mixture is applied over the CSM and hand roller is used to eliminate air bubbles. The same procedure is carried out up to desired thickness is obtained, and, the part is cure at room temperature for 24 hours and then, plate is release from the mold. The fabricated plate is finally cut into required size. The fabricated test specimens is shown in Figure 1.

Fig-1: Fabricated ENF Test specimens

1.3 Determination of void fraction

Burn out test is a common way to estimate the volume fraction of the specimen [8]. Glass fiber content and resin content can be calculated from this data. The burn out test is conducted based on ASTM D3171 – 11 standards.

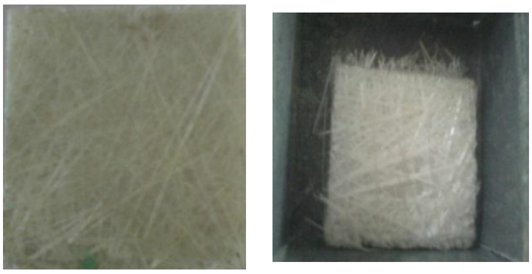

Fig-2: before and after Burn out Test sample

Place each specimen in a desiccated pre-weighed crucible. Place the crucible into a preheated muffle furnace at 500°C or lower depending on the composite system (a temperature below the temperature at which samples will spontaneously ignite). Heat to 565±30°C, or other temperature suitable with the composite system, that will burn off the matrix and leave the reinforcement. The maximum time for burn off should be 6 hours. Shorter times are dependent on the system and specimen size. The matrix is fully combusted. Ash and reinforcement should be the only items visible. Place the specimen and crucible in a desiccator and allow cooling to room temperature [8].The before and after burn out test sample is shown in Figure 2.

Among the various defects produced during the molding of a composite laminate, the presence of voids is considered the most critical defect in influencing its mechanical properties.

ASTM D2734-94 standard is used to analyze the void percentage in composite laminate. Normally up to one percent of voids indicate a good composite, but practical difficulties increase the voids percentages. The void content of a composite may significantly affect the mechanical properties like tensile, compressive and flexural strengths etc. higher percentages of voids usually greater susceptibility to water penetration mean lower fatigue resistance and weathering and increased variation in strength properties. Usually void percentage up to 8% is acceptable in a composite.

$$\text{Void fraction} (V_v) = \frac{\rho_{ct}-\rho_{ce}}{\rho_{ct}} \qquad (1)$$

Where,

ρ_{ct} is theoretical density of composite.

ρ_{ce} is experimental density of composite.

The theoretical and experimental densities of the composites with the corresponding void fraction are presented in Table 2.

Table-2: Density and void fraction of fabricated composite material

Volume fraction of fiber, V_f		Density, g/cc		Void fraction (V_v) %
Theoretical %	Experimental %	Theoretical (ρ_{ct})	Experimental (ρ_{ce})	
41.096	37.76	1.7671	1.7211	2.6054
41.912	38.43	1.8058	1.7553	2.7956
42.761	38.98	1.8460	1.7887	3.1010
43.645	39.54	1.8879	1.8229	3.4392

1.4 Experimental work

The End-notched flexure (ENF) test [9] is one of the methods designed to measure the interlaminar fracture toughness under mode II. In this research, the end notched flexure specimens are used to calculate the second mode energy release rate. The ENF Chopped strand mat E-Glass Fiber/Epoxy composite test specimens is tested by universal testing machine. The ENF tests are conducted on the 10 KN hydraulic test machine is shown in Figure 3. The loading speed is 1 mm/minute. The geometry of the ENF specimen is embedded through width delamination placed at the laminate mid surface. The delamination is placed at the specimen to accommodate the sliding deformation of the sub laminates that result from the flexural loading. A typical ENF specimen is 125 mm length, 20 mm wide, 4 mm thickness.

ENF specimen is subjected to transverse shear loading and flexural loadings. Each load type corresponds to an important mechanism that generates crack driving force at crack tip. The presence of transverse shear force generates interlaminar shear stress that distorts beam cross section and contributes the crack driving force.

Fig-3: Mode II Interlaminar fracture toughness test

Stress at the interface is tensile in the upper beam and compressive in the lower beam. At the crack tip, this discontinuity in stress is eliminated by the presence of the interlaminar shear stress singularity associated with mode II crack propagation.

