International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. XI, No. 2 / 2019

BEHAVIOUR OF GLASS FIBER-REINFORCED COMPOSITE WITH DELAMINATION UNDER IOSIPESCU SHEAR TEST

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Abstract: In recent times, polymer composites have become important engineering materials due to their multifunctional properties like high strength to weight ratio, high stiffness, and low thermal expansion. Polymer composites provide flexibility to the designer to tailor the properties using different types of fibers and matrices. In the present study, glass/epoxy composites have been fabricated to study their shear behaviour using Iosipescu shear test fixture. The study includes manufacturing of four types of glass/epoxy composites, one without delamination and other three with different delamination geometry such as circular, square, and rectangular. The strain developed in the composite specimen during shear testing was also measured using strain gauges and Wheatstone bridge circuit. The results showed that the specimen having circular delamination possesses lowest shear stress and strain.

Key words: Glass fiber, epoxy, delamination, Iosipescu shear test, strain gauge, Wheatstone bridge.

1. INTRODUCTION

A composite material is generally defined as a combination of two or more materials in different proportions to achieve the required properties that are better than those possessed by the individual materials. Thus a composite material possesses superior properties like high strength to weight ratio, high tensile strength, and low thermal expansion. Polymer matrix composites (PMCs) have found application in various fields due to their adequate strength, light-weight, toughness, and low-cost compared to conventional metals and alloys. Fiber reinforced polymer composites are widely used in structural materials because they provide more resistance to chemical attacks as compared to metals and ceramics (Florea, 2012). PMCs can be categorized according to the different reinforcing material such as glass fiber reinforced plastics, carbon fiber reinforced plastics, and Kevlar fiber reinforced plastics. Glass fibers possess very good properties like high strength, stiffness, flexibility, and resistance to chemical reactions (Sathishkumar et al., 2014). Glass fiber reinforced polymer composites are extensively used in automotive, construction, sports, marine, home appliances, and electrical industries (Chavan and Gaikwad, 2016; Vinay et al., 2015). Another new category of composite materials that is finding extensive applications in the field of aerospace structures is the fiber-metal laminates (FML). Glass reinforced aluminium (GLARE) is one of such FML. GLARE is generally a stack of aluminium sheets which are bonded with unidirectional glass fiber reinforced epoxy prepregs (Guocai and Yang, 2005). The mechanical behaviour of composites was investigated where glass fiber in the form of woven mat and chopped strand mat were considered under different loading conditions (Bhaskar and Srinivas, 2017). The study showed that mechanical properties of the composites based on chopped strand mat glass fiber are better than the woven mat glass fiber. The chopped strand mat glass fiber composite was further studied by varying the glass fiber content and performing the mechanical tests which showed the advantage of using higher proportion of glass fiber (Mathapati and Mathapati, 2015). The experimental results of delamination fracture toughness were studied for glass/epoxy composites developed by compression resin transfer moulding and conventional resin transfer moulding process (Treber et al., 2017). The results indicated that the fracture behaviour is significantly influenced by the fabric structure. The influence of delamination during drilling of a glass/epoxy composite was studied and a new delamination factor was proposed (Nagarajan et al., 2013). The bending, compression, and shear behaviour of stitched woven glass fiber reinforced epoxy composites fabricated by resin transfer moulding was studied (Yang et al., 2000). The shear test was done by short beam and grooved coupon test approaches for different patterns of stitching. It was concluded that the better resistance from delamination for increasing density of fiber stitching was in z-direction. The effect on shear behaviour due to four different fiber orientations was observed with four different types of test methods (Almeida Jr. et al., 2015). The 0^0 fiber orientation showed better shear strength as compared to the 90^0 fiber orientation. The double-notched and v-notched test methods were found to be more useful for determining the shear strength of the material. Investigation for determining the influence of adding carbon nanotubes in glass/epoxy composites by performing the single fiber push-out test was done (Godara et al., 2010). The results showed better interfacial shear strength when carbon nanotubes were introduced as an additional reinforcement in glass/epoxy composites.

