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Evaluation and Comparison of Fracture Toughness of Glass Fibre Reinforce Composites

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Abstract

The study of the behaviour of a broken structure or component under service conditions is known as fracture mechanics. Impurities, uneven curing, holes and notches are all sources of fractures. Cracks are common local discontinuities in materials caused by a variety of factors. Such discontinuities cause the structure's rigidity and consequently load bearing capability to deteriorate. It is known that for the crack to propagate, the stress in the locale of the crack tip should reach the critical value. Once stress level is critical, the crack propagates and leads to failure of the structure. A segment of the crack is divided into three modes namely Mode 1 (opening mode), Mode 2 (sliding mode), Mode 3 (tearing mode). The current study presents a computational and experimental study on fractography and notch sensitivity evaluation in glass-fiber-reinforced-laminate under quasi-static load. For both numerical and experimental damage assessments, three volume fractions of glass and resin plies (50/50, 60/40, and 70/30) have been used. The fracture toughness investigation was carried out in accordance with ASTM standards, utilising a universal testing equipment. The numerical study is conducted out using the J-integral approach. The fracture toughness increases with resin content and is determined by the ductility of the plastic zone surrounding the crack tip. Within an acceptable range, the numerical findings are equivalent to the experimental values. When compared to the other modes, Mode 1 is the fatal. The mode 2 fracture toughness of several materials is evaluated experimentally and compared in this study.

Keywords: *Factors, Fracture Toughness, Reinforce Composites, Cracks, Numerical Findings, Delamination Test, Microstructure.*

1.0 Introduction

Delamination in laminates is about the separation of two adjoining layers. It has evolved into the most dangerous failure in composite laminates because it divides the layers. The primary cause of delamination in composite laminates is the interlaminar stresses produced by fractures in the material or component. The ability of a material to withstand the brittle form of fracture when a crack is present is what is meant by the term "fracture toughness". K or G represents the fracture toughness. A component's crack front is often a line with variable degrees of curvature. As a result, from one place on the crack front to the next, the state of stress in the area of the crack front varies. Three modes, such as mode 1, mode 2, and mode 3, might be used to describe a section of the crack front.

Opening mode is mode 1, shearing mode is mode 2, and a hybrid mode of modes 1 and 2 are mode 3. The displacement in mode 1 is parallel to the fracture front, the displacement in mode 2 is in the plane of a plate, and the displacement in mode 3 is normal to the crack surface. Through relative tangential displacement normal to the fracture front, the

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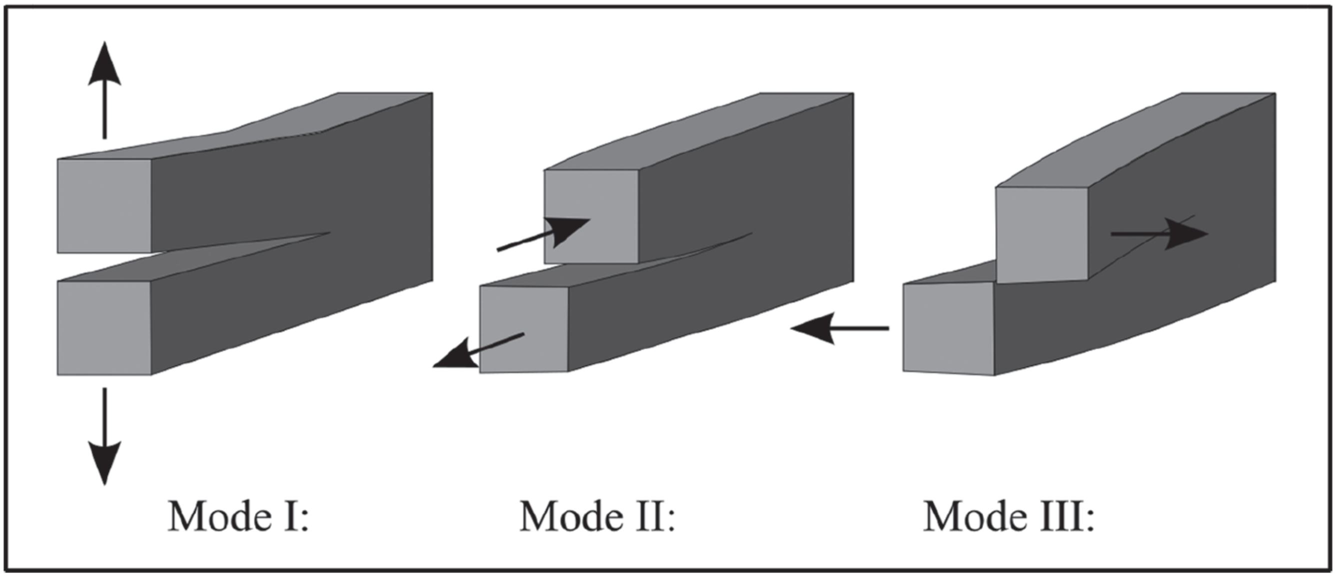

