

Characterization of Mechanical and Fracture Toughness of Hybrid Composites with Caco3 Fillers

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Abstract

Composites are made by addition of one or more materials combined at macroscopic level. By varying the percentage of composition of materials the strength and toughness can be obtained as per the end applications. The present work is to fabricate an E-glass epoxy composite using MY740 epoxy along with varying percentages of CaCO₃ as filler material. The filler materials are added at different percentages of 2.5 wt% and 5 wt% and the mechanical properties such as tensile strength, impact strength, flexural strength and fracture toughness of the composites are determined. Using the graphs, the failure modes of the composites are determined. It is found that the addition of fillers increases the tensile strength, but decreases the impact energy. Varying strengths are obtained at Flexural and Fracture test based on the filler percentage and temperature. ANSYS modelling is carried out to verify the fracture toughness of the composite. The SEM analysis is also carried out to determine the failure at micro-structural level.

Keywords: *E-glass epoxy, CaCO₃ fillers, Mechanical properties, Scanning Electron Microscope*

INTRODUCTION

A composite material is one which is made up of two or more different materials and when combined together, they produce better mechanical properties than the individual components. Fibre reinforced polymers are the ones which are made up of fibres and have high strength when combined with epoxy resin to form the matrix. E-glass fibres are the most commonly used fibres for composites, since they are relatively cheap compared to other glass fibres.

The properties of the composite can also be enhanced by the addition of filler particles in small percentage. Deogonda et al. stated that with filler incorporation, the mechanical properties increase. They also revealed that impact toughness is more for unfilled composite [1].

Channapagoudra et al. observed the behaviour of composite's mechanical performance with the addition of fillers. They concluded that, with the addition of fillers the mechanical properties can be enhanced compared to the composite without filler [2] [3].

Calcium Carbonate (CaCO_3) can be used as fillers in the composites. The dispersion and bonding between the fillers and the matrix are studied and the mechanical properties are determined. The nano particle fillers with a size of 30–40 nm are dispersed efficiently compared with solution-blending as observed with SEM [4]. Ayman et al. studied friction and wear behaviour of nano-filler composite. They concluded that nano-particles increased the mechanical properties of composites [5]. It is also seen that smaller the particle size, better are the interfacial properties [6] [7].

In this study, E-glass epoxy composite with nano sized CaCO_3 fillers are prepared and the mechanical properties are tested along with an ANSYS simulation.

MATERIALS USED FOR STUDY

For the matrix material of the composite we used Epoxy MY740. A 360 GSM woven roving E-glass fibre (00 and 900) was used as reinforcing material. The hardener used was HY918. Nano sized CaCO_3 particles were used as filler material. We took the ratio of Glass fibre and epoxy as 55% of Glass fibre and 45% of Epoxy. A composite without filler was used to compare the

results against the ones with varying percentage of fillers (2.5wt% and 5wt%)

METHODOLOGY AND FABRICATION TECHNIQUES

Epoxy resin was mixed with the hardener, the ratio being 10:1 by weight. Since Hand lay-up process is fairly simple, this method was employed for the composite preparation. To make sure that the part does not stick, a release agent was applied before the hand lay-up process. Release agent also helps in easy removal of the composite after the process is done. The composites obtained from the lay-up process should be further processed. These composites were compressed and cured using hot press. The amount of resin and fillers to be added for preparing the composite was calculated beforehand.

The plate dimension was kept to be 300x300mm and the thickness was kept at 3mm and 8mm. The material composition of composite is listed in table 1.

The following are the data used in the preparation of E-glass fibre epoxy composite materials with 0% filler, with 2.5% filler and with 5% filler.

$$\text{Density of Epoxy MY740} = 1.16 \text{ g/cm}^3$$

$$\text{Density of E-glass} = 2.57 \text{ g/cm}^3$$

$$\text{Thickness of 1 layer of glass fibre} = 0.167 \text{ mm}$$

$$\text{Weight of 1 layer of glass fibre} = \text{Volume} \times \text{Density}$$

$$= (300 \times 300 \times 0.167) \times (2.57)$$

$$= 38.63 \text{ g}$$

Table: 1 Material composition of composites fabricated

Sl No.	Sample (Designation)	Composition by wt%		
		Fibres	Epoxy	Fillers
1	G-E	55	45	--
2	G-E + 2.5% CaCO ₃	55	42.5	2.5
3	G-E + 5% CaCO ₃	55	40	5

Weight of glass fibres = Weight of 1 layer of glass fibre x Number of glass fibres.

