Predicting the Shear Properties in S-glass Epoxy Composite by Finite Element Analysis

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ABSTRACT

S-glass is technically significant glass fiber. It has high stiffness, strength and softening point. This fiber finds application in light weight armor. In the present work, S-glass reinforced composite is considered to examine the shear properties by finite element analysis. To examine the shear properties, the specimen mentioned in ASTM C 1425 is selected. In the standard, the sample dimension is 30 mm X 15 mm X 2 mm by maintaining the notch separation as 6mm. In the present work, shear properties will be examined at the sample thickness of 10 mm and the notch separation will be varied from 1 mm to 5 mm to understand the variation of shear properties. The shear properties examined from this work will be useful in design data considerations.

Keywords: *S- glass epoxy composite, woven fabric, FEA*

1. INTRODUCTION

S-glass (R Glass) has higher tensile strength and modulus than E glass (electrical glass), with better wet strength retention. Higher ILSS (inter laminate shear strength) and wet out properties are achieved through smaller filament diameter. S-glass (called R-glass in France) has better properties than E-glass, includinghigher thermal stability, but its higher cost has limited the extent of its use. Wallenberg and Brown [1] have recently described the properties of experimental calcium aluminates glass fibers with stiffness's as high as 180GPa. S-Glass has a typical nominal composition of SiO_2 65wt%, Al_2O_3 25wt%, MgO 10wt%. Some other materials may also be present at impurity levels.

Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain at least two epoxide groups. The epoxide group is also sometimes referred to as a glycidyl or oxirane group. A wide range of epoxy resins are produced industrially. The raw materials for epoxy resin production are today largely petroleum derived, although some plant derived sources are now becoming commercially available.

Epoxy resins are polymeric or semi-polymeric materials, and as such rarely exist as pure substances since variable chain length results from the polymerisation reaction used to produce them. High purity grades can be produced for certain applications, e.g., using a distillation purification process. One downside of high purity liquid grades is their tendency to form crystalline solids due to their highly regular structure, which require melting to enable processing.

The equivalent weight or epoxide number is used to calculate the amount of co-reactant (hardener) to use when curing epoxy resins. Epoxies are typically cured with stoichiometric or near-stoichiometric quantities of curative to achieve maximum physical properties. As with other classes of thermoset polymer materials, blending different grades

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of epoxy resin, as well as use of additives, plasticizers or fillers is common to achieve the desired processing and/or final properties, or to reduce cost.

The demand on material performance is so great and diverse that individual materials used alone are not able to satisfy them. Composites are those materials that can satisfy the desired requirements which were unattainable by these individual ones.

2. Literature Review

Over years several mathematical models are developed to predict the properties of composites [2]. Failure theories were proposed by Hinton and Soden [3, 4] in 1998. Soden et al. [5] and Chamis et al. [6] theory performed well to predict the ILSS (interlaminar shear strength) for unidirectional continuous fiber reinforced polymer. Murthy and Chamis [7] and Huang et al. [8] suggested micromechanical theory illustrated in Hinton and Soden's study. Liu et al [9] observed that twenty-five-point four percent (25.4%) increase in the ILSS while adding 0.5 wt.% MWCNTs (multi walled carbon nanotubes) and 10 phr n butyl glycidyl ether for GFRC. Pullela et al [10] predicted the distribution of ILSS in neat resin and CNT reinforced carbon epoxy composite as per ASTM C1425 by experimental method for thin laminate. For 120% increase in the applied load, ILSS enhanced by 87% upon adding 1 wt.% of amine functionalized long length multi walled nanotube. For thin laminate, the average ILSS value from experimental method is observed to be 34.98 MPa and its corresponding value from ANSYS is 36.99 MPa when the applied average load is 2,892.28 N. ILSS in neat resin and CNT reinforced carbon epoxy composite [11] from experimental method as per ASTM C1425 for thin laminate is 32 MPa and 60 MPa. When the distance between the notches is such that the stress fields around the notches interact, the measured interlaminar shear strength increases.