Figure 1

separation in mode 2 is anti-symmetric. In many engineering applications, mode 1 generally dominates. However, in some situations, the component fails due to the involvement of modes 2 and 3. Mode 1 fracture toughness may be evaluated using a variety of experimental techniques, and it is also the mode that has been investigated the most. Modes 2 and 3 fracture toughness experimental methodologies are still being developed.

2.0 Mode 2 Delamination Test

Sliding mode or in-plane shear mode of delamination is what mode 2 delamination has always been about. This mode is less often than mode 1 in comparison. To determine mode 2 fracture toughness G_{IIC}., two different types of tests – the end notch flexure test (ENF) and the end-loaded split beam test – are used. Figures 2 and 3 displays the conventional ENF specimen and end-loaded split beam specimens respectively.

The glass/epoxy laminate was used for the experiments on fracture toughness. 1mm/min was the constant speed used during the experiment. The mode 2 interlaminar fracture toughness is estimated using the corrected beam theory as shown below, and the results are shown in the accompanying plots of load v/s length and stress v/s strain.

$$G_{IIC} = \frac{9}{2B} \frac{P_c \delta_c a^2}{(2L^3 + 3a^3)}$$

Where, P_c – Critical load

δ_c – Critical displacement

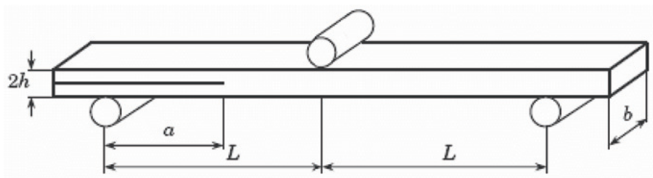

Figure 2: End Notched flexure specimen

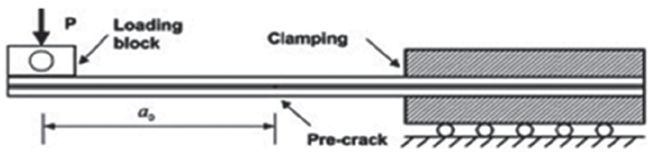

Figure 3: End loaded split beam specimen

a – Initial delamination length

L – Half of the span length

B – Specimen width

Fracture toughness of Glass fiber composites:

The load v/s length of the specimen GFRP 50:50 is plotted in Fig.4, where load is plotted on the Y-axis and displacement is plotted on the X-axis. Displacement is measured in millimetres and load is measured in Newtons (N). The specimen has a max load of 622.17N, as can be seen. Calculated Mode 2 fracture toughness is equal to 4.82KJ/m^2.

The GFRP specimen's stress v/s strain is plotted in Figure 5 at a 50:50 ratio. Calculated flexural strength for this specimen is 414.78 MPa.

