Fracture Toughness and Mechanical Properties of Aluminum Oxide Filled Chopped Strand Mat E-Glass Fiber Reinforced–Epoxy Composites

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Abstract- The knowledge of load bearing characteristics and failure of material is very important for mechanical engineers. Various metallic, non metallic and composite materials are used in different application. In view of this, the main objective of the present work is to analyze the influence of Aluminum Oxide filler on Fracture Toughness properties of Chopped Strand Mat (CSM) E-Glass Fiber reinforced Epoxy Resin Matrix Composites was evaluated using a Compact Tension (CT) specimen according to ASTM D5045 standard. Fracture toughness was conducted at six different compositions of composites. Three samples have to be tested for each composition of the composites. The entire specimens used have satisfied plain strain condition. The each composition of composites is fabricated by using hand layup technique. The epoxy resin and hardener are mixed in the weight ratio of 10:1. The result showed that the tensile strength for 4wt% aluminum oxide filled composite is more compared to 2wt%, 6wt%, 8wt%, 10wt% and neat composite. The fracture toughness of random-chopped mat E-Glass fiber composite material systems (GE, GEA4, GEA6, GEA8 and GEA10) were determined and reported in this manuscript. The fracture toughness of the GEA4 composite was found to be the highest fracture toughness followed by GEA2, GE, GEA6, GEA8 and GEA10 in the order of decreasing fracture toughness. It can be concluded that by the addition of small percentage of aluminum oxide filler there is marginal improvement in fracture toughness of glass fabric reinforced epoxy matrix up to 4wt%.

Index Terms- Chopped Strand Mat (CSM) E-Glass Fiber, Aluminum Oxide, Epoxy Resin, And Compact Tension Specimen.

1. INTRODUCTION

In material science, Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture and is one of the most important properties of any material for many design application. During last decades, there has been a tremendous growth in the use of composite materials in various field of application, ranging from sporting goods to structural component for the automotive and aerospace industries, where the long term properties are of primary importance. High performance polymer based composite materials are being used increasingly for engineering application under hard working condition. Polymer based composite materials play an important role in much industrial application. Because of their favorable properties such as high specific tensile and compressive strength, good electrical conductivity, good fatigue resistance, low coefficient of thermal expansion and suitability for the production of complex shape materials[1]. The main disadvantages of composite material system is their inability resist blemish initiation and propagation is characterized by the fracture toughness of the materials [2].So many researchers have been investigated the fracture toughness behavior in different continuous fiber reinforced composites. But there is a limited literature available on fracture toughness behavior of randomly oriented Chopped Strand Mat E-Glass fiber reinforced composites [3].In this study, fiber glass fiber mat or chopped strand mat is used because of their very good properties such as excellent performance in coating and performing, high strength, excellent flexibility, high dry and wet tensile strength and good transparency for end product.

Many researchers have been investigated the Mode-I interlaminar fracture toughness behavior of polymer composite materials Naveed, Siddique.et.al. [4] Investigated Mode-I interlaminar fracture toughness behavior and mechanical properties of carbon fiber reinforced with nanoclay filled epoxy matrix. The test was performed by using compact tension specimen on universal testing machine at a cross head speed of 5mm/min. The result showed that. Depending on the loading rate fracture toughness increased up to 60% with addition of 3wt% clay. Daniel and Coworker [5, 6] investigated the effect of loading rate on Mode-I fracture toughness properties of carbon/epoxy and carbon/elastomer modified epoxy at a displacement rate of 0.0075mm/sec to 460 mm/sec, they observed that fracture toughness increased for carbon and epoxy composites. But decreased in fracture toughness in elastomer epoxy composite with increasing loading rate. Gillespie. Jr. [7] investigated the effect of loading rate on Mode-I fracture toughness behavior of carbon/epoxy and carbon/PEEK at a cross head speed of 0.25mm /min to 250mm/min. the result showed that fracture toughness of carbon/PEEK decreases with increased loading rate and carbon /epoxy insensitive. Kusaaka et.al. [8] Studied the fracture toughness of carbon/epoxy at a displacement rate of 0.01mm/sec to 20m/sec. He observed that fracture toughness was rate independent.P.Karge-