Hardener HY918 = 10% of the epoxy added

The following table shows the required weights of the materials added

Table: 2 Weights of the materials added.

	G-E (3mm)	G-E (8mm)	G-E + 2.5%filler (3mm)	G-E + 2.5% filler (8mm)	G-E + 5% filler (3mm)	G-E + 5% filler (8mm)
Epoxy %	45%	45%	42.5%	42.5%	40%	40%
Glass fibre %	55%	55%	55%	55%	55%	55%
Layers required for thickness of 3mm and 8mm	18 layers	48 layers	18 layers	48 layers	18 layers	48 layers
Glass fibres required (55%)	10 layers	26 layers	10 layers	26 layers	10 layers	26 layers
Weight of Glass fibres (a)	386.3 g	1004.38 g	386.3 g	1004.38 g	386.3 g	1004.38 g
Weight of Epoxy (b)	316.06 g	821.7 g	298.5 g	776.11 g	280.9 g	730.45 g
Weight of hardener	31.6 g	82.17 g	29.85 g	77.61 g	28.09 g	73.045 g
Weight of filler added (c)	-	-	17.55 g	45.65 g	35.11 g	91.3 g
Total weight of composite (a + b + c)	702.36 g	1826.08 g	702.35 g	1826.14 g	702.31 g	1826.13 g

MECHANICAL TESTING METHODS

1. Impact test

The impact strength is determined using the Izod test apparatus, in which the test specimen is fixed vertically on a fixture and when the pendulum is released it breaks the specimen attached to fixture and the energy absorbed by specimen is noted down. In order to find the impact energy, we used a standard impact test apparatus. ASTM D256 was set as a standard for the specimen samples. The samples contained a notch with an angle of 45°. Two specimens were tested for each combination of glass-epoxy/filler to obtain the result.

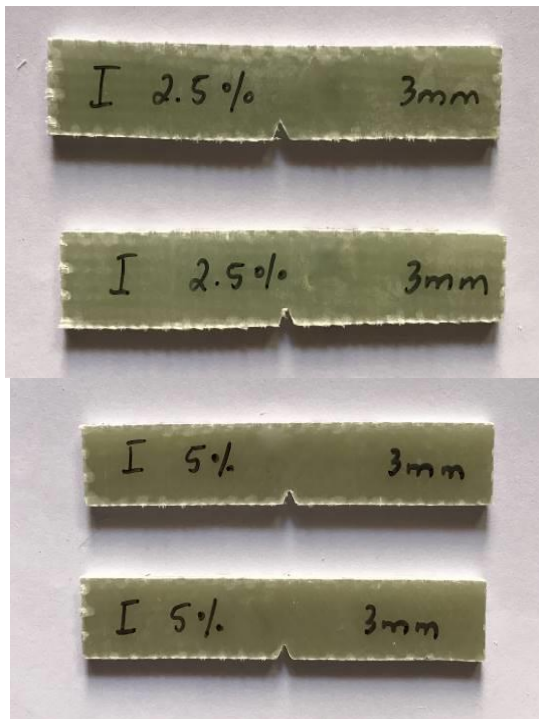


Fig 1 Impact Test Specimen

2. Tensile test

In this test, we used ASTM D638 as the standard for specimen samples. The test was conducted at The National Institute of Engineering using the Universal Testing Machine. Tensile strength of a composite is calculated with the help of tensile test. The test was carried at a test speed of 4mm/min. The test was conducted at room temperature. Load vs. displacement graph was plotted.



Fig: 2 Tensile Test Specimens

3. Flexural test

The flexural strength of composite is determined by using three point bending test. The specimen is prepared and placed on the fixture. The load is applied on the

specimen and the readings of peak load are noted. We used ASTM D790 to perform this test. The test was conducted using Universal testing machine at room temperature. The test speed was set at 3mm/min.