The load v/s length plot is shown in Fig.6. The specimen

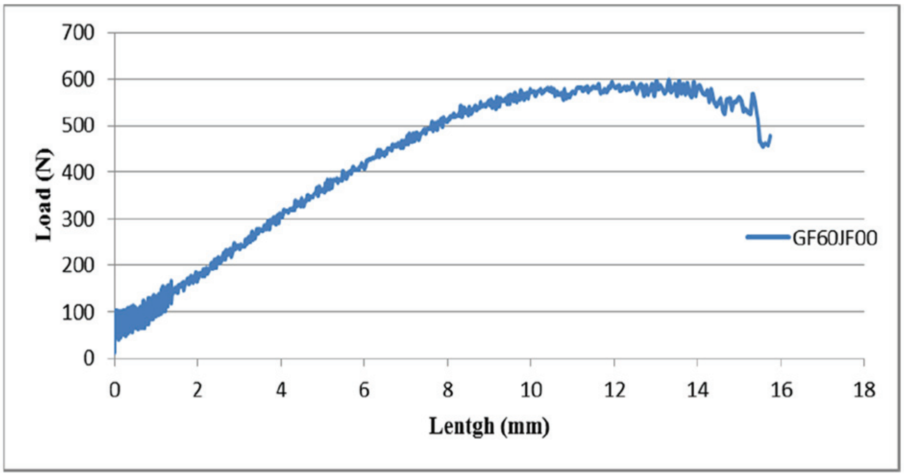

Figure 4: Load v/s Length plot (GFRP 50:50)

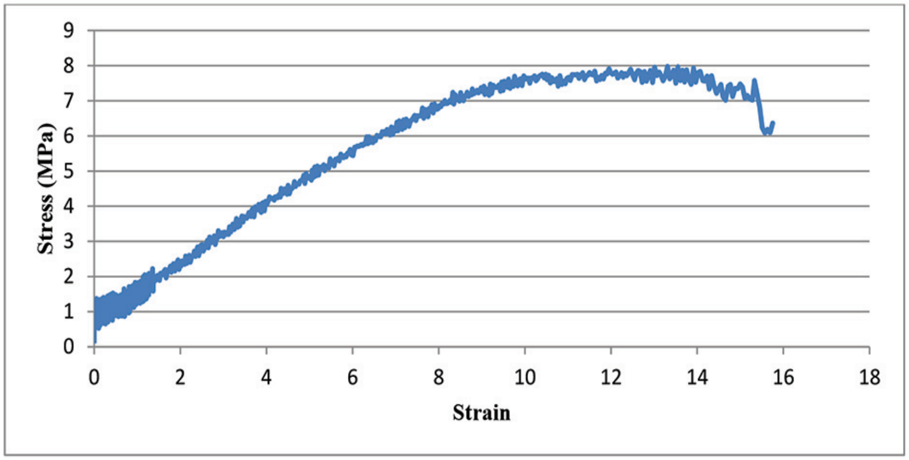

Figure 5: Stress v/s Strain plot (GFRP 50:50)

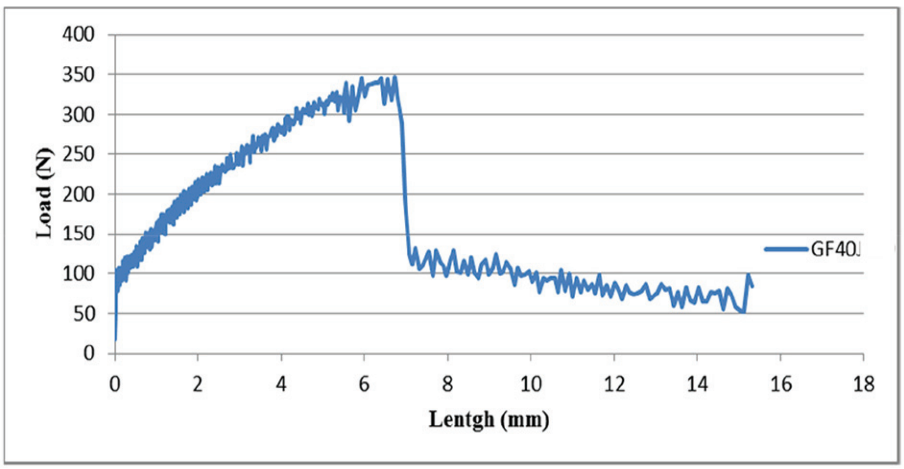

Figure 6: Load v/s Length plot (GFRP 60:40)

can withstand a maximum weight of 352N. Additionally, mode 2 fracture toughness is determined and is 3.02KJ/m^2.

The specimen GFRP 60:40's stress vs. strain is plotted in Fig.7. This specimen's determined flexural strength is equal to 234.66MPa.

The specimen GFRP 70:30's load v/s length plot is shown in Fig.8. The specimen can withstand a peak load of 313N. And after calculation, mode 2 fracture toughness is determined to be 2.04 KJ/m^2.

The specimen GFRP 70:30's stress vs. strain is plotted in Fig.9. Calculated flexural strength for this specimen is 208.66 MPa.

