Enhancement of Fracture Properties of Composite Laminate with Si C Additive

Abhijith U, Ramesh Kumar R

Abstract*: ASTM standards for short beam test, double cantilever beam and end notched specimen test are followed to compare control specimen with different percentage of Si C test data. Present study shows interlaminar shear strength (ILSS) and delamination fracture toughness values of multilayered composite laminate can be enhanced considerably with the use of Si C admixture in epoxy resin system as nonpolar elements compatible with to polar glass fiber. With respect to control specimen one percentage by weight of Si C w.r.t resin can bring up the ILSS value by as much 70% while the DCB test data on the critical energy release rate of mode I increases by 85% and mode II toughness value becomes double for 1% by weight of Si C. The bidirectional cloth provides more resistance for mode-I delamination fracture toughness when compared to UDL reported in literature and hence for higher fracture properties. The study is useful for design of rocket nozzles and input required for the cohesive zone model to assess the residual strength of composite structures with of delamination.

***Keywords* : Admixture, Fracture toughness, ILSS, Short beam**

I. INTRODUCTION

As per the design of rocket nozzles, the backwall temperature is at room temperature even though separation or ablation of sacrificial layers at elevated temperature region exists [1]. Nozzle can be fabricated using bi-directional silica - phenolic or glass- epoxy resin in sector winding around the circumferential direction and subsequent layers are placed to cover joining line of the previous layers. Under thermo-structural loads, one layer tries to slip one over the other. To avoid failure by means gas access its very much essential to bring up interfacial bond strength or laminar shear strength (ILSS). Si C is an industrial waste product available in the form of powder of 10 microns. By introducing a nonpolar element like Si C into the polar elements of glass-epoxy, one would expect an improvement in ILSS. Well-known cohesive zone model requires input data on delamination mode-I and mode-II toughness values to predict the residual strength of composite structures [2-3].

In the present study, role of Si C admixture in resin system for the glass-epoxy laminate is brought out when compared to the respective control specimens of ILSS, model -I and mode -II delamination fracture toughness values.

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II. METHODOLOGY

The most useful design variable of interlaminar shear strength of multilayered composite structure when compared to the delamination fracture toughness is evaluated first by progressively increasing percentage of Si C by weight with respect to resign mass. In the present study 1 – 5% of Si C is considered with 1% increase for each case and the respective values are compared with that of control specimen (0% Si C).

A. Specimen Preparation

Glass fiber laminates are fabricated using vacuum bagging process under (-) 0.3 bar pressure with and without admixture. Ten microns sized Si C powder are mixed with different weight percentage of resin system which is introduced in between each layer. Cured laminates are cut using water jet cutting to avoid burning of laminate edges.

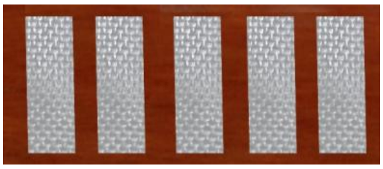

Fig. 1.Glass -epoxy specimens with Si C admixture

B. Procedure for evaluation of ILSS (ASTM D 2344)

For finding ILSS, short beam specimen of dimension 32.7 mm x 10 mm x 4 mm, span length 24 mm is loaded (compressive) using UTM shown in Fig 2 - 3 as per ASTM D2344/D2344M-16 [4].

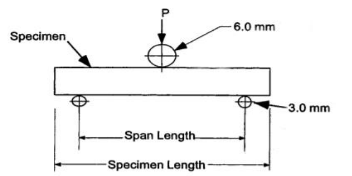

Fig 2 Short beam test diagram

Fig 3 Short beam test setup

C. Test parameters for ILSS

$$\text{Interlaminar shear strength (MPa)} = \frac{3P}{4bt} \qquad (1)$$

P – Breaking load (N)
b – Breadth (=10 mm)
t – Thickness (= 4 mm)

D. Procedures for the evaluation of G_{Ic} (ASTM D 6671)

A double cantilever beam (DCB) specimen of thickness *B* and height of each cantilever *h* is employed to determine critical energy release rate of mode-I [5].

The end of each cantilever is pulled in a tensile test machine and the loads are applied through hinges as shown in Fig. 4. An initial crack length is provided in the test specimen by placing a Teflon sheet in between two specimens.
The DCB specimen is pulled in a tensile test machine on displacement control with a low pulling speed and the crack is allowed to grow by a small distance usually in the range of 5-15 mm. The machine is stopped for some time (till the crack tip becomes stationary). The load at that point is noted as Pc.

