INVESTIGATION ON THE INFLUENCE OF THE CONSTITUENT ELEMENTS IN PMC LAMINATES ON INTER LAMINAR SHEAR STRENGTH (ILSS) AND IMPACT STRENGTH

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ABSTRACT

The behavior and response of the laminates under varied modes of loading depends on its constituent elements. The degradation and failure of laminates depends on the responses of the fiber and matrix of the composites. Considering the visco elastic nature of most of the polymer matrix composites, it is imperative to measure the extent of matrix load bearability, in particular against shear and impact conditions. While designing and analysis of the laminates that are used for high performance applications, like in Radome, ILSS and impact strength are the two significant properties that are matrix dependent and hence are often measured. Further enhancement of the stiffness of the matrix could be attained by dispersing second phase fillers like, glass spheres and fumed silica. Critical properties that influence the matrix in general viz., ILSS and Impact strength, were investigated under varying material constraints, like fiber diameters, weaving pattern of fibers, Stacking sequences and the number of the plies across the laminates. It was found that unidirectional fibers with higher gsm as used in thin cross plied laminates filled with fillers in the nano regime, found to exhibit better performances than their other counterparts.

KEYWORDS: Fillers, Impact & ILSS Strength

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INTRODUCTION

Epoxy blended with Cyanate ester have become a routine utility in making laminates for high performance application which require good structural as well as dielectrical properties. These applications basically need the testing to be done on the samples under varied loading conditions and also under varied sets of material constraints. (6-7) Interply delamination under impact, cracking & the mechanisms to retard it and ply orientation to delay the fracture are the specific topics often investigated by researchers. (8-10). The inter relation between the various variables on materials, processing, and geometry fronts like hybrid reinforcements, different types of curing methods and a variety of stacking sequence with different orientations besides the micromechanics meant for decelerating the damage causing modes are some of the investigations that are widely researched. (11-12). But, not much was done to relate the role played by fillers in improving ILSS and Impact strength. Hence to enhance these properties, fillers in the micro (glass spheres) and nano (fumed silica) regime are dispersed in the matrix and the

laminates are compression molded and oven cured. Curing influence the toughening of the matrix by increasing cross link density in the cyanate ester blended epoxy matrix, during polymerization process. Interlaminar shear strength and Impact strength are two vital properties that helps in assessing the versatility of the laminates for structural applications.

By varying the laminate geometry, material and processing constraints, the optimization of the laminated structures can be achieved. Fibers of random, bi directional and unidirectional orientations with different gsms, different ply numbers with cross ply stacking, hand lay and compression moulding procedures using room and oven curing conditions and with choices from fillers are the good number of variables that have been applied.

MATERIALS FABRICATION

The laminate composites were fabricated from neat epoxy and then from blended resin loaded with 0%, 5%, 10% and 15% of Cyanate ester for the Matrix and E-Glass fibers of types like., random oriented, bi directional and unidirectional fibres with 300,400 and 410 gsm for reinforcements, with an optimized stacking of four plies at (00/90) 2 reinforcement. Specimens were filled with adds on fillers of micro glass microspheres and nano fumed silica by 0%, 3%,5%,7%,10%,20% and 30% by volume. Also laminates in 2, 3, 4 and 5 plies were fabricated in both room and oven curing conditions to investigate the laminate geometry on the properties. Fabrication options of hand layup and compression moulding were introduced under room and oven curing conditions. A good number of variables were chosen to investigate the inter related factors that could influence the optimized laminate. ASTM guidelines were observed while fabricating and cutting the samples for testing against Impact and ILLS strength.

Figure 1: Few Impact Test Specimens.

Figure 2: Oven Curing Process of Laminates

Figure 3: Impact Tester.

Figure 4: Typical ILSS set up.

Figure 5: Some of the Tested Samples for ILS

3. EXPERIMENTAL OBSERVATION

Table 1: Ilss & Impact Strength

Test	L1	L2	L3	L4	Laminate Coding Description
Interlaminar shear strength (Mpa)	6	7	4.4	11	Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 300 GSM, Random oriented, 4 plied & cross plied, Hand layup method, Room cured
Impact strength (Joules)	2.2	2.7	4.6	3.1	

Table II: Ilss & Impact Strength

Test	L5	L6	L7	L8	Laminate Coding Description
Interlaminar shear strength (Mpa)	18	21	23	19	Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 400 GSM, Bi Directional, 4 plied & cross plied, Hand layup method, Room
Impact strength (Joules)	3.2	2.7	4.6	32	

					cured
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Table 3: Ilss & Impact Strength