Kocis and Friedrich et.al. [9] Investigated fracture toughness of short glass / PEEK composite material. The test was performed at displacement rate of 0.1mm/min to 100mm/min. the result showed that fracture toughness decreased with increasing the loading rate. Many researchers have studied the Mode - II fracture toughness behavior of polymer composite materials interns of loading rate. Davies et.al. [10] Investigated the influence of fiber volume fraction on Mode-II interlaminar fracture toughness of glass/epoxy using end notched flexure (ENF) specimen. The test was performed at displacement rate of 1mm/min and 10KN capacity. He observed that G_{IIC} increases with decreased with fiber content. Smiley and Pipes et.al. [11] Investigated the effect of loading rate on Mode- II fracture toughness properties of carbon/epoxy and carbon/PEEK. The test was performed at displacement rate of 0.042m/sec to 0.092m/sec. They observed that decreased in fracture toughness with increasing loading rate. Composton et.al. [12] Investigated Mode–II fracture toughness of glass/vinyl ester and glass/polyester at displacement rate of 1mm/min to 3m/sec. they observed that fracture toughness decreased with increasing loading rate.

Many scientists have investigated the mixed mode fracture toughness properties of polymer composite interns of loading rate. Blackman et.al. [13] Investigated fracture toughness behavior of carbon / epoxy and carbon / PEEK composite interns of loading rate of 1mm/min to 5m/sec. He found that fracture toughness to be invariant. Kusaaka et.al. [14] Studied the fracture toughness behavior of carbon / epoxy composites interns of loading rate of 10^{-6} m/sec to 10m/sec. He observed that fracture toughness decreases with increasing loading rate.

The main objective of the present work is to fabricate E-Glass chopped strand mat and Epoxy composite using Aluminum Oxide filler varying weight percentage using hand layup technique and to study the fracture toughness and mechanical behavior. The main reason why alumina is most commonly used material because of their good properties such as hard and wear résistance, excellent dielectric properties, good thermal conductivity, excellent size and shape capability, high strength and stiffness and epoxy resin is widely used because of their favorable properties such as high strength, low viscosity and low flow rates, low volatility during curing and low shrink rates which reduce tendency gaining large shear stress of bond epoxy and reinforcement.

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1. Material Selection and Composition

Chopped Strand Mat (CSM) E-Glass Fabric (Density 2.54 g/cm^3 and Modules 70GPA) having fiber thickness 0.45 to 0.50mm were used as the reinforcement material supplied by Suntech Fiber Private, Limited, Bangalore India. The Matrix material used is a general purpose epoxy resin (Lap ox L-12 3202,Hardener K-6 and Density 1.120g/cm^3) supplied by Yuje Enterprises Bangalore, India. Filler material used were Aluminum Oxide (Density 3.54g/cm^3 and Melting Point 2000^{o}C) active neutral white odorless powder having particle size 230 mesh (57 Micron) is supplied by Dutta Scientific Works Bangalore, India. All materials used in this study were fabricated by using hand layup technique. The detail of six different composition of composite are made shown in Table (1.1) for Fracture toughness test and tensile test

SL.No	Sample Code	Epoxy (Wt %)	Glass Fiber (Wt %)	Alumina (Wt %)	Specimens
1	GE	40	60	0	3
2	GEA2	38	60	2	3
3	GEA4	36	60	4	3
4	GEA6	34	60	6	3
5	GEA8	32	60	8	3
6	GEA10	30	60	10	3

Table -1.1 Composition of E-Glass Fiber-Reinforced with Aluminum Oxide particles.

2.2. Fabrication of the Specimen

The composite materials used in this study were manufactured by using hand layup technique. Before layup, Mold release sheet is placed to the granite plate to insure that the part will not adhere to the mold. Epoxy resin and hardener are mixed in the weight ratio of 10:1and kept for a minute. Then, this mixture is mixed with the alumina and applied to the release sheet. Then, reinforcement kept and again this mixture is applied to the mat. Then, the brush, roller and squeeze can be used to eliminate air bubbles. The same procedure carried out up to desired thickness is obtained and another granite plate is kept on this to remove air bubbles. And then, the part is allowed to cure at room temperature for 18 hour and then, finally part is release from the plate.

2.3. Specimen Design for fracture toughness test and tensile test

A compact tension specimen is a notched sample and is a standard dimension in accordance with ASTM D5045. The purpose of using a notch sample is to create a fatigue crack by cycling the maximum and minimum load. Compact tension specimen used extensively in the area of fracture mechanics and corrosion testing. In order to establish fracture toughness values for a material. According to the standards the constraining dimension of the CT specimen is the thickness of the material. Compact tension specimens are used for experiment where there is a shortage of material available due to their compact design. Fracture toughness test has to be carried out using a compact tension specimen having thickness B=5mm, crack length from loading point A=20mm, width= 40mm, Length=50mm and breadth =48mm in accordance to ASTM D5045 standard.