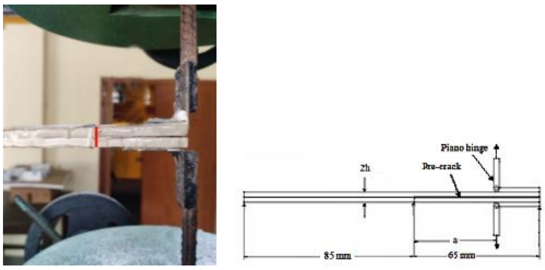

Fig 4 DCB test setup and schematic diagram [5]

Critical energy release rate of mode-I is given by

$$G_{Ic} = \frac{A_2^2}{EIB} \quad (2)$$

$A_2 = P_c\, a$

E – Young's modulus of bi directional glass fiber composite, 9GPa

I – moment of inertia of specimen

B – width of the specimen =25mm

P_c – Critical load (N)

a - initial crack length = 50 mm

2h -8mm

E. Procedure for the evaluation of G_{IIc} (ASTM D6671 b)

Interlaminar critical energy release rate for Mode II is determined by employing an end notched flexure specimen shown in Fig 6. The edge crack is on the mid plane where the shear stress is the highest. The initial crack length is approximately equal to 0.5 L but it should not exceed 0.69L. The specimen is loaded in a 3-point bend fixture as shown in Fig. 5.

Critical energy release rate of mode-II is given by

$$G_{IIc} = \frac{9Pc^2Ca^2}{2B\,(2L^3+3a^3)} \quad (3)$$

Pc – critical load

C – Compliance (load -deflection)

B – Thickness

L – Length and A – Initial crack length

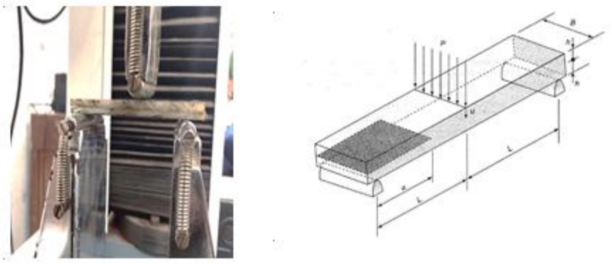

Fig. 5End notched specimen and schematic diagram [5]

where C is the compliance. The compliance can be found using the beam theory as

$$C = \frac{2L^3+3a^3}{8EBh^3}$$

However, C is not evaluated using this formula due to uncertainty in the modulus of a laminate. It can be determined directly from the *P-u* graph.

III. RESULTS AND DISCUSSIONS

The test results on ILSS values using short beam test for different percentage of Si C are compared with control specimen values (Table I). A comparison of average value of ILSS for different percentage of Si C with control specimen is shown in Fig.6. Table II gives the DCB test results on delamination fracture toughness corresponding to 1% Si C admixture with control specimen. Similar values obtained from the end notched test results on mode II delamination fracture toughness corresponding to same 1% Si C admixture with control specimen is also given in Table II.

A. Variation in ILSS Values

The failure loads of the six specimens tested and associated ILSS values with variation in the percentage of Si C admixture are given in Table I. It can be noted from Fig. 6 that for 1 % of Si C by weight w.r.t to resin mass gives the maximum value of ILSS which is 72% than when compared to the control specimen value.

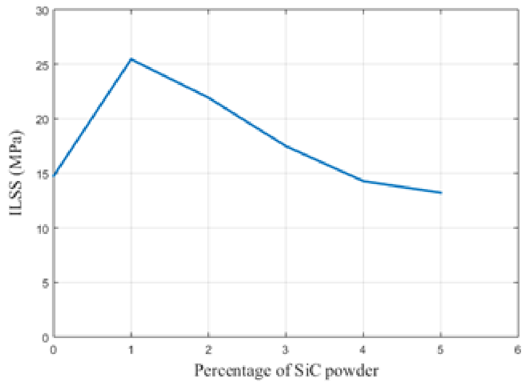

Fig. 6Variation of ILSS with Si C admixture

Table- I: Comparison of ILSS values for various percentage of Si C with control specimen

Specimen No.	Breaking load in N	ILSS in MPa	Breaking load in N	ILSS in MPa	ILSS in MPa	ILSS in MPa	ILSS in MPa	ILSS in MPa
	0% SiC		1% Si C		2% Si C	3% Si C	4% Si C	5% Si C
1	778.5	14.6	1269.8	23.8	19.5	17.8	18.1	10.5
2	779.7	14.6	1469.7	27.5	20.2	18.5	14	13.3
3	787.7	14.8	1023.9	19.2	21.2	15	14.4	15.5
4	804.1	15.1	1561.8	29.3	21.4	15.9	12.1	16.6
5	836.7	15.7	1371.7	25.7	23.1	19.4	13.4	12.9
6	738.3	13.8	1448.7	27.2	26	18.2	13.6	10.4

It may be noted that Si C being nonpolar element similar to the resin system provided very good adhesive bonding with polar glass fibre. Present study is confined to epoxy resin and at room temperature.

