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Experimental Investigation of Repair of Glass Epoxy Composite with Edge and Center Crack by Epoxy Resin

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ABSTRACT

The aerospace and automotive industries widely use composite materials due to their weight-to-strength ratios. One of the most significant problems with composites is repair and maintenance. This study attempts to repair glass epoxy composites. The repair process involves two stages: 1)optimization of the position of the hole and 2) repair work. To optimize the repair techniques, two distinct holes were performed: 1) at the center of the specimen and 2) at the edges of the specimen. As a result, the hole drilled at the center gives higher strength than the hole drilled at the edges. After the optimization, samples were repaired with a single hole in the center and peak loads of 60% and 90%. The cracked and delaminated areas were repaired with epoxy/hardener. The repaired samples were subjected to a three-point bending test, and the results were compared with the Neat GFRP samples. The results show that the curves of the repaired samples aligned with both the post and the residual flexural strength. The residual flexural strength of the 60% and 90% peak-loaded repaired samples retains about 47% and 76%, respectively.

1. Introduction

Many studies have studied the mechanical properties of the glass/epoxy composite[1], [2], and the influence of filler material on its mechanical properties [3], [4],[5] and with the biocomposite materials[6] Some studies involve the impact on the composite material [7], [8], [9], and investigating its energy absorption [10]. Similar studies have also been conducted to compare their residual strength [11]. The limitations of the composite materials are mainly related to maintenance and repair work. Various factors influence the selection of techniques required for the repair of damaged laminates. It is expensive, time-consuming, and difficult to replace structures that are closely connected. Repairing the slightly damaged area of composite laminates can restore their mechanical properties at a low cost [12]. Mechanical fastener repair and adhesively bonded repair are the two most commonly utilized repair techniques for laminated composites [13], [14]. Adhesively bonded repair has several advantages over mechanical fastener repair, including enhanced formability and higher specific mechanical properties. The limits of mechanical fastener repair on fiber-reinforced polymer (FRP) laminates limit their use in a variety of applications [15]. However, [16] investigates the

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deterioration behavior of glass fiber epoxy composites repaired using patches embedded with ZnO whiskers. The strong bonding between ZnO whiskers and resin matrix increases load at failure and matrix strength, improving stiffness and deformation resistance. It was also found that the addition of ZnO whiskers can also increase patch strength. [17] Surface treatments and bonding chemicals affect shear bond strength, with higher values requiring green carborundum stone or sandblasting and lower values requiring hydrofluoric acid or an unfilled resin bonding agent. [18] The study investigated the impact of mechanical and adhesive treatments on bond strength between pre-existing and repair composites. The research used three methods of mechanical roughening and adhesive treatments, with the CoJet Sand/OptiBond FL Adhesive being the most effective. The study concluded that mechanical roughening is necessary for strong repair bonds, and additional primer may be needed for areas with exposed dentin. [19] Experimental methods like AF-ESPI and modal testing were used to analyze the patching efficacy of a composite patch on an edge-cracked aluminum alloy plate. Results showed no discernible difference in vibration before and after patching, with patching A being the most efficient choice. [20] Glass fiber-reinforced polymer (GFRP) was used to repair fractures in damaged aluminum plates. The repair had a strength recovery ratio of over 80% compared to the original plates. The primary failure mechanisms were delamination and fiber breaking, with damage primarily induced in the area closest to the fracture surface. The study's results suggest GFRP's potential for future metallic construction applications. [21] A novel method using unidirectional M40J/epoxy composites for the repair of damaged equipment extends its life. The process improves tensile strength and fatigue life; double-sided repaired specimens have 76 times longer fatigue life. [22], [23] Glass fiber-reinforced polymers (GFRP) are used in various industries, but defects can arise from metallic inserts. Experimental tests showed that re-infused samples can recover 80% and 73% of their tensile strength and flexural strength when bent. The parent and repair laminates determine the dominant failure mechanism for re-infused samples. [24] The study investigates the use of a carbon fiber-reinforced polymer (CFRP) patch for repairing an Al 2024 T3 plate with edge and center fractures. The research reveals that the BD CFRP patch successfully increases peak load and prevents crack propagation. According to Bachir Bouiadjra et al. [25], the adhesive properties need to be tuned in order to allow stress transmission toward the patch while preventing adhesive breakdown. Because of their higher load transfer qualities, only boron/epoxy and graphite/epoxy combinations are used for the mechanical properties of the patch [26]. It is clear that testing adhesive and composite properties to improve patch performance is a more difficult and expensive operation. The patch thickness is the sole remaining variable. Using multiple layers of bonded composite patch is preferred for a better distribution of stresses, according to Bachir Bouiadjra et al. [27], because it reduces stress intensity factors in the same order when patch thickness increases by around 50% for single patch repairs. One technique to support these concepts is to use a double-sided symmetric patch. Many studies have been conducted to investigate the differences between double and single symmetric patches [28], [29], [30], [31], and [32]. The application of double-symmetric patches was shown to increase the fatigue life of the repaired structures. In this study, the research focuses on the optimization of hole location and repair of the composite material with various peak loads such as 60% and 90%.