3.0 Comparison of responses for various specimens

According to Fig.10, the load rises sharply as displacement increases. The peak load for a composite made of glass fibres is 622.17 N, while a composite made of resins has a peak load of only 202 N. The load carrying capability of the hybrid composition of 60% glass fibre and 40% resin fibre (352 N) is more than that of the resin composite and the hybrid composition of 65% glass fibre and 35% resin (313 N).

The stress v/strain data provided in Fig.11 was used to compute the flexural strengths of each specimen. The composite 65:35 has the least flexural strength, whereas the glass fibre composite 50:50 has the strongest (414.78 MPa) (134.66 MPa). Better than e-fiber composite and hybrid composite with a composition of 70:30 is the composite material's flexural strength (234.66 MPa) (208.66 MPa).

It is clear from Table 1 that the composite made with 50% glass fibre has the maximum fracture toughness rating.

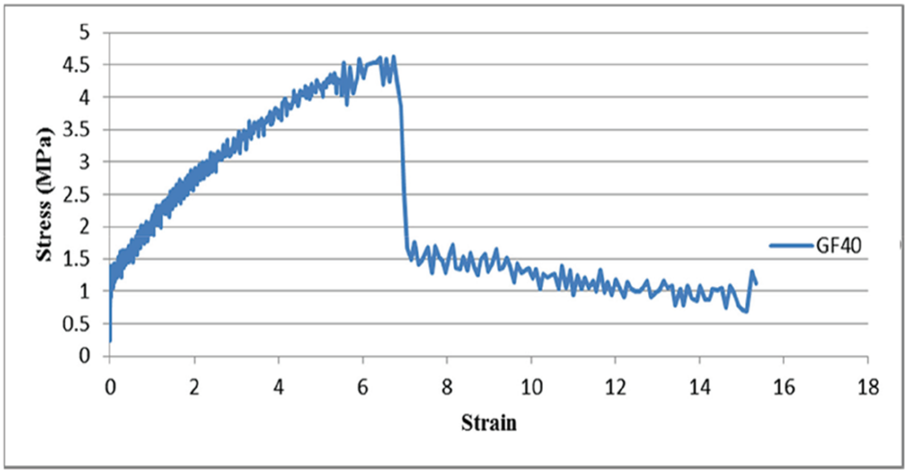

Figure 7: Stress v/s Strain plot (GFRP 60:40)

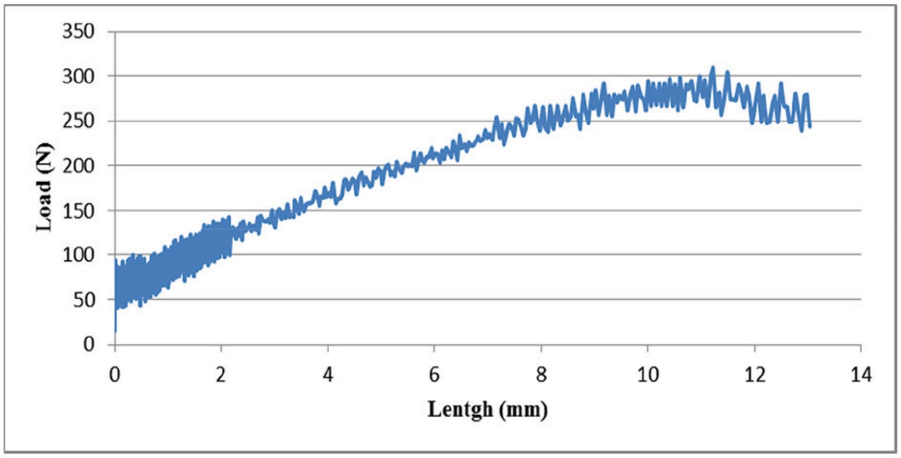

Figure 8: Load v/s Length plot (GFRP 70:30)

