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Estimation of ILSS in Neat Resin and CNT Reinforced S Glass Composites by Finite Element Analysis

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Abstract: In literature review, experimental work and finite element analysis was carried out as per ASTM 1425 and ASTM 2344 to understand the distribution of ILSS (interlaminar shear strength) in S glass epoxy composite for thin and thick laminates. Comparison of the ASTM methods is made and ASTM 1425 is recommended since sustainability can be achieved while understanding the properties of the composite. The objective of the present work is to estimate ILSS in CNT (carbon nanotube) reinforced S glass epoxy composites by finite element analysis.

Key words: ILSS, S glass epoxy, CNT, ANSYS.

Nomenclature

ILSS:	Interlaminar shear strength
CNT:	Carbon nanotube
ISM:	Instantaneous shear modulus

1. Introduction

A composite material is formed when two or more materials are combined to obtain better properties than the individual components. The individual components are reinforcement and matrix. High strength and stiffness, combined with low density, allowing for a weight reduction in finished part is the main advantage in composite materials. For exterior and interior fixtures with variety of styles, textures, shapes in new buildings or restorative projects, GFRC (glass fiber reinforced composite) is used [1].

S-glass has a composition of SiO_2 65 wt%, Al_2O_3 25 wt%, MgO 10 wt%. Other materials may also be present at impurity levels. 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.

Several mathematical models are developed over years 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. CNF (carbon nano fiber) reinforced GFRC showed high value of ILSS [9] due to improvement in the bond strength between fiber, matrix and CNT (carbon nanotube). Twenty five point four percent (25.4%) increase in the ILSS is observed [10] while adding 0.5 wt% MWCNTs (multi walled carbon nanotubes) and 10 phr n butyl glycidyl ether for GFRC. Lakshmi [11] predicted the distribution of ILSS in neat resin and CNT reinforced carbon epoxy composite as per ASTM 1425 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.

In literature review, the distribution of ILSS was estimated by experimental method and finite element analysis as per ASTM 1425 for S glass epoxy

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composite [12]. For thick laminate, when the average load is 2,787 N, its experimental ILSS value is 28.64 MPa and its corresponding finite element analysis value from ANSYS is 28 MPa. The deviation from both the methods is 2.2%. 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 1425 for thin laminate is 32 MPa and 60 MPa.

2. Materials and Methods

In the present work, ASTM 1425 and ASTM 2344 are selected to understand the distribution of ILSS in neat resin and CNT reinforced S glass epoxy composites by finite element analysis. Section 2.1 describes element adopted from ANSYS library to generate the finite element model, and assumptions made while estimating the properties of composite. Headings 2.2 and 2.3 describe the boundary conditions that are imposed on the specimen as per ASTM 2344 and ASTM 1425.

2.1 Finite Element Analysis

Shell 281 is selected to generate the finite element model. The element has four corner nodes and four mid side nodes [13]. Each node has three translational and three rotational degrees of freedom. Extended rule of mixtures [14] is used to estimate the material properties of woven fabric and is presented in Table 1.

2.2 Finite Element Model as per ASTM 2344

For ASTM 2344, apparent inter-laminar shear strength of parallel fibre composites by SBS (Short-Beam-Shear) is examined. During bending in SBS, the load increases proportionally with deformation, until a peak load is reached. If the load drops by 30% or more immediately after the peak load is reached, it is assumed that the specimen failed in lamina shear and the peak load is then used to determine the apparent ILSS. The test fixture is set up so that the line of action of the applied load passes through the midway between the support roll centers. The sample is subjected to bending load.

2.3 Finite Element Model as per ASTM 1425

To find out the distribution of ILSS, boundary conditions existing in ASTM 1425 have been applied to FE model. Here the left side of the specimen is fixed and compressive load is applied on the right. Notches are modeled as per specifications and three zones of interest are assumed while examining the distribution of ILSS along the length of the specimen.

3. Results and Discussion

3.1 ILSS Distribution as per ASTM 2344 in Neat and CNT Reinforced Matrix for Thin and Thick Laminates

Tables 2 and 3 show the distribution of ILSS in neat resin and CNT reinforced S glass composite for thin and thick laminates as per ASTM 2344. The mean percentage increase in thin laminate while including CNTs was 19.9 %. From Ref. [15], the ILSS value is 23 MPa while in CNT reinforced S glass epoxy composite for thin laminate is more. This can be due to the variation in the volume fraction while estimating the properties and is elaborated in the section 3.2.

Table 1 Estimated material properties in neat resin and CNT reinforced S glass epoxy composite.

	Type of reinforcement	
	Neat resin	CNT
E_1 (GPa)	35.11	35.91
E_2 (GPa)	35.11	35.91
E_3 (GPa)	11.87	13.104
G_{12} (GPa)	4.42	4.72
G_{23} (GPa)	4.42	4.74
G_{13} (GPa)	4.42	4.74
V_{12}	0.089	0.0935
V_{23}	0.87	0.849
V_{13}	0.87	0.849

Table 2 Distribution of ILSS in S glass epoxy laminates.