From the literature, it is evident that the shear behaviour for different shapes of delamination in the context of glass/epoxy composite has not been investigated. In this paper, the shear behaviour of glass/epoxy composite has been carried out using Iosipescu test fixture for circular, square, and rectangular delamination and then compared with a delamination free specimen. Also, the local strain developed during shear loading was measured using strain gauge and Wheatstone bridge.

2. EXPERIMENTATION

2.1 Selection of materials

E-glass fiber in the form of woven mat and epoxy resin (Araldite AW106) was used as reinforcing and matrix material to develop the composite laminates. The range of curing temperature for chosen epoxy resin is around 20^o to 150^oC and that of minimum curing time is 15 hours to 5 minutes, respectively. The epoxy AW106 and hardener HV953 was mixed in a ratio of 1:1. The mixture of AW106 and HV953 do not release any volatile constituents and gives good resistance to static and dynamic loads. Figure 1 shows the glass fiber mat and the mixture of epoxy and hardener used for fabricating the glass/epoxy composite laminates.


(a) (b)

Fig. 1. (a) Woven glass fiber mat, and (b) Epoxy/hardener mixture

2.2 Fabrication of glass/epoxy composites

2.2.1 Fabrication of composite specimen without delamination

A mild steel mould having flat surface of 200mm×200mm has been prepared for fabricating the composite laminates. The composite was fabricated on the lower part of the mould and then covered by the upper part of the mould to apply pressure. A transparent sheet was placed over the surface of the mould to prevent any contact of the resin mixture with the mould surface. The Araldite AW106 resin and Araldite HV953 hardener were mixed in a ratio of 1:1 and stirred until the mixture becomes uniform. The resin mixture was then applied on the transparent sheet placed over the mould plate and spread evenly using a brush. The fiber mat is then cut to desired shape and placed over the resin layer. A uniform pressure was applied over the fiber mat using a roller. This helps in proper adhesion between the glass fiber mat and resin without leaving any air bubbles or voids. The resin mixture was applied again over the glass fiber mat and the process is repeated till the required thickness of the composite is achieved. Another transparent sheet was used to cover the top layer before applying continuous pressure with the help of upper part of the mould. The mould was left for curing for about 24 hours under room temperature. Then the upper mould was removed and the final glass/epoxy composite was taken out by peeling off the transparent sheets attached on both side of the laminate. A glass/epoxy composite specimen having 16 layers of glass fiber mat and total thickness of 3.6mm was manufactured by this process. The flowchart for the manufacturing process of glass/epoxy composites is shown in Figure 2. The steps involved in fabricating glass/epoxy composites are illustrated in Figure 3.