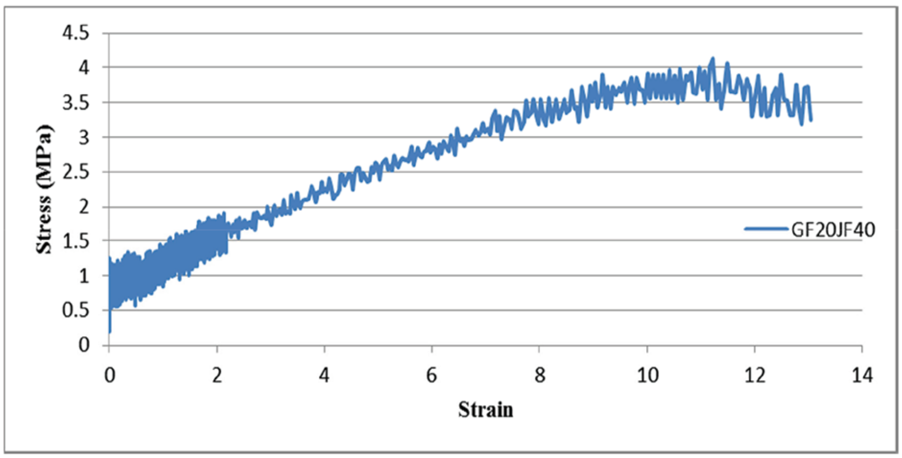

Figure 9: Stress v/s Strain plot (GFRP 70:30)

4.0 Microstructure analysis

The tensile fracture surfaces of epoxy/glass composites and notched epoxy/glass composites, respectively, are shown in Figs. 12(a) and (12(b-c)). Because fracture initiation is delayed and interfacial strength is stronger, unnotched composites exhibit reduced fibre pull-out (Fig. 12(a)). Because of early damage and decreased interfacial strength, the notched composites demonstrated substantial fibre breakage. Figure 12 shows that the resin-fibre linkages have broken and resin lumps are now amorphous (b-d).

5.0 Conclusion

In the present research, GFRP was fabricated with different compositions. Each type of specimen is subjected to end notch flexure tests in order to obtain mode-2 fracture toughness. Results such as Mode 2 fracture toughness (and f+lexural strength were calculated for each specimen.

From the results obtained, the following conclusions are made:

- It is found that 50:50 glass fiber composite shows highest fracture toughness (4.82KJ/m^2) than other composition.
- Composites containing 60:40 and 70:30 glass fiber shows nearer values to that of the 50:50 glass fiber composite.
- Glass fiber has the better load carrying capacity when compared to the resin and hence the strength of the composite improves with increase in the glass fiber content. Thus, we can improve the fracture property of the composite by increasing the glass fiber content.

