TENSILE AND FLEXURAL PROPERTIES OF DELAMINATED WOVEN E-GLASS/EPOXY COMPOSITES

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Abstract

The woven E-glass/epoxy composite with circular artificial defect located at center position between first and second plies was manufactured using hand lay-up method. The composite consisted of twelve layers of glass cloth. Experiments were conducted in tension and flexure with four-point loading to determine the behavior of laminate. The results were compared with those of laminates without artificial defect. A knee was observed on the load displacement curve for the laminate without defect loaded in tension. Results show that the defect does not affect considerably the tensile strength of the composite and the existence of defect influences highly the flexural properties.

Keywords : Tension, Flexure, Artificial defect, Knee, Four-point loading, Delamination

I. Introduction

Composites are manufactured from two or more materials to produce desirable characteristics. Strength to weight and stiffness to weight ratios are the important properties gained by the composites better than metallic parts for structural applications. For this reason, they are used for aircraft, automobile and military applications. A variety of damage forms namely matrix cracking, fiber failure, debonding of fiber from matrix and delamination occur in reinforced composites.

Delamination is the out-of-plane failure in the laminate which leads to separation between consecutive layers [IX]. This is a most important damage mode which can occur during the manufacturing of the component or it may be induced by
various service loads. When a delaminated composite is subjected to bending, local buckling occurs. This will reduce the strength and flexural stiffness of the composite.

Reis et al. [V] conducted experiments to examine the influence of rectangular artificial delaminations of different lengths on strength and stiffness of bi-directional carbon fiber/epoxy composites under tensile loading. The results indicated a drop in tensile strength and stiffness in the existence of interlayer delamination. But the size of artificial delamination did not influence significantly the strength and stiffness. Moniruddoza et al. [III] investigated experimentally to observe the effect of local defect placed at various locations in CFRP composites under tensile and bending loads. According to them, the location of defect influenced the mechanical performance of material and which was lower when the defect was located on the neutral axis. Pradeep et al. [VII] studied the compressive and flexural behavior of glass/epoxy composites containing defects of various sizes induced at different locations. It was concluded that the location of defect does not affect the compression strength. Moreover, the flexural strength was higher for defect located at mid-plane. Zhe et al. [X] studied the influence of rectangular delamination at different locations in unidirectional CFRP laminates under flexural loading. The delamination reduced flexural properties at failure.

Few authors reported on the behavior of artificial delaminated plain weave GFR composites subjected to tensile and bending loads. Hence, focus was done on E-glass/epoxy composites containing an artificial circular PTFE between the first and second layers at the center of the specimen to determine strength and stiffness.

II. Experimentation

Materials and Methods

The laminates consisted of commercial grade epoxy (LAPOX L12) as matrix and plain weave E-glass fabric (7 Mil) as the reinforcement. The laminates were molded by hand layup technique to the size of 400 mm x 470 mm x 2 mm. Four spacers were located between top and bottom plates of the match die mold to produce the laminate of desirable thickness (2 mm). The laminates had twelve layers of glass cloth with 0.18 mm thickness. Two different laminates with and without artificial defect were manufactured with 0.5 volume fraction.

A circular poly-tetra-fluoro-ethylene (PTFE) film of thickness 80 µm was used as artificial defect. This defect (artificial delamination) was placed at the center of the specimen between first and second layers as shown in Fig. 1. The diameter of defect is 9 mm. The specimens were separated from the laminates on CNC machine operating at the speed of 970 rpm. The edges of cut specimens were finished with emery paper of 320 grit size. A specimen containing circular artificial defect and separated from laminate is shown in Fig. 2. For performing tensile tests, the geometry of specimen was taken as per ASTM D3039/D3039M 17. Four-point flexural tests were run on the specimens confirming to the dimensions 100 mm x 20 mm x 2 mm as per ASTM D6272. Both tensile and four-point bending tests were done on 40 tonne universal testing machine (Instron: model KUT 40). The loading diagram with support spans of four-point bending is shown in Fig. 3. Five samples were tested for...
each data point in tensile and flexural tests to determine tensile strength, $\sigma_u$ and flexural strength, $\sigma_f$, respectively. Tests were run to complete failure of the specimens. No failure was noticed at the grips in tension tests.

![Fig. 1: Location of defect between layers 1-2](image1.png)

![Fig. 2: Defect specimen separated from laminate](image2.png)

![Fig. 3: Loading diagram in four point bending](image3.png)

**III. Results and Discussions**

**Tensile Tests**

The tensile properties for GFR laminates with and without artificial delamination are obtained from tension tests and given in Table 1 with standard deviations (SD). Typical plots of load versus displacement are shown in Fig. 4. The
plot for composite without delamination consisted of three linear parts separated by points A and B. The misalignment between fibers decreases slowly with increasing tensile load and consequently the fibers become parallel [VI]. The reduction in misalignment forms micro damage in matrix as the warp fibers tend to get lengthened gradually. This micro damage led to formation of a knee at A for woven fabric composites [IV], at which slope of the curve changes indicating change in modulus.