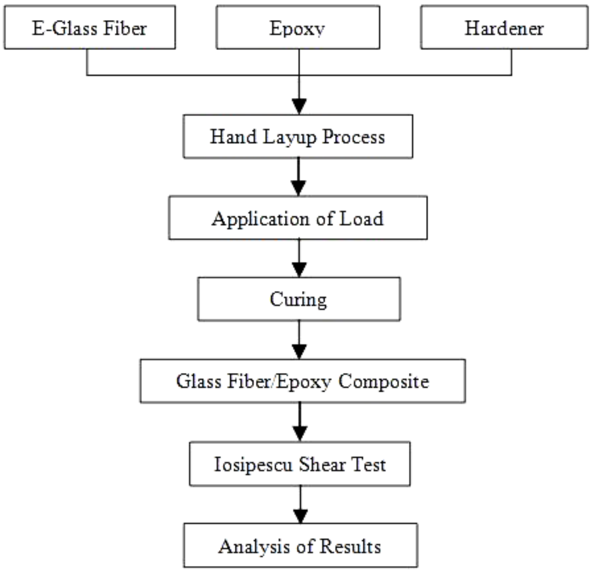


Fig. 2. Flowchart for manufacturing of glass/epoxy composites

2.2.2 Fabrication of composite specimen with delamination

Teflon tape cut into the required shape and dimension was introduced at the middle i.e., after the eighth layer of glass fiber mat to create the delamination in composites. Teflon tape does not allow adhesion between the eighth and ninth layer of glass fiber and thus create a delamination in the final specimen. The cured glass/epoxy composite was taken out of the mould and cut in the form of a double-edged notched specimen as recommended (Odegard and Kumosa, 2000) for performing the Iosipescu shear test. The dimensions of the specimen according to ASTM D5379-93 standard are: length of 78mm, width of 20mm, thickness of 3.6mm, notch angle of 90° and notch depth of 4.4 mm. Figure 4 shows the schematic of the four shear test specimens prepared as per ASTM D5379-93 standard. The final glass/epoxy composite specimens ready for undergoing shear test are shown in Figure 5.

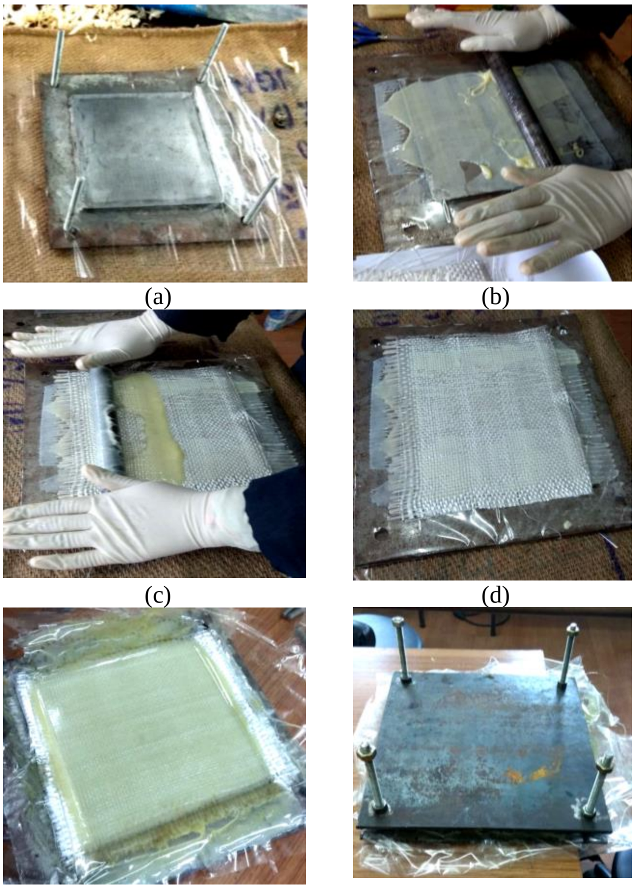
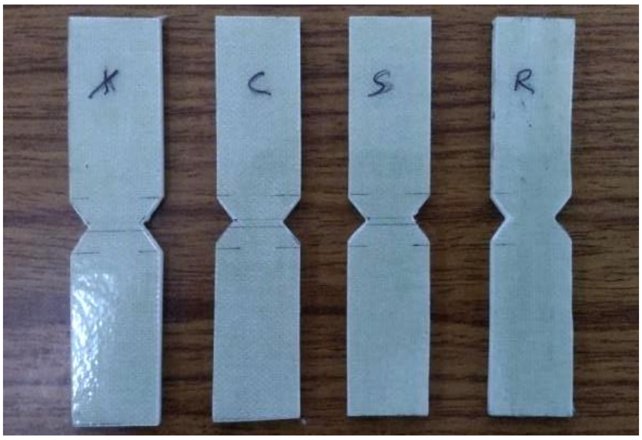

(a) (b) (c) (d) (e) (f)

Fig. 3. Fabrication of glass/epoxy composites



(a) (b) (c) (d)

Fig. 5. Shear test specimens (a) without delamination, with (b) circular delamination, (c) square delamination, and (d) rectangular delamination