2. Fabrication

The Glass fiber of 220 gsm is chosen for the fabrication of the specimen. The epoxy LY556 with Hardener HY951 is taken as a matrix in a 10:1 ratio. The vacuum bagging process is employed for the fabrication of the panels of size 300 mm x 300 mm x 4 mm. After set up, all 24 plies, vacuum bagging is done at atmospheric pressure and room temperature for 3 hours, then pumps are removed, leaving the panel for 24 hours. The processed laminate was then taken out of the vacuum bagging and made into a specimen as per the ASTM standard D390.

3. Repair of Composite

3.1. Repair of Specimen

The pair of samples are prepared in two ways. Failed and 90%, 60% loaded specimens are repaired. Initially failed samples are repaired in two ways for optimization. The failed samples are drilled using a 2 mm drill bit. One hole at the center (RS_2) and two holes at the edges (RS_1) are both drilled up to half depth.

3.2. Drilling of Failled Specimen

Drilling of failed glass/epoxy composite materials follows a similar process as drilling in other materials. To begin, prepare the specimen for drilling and secure the composite material securely, as shown in Fig. 1. A carbide drill bit is chosen to perform the drill as per the hole diameter. Mark the drilling location using a marker or punch, and then cutting fluid is applied to reduce the heat produced during the drilling process. Constant speed is maintained to avoid overheating of the composite material and continued drilling up to half depth. After drilling, the hole was inspected for delamination and splintering, and sandpaper to smooth the edges.

Fig. 1. Specimen drilled for Repair work.

4. Experimental Setup

The fabricated glass epoxy composite is cut into specimens in accordance with the ASTM standards D390, respectively, as shown in Fig 2. This is done in order to assess the flexural properties of the material and its repair strength after the repair work. A three-point bending test is conducted at the Hindustan Institute of Technology and Science, Department of Aeronautical Engineering, using a 100N universal testing machine. The specimen is marked for the support point and midpoint for easy positioning of the supports in the 3-point bending fixture. The specimen is placed in the lower fixture as per the marking, and the upper fixture is moved to the midpoint of the specimen, after it touches the specimen, the position is fixed. The gauge length, span, and thickness of the specimens are measured before the conduct of the test. The experiment was performed in a UTM using a machine that had a capacity of 100 kN at a stroke rate of 1 mm/min. All data from the experiment were recorded so that they could be analyzed later.

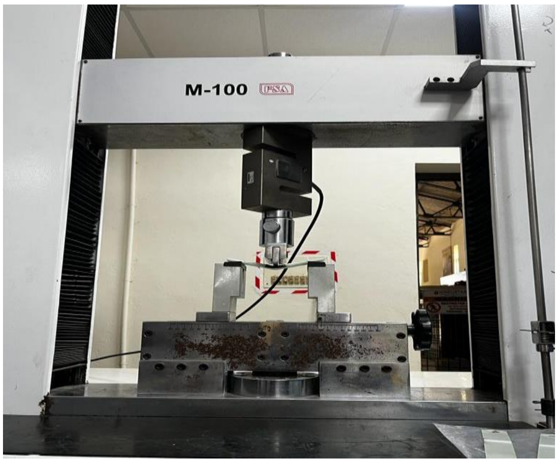

Fig. 2. Specimen mounted in UTM.

Fig. 3. Delamination of glass fiber laminate after 3-3PBT

5. Result and Discussion

The flexural test curve of a glass/epoxy composite material provides its mechanical properties and performance under bending loads. The curve begins with an initial linear elastic region. In this region, the material behaves elastically and follows Hookes's law. As the load increases, the material reaches its proportional limit and forms a plastic region. The ultimate load or stress is the peak where the material reaches its maximum load or stress, where significant deformation may occur but not yet fail. The post-peak region transitions to a post-peak region where the material continues to deform and the load or stress decreases. The failure point signifies the ultimate flexural strength. Damage depicted in Fig. 3.