3. Problem Definition

Ramalakshmi et al [10] examined S-glass epoxy composite by experimental method and finite element analysis for thin and thick laminates by maintaining the notch separation as 6 mm as per ASTM C 1425. In the present work, the notch separation will be varied from 1 mm to 5 mm and its shear properties will be examined for thick laminate at an average load of 2787 N. The boundary conditions and volume fraction of the composite mentioned in [10] will be imposed on the present problem statement.

Table 1: Recommended Dimensions for Double-Notched Compression Specimen in ASTM C 1425

Dimension	Description	Value, mm	Tolerance, mm
L	Specimen Length	30	±0.10
h	Distance between the notches	6	±0.10
w	Specimen Width	15	±0.10
d	Notch Width	0.5	±0.05
t	Specimen thickness	2	-

ISBN - 978-93-95038-50-8

Table 2: Recommended Dimensions for Double-Notched Compression Specimen in the present work

Dimension	Description	Value, mm	Tolerance, mm
L	Specimen Length	30	±0.10
h	Distance between the notches	1 to 5	±0.10
w	Specimen Width	15	±0.10
d	Notch Width	0.5	±0.05
t	Specimen thickness	10	-

4. Research Methodology

The sample size from reference [10] was 30 mm X 15 mm X 10 mm and acid digestion was conducted as per ASTM D 3171. The volume fraction of the fiber, matrix and void content was 60.8 %, 38.7% and 0.5% respectively. Table 1 shows the material properties of the composite by extended rule of mixtures [12]. Orthotropic material properties are used to develop the finite element model.

Table 3: Properties of S-glass epoxy composite

Elastic constant	Volume fraction of fiber is 60.8
E_1 (GPa)	35.72
E_2 (GPa)	35.72
E_3 (GPa)	12.86
ϑ_{12}	0.095
ϑ_{23}	0.912
ϑ_{13}	0.912
G_{12} (GPa)	4.42
G_{23} (GPa)	4.41
G_{13} (GPa)	4.41

In the present work, ANSYS finite element analysis software is used to predict the shear properties of S-glass epoxy composite. There are three modules in this software. In the preprocessor module, geometric model is generated and Shell 281 from ANSYS library [13] is selected for the generation of finite element model. Shell element has four corner nodes, four mid-side nodes. Each node has three translational and rotational degrees of freedom. Orthotropic materials properties are provided as input and finite element model is generated. The finite element model has 2149 nodes and 680 elements. In the solution module, boundary conditions mentioned in ASTM 1425 are imposed and load mentioned in reference [10] is applied. In the general post processor module, by element table the shear properties [11] of S-glass epoxy composite are predicted.

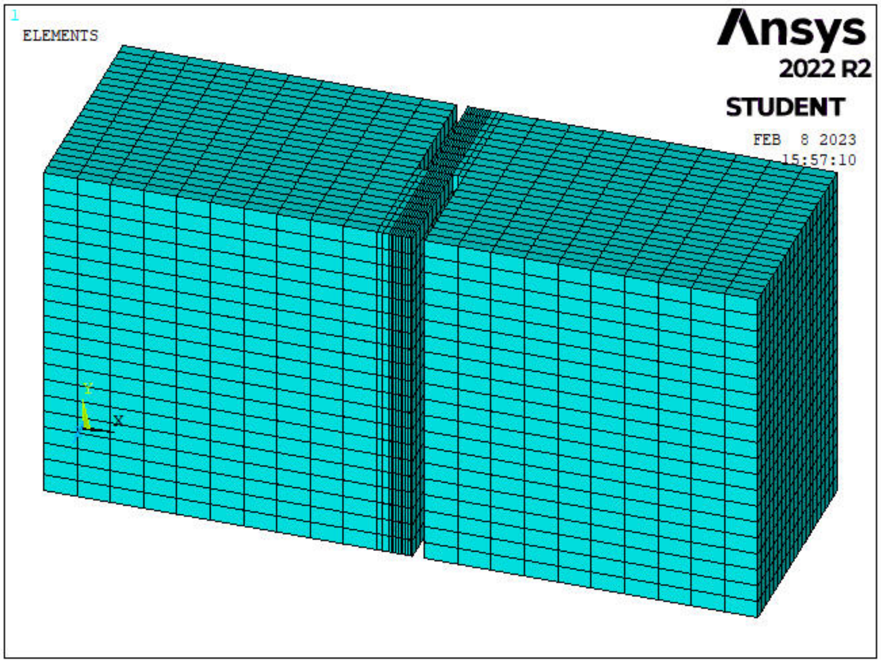

Figure 1: Finite element model of thick laminate whose sample size is 30 mm X 15 mm X 10 mm at notch separation of 1 mm.