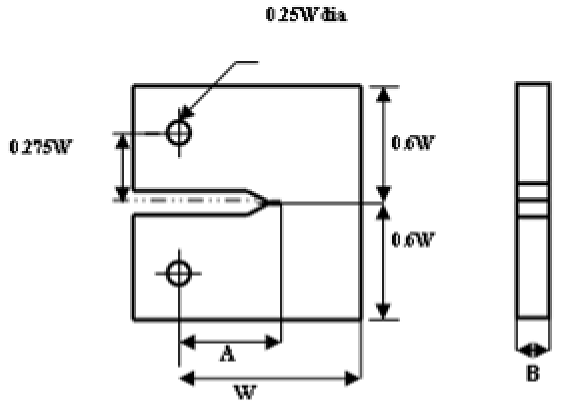

Fig 2.1. Compact Tension specimen according to ASTM D5045

2.4. Calculation of Mode – I stress intensity factor

The mode-I stress intensity factor (Fracture Toughness).K_{IC}, At the point of fracture initiation was determined using equation 1.the load - displacement curve was recorded from the experiment to determine P_Q As explained in ASTM D5045 standard. In order to establish a valid stress intensity factor $K_{IC,}$ a conditional result K_Q was calculated using equation 1

$$K_Q = P_Q / (B)^{½}\ f(x) \text{ -- } (1)$$

Where
B= Specimen thickness, W= Specimen Width and

$$f(x) = \frac{(2+x)\,(0.866x+4.64x-13.32x^2+14.72x^3-5.64x^4)}{1-x^{3/2}} \qquad \text{-- --}\ (2)$$

P_Q is determined by Load- displacement graph, In order to ensure plain strain condition. The size criteria are validated by the above equation.

$$B,\ a,\ (W-a) > 2.5\ (K_Q / \sigma_{ys}) \text{ --- } (3)$$

Where (W-a) the ligament and σ_{ys} is the yield stress of the specimen. K_Q satisfies equation 2 and then K_Q is equal to K_{IC}.three samples have to be tested for each composition of composites. The entire specimens used have satisfied the plain strain condition.

2.5. Determination of Fracture Toughness

Stress intensity factor, K_{IC} is one of the most important properties of a material. It is used to design for dynamic application where the material must encounter many mechanical shocks and vibration. The toughness of a material is defined as the energy absorbed by a material before fracture, and expressed as impact energy. Fracture toughness describes the resistance of a material with a crack to fracture. Because it is almost impossible to make material for practical purpose free from crack defects.

Fracture toughness analysis is extremely important for many design application. The fracture properties of a thermo set material are determined using compact tension specimen accordance to ASTM D5045 standard. The critical stress intensity factor and impact energy are determined. Test is carried out with a universal testing machine (UTM) using compact tension or bending mode. An initial crack machined in a rectangular specimen and natural crack generated by tapping on fresh razor blade placed in the notch. The thickness of the specimen should be higher than the critical value below which the material shows plain stress behavior. The K_{IC} and G_{IC} of a given material are function of testing speed and temperature. The value may be different under cyclic load. Therefore, K_{IC} and G_{IC} in the design of service component should be made considering different that may exist between test condition and field condition.

2.6. Density and Fiber Volume Fraction

Density is a physical property of matter, as each element and compound has unique density associated with it. The density of a material varies with temperature and pressure. The density of a composite material is measured according to ASTM D792-98 standard [15].the specimen from each composite was tested, the volume of a fiber in a cured composite. The fiber volume of a composite material may be determined by ignition loss or burnout method. commonly used for glass fiber reinforced composite in the resin burn-off method described in accordance to ASTM D2584-94 standard[16].the specimen from each composite was tested

2.6. Tensile Test

Tensile test is most commonly used to assess the performance of a material or identify the material for particular application. The test indicates that the ability of a material withstand full out of force and is used to determine extent of stretching before break. The test is carried out by universal testing machine using dog bone shape specimen according to ASTM D683 standard. The tensile test specimen of different size as specified by the standard can be used. Depending upon the nature of the sample different speed of the testing can be used. The most commonly used speed of testing is 5mm/min. in this study, tensile test was conducted at six different compositions of the composites.