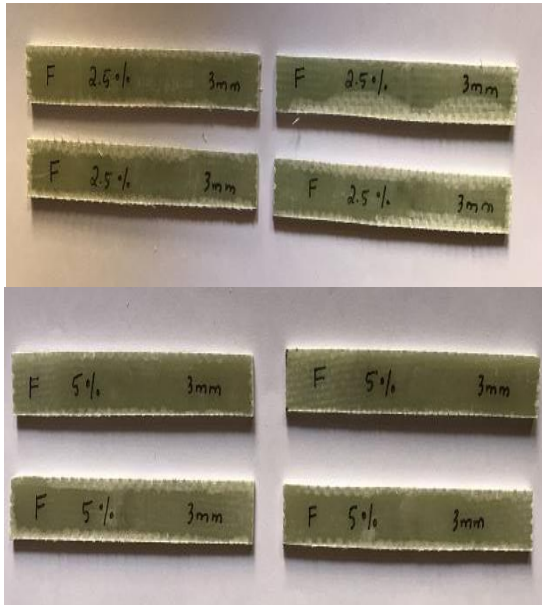


Fig: 3 Flexural Test Specimen

4. Fracture toughness

Fracture toughness is a material's ability to oppose the propagation of crack formed earlier. The test is useful to find the fracture toughness of a material. The test was conducted according to ASTM D5045 for Single Edge Notch Bending (SENB) using the Universal testing machine at two different temperatures- room temperature and 500C. Test speed of 3mm/min was set to conduct the procedure.



Fig: 4 Fracture Test Specimens

RESULTS AND DISCUSSIONS

1. Impact energy

It is the measure of the energy absorbed by the specimen. With the addition of CaCO₃, the average impact energy decreases when compared to clean glass epoxy. From the results it can be concluded that best impact strength is obtained when no CaCO₃ fillers are added. However, if the filler percentage becomes more than 5wt%, the composite starts to attain brittleness, thus resulting in lesser impact strength. The impact strength of the composite with CaCO₃ filler is shown in table 3.

Table: 3 Impact strength of the composite with CaCO₃ filler

Sample Name	Average impact energy (J)	J/m
G-E	4.2	1355
G-E + 2.5% CaCO ₃	3.95	1392.8
G-E + 5% CaCO ₃	3.5	1540.5

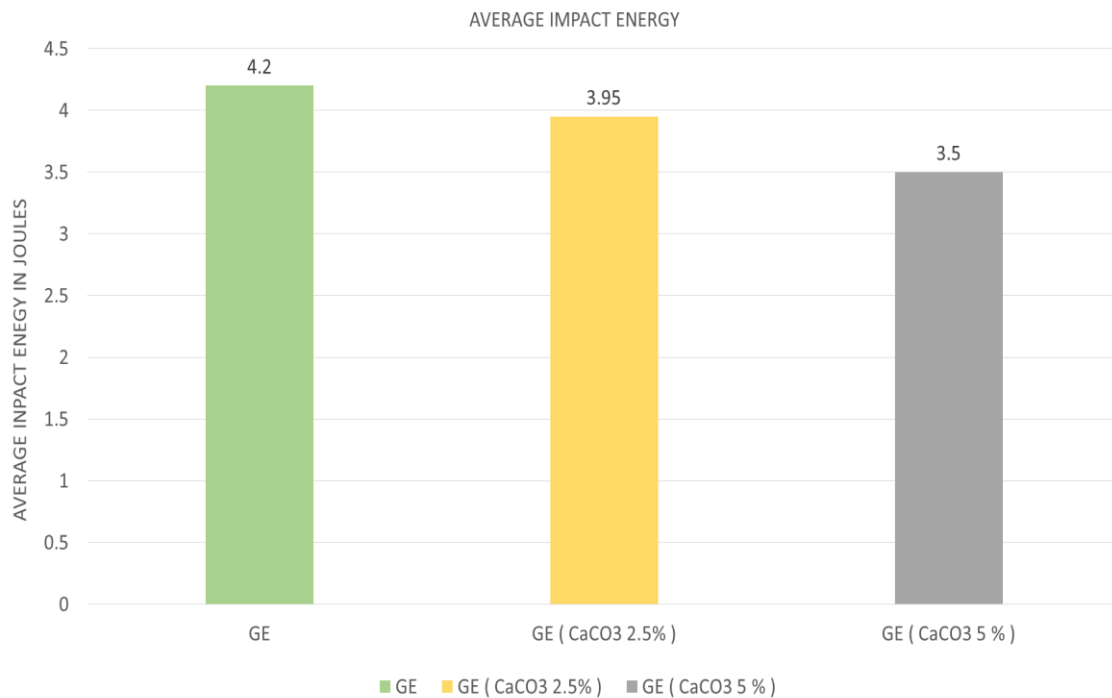


Fig 5.Bar chart of average impact energy of G-E Composites

2. Tensile Strength

Tensile strength is important in determining when the material fails when subjected to tensile forces. The ultimate tensile strength

enhances with rise in filler percentages for CaCO₃. The UTS has a maximum value at 5wt% of CaCO₃. The tested results are shown in table.