The specimens are placed in the 3-point bending fixture, and all initial procedures are done. The load is applied as per the stroke speed of 2 mm/minute. The force vs. displacement curve is plotted as depicted in the figure for the neat glass/epoxy composite material. All three samples are shown in Fig. 4, with similar trends in the graph. There is not much variation in the material's loading behavior.

Initially, when the load is applied, the displacement increases and behaves as the elastic material; the load starts to fall, and the cracking sound during the load indicates the initiation of failure of the sample. This may be due to a failure of the matrix. This is due to the slip-stick condition [33].

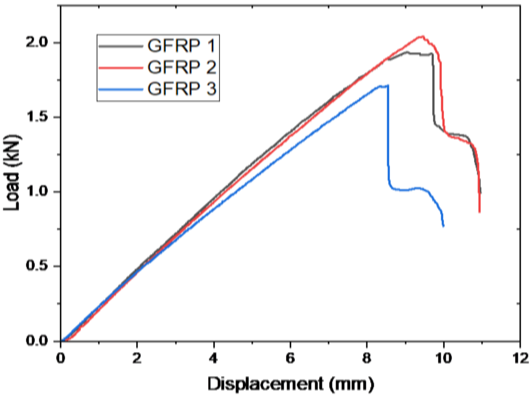

Fig. 4. Three Point Bending Test Load and Displacement Glass epoxy composite

Once it reaches the peak load, the material has the capacity to withstand the load due to the fiber strength; it again gains the load to some point and falls. This is due to the crack initial and debonding. Once the fiber fails, delamination occurs, and it is indicated as a sudden fall in the plot. The average load taken by the specimen is 1.78 kN, with the highest displacement of 11.3 mm.

The tested samples are prepared for repair using the drilling method. The failed samples are taken for a hole. Partial drilling is employed, one set with one hole and the other set with two holes with a 2 mm depth, as represented in Fig 5.

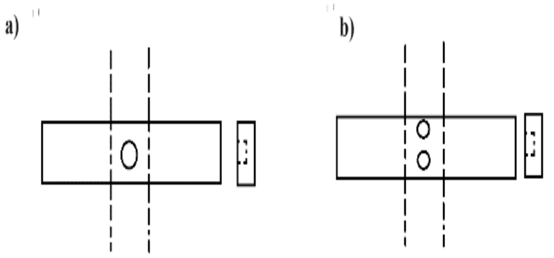

Fig. 5. a) 2mm drill at center as RS_1, b) 2mm drill near edges as RS_2

The drilled specimen is repaired using epoxy resin. Repaired specimens are taken and tested for three-point bending. Results are plotted into a graph and shown in the figure.

The repaired specimen also showed similar trends as in neat GFRP, both one-hole and double-hole.

The peak load attained by the one-hole repaired specimen showed a better result than the double hole. The maximum load of the one-hole repaired specimen RS_2_1 is 1.6 kN, and the two-hole maximum load at RS_1_1 is 0.987 kN. The flexural strength is also higher for the specimen having one hole.

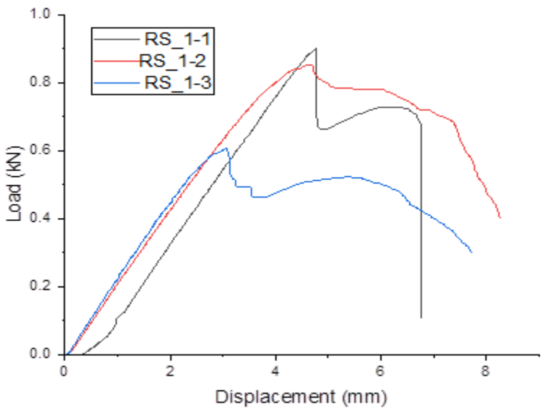

Fig. 6. Repaired specimen at various load levels for the first set of specimen RS_1

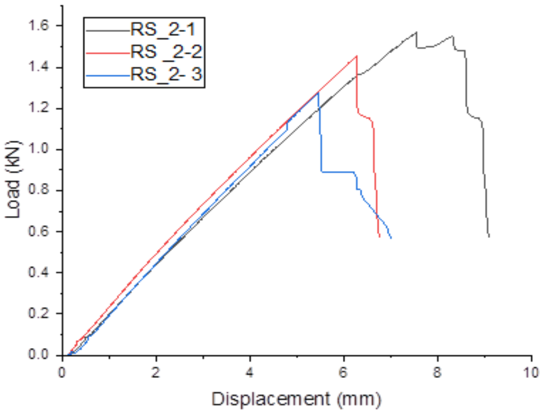

Fig. 7. Repaired specimen at various load levels for the first set of specimen RS_2