3. RESULT AND DISCUSSION

3.1. Density and Fiber Volume Fraction

The theoretical and measured densities of the composites along with the corresponding volume fraction of voids are presented in table 3.1 The composite density values calculated theoretically by using equation are not equal to the experimentally determined values. This difference represents the void and pores present in the composites.

Sample Code	**Measured Density(g/cm^3)**	**Theoretical Density(g/cm3)**	**Volume fraction of void**
GE	1.6403	1.6853	2.6704
GEA2	1.6714	1.7224	2.9610
GEA4	1.7015	1.7612	3.3897
GEA6	1.7373	1.8018	3.7126
GEA8	1.7750	1.8443	3.7575
GEA10	1.8144	1.8889	3.9940

Table 3.1 Tabulation of results for physical properties of density and volume fraction

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 properties of the composites. The void content is the cause for the difference between actual density and the theoretical density. The voids significantly affect the mechanical properties and the performance of the composites at the work place. Higher void content mean lower fatigue resistance, greater susceptibility to water penetration and weathering. The knowledge of void content is desirable for estimation of the quality of composites. A good composite should have fewer voids. However presence of voids is unavoidable in hand layup process.

In the present investigation it was noticed that the Aluminum Oxide filler filled composites have higher void contents than that of the neat composites

3.2. Tensile Test

Sample Code	**Maximum Load in KN**	**Tensile Strength (MPa)**	**Young's Modulus (MPa)**	**Elongation %**
GE	5.41	111.21	7524.27	3.51
GEA2	4.89	148.42	7819.11	4.33
GEA4	4.19	158.26	8692.06	4.53
GEA6	5.05	120.67	4155.26	4.37
GEA8	4.77	127.55	5517.65	4.14
GEA10	4.65	125.18	5661.37	4.22

Table 3.2.Tabulation of results for tensile test

The ASTM D638 standard test method for tensile properties of fiber resin composites is used. The tensile test is performed in universal testing machine KIC-2-1000-C at the cross head speed of 5mm/min. The results are analyzed to calculate the tensile strength of composite samples. The table 3.2 gives the tensile properties of various samples.

The aluminum oxide filled composite showed max tensile strength compared to neat composite. Increasing the percentage of fillers to 2 wt % resulted in increasing the tensile strength. Further increase in filler content (up to 10% Wt) resulted in decreased tensile strength. This is due to increased filler percentage in the composites resulting in improper distribution. Composite filled 4wt% aluminum Oxide showed maximum value of Young's modules compared to unfilled composite. Further addition of filler reduce the same, this can attributed the increased brittleness of the composites with higher percentage of the filler the filler content. It can also be observed that these variations are very significant. Composite filled with 4wt% of aluminum oxide filler showed max percentage elongation compare to unfilled composite. Increased percentage of filler deteriorated the situation. Increased filler content make the composites brittle which could result in early brittle fracture. In tensile test result, the tensile properties of tensile strength, young are modules and percentage elongation values are increases marginally up to 4wt%.

3.3. Fracture Toughness Test

The fracture toughness test has to be carried out in universal testing machine KIC-2-1000-C using compact tension specimen at the cross head speed of 5mm/min.The table 3.3.gives the fracture properties of various samples. The standard deviation of the results was a little higher than expected – possibly due to cracks in certain samples that led them to fracture more easily

Sample Code	Maximum Load in KN	Stress intensity factor in MPa(mm)$^{1/2}$	Maximum Displacement in mm
GE	4.19	16.47	3.51
GEA2	4.89	19.95	4.33
GEA4	5.41	20.38	4.53
GEA6	5.05	17.57	4.37
GEA8	4.77	17.32	4.14
GEA10	4.65	17.45	4.22