Table: 4 UTS values of the composites.

Sample name	Peak load (N)	UTS (MPa)
G-E	6895.22	286.4
G-E + 2.5% CaCO ₃	9252.9	301.305
G-E + 5% CaCO ₃	10217.48	317.815

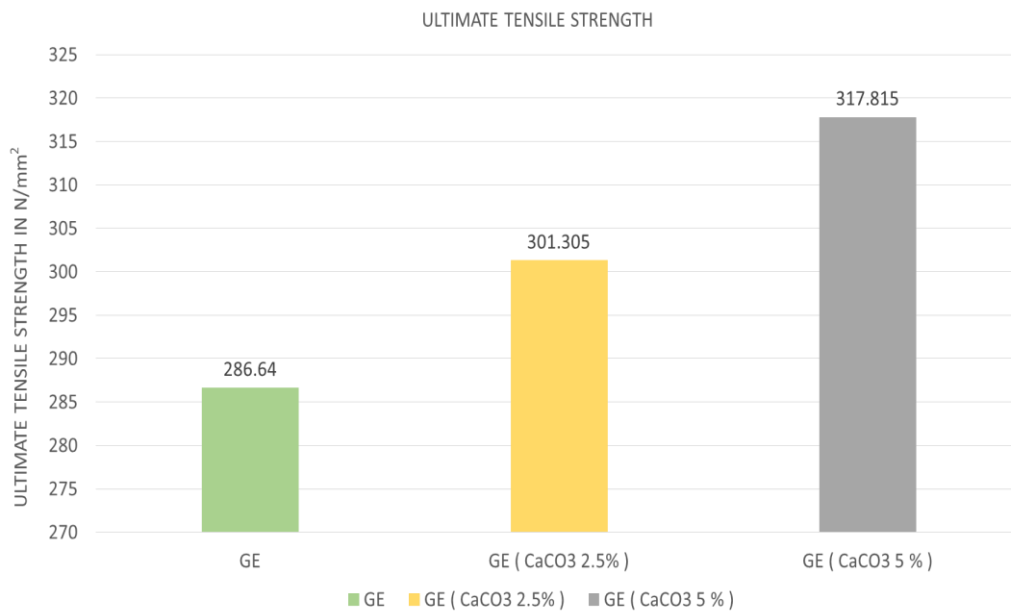


Fig 6. Bar chart of ultimate tensile strength of G-E composites

3. Flexural Strength

Flexural strength is important in knowing the bending properties of the material. The result values of flexural strength and modulus of E-glass/epoxy composites with

varying percentage of CaCO₃ is shown in table. The flexural strength increases from 0% filler to 2.5% CaCO₃, but decreases at 5wt% of CaCO₃.

Table: 5 Flexural strength and modulus of E-glass/epoxy composites

Sample name	Peak load (N)	Flexural strength (MPa)	Flexural modulus (MPa)
G-E	174.36	159.87	4230.56
G-E + 2.5% CaCO ₃	245.75	283.06	12118.23
G-E + 5% CaCO ₃	267.09	213.52	7431.025