	Thick laminate, 10 mm		Thin laminate, 2mm	
	Load in N	ILSS in MPa	Load in N	ILSS in MPa
	160.24	5.58	254.9	11.24
	217.35	7.57	331.19	14.65
	308.34	10.74	357.66	15.8
	362.07	12.62	388.71	17.2
	370.84	12.96	389.85	17.22
	518.4	18.07	408.28	18.06
	520.83	18.15	475.99	21.03
	551.88	19.02	517.05	22.89
Average	376.24	13.08	390.45	17.26
Ref. [15]			23 MPa	

Table 3 Distribution of ILSS in CNT reinforced S glass epoxy laminates as per ASTM 2344.

	Thick laminate, 10 mm		Thin laminate, 2 mm	
	Load in N	ILSS in MPa	Load in N	ILSS in MPa
	192.3	6.70	305.89	13.51
	260.82	9.087	397.43	17.55
	370.01	12.89	429.19	18.96
	434.48	15.14	466.45	20.60
	445.01	15.50	467.82	20.66
	622.08	21.68	489.94	21.64
	624.7	21.77	571.2	25.23
	662.26	23.07	62.47	27.40
Average	451.49	15.73	468.55	20.70

Table 4 Distribution of ILSS in S glass epoxy laminate as per ASTM 1425.

	Thick laminate, 10 mm		Thin laminate, 2 mm	
	Load, N	ILSS, MPa	Load, N	ILSS, MPa
	1,187	10.30	1,888.19	21.83
	1,610	13.97	2,453.29	28.37
	2,284	19.82	2,649.33	30.63
	2,682	23.27	2,879.36	33.29
	2,747	23.86	2,887.81	33.39
	3,840	33.32	3,024.32	34.97
	3,858	33.48	3,525.92	40.77
	4,088	35.47	3,830.04	44.29
Average	2,787	24.18	2,892.28	33.44
Ref. [15]			23 MPa	

3.2 ILSS Distribution as per ASTM 1425 in Neat and CNT Reinforced Matrix for Thin and Thick Laminates

3.2.1 ILSS Distribution in Neat Resin for Thick Laminate

In the presence of 1,187 N on thick laminate neat resin, the variation of ILSS along the specimen is studied in three phases. In the first and last phases the ILSS value is positive and in the middle phase it is negative. There is a gradual growth in ILSS from 0.4 MPa to 8.8 MPa until 10.8 mm and in the second phase the value is almost constant which is between the notches at -28 MPa. Finally from 19.2 mm to 28.6 mm it varies between 10 MPa and 5.4 MPa.

3.2.2 ILSS Distribution in Neat Resin for Thin Laminate

For a load of 1,888.19 N applied on thin laminate, as the length of the specimen is varying from 6.47 mm to 10.78 mm, the ILSS has increased from 1.75 MPa to 21.69 MPa. There is a sudden drop in the distribution of ILSS value to -27.92 MPa at 12.38 mm. After this region, there is a rise and fall in the distribution of ILSS from -19.17 MPa to -28.04 MPa. This huge variation is due to the presence of notches in the specimen from 11.5 mm to 18.5 mm along the length. And thereafter, ILSS value increased from -28.04 MPa to 21.83 MPa. Finally, minimum value of 4.09 MPa is seen at a length of 22.09 mm.

3.2.3 ILSS Distribution in CNT Reinforced Resin for Thick Laminate

When 1,424 N (120% that of neat resin) is applied on CNT reinforced glass epoxy of thick laminate, a similar pattern is seen compared to neat resin where the distribution of ILSS values is on higher side.

3.2.4 ILSS Distribution in CNT Reinforced Resin for Thin Laminate

When 2,265.83 N of load is applied on CNT reinforced glass epoxy composite of thin laminate, there is a sharp rise in the ILSS value from 1.9 MPa to 27.5 MPa in the span of 6.4 mm to 10.7 mm. Until 12.38 mm rapid fall of ILSS to a value of -35.34 MPa takes place.

A similar pattern as in the case of thin neat resin is observed here with ILSS of -35.5 MPa. In the last phase, an increase in distribution of ILSS to 27.7 MPa at 19.2 mm is followed by decrease to 4.7 MPa at the end.

3.2.5 Estimation of ISM (Instantaneous Shear Modulus) in Neat and CNT Reinforced S Glass Epoxy Composite for Thin Laminate as per ASTM 1425

Fig. 2 shows the distribution of ISM in neat and CNT reinforced S glass epoxy composite. The sample size is selected as per ASTM 1425 and finite element analysis by ANSYS is carried out to understand the distribution of ISM. The sample size for thin laminate is $30 \times 15 \times 2$ mm^3. The notch exists at the mid way for the thickness of the specimen. In this work, 10.5 mm to 18.5 mm along the length of the specimen is selected to estimate ISS. The plot is symmetric along the length of the specimen. The maximum and minimum values of ISS are seen at 10.5 mm and 15 mm respectively. Least value of 1.0 is observed at the midway since there is existence of the notch as per the standard.

Table 5 Distribution of ILSS in CNT reinforced S glass epoxy laminate as per ASTM 1425.