Table 3.3 Tabulation of results for Fracture toughness test

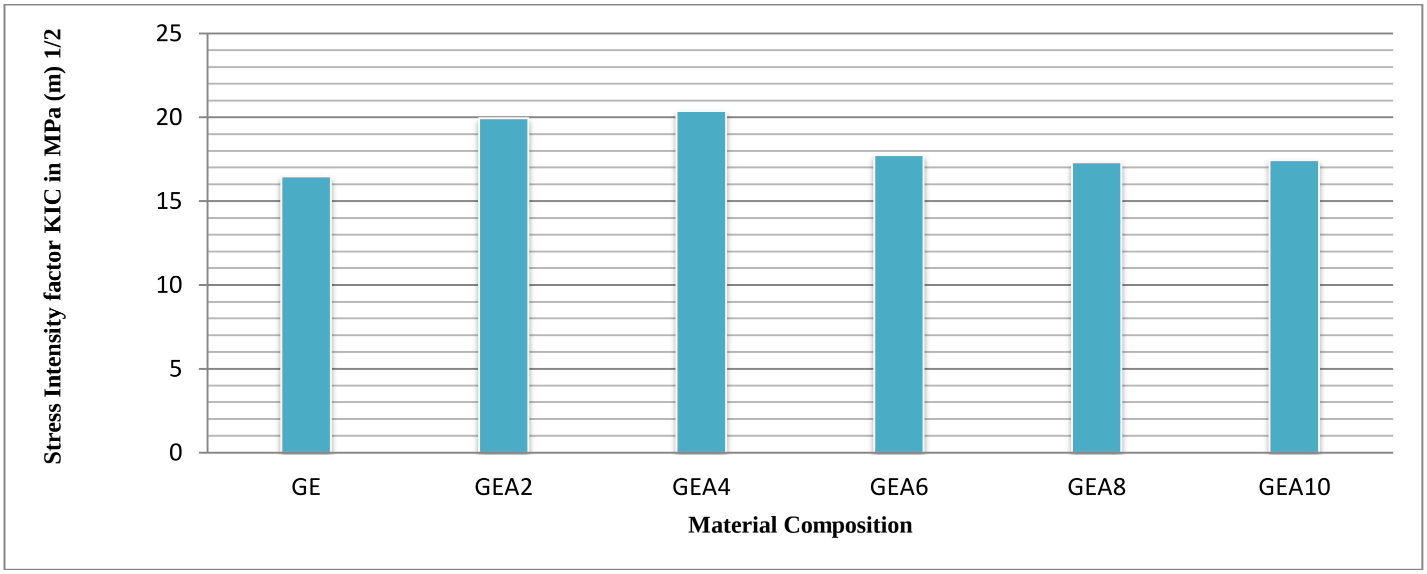

Figure 3.1 Shows graph plotted between stress intensity factor and material composition

The result table showed that the fracture toughness properties of various parameter such as stress intensity factor, maximum load and displacement. Stress intensity factor usually expressed in MPa (m) $^{1/2}$. From the above table, we found that the maximum value of stress intensity factor found at 20.38Mpa (m) $^{1/2}$. Table 3.3 shows the obtained results. The 4wt% aluminum oxide filled composite had a significantly higher fracture toughness compared to the neat composite (K_{IC} = 16.47 MPa (m) $^{1/2}$. The obtained results were K_{IC} = 19.95 MPa (m) $^{1/2}$ [GEA2], K_{IC} = 20.38 MPa (m) $^{1/2}$ [GEA4], K_{IC} = 17.57 MPa (m) $^{1/2}$, K_{IC} = 17.32 MPa (m) $^{1/2}$ and K_{IC} = 17.45 MPa (m) $^{1/2}$ surprisingly, the sample contain 4wt% alumina filled composite showed a higher fracture than all other samples, besides containing numerous void. Therefore, achievable fracture toughness marginally up to 4wt%. Then, increases the filler content resulting in decreases in fracture toughness due to improper distribution of filler and brittleness of the composite with higher percentage of filler which could results in early fracture.

LOAD – DISPLACEMENT GRAPH

The average values of load versus displacement curve of the fracture toughness behavior of neat composite and aluminum filled chopped strand mat E-Glass fabric and epoxy composites are shown in figure 3.2. In the load displacement graph. The load drops sharply at several points after the peak load, corresponding to unstable or fast crack propagation. Fiber bridging and breaking behind the crack tip are not observed macroscopically in crack propagation during the test. Due to relatively thick matrix inter laminar layer. The peak load much higher for the 4wt% aluminum oxide filled composite than for the neat composite, the maximum displacement and peak load observed in 4wt% aluminum oxide filled composite compare to others. Further, increases in filler content resulted in load drops slowly at several points after the specimen break at maximum load. This is mainly due to manufacturing flaw and improper distribution of filler.