5. Results and Discussion

In this section, the distribution of interlaminar shear strength (ILSS) and instantaneous shear modulus (ISM) in S-glass epoxy composite is presented in table 4 when the notch separation (h) is varying from 1 mm to 5mm. The plot of interlaminar shear strength at a notch separation of 1 mm is presented in figure 2 and its corresponding instantaneous shear modulus is shown in figure 3.

Table 4 Distribution of Interlaminar Shear Strength and Instantaneous Shear Modulus in S-glass epoxy composite

Sl Num	h in mm	ILSS in MPa	ISM in MPa
1	1	5.12	5.03
2	2	4.77	4.62
3	3	4.47	4.39
4	4	4.21	4.08
5	5	3.98	3.39

From table 4, it is inferred that as the notch separation increases from 1 mm to 5mm, the distribution of interlaminar shear strength and instantaneous shear modulus decreases due to weak interaction of forces between the fiber and the resin. Peak value of ILSS and ISM is noticed to be 5.12 MPa and 5.03 MPa when the notch separation is 1mm due to the strong interaction of the shear stresses among the constituents of the composite.

From figure 5.1, least value of -0.31 MPa is noticed in the thick laminate due to the resistance offered by the fiber and the matrix. At the vicinity of the notch, ILSS is varying from 4.51 MPa to 5.12 MPa due to the strong interaction of the stresses between the notches.

ISBN - 978-93-95038-50-8

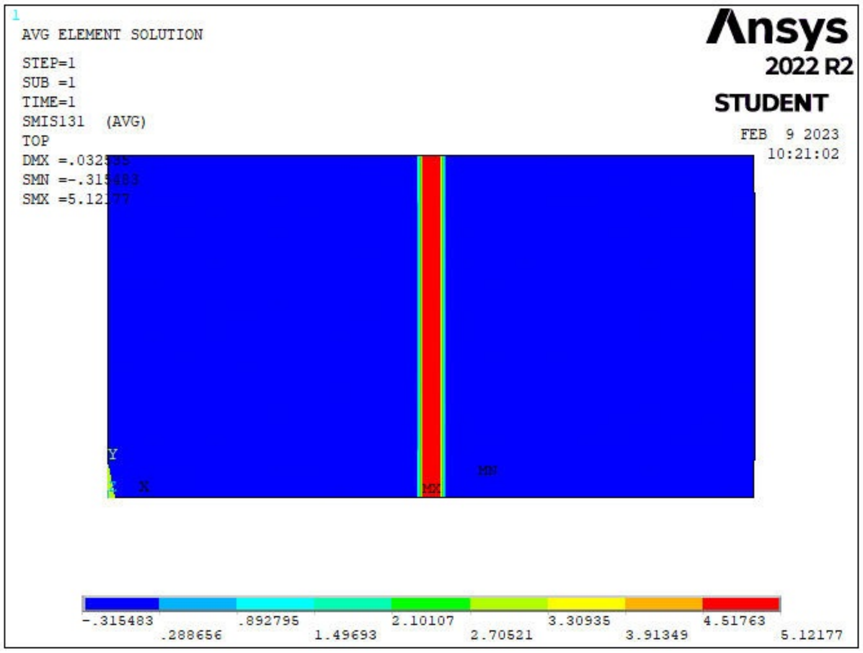

Figure 2: Distribution of Interlaminar shear strength in S-glass epoxy composite at a notch separation of 1mm