	Thick laminate, 10 mm		Thin laminate, 2 mm	
	Load in N	ILSS in MPa	Load in N	ILSS in MPa
	1,424.4	13.9	2,265.83	24.71
	1,932	18.86	2,943.95	33.01
	2,740.8	26.76	3,179.19	35.89
	3,218.4	31.42	3,455.23	39.26
	3,296.4	32.18	3,465.37	39.39
	4,608	44.99	3,629.18	41.39
	4,629.6	45.2	4,231.10	48.76
	4,905.6	47.89	4,596.04	53.22
Average	3,344.4	32.65	3,470.74	39.26

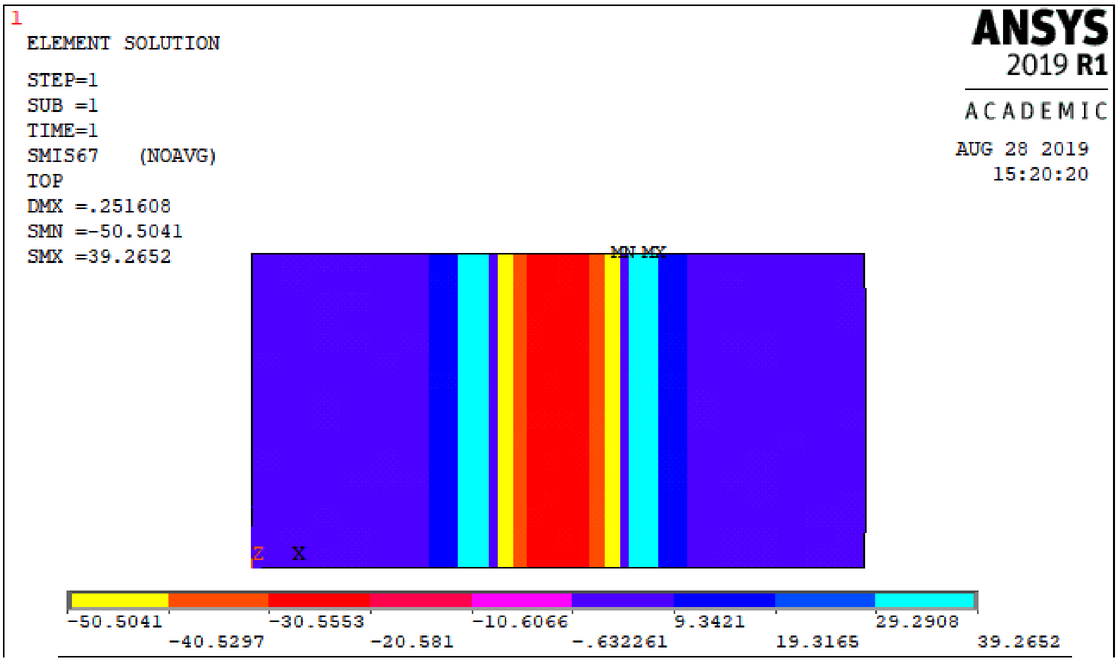

Fig. 1 Distribution of ILSS in CNT reinforced S glass epoxy composite by finite element analysis in ANSYS.

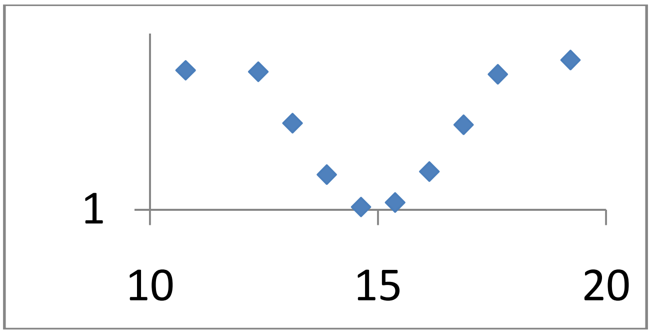

Fig. 2 Distribution of ISM in neat and CNT reinforced S glass epoxy composite along the length of the specimen.

4. Conclusion

In the present work, ILSS in CNT reinforced S glass epoxy composite in thin and thick laminate as per ASTM 1425 is estimated by finite element analysis in ANSYS. When the applied average load is 3,344.4 N in thick laminate, its ILSS is 32.65 MPa while in thin laminate, 39.26 MPa at a load of 3,470.74 N is seen. Shinde and Kelkar [15] studied the effect of enhancement in the estimation of ILSS in S glass fiber epoxy composite as per ASTM 2344 by including additives. The sample size was 41 mm × 6.3 mm and the span to thickness ratio was 6. In neat resin composite, the ILSS was observed to be 23 MPa.

When the sample size of neat resin is 32 mm × 10 mm × 2 mm, its average ILSS is noticed to be 17.26 MPa while for thick laminate it is 13.08 MPa respectively.

Decrease in the interlaminar shear stress is noticed while moving from thin laminate to thick laminate due to the internal resistance offered by the fibers in thick laminate.

ILSS improved from 34.98 MPa to 39.26 MPa by including CNT reinforcement in the material property estimation as per ANSYS.

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