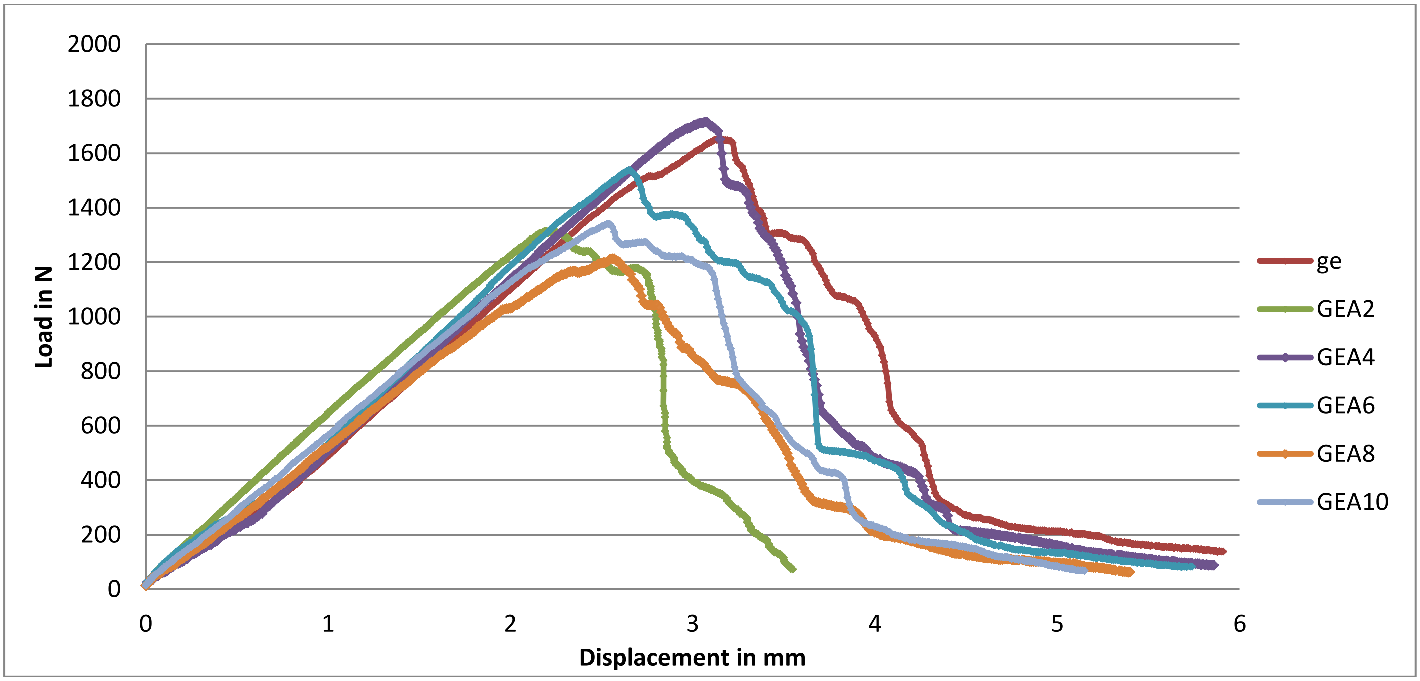

Fig 3.2 shows load – displacement graph for GEA4 and GEA6 composition

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4. CONCLUSION

Chopped strand mat E-glass fiber and epoxy composite of aluminum oxide is prepared with six different wt% of aluminum oxide viz 0wt%, 2wt% , 4wt% , 6wt% , 8wt% and 10wt%. From the study, following observations were made:

1. The voids significantly affect the mechanical properties and the performance of the composites at the work place. Higher void content mean lower fatigue resistance, greater susceptibility to water penetration and weathering.. However presence of voids is unavoidable in hand layup process. In the present investigation it was noticed that the Aluminum Oxide filler filled composites have higher void contents than that of the neat composites.

2. The result obtained from the tensile test, the tensile properties such as tensile strength, young's modules and percentage of elongation for 4wt% aluminum oxide filled composite is more compared others. Further increases in filler contents up to 10wt% resulted decreases in tensile strength. This is due to increased filler percentage in the composites resulting in improper distribution and poor manufacturing process.

3. Fracture toughness values were determined using compact tension sample. The fracture toughness values were increases with addition of 2wt% and 4wt% aluminum oxide filler. The presence of aluminum oxide filler provide crack tip blunting by shear deformation process near the crack tip. However at high percentage of aluminum oxide filler the particle matrix adhesion is reduced which reduces the toughness. It can be concluded that by the addition of small percentage of aluminum oxide filler there is marginal improvement in fracture toughness of glass fabric reinforced epoxy matrix marginally up to 4 wt%.

5. REFERENCES

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