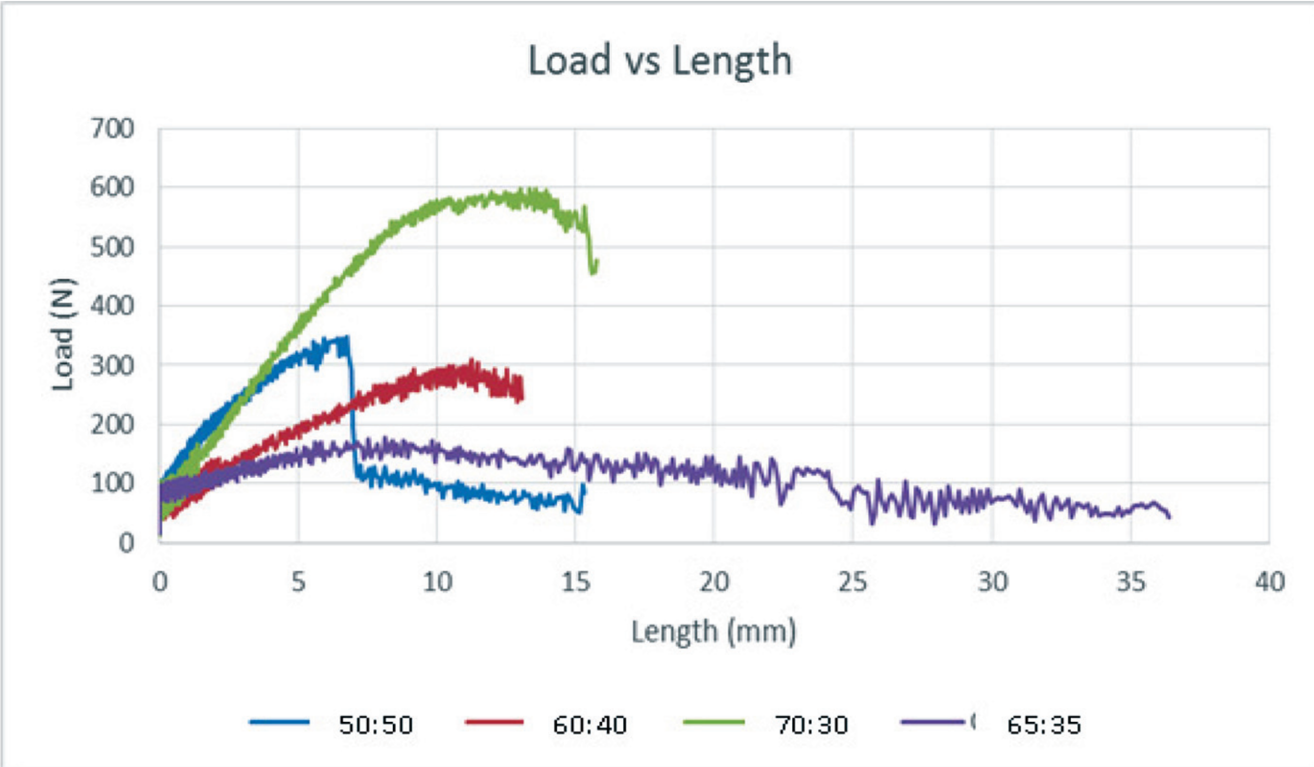

Figure 10: Load v/s Length plot for different ratio

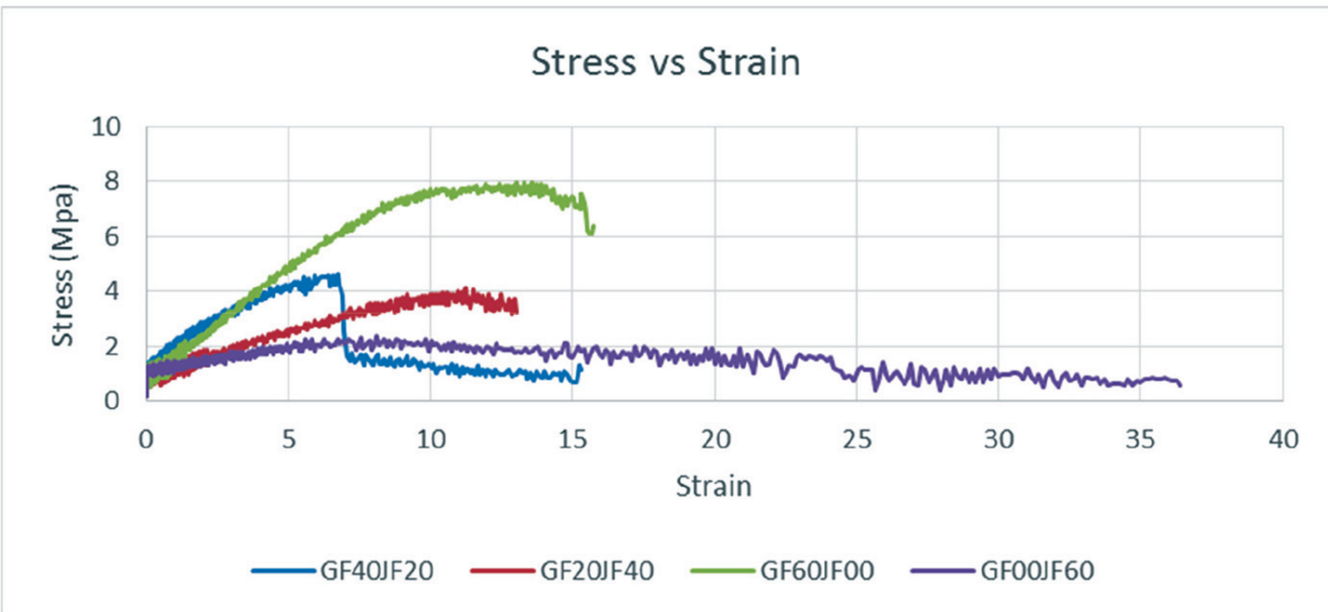

Figure 11: Stress v/s Strain plot for different ratio

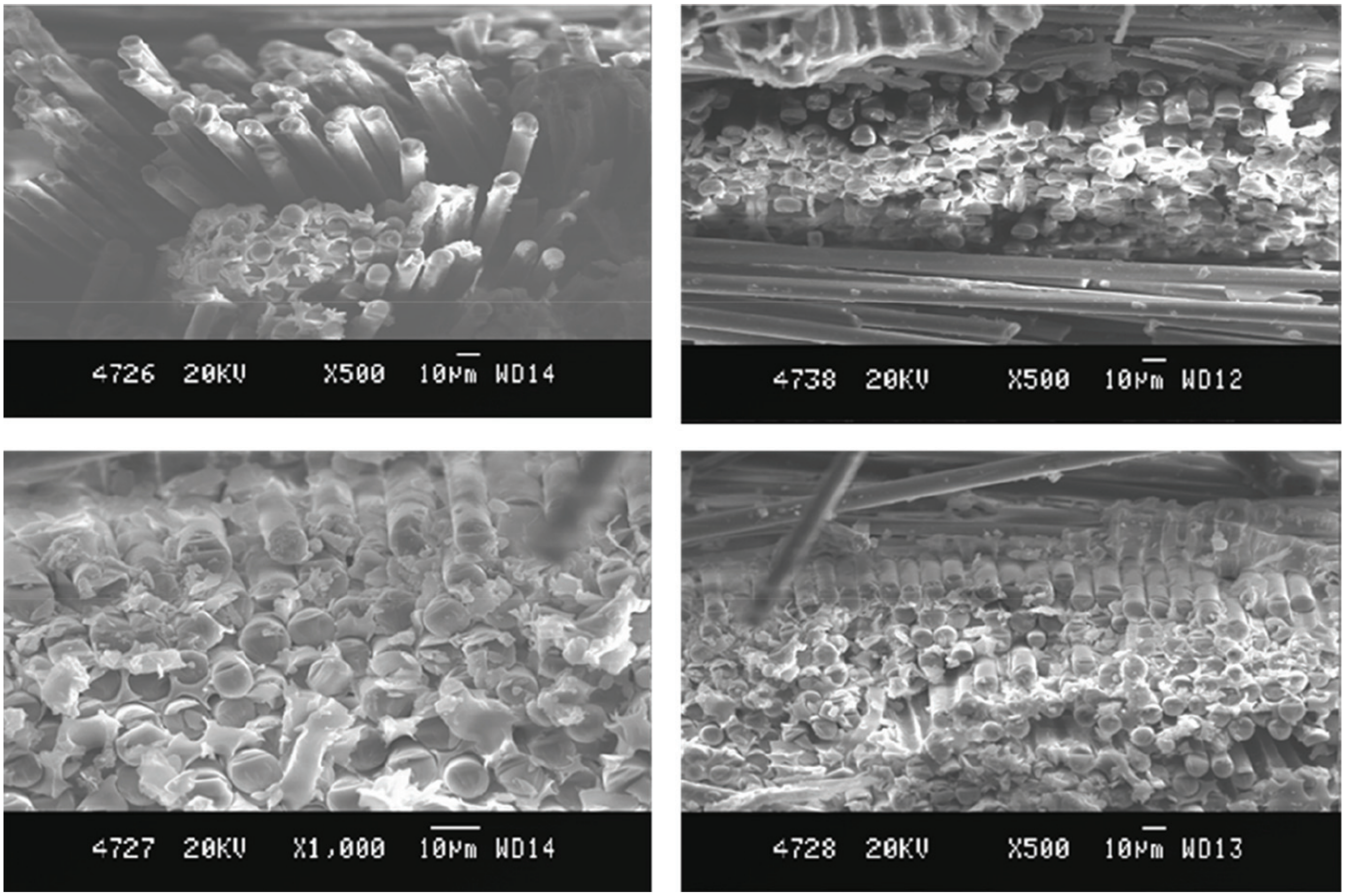

Figure 12: Fracture surfaces of laminates made of epoxy and glass

Table 1: Materials' flexural strength and fracture resistance

Sl. No	Material	Peak Load (N)	Mode II Fracture toughness G_{II} ($\frac{KJ}{m^2}$)	Flexural strength (MPa)
01	GFRP 50:50	622.17	4.82	414.78
02	GFRP 60:40	352	3.02	234.66
03	GFRP 70:30	313	2.04	208.66
04	GFRP 65:35	202	1.02	134.66

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