Test	L9	L10	L11	L12	Coding Details Description
Interlaminar shear strength (Mpa)	9	11	15	22	Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 410 GSM, Uni Directional, 4 plied & cross plied, Hand layup method, Room cured
Impact strength (Joules)	2.2	2.8	5	8	

Table 4: Ilss & Impact Strength

Test	L13	L14	L15	L16	L17	Laminate Coding Description
Interlaminar shear strength (Mpa)	10	1.3	26	30	25	Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Hand layup method, Room cured
Impact strength (Joules)	6	5	8	10	9.2	

Table 5: Ilss & Impact Strength

Test	L18	L19	L20	L21	L22	Laminate Coding Description
Interlaminar shear strength (Mpa)	22	30	34	34	26	Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Hand layup method, Oven cured
Impact strength (Joules)	7.7	8.4	10.3	12	10.6	

Table 6 & 7: Ilss & Impact Strength for Glass Filled Cyanate Blended Epoxies

Test	L23	L24	L25	Laminate Coding Description		
Interlaminar shear strength (Mpa)	79	55	39	Epoxy 4 plied + 15% Epoxy cyanate blended epoxy + 0% Glass filled Cyanate Blended Epoxy + 10% Glass filled Cyanate Blended Epoxy + 20% Glass filled Cyanate Blended Epoxy, 30% Glass filled Cyanate blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Compression moulding, Oven cured		
Impact strength (Joules)	25	20	18			
Test	L26	L27	L28	L29	L30	Laminate Coding Description
Interlaminar shear strength (Mpa)	17	18	41	29	20	Epoxy 4 plied + 15% Epoxy cyanate Blended epoxy + 0% Glass filled Cyanate Blended Epoxy + 10% Glass filled Cyanate Blended Epoxy + 20% Glass filled Cyanate Blended Epoxy, 30% Glass filled Cyanate blended Epoxy, 1200 GSM, Uni Directional, 3 plied & cross plied, Compression moulding, Oven curing
Impact strength (Joules)	6	9.3	19	15	14	

Table 8: Ilss & Impact Strength for Glass Filled Cyanate Blended Epoxies

Test	L31	L32	L33	Laminate Coding Description
Interlaminar shear strength (Mpa)	76	53	17.8	15% Epoxy + 3% Glass filled Cyanate Blended Epoxy + 5% Glass filled Cyanate Blended Epoxy + 7% Glass filled Cyanate Blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Compression moulding, Oven cured
Impact strength (Joules)	29.2	23	15	

Table 9: Ilss & Impact Strength For Cyanate Blended Epoxies

Laminate	Inter Laminar Shear Strength	Impact strength	Laminate Coding Description
L34	15	3	15 % Cyanate Blended Epoxy, 2 Plied, Room Cured, Compression Molding
L35	10	6	15 % Cyanate Blended Epoxy, 2 Plied, oven Cured, Compression Molding
L36	13	7	15 % Cyanate Blended Epoxy, 3 Plied, Room Cured, Compression Molding
L37	15	10	15 % Cyanate Blended Epoxy, 4 Plied, Room Cured, Compression Molding
L38	13	11	15 % Cyanate Blended Epoxy, 5 Plied, Room Cured, Compression Molding
L39	29	13	15 % Cyanate Blended Epoxy, 5 Plied, Compression Moulding Oven Cured

Figure 6: Comparison of ILSS (Mpa) & Impact Strength (Joules) Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 300 GSM,

Figure 7: Comparison of ILSS (Mpa) & Impact Strength (Joules) Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 400 GSM, Bi Directional, 4 plied & cross plied, Hand layup method, Room Cured

Figure 8: Comparison of ILSS (Mpa) & Impact Strength (Joules) Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 410 GSM, Uni Directional, 4 plied & cross plied, Hand layup method, Room cured

Figure 9: Comparison of ILSS (Mpa) & Impact strength (Joules) Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended Epoxy + 15% Cyanate Blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Hand layup method, Room cured

Figure 10: Comparison of ILSS (Mpa) & Impact Strength (Joules)

Epoxy + 5% Cyanate Blended Epoxy + 10% Cyanate Blended
Epoxy+15% Cyanate Blended Epoxy, 1200 GSM, Uni-
Directional, 4 plied & cross plied, