Static Analysis of Low Cost Glass/Epoxy Composite Laminates

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Abstract: In composite laminates the delamination is one of the most critical failure modes. In determining the ability Interlaminar Shear Strength (ILSS) is an important parameter to resist delamination damage of a composite material in laminates. This gives rise to a need for accurate prediction of the Interlaminar Shear Strength of the delaminated composites which in turn help in correction of fault designs and also may be properly designed to overcome failure. In the present investigation, ILSS of delaminated woven glass/epoxy laminates are studied at different loading speeds and the results are observed accordingly.

Keywords: Delaminated Composites, Glass/Epoxy, Interlaminar shear strength (ILSS).

1. Introduction:

The most commonly used structures of Laminated composite which are widely used because of the higher value of specific strength and stiffness in aircraft, marine, automobile, civil engineering, nuclear, and other industrial fields.[1-4] These can be modified using various approaches in terms of varying the fiber orientation, aspect ratio, number of layers and stacking sequence which improves in obtaining the better efficient design. An analytical approach could be the possible solution to create the laminated structures demands in very effective way.[5-7] Dynamic stability problems is complicated due to the presence of varying coupling stiffness and anisotropy of laminated plates for obtaining a suitable theoretical solution in addition to inherent problems due to the diverse loading and boundary conditions encountered. The defect problems in composite structures increased the demand for composite materials among them; delamination is one of the common defects, which is induced due to improper handling in the process of manufacturing, low velocity impact or excessive interlaminar stresses at the free edges under loading.[8-11] On the surface delaminations may not be visible or barely visible, since they are embedded inside the body of the composite structures. However, the design parameters may adversely affect the presence of delamination in composite laminates. The design parameters are like interlaminar shear strength, vibration characteristics, buckling strength of the structure, dynamic stability characteristics, safety and durability of structures etc.[11-13] Therefore, a comprehensive functional understanding in respect of vibration, static and dynamic stability characteristics of delaminated plates is very much essential. In a composite laminate structure the presence of one or more delaminations may lead to a premature collapse of the structure due to buckling at a lower level of compressive loading. A problem of current interest constitutes the effect of delamination on stability of composite structures which needs greater attention.[13-16] The location of dynamic instability region (DIR) is quite essential for the study of dynamic stability. In terms of the spectrum of natural frequencies the calculation of dynamic instability region (DIR) spectra is often provided and the static buckling loads. Furthermore, composite plates with delamination may result in significant changes of these characteristics.[17,18] Therefore it is an important task to calculate both of them with sufficiently high precision. Thus, the problems of vibration and static stability can be studied by a special investigation on basic of dynamic stability itself. Thus, the great technical importance for parametric instability characteristics is possible by understanding the dynamic system of delaminated plates under periodic loading.

2. Experimental Procedure for Static Analysis

2.1 Materials

The materials used for fabricating the laminate was initially considered with woven roving glass fiber as reinforcement, Epoxy as resin, Hardener, Polyvinyl alcohol as a releasing agent, Teflon foil for artificial introduction of delamination.

1. Fabrication Process

The glass:epoxy laminate was fabricated in a proportion of 50:50 by weight fractions of fiber: matrix. Araldite LY-556, an unmodified epoxy resin based on Bisphenol-A and hardener (Ciba-Geig, India) HY-951, aliphatic primary amine were used with woven roving E-glass fibers treated with silane based sizing system (Saint-Gobain Vetrotex) to fabricate the laminated composite. Woven roving glass fibers were cut into required shape and size for fabrication. Epoxy resin matrix was prepared by using 8% hardeners. Contact moulding in an open mould by hand lay-up was used to combine plies of woven roving (WR) in the prescribed sequence. A flat plywood rigid platform was selected. A plastic sheet i.e. a mould releasing sheet was kept on the plywood platform and a thin film of polyvinyl alcohol was applied as a releasing agent. Laminating starts with the application of a gel coat (epoxy and hardener) deposited on the mould by brush, whose main purpose was to provide a smooth external surface and to protect the fibers from direct exposure to the environment. Subsequent plies were placed one upon another with the matrix in each layer to obtain sixteen stacking plies. The laminate consisted of 16 layers of identically 0- 90^o oriented woven fibers as per ASTM D2344/ D2344M specifications. Delaminations were introduced at 1, 2.5 and 3.5 cm lengths by providing Teflon film at the mid plane of the laminates through full width and equidistant from both ends of the specimen. The mould and lay up were covered with a release film to prevent the lay up from bonding with the mould surface. Then the resin impregnated fibers were placed in the mould for curing. The laminates were cured at normal room temperature under a pressure of 0.2 MPa for three days. After proper curing of the delaminated plates, the release films were detached.

