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Research Paper

EXPERIMENTAL EVALUATION OF INTER LAMINAR SHEAR STRENGTH OF FIBRE REINFORCED COMPOSITES

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In present day several industries such as aeronautical industries, automobile industries, marine industries, chemical industries and transportation industries relay on fibre reinforced composites to manufacture several components such as flaps, doors, gears and other components. These fibre reinforced composite laminates are susceptible to de-lamination damage causing catastrophic failure of the components. The anisotropic nature of laminated composite materials become the source of de-lamination, de-lamination growth is the fundamental issue in the evaluation of laminated composite systems for durability and damage tolerance. Prediction of the Inter laminar shear strength of the fibre reinforced composites is important for engineering applications yet difficult in nature. The mechanical behaviour of materials and its properties becomes complex with the addition of fibres. These materials subjected to various loads such as tension, compression and flexural loads are susceptible to mechanical damages which results in de lamination in the inter layers of the composites. The effect of de lamination may result in the catastrophic failure of the component with the increase in the external load. This paper out lines the experimental investigation of inter laminar shear strength as a critical mechanical property of fibre reinforced composite laminate. The main objective of this paper is to find the inter laminar shear strength (trans-plane properties) to study the effect of de lamination in the composite laminates and to evaluate inter laminar shear strength of various fibre reinforced composites and to draw appropriate conclusions.

Keywords: Polymer Laminate, Polymer matrix composite, Inter laminar shear test, De-lamination, Shearstress

INTRODUCTION

The fibre reinforced composite materials are presently used in exhaustive manner because of their enhanced mechanical properties. The fibre reinforcing composites with brittle materials, having glass fibres, ceramic, graphite and carbon have potential to be used in the structural applications (Schwartz MM, 1997). The fibre reinforced laminated composites exhibits typical

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mechanical behaviour when loaded, which is complex in its nature to analyse, the addition of the reinforcing fibres makes it further complex to determine the mechanical properties of these materials .The laminated composites are subjected to de lamination at the boundaries making the laminate weak and this will result in the development of a crack and the progression of this crack may result in the catastrophic failure of the laminated structure. The significance of the shear strength lies in the fact that for all types of composites it is strongly influenced by factors weakening the interface binds. Boundary interfaces between the fibres and the matrix, as well as the thin matrix layer between the fibres represent the potential sources of composite weakening, shear force in these regions can easily cause shear damages (Kim J *et al*., 2004). Hence to evaluate the occurrence and progression of the de lamination in the laminated composites Inter laminar shear test is an appropriate method employed, even though it is critical to investigate the occurrence and progression of the crack using this method, does not provide complete information of the mechanical behaviour it provides the initial indications by providing the shear strength of the laminates. To evaluate the ILSS, three point bend test ASTM D 2344, also known as short beam shear (SBS) is adopted in this experimental investigation. Advantage of this method is its simplicity and ability of being performed rapidly and in much more reliable manner than other methods. It is easy to measure the shear strength of uni-directional laminates where as the laminated composites with bi woven patterns offers challenge. From beam theory it is known that peak inter laminar shear occurs at the mid plane of a beam loaded in three point bending and is inversely related to the specimen width and thickness. Several methods are developed to evaluate the inter laminar shear strength (ILSS) including short - beam flexural test (K T Kedward, 1972). Ouyang Z *et al*., 2009) used end notched flexural specimen with sufficiently long bond length to evaluate interface shear fracture. (Chen L *et al*., 2001) analysed the effect of transverse stitching or pinning the fabric across the laminate to hold the plies together to increase inter laminar shear strength. It is well known that by employing lamination theory, one can determine the in-plane stress distribution in each layer of a laminate from the knowledge of the applied force and moment results. The distribution of the inter laminar shear stresses in each layer from the applied shear resultants are not readily available from the standard lamination theory equations. Inter laminar shear properties are important data required for the analysis of polymer matrix composite structures, studies are carried out on inter laminar shear behaviour of typical polymer matrix composites under high strain rate shear loading. Sierakowski and Chsturvedi [6] adopted the Split Hopkinson pressure bar (SHPB) the most widely used technique to determine shear properties of composites under high strain rate loading. Werner and dharan (Werner S M, Dharan C K H, 1986) carried out inter laminar shear tests on woven graphite/epoxy using compressive SHPB apparatus. The short beam shear specimen Inter laminar shear strength can be calculated using the equation (High performance composites source book 2009). Sayers and Harris, 1973 used drop weight impact test techniques for determining the inter laminar shear properties of carbon/epoxy composites. ASTM 2344 is the recommended standard for the Apparent inter laminar shear strength of unidirectional parallel fibre composite by short beam method. The shear stress is calculated using the formula.

$$\tau = \frac{3}{4}\frac{P}{bd}$$

Where **τ-** is inter laminar shear stress (MPa),

P- (P_{max}) -is maximal force at which speci-men de lamination occurs (N),

b- Specimen Width (mm),

d- is specimen thickness

PREPRATION OF SPECIMENS (MATERIALS)

The composite specimen is fabricated as per standard procedure and test.