3. DATA REDUCTION SCHEME

Energy release rate is defined as energy release during fracture per newly created unit area. It is denoted by the symbol G. The most common approach to delamination analysis is the calculation of the strain energy release rate (SERR), based on linear elastic fracture mechanics (LEFM). This method is limited to “brittle matrices”; for tough matrices, another method like elastic-plastic fracture mechanics may be employed, i.e., J integral. Energy release rate (G) is a measure of how tough the material is in resisting delamination and can be calculated from the load-deflection curve [5]. ENF test specimen geometry is shown in Figure 4 where ‘*h*’ is the thickness of the specimen; ‘a’ is the length of a propagated crack; ‘*d*’ is the deflection due to applied forces *P*. The detail of the loading and measurement method is given in the experimental part.

Energy release rate $G = \frac{P^2}{2B}\frac{dC}{da}$ (2)

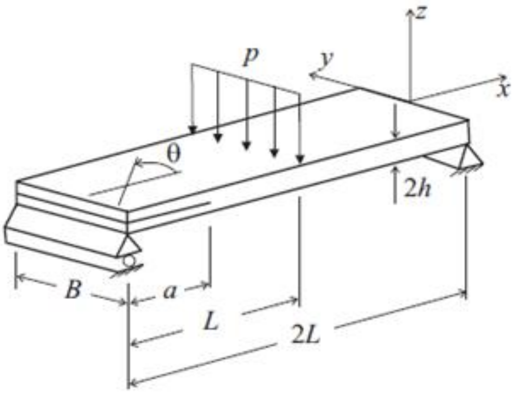

Fig-4: Geometry of ENF specimen

Here c is the compliance $= \frac{u}{P}$. There are no assumptions in equation (2) about the type of the crack tip structure were made, therefore equation (2) is general and should be valid for any bridging and specimen shape. But the G values obtained can functions of the specimen shape, not only the characteristics of the material. G depends on the compliance which is measured experimentally.

The deflection of an simple support beam subjected to a point load at the mid of the beam, with cracked length (a) and bending stiffness EI = $\frac{Ebh^3}{12}$

$$u = d = \frac{Pa^3}{48E_1I} \tag{3}$$

$$c = \frac{(2L^3 + 3a^3)}{8E_1Bh^3} \tag{4}$$

The equation (4) is differentiating with respect to crack length (a) and substitute equation (2). We get mode II ERR formula. In this formula is use to determine G_{II} from the results of applied load (P) and corresponding propagated crack length (a).

$$\frac{\partial C}{\partial a} = \frac{9a^2}{8E_1Bh^3}$$

$$G_{II} = \frac{P^2}{2B} \times \frac{9a^2}{8E_1Bh^3}$$

$$G_{(P,a)} = \frac{9P^2a^2}{16E_1B^2h^3} = \frac{3P^2a^2}{64BE_1I} \qquad (5)$$

In the experiment, Mode II test can be thought a simple support beam subjected to a point load at the mid of the beam, the deflection d,

$$d = \frac{Pa^3}{48E_1I}$$

$$a^2 = \frac{48E_1Id}{pa} \qquad (6)$$

Combining equations (5) and (6), we get the first modified formula for G_{II} from the results of applied load (P) and corresponding deflection (d) and propagated crack length (a).

$$G_{(P,a,d)} = \frac{3P^2}{64BE_1I} \times \frac{48E_1Id}{pa}$$

$$G_{(P,a,d)} = \frac{9Pd}{4Ba} \qquad (7)$$

Then we get second modified formula for G_{II} ,

$$a^3 = \frac{48E_1Id}{p}$$

$$a^2 = \left(\frac{48E_1Id}{p}\right)^{2/3}$$

$$G_{(P,d)} = \frac{3P^2}{64BE_1I} \times \left(\frac{48E_1Id}{p}\right)^{2/3} \qquad (8)$$

In this case the load (P) and corresponding deflection (*d)* are obtained from the experimental result. Therefore we used the equation (8) to determine the second mode energy release rate (G_{II}).

4. FINITE ELEMENT ANALYSIS

The fracture mechanics based approach can be used for sharp crack of linear elastic material to study the problem. As to the energy based criterion (strain energy release rate, SERR), the virtual crack closure technique (VCCT) is powerful tool to compute SERR by using finite element analysis (FEA). Some application of VCCT to study the crack growth can be found. However, in reality, neither the idealized sharp crack nor the linear elastic material does exist. The effect is particularly true for composite materials and adhesively bonded joints. Therefore, recently, using of cohesive zone model (CZM) is increasing. The CZM idea is straightforward. It is a natural extension of BD model, which was suitable for perfect plastic materials. However, the implementation of CZM with FEA varies. There are two major models such as continuum cohesive zone model (CCZM) and discrete cohesive zone model (DCZM). Interface delamination can be modelled by conventional fracture mechanics methods such as the nodal release technique. Alternatively, techniques that directly introduce fracture mechanism by adopting softening relationships between tractions and the partitions, which in turn introduce a critical fracture energy that is also the energy required to break beyond the interface surfaces and this technique is called the cohesive zone model. The interface surfaces of the materials can be represented by a special set of interface elements or contact elements, and a cohesive zone model can be used to characterize the consolidated behaviour of the interface.

The ENF specimen dimensions is shown in Figure 5. The initial crack is 37.5 mm. width of the cracked specimens was 20 mm. The length of the specimen is 125 mm and the thickness of the specimen is 4 mm.

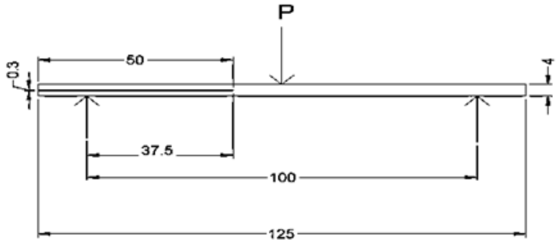

Fig-5: ENF Specimen dimension

The model is meshed with two elements which are PLANE 182 and INTER 202. INTER202 interface elements are used for this purpose. The property of interface element is given by using TBDATA code. The CZM command is used for applying interface element and cohesive meshing of the interface element is done by using CZMESH command.

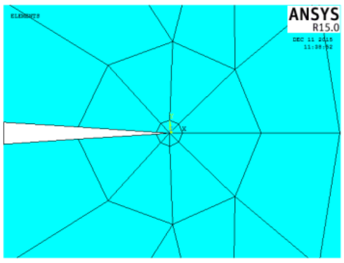

Fig-6: Mesh creation using Concentrate Key Point Method

In the pre-processor stage, first the material curve is generated using material properties. The material properties taken from calculated experimental value. The cracked ENF specimens are modelled and the crack is modelled by using concentrate key point method is shown in figure 6.

5. RESULTS AND DISCUSSION

The theoretical and measured densities of composite are not equal, this is represent the void are presented in the fabricated composite. In the present investigation it was noticed that the addition of Aluminum Oxide filler in the neat composite to increase the void contents is shown in Chart 1.

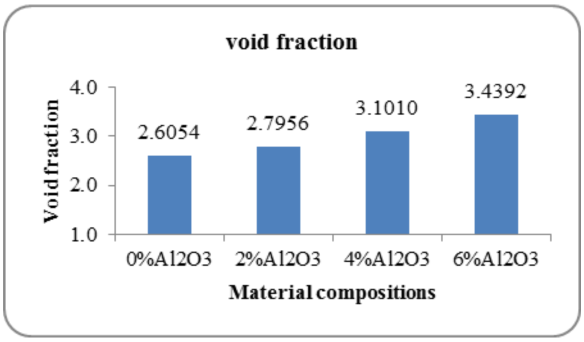

Chart-1: Void fraction of fabricated composite material

The density of a composite depends on the relative proportion of matrix and reinforcing material and this is one of the most important factors for determining the composites properties. The void content is the major cause for the difference between actual density and the theoretical density. The voids significantly affect the mechanical properties and the performance of the composites. However voids presence is unavoidable in hand layup process.

The experimental investigation on delamination of ENF specimen of chopped strand mat glass fiber / Epoxy composite has been carried out by using universal test machine. The specimen is taken in four different compositions.

Table-3: maximum deflection and energy release rate of test specimen.

Sample name	Maximum load KN	Maximum deflection mm	Energy release rate KN/mm
0% Al_2O_3	4.6	20.2	0.016089
2%Al_2O_3	4.6	23	0.017164
4%Al_2O_3	4.65	25.1	0.018027
6%Al_2O_3	4.55	22	0.01666

The displacement and the load are converted into energy release rate by using the derived equation (8). From the Table 3, the maximum value of Energy release rate occurs at 4wt% aluminum oxide addition. Figure 9 shows that the 4wt% aluminum oxide filled composite had a significantly higher Energy release rate compared to other and also more than 4wt% aluminum oxide filler content resulting in decreasing Energy release rate.

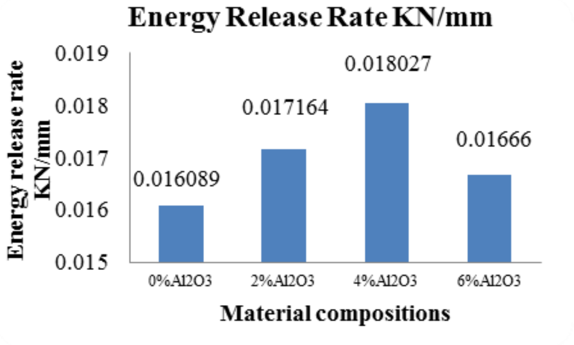

Chart-2: Mode II Energy release rate

The ENF Model the presence of contact requires contact elements to be used in the finite element model. Otherwise, the beam halves would overlap is shown in Figure 7. Two contact elements are used in this analysis CONTA172 and TARGE169.

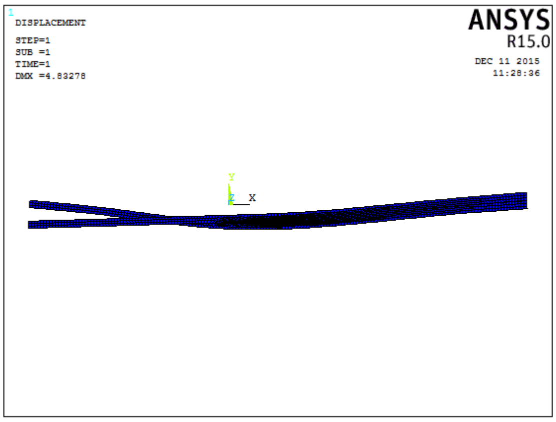

Fig-7: Deformed shape of ENF specimen without contact element

The contact between two bodies, the surface of one body is usually taken as a contact surface and the surface of another body as a target surface. There are two types of contact pair available in finite element analysis. One is rigid-flexible contact pair and another one is flexible-flexible contact pair.

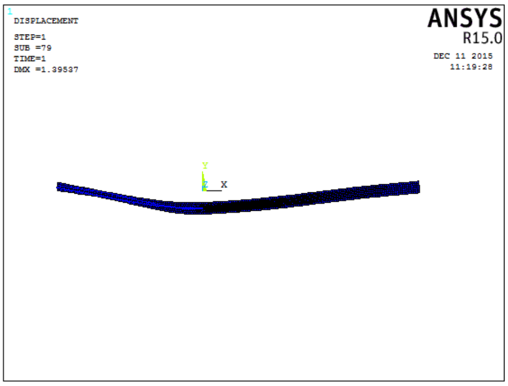

Fig-8: Deformed shape of ENF specimen with contact element

For rigid-flexible contact, the contact surface is associated with the deformable body; and the target surface must be the rigid surface. However for flexible-flexible contact, both contact and target surfaces are associated with deformable bodies. In this work require a flexible-flexible contact pair. The contact element based ENF model deformed shape is shown in Figure 8.

Table-4: Comparison of experimental and Numerical results

S. No	Load (KN)	Displacement (mm)		Energy release rate (KN/mm)	
		Experimental	FEA	Experimental	FEA
1	4.6	20.2	19.36	0.016089	0.01564
2	4.6	23	22.31	0.017164	0.01682
3	4.65	25.1	25.92	0.018027	0.01695
4	4.65	22	17.02	0.01666	0.01404

6. CONCLUSIONS

The crack propagation of the ENF composite specimens is experimentally investigated and also investigated the void fraction in ENF composite test specimens. Void fraction investigation was noticed that the Alumina Oxide filler filled composites have higher void contents than that of the neat composites. The Energy release rate values increase with addition of aluminum oxide filler and more than 4% by weight of aluminum oxide filler content result in decreasing the Energy release rate. It is concluded that by the addition of aluminum oxide 4% by weight of filler there is improvement in energy release rate of glass fiber reinforced epoxy composite. Then the results are compared with numerical results. Thus the numerical simulation of delamination using cohesive element provides better results in the evaluation of fracture parameter.

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