3. Results and Discussions

The experimental results on vibration and buckling of industry driven woven fiber glass/epoxy delaminated composite panels are also used to support the numerical predictions. The various studies made are presented below.

3.1 Static analysis

Delamination is one of the most critical failure modes in composite laminates. Interlaminar shear strength (ILSS) is an important parameter in determining the ability of a composite material to resist delamination damage in laminates. Therefore, there is a need for accurate prediction of the interlaminar shear strength of the delaminated composites in order that they may be properly designed to overcome failure. In the present investigation, ILSS of delaminated woven glass/epoxy laminates are studied at different loading speeds and the results are presented as shown in below figures 1(a) and (b). The below table 1 and 2 shows Mean, SD & CV in ILSS (MPa) value of glass/epoxy composite laminates at different delamination lengths and loading speeds.

Loading speed (mm/min)	**Delamination Length(cm)**			
	Control (0 cm)	**1 cm**	**2.5 cm**	**3.5 cm**
5 mm				
ILSS	**28.32**	**27.78**	**28.17**	**25.64**
SD	0.63	0.71	1.47	1.28
CV	2.17%	2.59%	4.89%	5.18%
50 mm				
ILSS	**28.94**	**28.24**	**27.84**	**27.15**
SD	1.19	0.78	1.49	1.78
CV	3.67%	2.38%	4.78%	5.23%

Table1: *Mean, SD & CV in ILSS (MPa) value of glass/epoxy composite laminates at different delamination lengths and loading speeds*

Delaminated	**Loading speed (mm/minute)**			
	5mm	**50mm**	**Mean**	**% reduction**
0 cm	**28.32**	**28.94**	**28.63**	------
1 cm	**27.78**	**28.24**	**28.01**	**4.83**
2.5 cm	**28.17**	**27.84**	**28.11**	**7.92**
3.5 cm	**25.64**	**27.15**	**26.40**	**13.13***

Table2: *Percentage reduction in ILSS (MPa) value of 1 cm, 2 cm & 3.5 cm delaminated specimen,* *indicates significant at 5% probability level

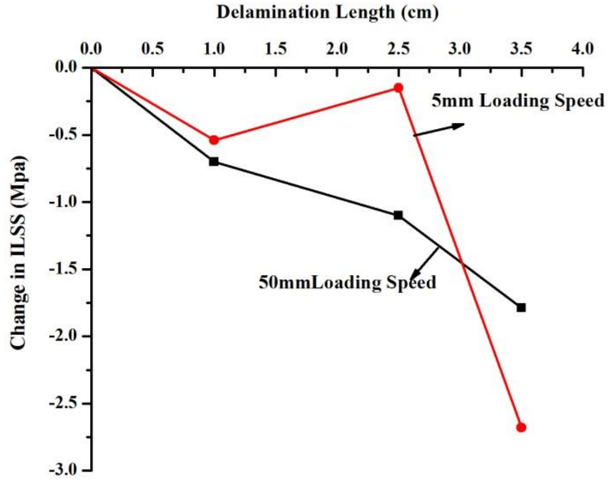

Figure1 (a): *Variation of change in ILSS vs. delamination length of glass/epoxy at 5 mm/min loading speed and 50mm/min loading speed respectively.*