II a. Fabrication of Glass Fiber Laminates

The fibres chosen were bi-woven glass fibre with density of 360 gsm. The laminate will be cut to the required size and bonded to the glass fibre cloth by using an adhesive made from a mixture of LY556 resin & HY 951 hardener in proportions of 100:10 by weight. The surfaces will be thoroughly cleaned in order to ensure that they were free from oil, dirt, etc., before bonding at room temperature and pressure. The models will be allowed to cure for about 24 hours. Thicknesses of the Specimens was be maintained at 2 mm & 4 mm throughout the experiments for all the specimens prepared.

II b. Fabrication of Graphite Fiber Laminates and Carbon fiber Laminates

The material used in this work was plain weave graphite fiber/carbon fiber with epoxy resin as matrix. The table on which laminate were stacked is cleaned with acetone. The ply stacks were compression molded in a hot plate press under a pressure of 2 bars until a temperature of 120°C reached at a heating rate of 9°C per minute, after which the pressure was increased to 8 bars and held at this temperature and pressure for 120 minutes. Finally, the laminate was cooled down to room temperature at a cooling rate of 25°C per minute. The specimens were cut from the laminates with a diamond disc cutter and dried in a vacuum oven for at least 24 hours. Figure below depicts the vacuum bagging process. Specimens are machined to minimize the influence of manufacturing related defects on test results. The presence of voids which present may act as the de-lamination points can be reduced by the use of the vacuum bagging.

EXPERIMENTATION

The inter laminar shear strength is the ability to resist inter laminar deformation under load for a material. Three point bend test, also known as short beam shear(SBS) test is often used to measure the apparent inter laminar shear strength (ILSS) of composite laminates. In the short beam shear test, the determination of Inter laminar shear stress is based on classical (Bernolli-Euler) beam theory. The specimen with the given span is supported between two supports as a simply supported beam and the load is applied at the centre by the loading nose producing three point bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. These parameters are based on the test specimen thickness and are defined differently by ASTM. Under ASTM D 790 (Kim J *et al*., 2004), the test is stopped when the specimen breaks. For a beam of rectangular cross section loaded in three point bending, the maximum inter laminar shear stress occurs at the mid thickness of the beam between the centre and end supports.

Figure 1: Closer Look of Specimen Subjected to Inter laminar Shear Test (ILSS)

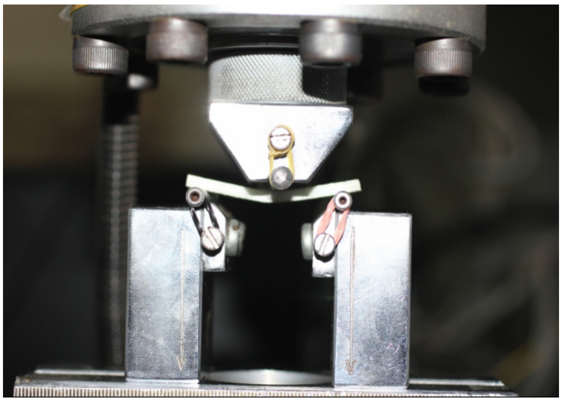
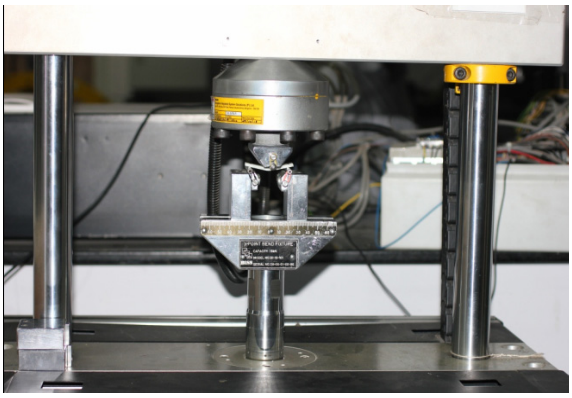


Figure 2: [ILSS] Inter Laminar Shear Test (Test Rig)

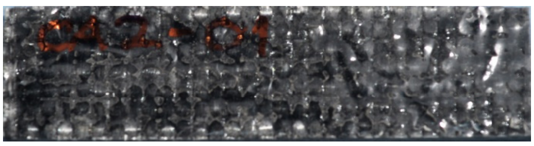


STANDARD SPECIMEN SIZE

The most commonly used specimen size for ASTM is 3.2mm x 12.7mm x 50mm (0.125" x 0.5" x 5.0"). The 3-point Inter Laminar Shear Tests were performed in a servo controlled machine according to the procedure outlined in ASTM 2334. At least 3 specimens were tested for each thickness of laminate. The crosshead speed was maintained at 2mm/min. The tested specimens were examined using through visual inspection for failure of fibres and matrix.