**Table 1: Tensile properties of virgin and defect specimens**

| Specimen | Tensile strength (MPa) | SD  | CV (%) | Modulus (GPa) | SD  | CV (%) |
|----------|------------------------|-----|--------|---------------|-----|--------|
| Virgin   | 278.76                 | 6.69| 2.40   | 2.66          | 0.10| 3.84   |
| Defect   | 245.46                 | 5.09| 2.07   | 2.64          | 0.06| 2.52   |

**Fig. 4: Comparison between load displacement curves of virgin and defect samples**

The transverse micro cracks in the matrix then reach to the regions of interface at warp and weft inside the same ply. Later, the cracks will multiply and grow in the direction of thickness from ply to ply. Hence, the degradation of plies occurring in loading direction is the reason for the change in modulus beyond the knee occurred at 20% $\sigma_u$. The whole material behaved as a single element up to the knee without any damage. The appearance of discontinuity at 92% $\sigma_u$ indicated by point B might represent the change in stiffness in further stage due to the breakage of fiber in the composite which was noticed by audible sound. The curve drawn for specimen with artificial delamination is approximately linear up to final fracture exhibiting brittle behaviour without any damage in it. From both the curves, it may be suggested that the delamination does not produce considerable influence on the ultimate tensile strength of the material but the occurrence of delamination promotes a reduction of strength [V]. The stress concentration offered by the delamination can be another reason for the reduction in modulus and strength [VIII].
Flexural Tests

The four-point bending induces maximum stress in the outer fibers between two central loading points of the load span. The fibers at the top surface were under compression and whereas fibers at the bottom were in tension. The ultimate flexural strength, $\sigma_f$ and modulus of elasticity, $E_b$ were calculated [I] using equations given below.

$$\sigma_f = \frac{3P_{\text{max}}L}{4bd^2}$$  \hspace{1cm} (1)

$$E_b = \frac{0.17 mL^3}{bd^3}$$  \hspace{1cm} (2)

In the above,  
$P_{\text{max}}$ Maximum bending load  
$L$ Support span  
$b$ Width of the beam  
$d$ Depth of the beam  
$m$ Slope of initial straight portion in load-displacement curve

The flexural strengths obtained for GFR laminates with and without artificial delamination are given in Table 2 with standard deviations. The results revealed that flexural strength of the laminates without delamination is about 28.83 % higher than for composites containing delamination.

Table 2: Flexural properties of virgin and defect specimens

| Specimen | Flexural strength (MPa) | S.D | CV (%) | Modulus (GPa) | S.D | CV (%) |
|----------|-------------------------|-----|--------|---------------|-----|--------|
| Virgin   | 341.49                  | 5.79| 1.69   | 46.72         | 2.73| 5.86   |
| Defect   | 265.06                  | 4.91| 1.85   | 37.62         | 1.66| 4.41   |

A typical comparison of bending load versus displacement curves drawn with flexural test data is shown in Fig. 5. From these curves, one can notice the effect of existence of artificial defect on flexural strength and modulus of the composite. For sample without artificial delamination, the curve has practically a longer linear elastic portion representing higher linear elastic behavior than that of artificial delaminated specimen. Both composites present nonlinearity relatively at higher loads. Moreover, no discontinuities appeared on the curves up to the peak load. The nonlinear elastic behavior can be due to visco-elastic behavior of the matrix [VII]. Figure 6 shows an artificial defect specimen failed under flexure. In this specimen during flexure, the
major failure mechanisms were the fracture of warp fibers accompanied with propagation of delamination present between first and second plies on compression side of the specimens along with some other interlayer delaminations. The outer ply existing on compression side of the sample could displace away from the supporting ply at the region of defect in the transverse direction due to compressive force induced by flexure. The amount of deflection in the outer ply gradually increased with increasing bending load and at peak load it broke as viewed in Fig. 6. Additionally, the delamination length also increased with increased deflection of the outer ply. Probably this might be the reason for drastic decay in modulus of the defect sample beyond the peak load.

Fig. 5: Bending load versus displacement curves of virgin and defect specimens

Fig. 6: Fracture of artificial delaminated specimen in flexure

IV. Conclusions

The tensile and flexural properties of E-glass/epoxy composite laminate due to the existence of circular artificial delamination introduced between the two extreme plies were studied. Knee was noticed on the load displacement curve for laminate without defect which indicated change in modulus due to formation of micro damage in the resin. The defect inserted between the first two plies of the laminate could not show any significance on tensile strength in comparison with defect free composite. However, its existence affected highly the flexural properties of the artificial laminated composite.
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