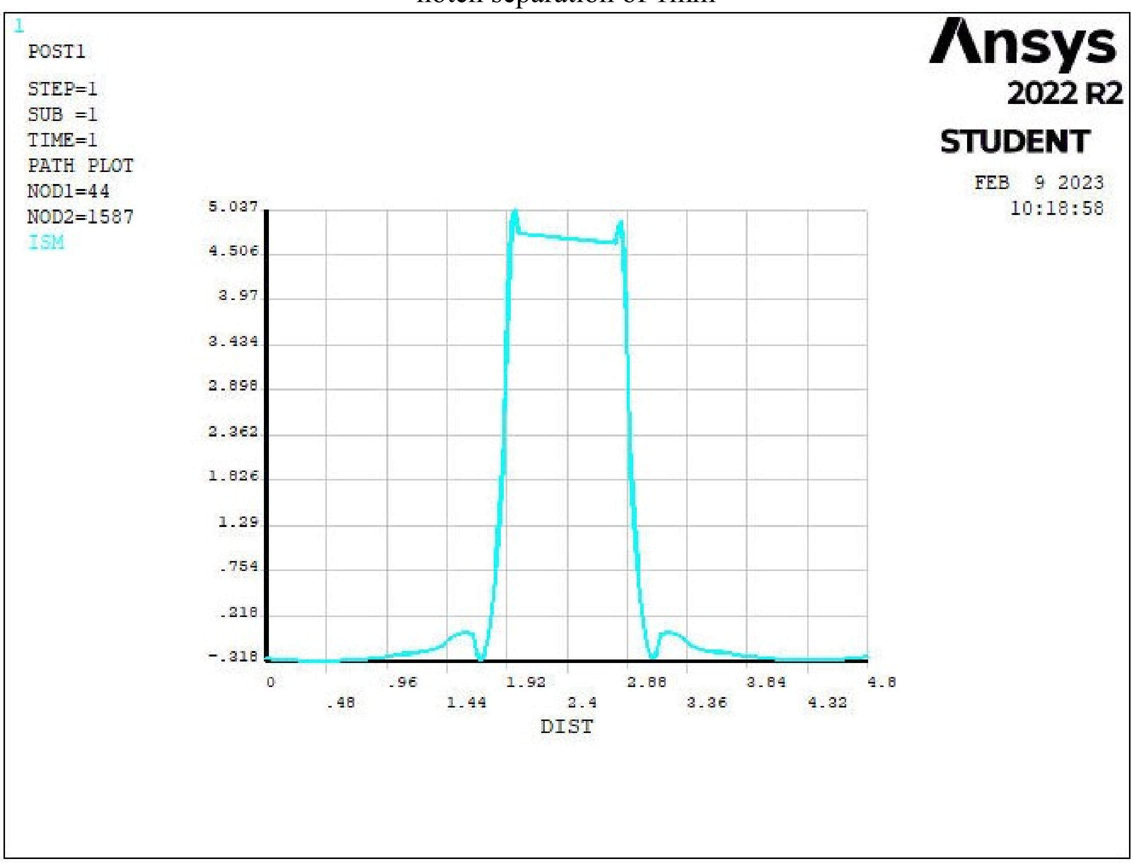

Figure 3: Instantaneous Shear Modulus in S-glass epoxy composite at a notch separation of 1 mm

Path is plotted along the length of the specimen (DIST) with special focus on the notch separation to understand the distribution of ISM. The variation of ISM is shown in figure 5.2. When DIST is zero, minimum value of -0.31 MPa ISM is noticed and a sharp rise to 5.03 MPa is seen when DIST is 1.68 due to the strong interaction of the shear stresses between the notches. Between the notches, the variation of shear modulus is uniform and a sudden drop to -0.31 MPa is noticed due to the weak interaction of the stresses when the notches are far apart.

6. CONCLUSIONS

In the present work, instantaneous shear modulus in S-glass epoxy composite is predicted from the distribution of interlaminar shear stress and its corresponding deformation. It is concluded that when the notches are far apart, due to weak interaction of the stresses, shear properties are less. When the separation between the notches is 1mm, high values of interlaminar shear stress and instantaneous shear modulus is inferred due to the strong resistance offered by the constituents of the composite.

ACKNOWLEDGEMENTS

The authors thank Smt G Rohini Devi, Shri Anil Kumar, Dr I Srikanth and his team members of Ceramic Matrix Composite Division, HTCC at Advanced System Laboratory for their invaluable guidance provided in reference [10].

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