2.3 Experimental setup

The experimental setup that was used for carrying out the Iosipescu shear test comprises of an ultimate testing machine (shown in Figure 6) and a Wyoming Iosipescu shear test fixture (shown in Figure 7) fabricated in-house. Iosipescu shear test has been developed by Iosipescu in 1967. The test consists of a double-edged notched specimen subjected to two opposing force couples. This is considered as a type of four point load test for determining the interlaminar shear strength of the composite specimen. By considering a notch angle of 90° and notch depth of 22% of the width, a constant shear stress can be obtained (Iosipescu, 1967). In case of fiber reinforced composite, there is a stress concentration near the notch tip which is dependent on fiber volume fraction and fiber orientation. Additionally, the strain developed in the composite specimen was determined using strain gauges connected to a Wheatstone bridge circuit. The Wheatstone bridge circuit includes a 5 V DC power supply, two 100Ω resistances, two strain gauges (glued to the specimen surface) and a digital storage oscilloscope (DSO), as shown in Figure 8.

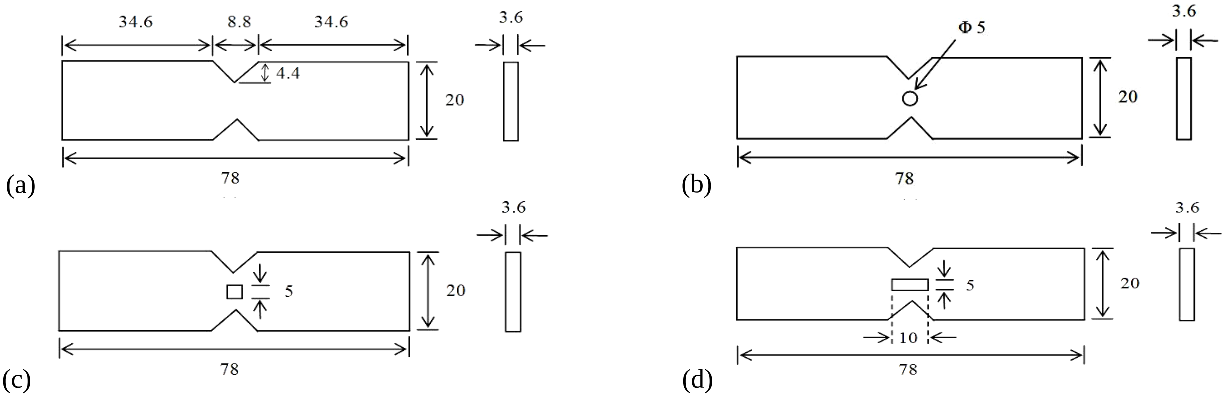


Fig. 4. Schematic of shear test specimens: (a) without delamination; (b) with circular delamination; (c) square delamination; (d) rectangular delamination