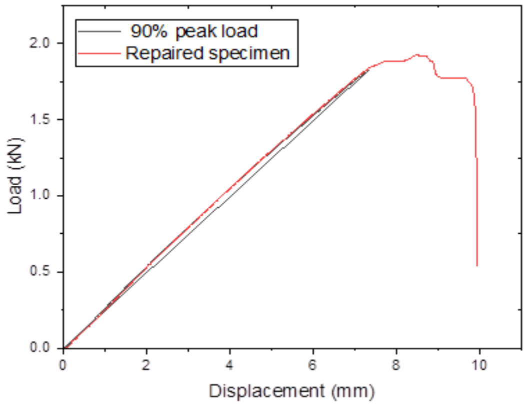

Fig. 8. Comparison of Repaired specimen at 90% peak load with Neat Glass/Epoxy specimen

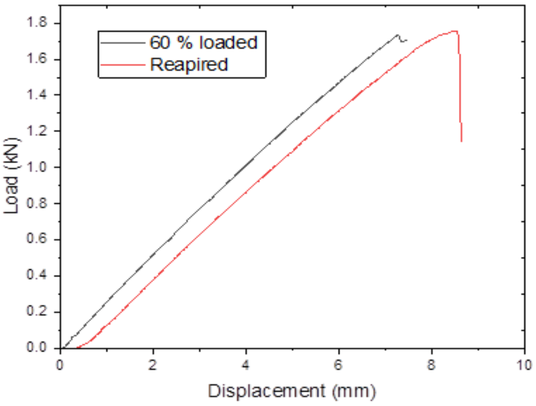

Fig. 9. Comparison graph of Repaired specimen of 60% peak load with base Specimen

Table 1. Flexural properties of Neat and Repaired sample

Sample	Peak Load (kN)	Width (mm)	Thickness (mm)	Gauge Length (mm)	Flexural Strength (Mpa)
GFRP	2.1	25	4	100	525.5
RS_2	1.8	25	4	100	450.2
RS-1	0.989	25	4	100	247.25

Flexural strength is calculated using the formula following formula

$$f_b = (\mathrm{P} \times \mathrm{L})/\mathrm{b}d^2. \quad (1)$$

From the flexural strength also, the specimen having one hole has the highest strength than the specimen having two holes with repair. The residual strength achieved 90% for the neat GFRP. Retainment of the strength as correlated with Jefferson et al. [34].

From the graph, it is shown that the peak load is increased when compared with the base sample, as represented in Figures 6, 7.

From Figures 6, 7, it is evident that the displacement is increased for the repaired specimen; this may be due to shear load transfer between the matrix phase and fiber phase, which delays the failure of the material.

The graph represented in Figures 8, 9 shows the results of a repaired 90% peak load specimen and a 60% peak load specimen. The curves are in line with the base sample, which shows the optimized repair work. After that, it attains a new peak load and the load drops. This increase, however, is due to the strength of the repair work.

For the respective peak load, the flexural strength is calculated and represented in Table 1, specimen having two holes with repair. The residual strength achieved 90% for the neat GFRP.

6. Conclusions

This work is done on the repair of glass/epoxy composites on delaminated areas and edge cracks by using epoxy resin. Failed samples are first tested for optimization of the hole for repair work. The edge hole and center hole repair performed the flexural test, which shows that the center hole samples give better performance than the edge hole. Failure was found that it is delayed for center hole repaired samples. This may be due to the behavior of the material, which takes load from the inner and gradually to the outer surface during loading. Both RS_1 and RS_2 have shown similar trends of curve. RS_2 is chosen for further 3PBT of 90% and 60% peak load repair. From the result, it is evident that after the repair work, the strength of the material is increased compared to the non-repair work [33]. From the result, it is shown that the one-hole sample retains its strength up to 47%. Thus the repaired specimens can withstand even after BVD of 90% and 60% peak loaded specimens; this is due to the fact the fact that epoxy resin has the ability to transfer load and withstand shear load as well.

Nomenclature

ASTM	American Society for Testing and Materials
GFRP	Glass Fiber Reinforced Polymer
GSM	Grams per Square Meter
3PBT	Three-point bend test
BVD	Barely visible damage
RS_1	Two holes at the edge
RS_2	One hole at center
f_b-	Flexural strength
P	Peak load
L	Guage length
b	Width
d	Thickness
mm	Millimeter
MPa	Mega pascals
kN	Kilo newton

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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