Figure 3: Graphite Fibre Reinforced Laminate

Figure 4: Carbon Fibre Reinforced Laminate



RESULTS AND DISCUSSION

Three-point bending test, also known as short beam test is used to measure the apparent inter laminar shear strength (ILSS) of fibre reinforced composite laminates. For the sake of accuracy in determination of the inter laminar shear strength, for each combination of pattern three specimens were tested experimentally, confirming to the appropriate standards. For each specimens initial dimensions were measured, & then the maximum shear force P_{max} (N), that is the force causing the de lamination of the specimen was determined. The inter laminar shear stress of the composites have been calculated from the formulae, the load versus deflection curves were plotted using the digital testing machine. Typical load versus deflection curves have been obtained for different types of fibre reinforced composites. The data obtained from the independent tests from the three point shear tests were used in the calculations. The graph of load versus deflection were linear until the breaking point. During testing, it was observed that observed that other failure modes including bending. Further it was observed that the damage in the specimen is characterised by a single crack that propagates from a region located usually at the axis symmetry. The short beam test is adopted to conduct inter laminar shear test because of its simplicity, ease of mounting the specimens on the test rig. During bending in short beam shear , the load increases proportionately with deformation, until a peak load is reached, if the load drops by 25-30% or more immediately after the peak load is reached, it is assumed that the specimen failed in laminar shear and the peak load is then used to determine the apparent ILSS.A sharp drop in the load -displacement curve and an audible cracking sound accompany catastrophic de lamination, which is at some times hard to detect with out the aid of a microscope. After the first -ply failure, the load may pick up again and in some cases it may reach the pristine value, refer load versus displacement curve. The de lamination is generally more visible to the naked eye, and in the large majority of the specimens it is located near the vertical axis of symmetry, and at the mid plane, actually one ply above it.

Table 1: Specimen Details

Sl. No.	Specimen Details	Specimen ID	Thickness(d), mm			Average Thickness(d) mm	Width (b), mm			Average Width(b) mm	Length mm
			1	2	3		1	2	3		
1.	Glass Fibre Reinforced Composite	GL2-01	1.53	1.52	1.53	1.53	14.08	13.97	13.71	13.92	50
2.		GL2-02	1.58	1.53	1.52	1.54	14.64	14.65	14.53	14.6	50
3.		GL2-03	1.51	1.51	1.53	1.51	14.37	14.40	14.31	14.36	50
4.	Graphite Fibre Reinforced	GR2-01	2.17	2.22	2.18	2.19	13.01	13.06	12.12	12.73	50
5.		GR2-02	2.26	2.25	2.16	2.22	13.16	13.21	13.28	13.21	50
6.		GR2-03	2.24	2.19	2.36	2.26	12.99	12.94	13.01	12.98	50
7.	Carbon Fibre Reinforced	CA2-01	2.17	2.15	2.18	2.16	13.54	13.30	13.05	13.29	50
8.		CA2-02	2.19	2.19	2.17	2.18	12.58	12.80	12.89	12.75	50
9.		CA2-03	2.33	2.28	2.19	2.26	13.42	13.59	13.63	13.54	50

Table 2: Load and Shear Strength for 2mm Specimen (Inter Laminar Shear Strength)

Sl. No.	Specimen Details	Specimen ID	P_{Max} N	Average load, P_{avg} N	ILSS τ, MPa	Average Shear Stress, τ MPa	Deflection mm	Average Deflection mm
1.	Glass Fibre 2mm	GL2-01	216.9		7.68		4.63	
2.		GL2-02	221.3		7.38		4.56	
3.		GL2-03	192.9	210.3	6.67	7.24	5.34	4.84
4.	Graphite Fibre 2mm	GR2-01	296.9		7.98		3.77	
5.		GR2-02	282.2		5.68		5.55	
6.		GR2-03	286.6	288.5	7.32	6.99	3.86	4.39
7.	Garbon Fibre 2mm	CA2-01	308.1		8.04		4.09	
8.		CA2-02	284.9		7.68		3.93	
9.		CA2-03	294.4	295.8	7.21	7.6	4.2	4.07