Fig. 6. Universal testing machine

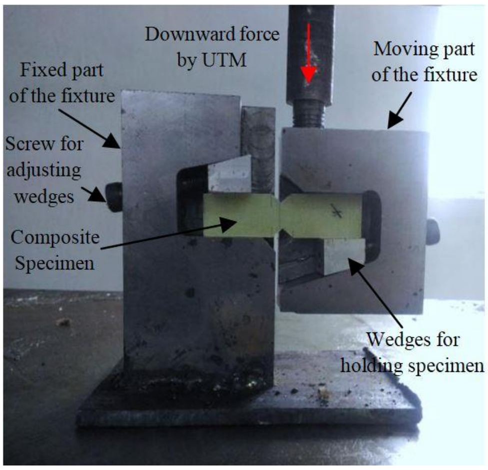


Fig. 7. Iosipescu shear test fixture

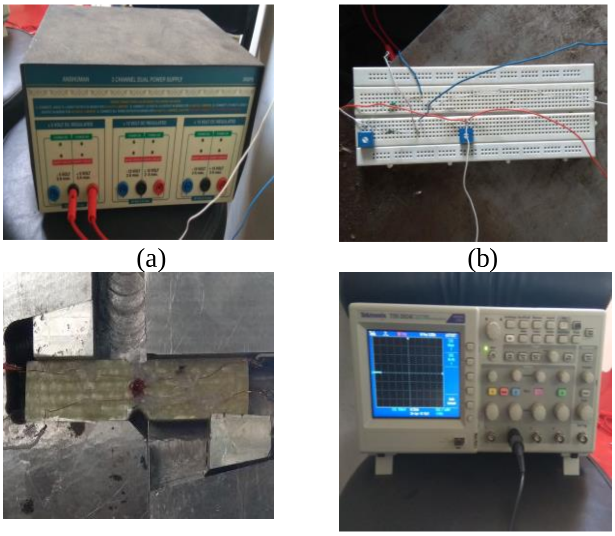

(a) (b) (c) (d)

Fig. 8. Strain measurement system: (a) Power supply unit; (b) Wheatstone bridge circuit; (c) Strain gauges glued to specimen; (d) Digital storage oscilloscope

2.4 Determination of local shear strain using strain gauge

The strain generated in the composite specimen during Iosipescu shear test can be determined by using strain gauge. The strain gauges are glued to the composite specimen at the location where the local strain needs to be measured. In this case, the strain gauges are glued at the centre of the specimen surface between the two v-notches, as shown in Figure 9(a). In order to measure the strain, the strain gauges are connected to a Wheatstone bridge circuit having a continuous 5 V DC power supply, resistances, potentiometer, and an oscilloscope, as shown in Figure 9(b). Wheatstone bridge is said to be balanced and there will be no voltage output if the ratio of resistances at one side of the bridge is equal to the other side of the bridge. In practical, the output voltage is not equal to zero as the resistances used are not always equal to their mentioned ratings. Therefore, a potentiometer was used with the circuit to vary the resistance at one side of the bridge to get a zero output voltage. The strain gauge experiences a load and changes its resistance due to elongation or compression of the strain gauge as the load is applied to the specimen. This leads to an unbalanced Wheatstone bridge, as it shows some value of output voltage. The equation used to calculate the strain generated in the composite specimen is the ratio of output voltage to the input voltage. Single strain gauge is not enough to measure the shear and torsional strain as it can measure strain only in one single direction. The half bridge (two strain gauges) or full bridge (four strain gauges) configuration of the Wheatstone bridge is used to measure the shear strain. In the present work, a half bridge configuration of the Wheatstone bridge was used where two strain gauges at one side and two resistances on the other side of the Wheatstone bridge are connected, as shown in Figure 9(b). The two strain gauges are placed between the v-notches making a +45^{o} and -45^{o} angle with the longitudinal axis of the test specimen. The ratio of the resistances before applying the load is given by equation (1):

$$\frac{R_1}{R_2}=\frac{R_3}{R_4}=\frac{R_{G1}}{R_{G2}}=1 \qquad (1)$$

Here, R_1 and R_2 are the resistances at the left side of the bridge, R_3 and R_4 are the resistances at the right side of the bridge. The R_3 and R_4 resistances are replaced by two strain gauges R_{G1} and R_{G2}. The resistances used for the half bridge circuit are $R_1 = R_2 = 100\Omega$ and $R_{G1} = R_{G2} = 120\Omega$. The Gauge factor (GF) for the strain gauges used is 2.1. The output voltage for the Wheatstone bridge can be calculated by the relation (2):

$$V_{out}=V_{in}\left[\frac{R_{G2}}{R_{G1}+R_{G2}}-\frac{R_2}{R_1+R_2}\right] \qquad (2)$$