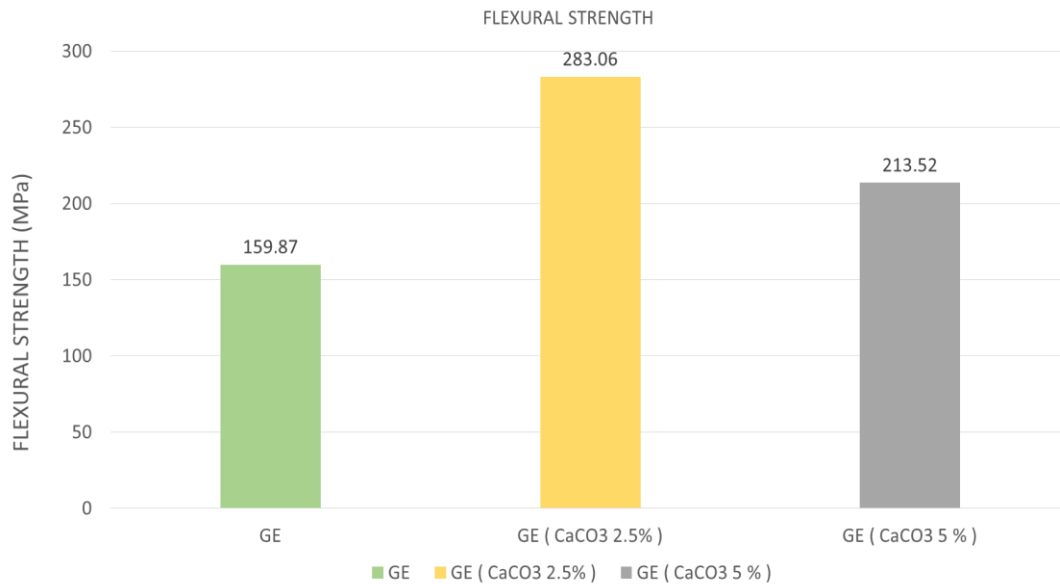


Fig 7. Bar chart of flexural strength of G-E composites

4. Fracture Toughness

Fracture toughness is a property which describes the materials ability to resist fracture from the pre formed crack. Fracture toughness of a material is obtained by calculating stress intensity factor (K_{ic}). The tests are carried out at room temperature and at 500C. The fracture toughness of E-

glass/epoxy composite with varying percentage of filler is shown in the table below. ANSYS models of the composites were created and tested in the software. As shown in the table, we can observe that the stress intensity factors from ANSYS and the experiment almost match up.

Table 6. Fracture toughness test results at Room temperature

Room temperature			
Sample name	Stress intensity factor (K_{Ic}) MPa $\sqrt{m}$	Strain energy release rate KJ/m ²	K_{Ic} (ANSYS value)
G-E	25.1	8.27	29.03
G-E + 2.5% CaCO ₃	34.2	15.35	36.45
G-E + 5% CaCO ₃	26.6	9.29	29.64

Table 7. Fracture toughness test results at 50^o C

50 ^o C			
Sample name	Stress intensity factor (K_{Ic}) MPa $\sqrt{m}$	Strain energy release rate KJ/m ²	K_{Ic} (ANSYS value)
G-E	24.5	7.88	28.45
G-E + 2.5% CaCO ₃	31.5	13.02	33.96
G-E + 5% CaCO ₃	32.7	14.04	36.39

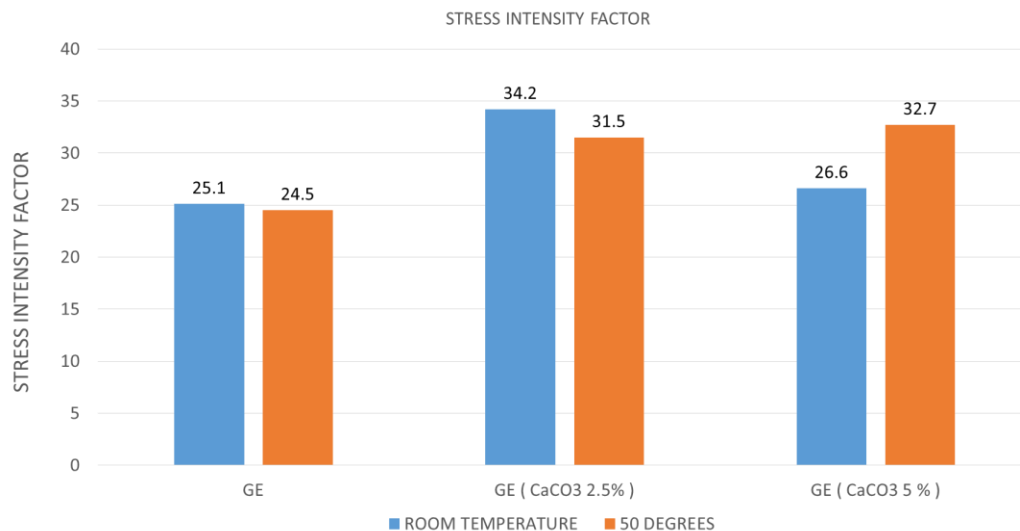


Fig 8. Bar chart of stress intensity factors of G-E composites

ANSYS screenshots

The samples are recreated in the ANSYS software using the mechanical properties of the material. The samples are tested using 3 point bending fracture method where the load is applied till a fracture is obtained at

the crack. The stress intensity factors are noted for all the samples. Following are a few screenshots of the sample at room temperature fracture testing in ANSYS. The ANSYS modelling is also carried out at 50°C as shown in the above table.