P_{Max}- Maximum load In Newtons ILSS τ)- Inter laminar Shear stress MPa.

$$\tau = \frac{3}{4}\frac{P}{bd}$$

Table 3: Load and Shear Strength for 4mm Specimen (Inter Laminar Shear Strength)

Sl. No.	Specimen Details	Specimen ID	P_{Max} N	Average load, P_{avg} N	ILSS τ, MPa	Average Shear Stress, τ MPa	Deflection mm	Average Deflection mm
1.	Glass Fibre 4mm	GL4-01	850.7		14.97		3.709	
2.		GL4-02	865.5		16.32		3.765	
3.		GL4-03	810	842.06	15.14	15.47	3.435	3.63
4.	Graphite Fibre 4mm	GR4-01	803.3		14.42		3.672	
5.		GR4-02	922.9		15.24		2.835	
6.		GR4-03	979.1	901.7	15.88	15.18	3.337	3.28
7.	Garbon Fibre 4mm	CA4-01	846.5		15.06		3.340	
8.		CA4-02	934.8		15.94		2.525	
9.		CA4-03	857.4	879.5	15.43	15.47	3.003	2.95

Figure 5: Load Vs Displacement (Glass Fibre Reinforced Composite 2mm Thick)

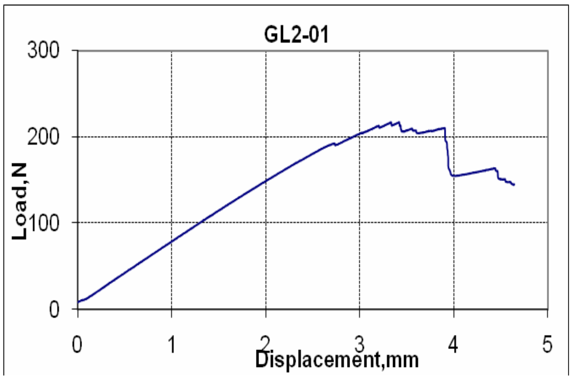


Figure 6: Load Vs Displacement (Graphite Fibre Reinforced Composite 2mm Thick)

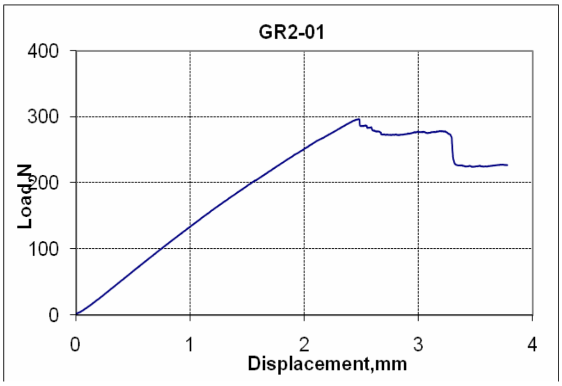
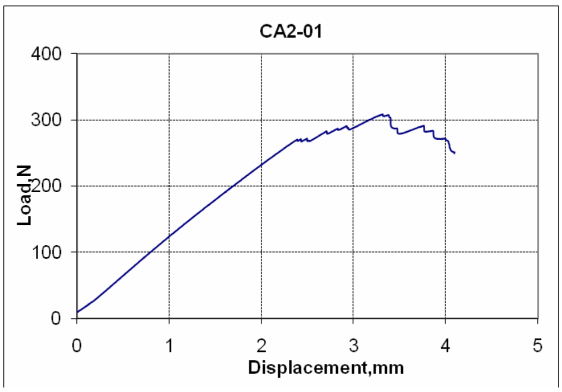


Figure 7: Load Vs Displacement (Carbon Fibre Reinforced Composite 2mm Thick)



CONCLUSION

Inter laminar shear strength of different fiber reinforced polymer composites have been successfully evaluated under short beam shear test. Determination of the flexural shear strength of unidirectional fiber laminated composites are relatively simple when compared with the much complicated woven fiber reinforced composite laminates which experiences a variety of different failure and damage modes before inter laminar shear failure occurs under short beam shear test. In the load deflection curve, the curve rises gradually (proportionately) and then drops suddenly showing a distinct failure load developed in the sample, the curve rises, flattens for some time and then shows a small drop. The test helps to understand the de lamination principle under static loading under short beam test, it is observed that the de lamination occurs in the centre plane at one end of the specimen. The inter laminar shear strength(τ) is calculated using the formula shown. Further it is evident that the carbon fiber reinforced polymer can with stand maximum load(Inter laminar shear strength) when compared with the other two types of reinforced composites for the same thickness.

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