When the bridge is balanced, equation (2) reduces to:

$$\frac{R_{G2}}{R_{G1}+R_{G2}}=\frac{R_2}{R_1+R_2} \qquad (3)$$

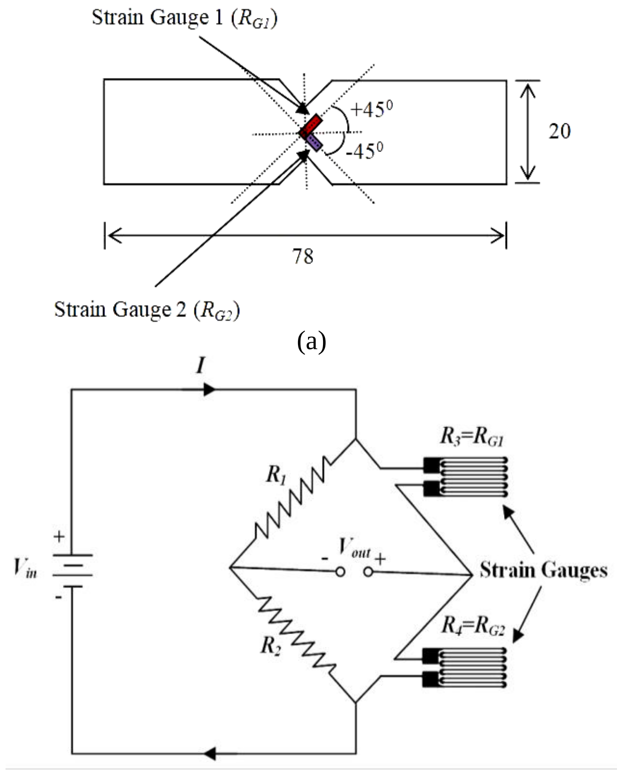
The resistance of the strain gauges change due to expansion and compression as the load is applied during the test. Therefore, equation (2) becomes:

$$V_{out}=V_{in}\left[\frac{R_{G2}+\Delta R_{G2}}{\left(R_{G1}+\Delta R_{G1}\right)+\left(R_{G2}+\Delta R_{G2}\right)}-\frac{R_2}{R_1+R_2}\right] (4)$$

The value of ΔR can be positive or negative depending on whether the resistance is experiencing expansion or compression. The change in resistance, ΔR due to the strain is given by the equation (5):

$$\Delta R = R_G \times G.F. \times \varepsilon \qquad (5)$$

Where, *G.F.* is the gauge factor, and *ε* is the induced strain. The maximum strain generated in the specimen can be calculated by substituting the voltages, resistances, and the gauge factor in equation (4).



(a)

(b)

Fig. 9. Strain measurement: (a) Arrangement of strain gauges on test specimen; (b) Wheatstone bridge circuit

3. RESULTS AND DISCUSSIONS

The properties of glass/epoxy composites depend on its composition, orientation of the fibers, and the number of fiber layers used. In the present work, 16 layers of woven glass fiber mats were used to bond with the epoxy resin. The properties of the composites also depend on the bonding strength between the glass fiber and epoxy resin. Thus, the shear properties of glass/epoxy composites (with and without delamination) were evaluated using Iosipescu shear test fixture. Table 1 shows the maximum load and maximum shear stress measured for two sets of specimen. The fractured specimens after performing the Iosipescu shear test are shown in Figure 10.