At Room Temperature:

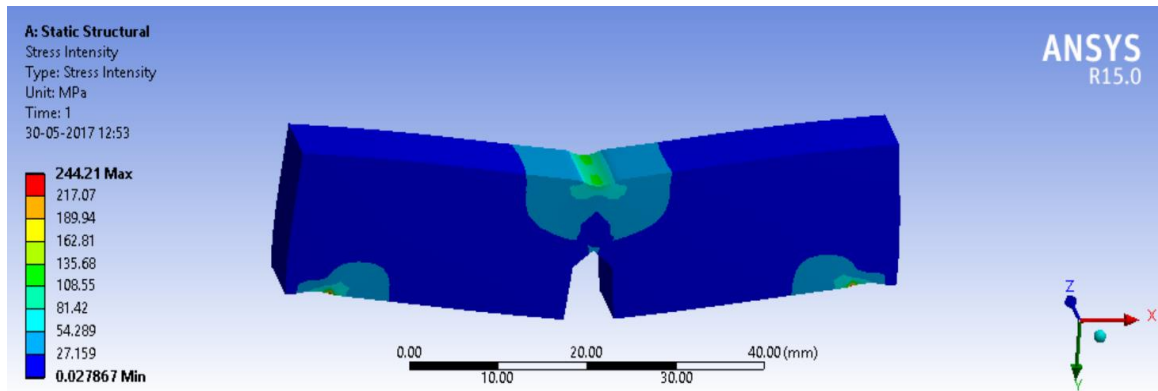


Fig 9 Stress intensity for G-E composite

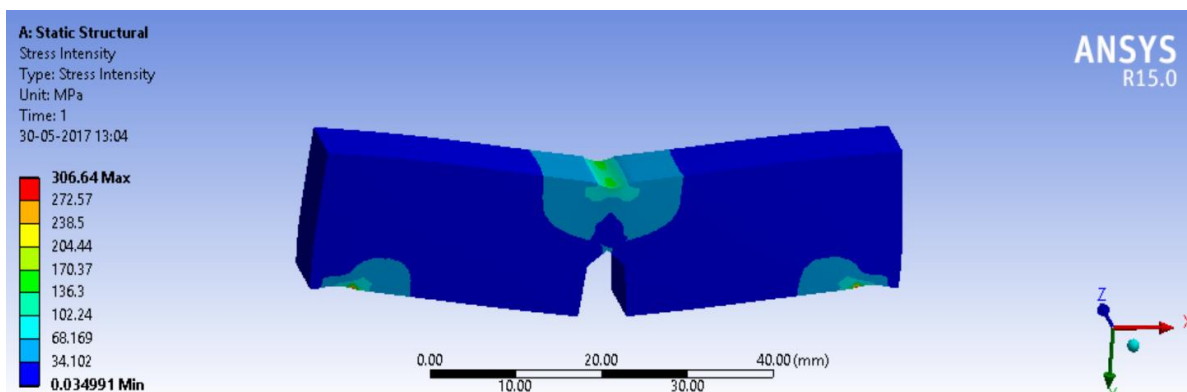


Fig 10 Stress intensity for 2.5 wt% CaCO₃ G-E composite

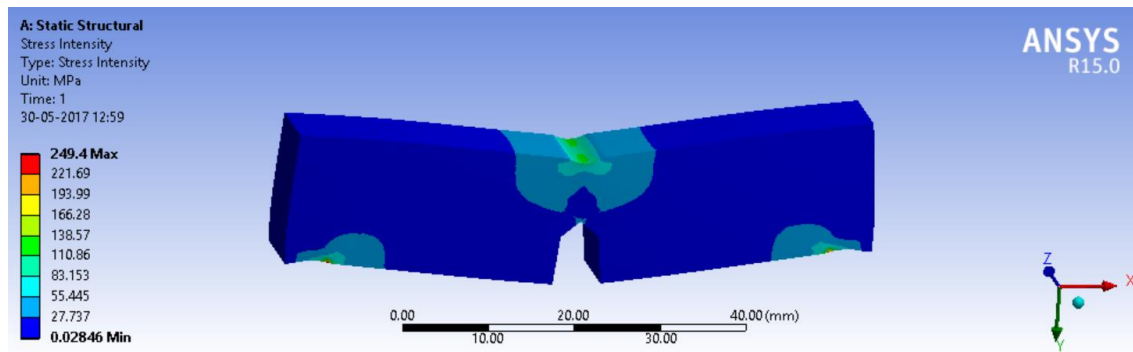


Fig 11. Stress intensity for 5 wt% CaCO_3 G-E composite

SEM (Scanning Electron Microscope) analysis

SEM uses a focused beam which is made to focus on the specimen to generate a signal at the specimen surfaces. The test helps in getting information from the sample concentrated on selected point locations. In most cases the data is collected by focusing