3.2 Determination of material constants

The composite laminates of eight layers are fabricated to evaluate the material constants. Tensile tests on samples are performed following the procedure described in ASTM D2309/ D2309M standard and the characteristics of woven fiber glass/epoxy composite plate used for numerical study are presented in Table 3**.**

Table 3: Material properties of plates used for vibration

Lay-up	**N**	**E_1(GPa)**	**E_2(GPa)**	**E_{45}(GPa)**	**G_{12}(GPa)**	**I_{12}**	**D(kg/m^3)**
WR	8	7.9	7.9	7.17	2.93	0.21	1687.38

Where,

N : - Number of layers
E_{45} :- Tensile modulus obtained in 45 tensile test
E_1, E_2 :- Elastic modulus in longitudinal (1) and transverse direction(2) respectively.
G_{12} :- In-plane shear modulus , I_{12} :- Poisson's ratio, D :- Density

3.3 Bending test

The three point bending test is one among the most commonly used test for short beam strength (SBS) in ILSS. The testing machine INSTRON 1195 was used to SBS test for ASTM D 2344/ D 2344 M (2006) material standards. The testing was done at various velocities such as 5 and 50 mm/minute with a constant span of 34 mm to obtain interlaminar shear strength (ILSS) of intact and delaminated samples.

Initially the thickness and width of the specimens before testing were measured accurately. On the test fixtures the test specimen was placed and aligned so that its midpoint was centered and its long axis was perpendicular to the loading nose. At a specified cross head velocity the load was applied to the specimen. The sample breaking load was recorded. About five samples were tested at each level of experiment and their average value along with standard deviation (SD) and coefficient of variation (CV) were as mentioned in the above section. The interlaminar shear strength was calculated using the formula,

$$S = (0.75P_b)/bd \text{ as per ASTM D 2344}$$

Where, P_b is the breaking load in kg; b is the width in mm and d is the thickness in mm.

3.4 Tensile test

The samples were loaded in INSTRON 1195 universal testing machine for measuring the Young's modulus. Initially the samples were fixed in the upper jaw first and then gripped in the movable lower jaw. Here, for the purpose of gripping on each side the 50mm was considered with strain value maintained at zero. With the help of load cell and extensometer was used to measure the load and the extension which was digitally recorded. The INSTRON 1195 and Glass epoxy woven is as shown in figure below.


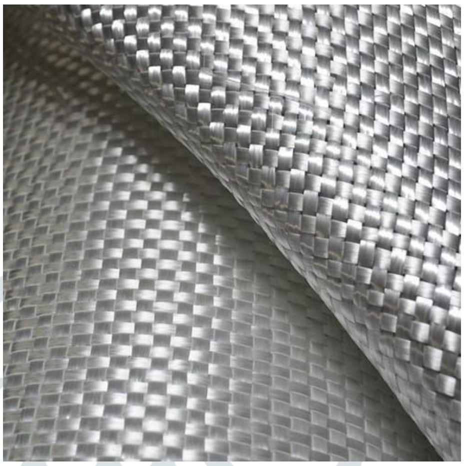

Figure 3 (a): *INSTRON 1195 universal testing machine.* **(b)** Glass epoxy woven

4. Conclusion

The delamination of composite glass:epoxy laminates was fabricated and determined the ability of Interlaminar Shear Strength (ILSS). Mean, SD & CV in ILSS (MPa) value of glass/epoxy composite laminates at different delamination lengths and loading speeds. The values so obtained were found better than earlier reported values. Percentage reduction in ILSS (MPa) value of 1 cm, 2 cm & 3.5 cm delaminated specimen was also calculated. Variation of change in ILSS vs. delamination length of glass/epoxy at 5 mm/min and 15mm/min loading speed were plotted. The determination of material constants were also calculated for the so fabricated composite of glass:epoxy laminate.

5. References

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