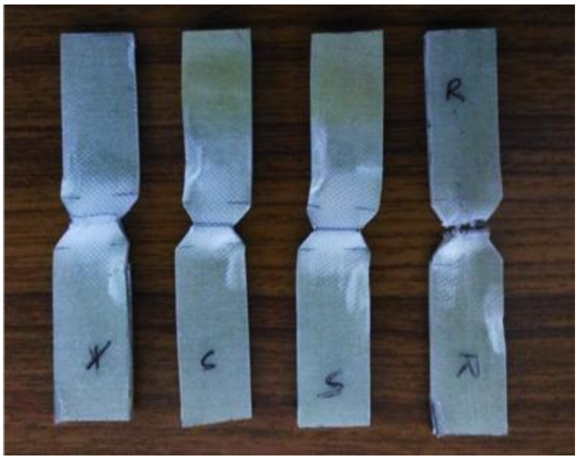
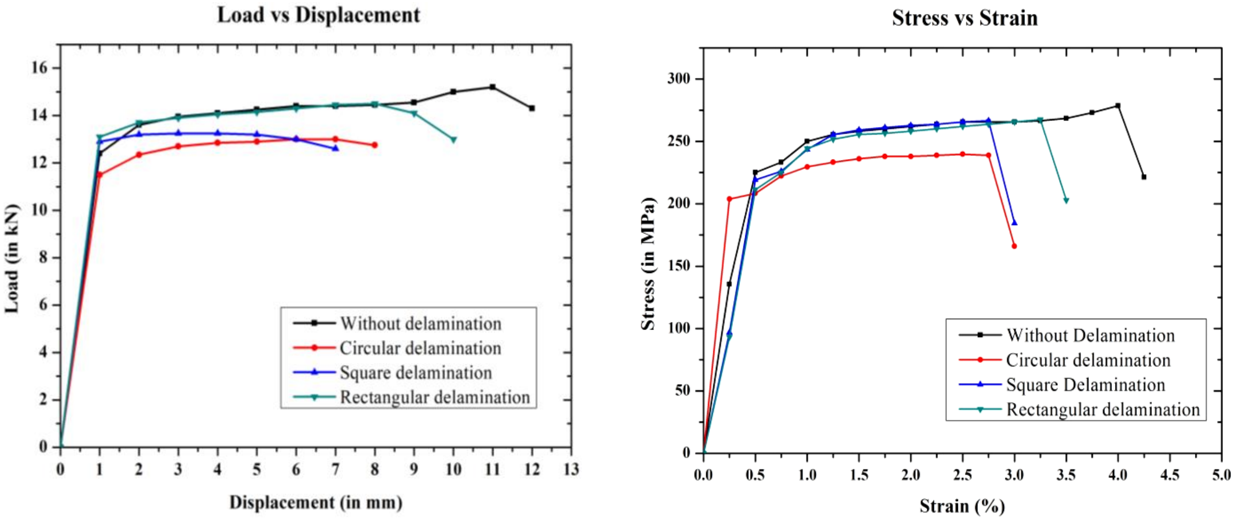


Fig. 10. Fractured test specimens after performing Iosipescu shear test

The shear test on the glass/epoxy composite specimen with double edge notch shows that a maximum load of 14.75kN is obtained for a displacement of 12mm for the specimen without delamination, as shown in Figure 11(a). Figure 11(b) shows that the maximum shear stress for the developed glass/epoxy composites without delamination is around 272.06MPa. The specimen breaks as the maximum shear stress is reached during testing. The results obtained for the glass/epoxy composite with different shapes of delamination namely circular, square, and rectangular are also illustrated in Figure 11. From this figure, it can be observed that the maximum load (13.48kN) that can be sustained is much lower in case of circular delamination followed by rectangular delamination (13.50kN) and square delamination (13.88kN), respectively. Similarly, the stress versus strain plot shows a same trend where the maximum shear stress for circular delamination (248.54MPa) was found to be lower than that of the square delamination (255.92MPa) and rectangular delamination (249.01MPa). If a GFRP specimen with elliptical delamination was to be considered in the study, the maximum shear stress would depend on the orientation of the elliptical delamination with respect to the specimen centreline. Figure 12 shows elliptical delamination with the cases of +45° and -45° orientation from the specimen centerline. When the delamination is at -45° with the centre line, as illustrated in Figure 12(a), the delamination edge experiences a longitudinal stress along its major axis. This lead to the growth of delamination edges, to form an ellipse with very large major axis and much smaller minor axis. This may result in a catastrophic failure of the specimen due to very high rate of delamination edge propagation. On the other hand, the elliptical delamination with +45° orientation will experience a transverse stress as shown in Figure 12(b). The elliptical delamination in this case, tends to grow along its minor axis and start imitating the case of a circular delamination. Thus, it can be concluded from the present experimental investigation that the glass/epoxy composite with circular delamination is more prone to damage and crack growth as compared to square and rectangular delamination under shear loading. The local strain developed between the two v-notches of the composite specimen is obtained by using strain gauges. The shear strain measured by using strain gauges connected to a Wheatstone bridge circuit is shown in Table 2. The maximum shear strain for both the specimen sets were calculated using equation (4) and equation (5). The average value of the two shear strains is compared with the shear strain obtained from the UTM. It was observed that the average value of the maximum shear strain obtained from strain gauges are approximately equal to the value obtained in the stress versus strain plot. Thus, the shear strain results also show a similar trend like that of the shear stress with the minimum average strain value of 2.49% for circular delamination, followed by square delamination at 2.83%, rectangular delamination at 3.34% and the specimen without delamination having maximum strain of 4.18%.