on selected area of surface of the sample and the image generated reveals the information which includes texture, material orientation and chemical characterization. In the present work, SEM analysis is performed to determine the surface texture of fibre and the reason for failure of the samples under different loading conditions.

1. Impact test:

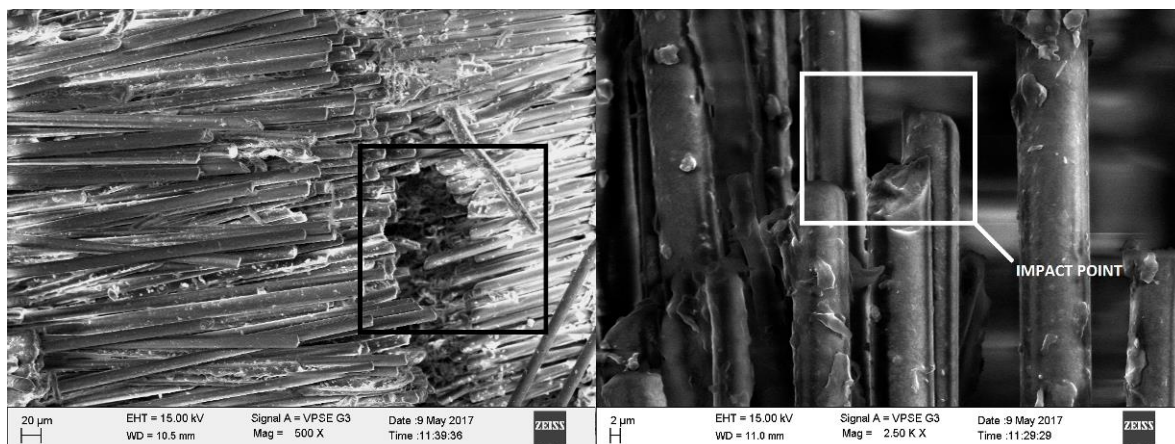


Fig 12. SEM images of 2.5wt% and 5wt% CaCO_3 impact test specimen

2. Tensile Test:

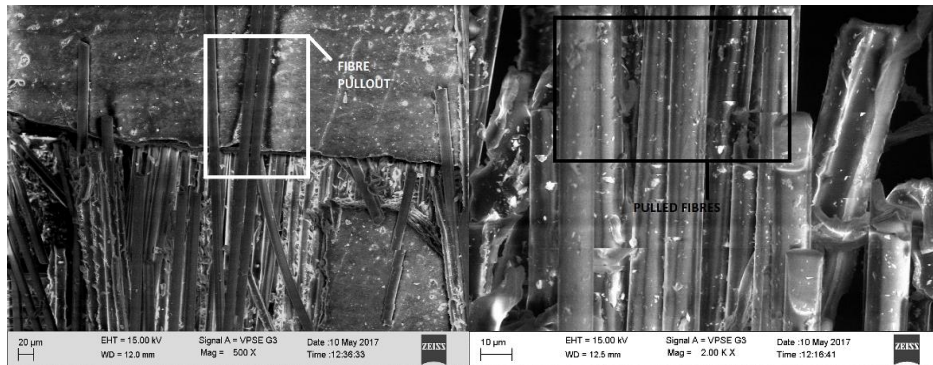


Fig 13.SEM images of 2.5wt% and 5wt% CaCO_3 tensile test specimen

3. Flexural Test:

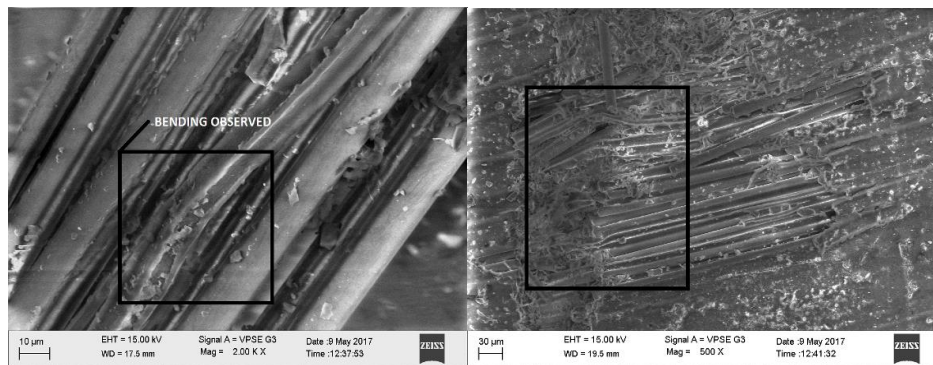


Fig 14.SEM images of 2.5wt% and 5wt% CaCO_3 flexural test specimen

3. Fracture Test:

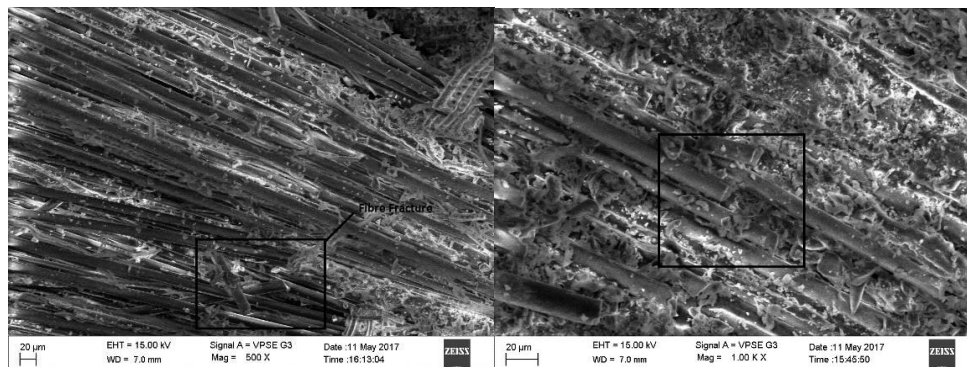


Fig 15.SEM images of 2.5wt% and 5wt% CaCO_3 fracture test specimen

CONCLUSION

E-glass epoxy composites with varying percentage of CaCO_3 filler were successfully fabricated. Fracture toughness, tensile, flexural and impact features of CaCO_3 E-glass epoxy composites were noted. The fracture toughness of the samples was positively confirmed by ANSYS. Finally, the SEM images were obtained to determine the nature of failure. The following are the significant outcomes observed from the test.

- Addition of CaCO_3 fillers to the E-Glass Epoxy composite reduces the average impact energy when compared to 0wt% composite. This is because, the higher filler loading increases the volume occupied by the filler, thus reducing the matrix.
- The addition of CaCO_3 fillers increases the ultimate tensile strength. It was observed that the peak values of ultimate tensile strength were obtained at a filler percentage of 5wt% of CaCO_3 . This can be attributed to the better interfacial properties of the nano sized filler particles at higher filler percentage (5wt%).