Table- II: Comparison of Mode -I delamination fracture toughness for various percentage of Si C with control specimen

Failure load from the test (N)			G_{Ic} (J/m²)	
Specimen No.	0% Si C	1% Si C	0% Si C	1% Si C
1	150	210	234.37	462.82
2	153	203	246.67	432.42
3	155	211	252.84	468.44

B. Critical Energy Release Rate of mode-I (G_{Ic})

From the interlaminar shear strength test result, it is clear that 1% Si C gives the optimum ILSS value and further progressive increase in the Si C to 5 percentage resulted in the gradual reduction of interlaminar shear strength. So in the present study, specimen with 1 percentage of Si C (three number each) is considered for testing to evaluate both mode -I and mode – II delamination fracture toughness in terms of strain energy release rates.

From Table II the average critical energy release rate of mode I of control specimen obtained from DCB specimen teste is 244.6 J/m^2 and specimen with 1% Si C the value becomes 454.6 J/m^2, which is 85% higher than control specimen value.

C. Critical Energy Release Rate of Mode -II (G_{IIc})

It may be noted from Table III that the average critical energy release rate of mode- II of control specimen(three) obtained from End notched specimen test is 536.7 J/m^2 and with 1% Si C value has increased to1066 J/m^2, which is almost double when compared to the control specimen. It may be noted that in case of carbon -epoxy unidirectional (prepreg) laminate reported in Ref. 6. G_{Ic} for carbon epoxy laminate was reported as 66 J/m^2, while for G_{IIc} it was 240 J/m^2[4]. In the present study both G_{Ic} and G_{IIc} are found to be much higher for glass epoxy laminate even though cured at room temperature resin under low pressure. This may be mainly due to the bidirectional glass cloth used which provides more resistance against opening for the mode-I failure and the present resin system (HV 103 resin & HV 103 hardener 10:1 by weight).

IV. CONCLUSIONS

Experimental studies have been carried out to evaluate the role of Si C of 10microns particle size as an additive on ILSS value, mode-I and mode- II interlaminar delamination fracture properties. It is observed that ILSS value significantly increased by 72% for 1% by weight of Si C additive with respect to control specimen.

Table- III: Comparison of Mode -II delamination fracture toughness for various percentage of Si C with control specimen

Failure load from the test (N)			G_{IIc} (J/m²)	
Specimen No.	0% Si C	1 % Si C	0% Si C	1 % Si C
1	870	1278	527.75	1140.41
2	883	1212	543.65	1024.73
3	878	1216	538.70	1032.38

Further increase in Si C gradually reduces the ILSS values. For the case of delamination fracture toughness, the critical energy release rate of mode-I increases by 85% for the case of 1% Si C with respect to control specimen value. Similar value for mode-II is doubled that of control specimen.

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REFERENCES

1. R. R. Kumar, G. Vinod, S. Renjith, G. Rajeev, M. K. Jana and R. Harikrishnan, "Thermo-structural analysis of composite structures. Materials Science and Engineering", 2005, A, 412(1-2), pp. 66–70. doi:10.1016/j.msea.2005.08.065.
2. K. C. Goplakrishnan, Kumar, R. R and S. Anillal S, "Cohesive zone modeling of coupled buckling- debond growth in metallic honeycomb sandwich structure", J. Sandwich structures and materials, 14(6), pp. 679-691, 2012.
3. K. C. Goplakrishnan and R. R. Kumar, "Delamination of secondary bonding around cutouts in a compressively loaded CFRP Skinned Sandwich Structure", 3rd International Conference on Buckling and Post buckling behaviour of composite laminated Shell structures, held at DLR, Braunschweig, Germany, March 25-27, 2015.
4. Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates, ASTM D2344/D2344M-16.
5. Standard Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites, ASTM D 6671/D 6671M –06.
6. S. Jose, R. R Kumar, G.V. Rao, and P. Sriram, "Studies on mixed mode interlaminar fracture toughness of M55J/M18 carbon epoxy laminate", Advanced composite letters, 2000, vol. 9(5), pp. 335-340.

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