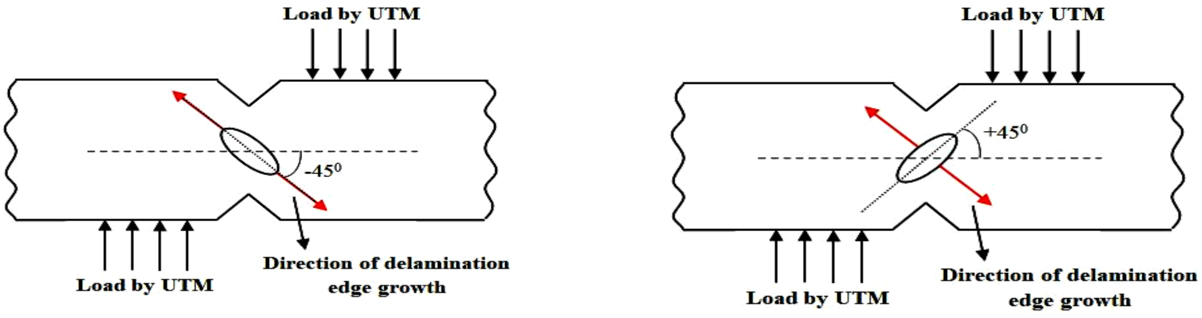
Table 1. Maximum load and maximum shear stress obtained from Iosipescu shear test

Specimen Type	Maximum load (kN)			Maximum shear stress (MPa)		
	Specimen Set 1	Specimen Set 2	Average Value	Specimen Set 1	Specimen Set 2	Average Value
Without delamination	14.25	15.25	14.75	262.84	281.28	272.06
Circular delamination	13.95	13.00	13.48	257.30	239.78	248.54
Square delamination	13.25	14.50	13.88	244.39	267.45	255.92
Rectangular delamination	12.50	14.50	13.50	230.56	267.45	249.01



(a) (b)

Fig. 11. (a) Load versus displacement curve and (b) Stress versus strain curve



(a) (b)

Fig. 12. Elliptical delamination with (a) longitudinal, and (b) transverse growth of delamination edge

Table 2. Maximum shear strain obtained from strain gauge using Wheatstone bridge circuit

Specimen Type	Maximum shear strain (%)		
	Specimen Set 1	Specimen Set 2	Average Value
Without delamination	4.26	4.09	4.18
Circular delamination	2.46	2.52	2.49
Square delamination	2.79	2.87	2.83
Rectangular delamination	3.44	3.23	3.34

4. CONCLUSIONS

In the present study, glass/epoxy composites were manufactured using the hand layup process. A circular, square, and rectangular delamination was created in the composite specimen by introducing Teflon tape in between the glass fiber layers. The Iosipescu shear tests were successfully carried out for all type of specimen viz. with delamination and without delamination in order to study their behaviour under shear loading. The load versus displacement graph was studied and the ultimate shear stress was measured for each test specimen. It was observed that the composite specimen having no delamination has the highest shear strength as compared to the specimens having delamination. The specimen having circular delamination has the lowest shear strength among the different shapes of delamination. This indicates that the circular delamination significantly influence the crack growth and failure of the composite constituents under shear loading. The maximum shear strain of the glass/epoxy composite was also determined using strain gauges connected to Wheatstone bridge circuit. The shear strain results from the strain gauges show minimum strain for the specimen having circular delamination.

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Received: July 13, 2019 / Accepted: December 15, 2019 / Paper available online: December 20, 2019 © International Journal of Modern Manufacturing Technologies