- Also, the addition of CaCO_3 increases the flexural strength drastically because the filler concentration increases in the matrix. This leads to more resistance towards bending. It increases around 40-45%.
- Increase in the temperature at 50°C , CaCO_3 at 5 wt% increases the stress intensity factor compared to CaCO_3 at room temperature. However, the stress intensity factor decreases for 0wt% and 2.5wt% filler composite. This is because of the fact that there is a reduction of matrix in 5wt% filler composite, thus making the filler particles more excited at 50°C . Also, better interfacial properties lead to this observation.
- The minor difference in the stress intensity factor values between the experiment and ANSYS can be accounted for varying environmental conditions, human reading errors and mechanical equipment errors.
- From SEM micrographs, fibre fracture, fibre bending, fibre pull out and impact point was observed in the composites. A de-bonding between fibre and matrix was also observed.

Scope for future study

In the project we have studied various mechanical properties of the composite materials. Various tests like fracture toughness test, tensile test, flexural test and impact test were conducted. SEM test was done to analyse the micro structure of the composite materials.

We have performed basic test for this set of materials. There is scope for future study for these materials by conducting the above test at various conditions such as varying cross head speed, conducting these tests at varying temperatures, varying the environment etc. Also using different fillers we can differentiate between composites possessing enhanced or decreased mechanical properties. So more test can be conducted to obtain a data base of results of composite obtained from tests and these results can be used for to build materials for various real world applications.

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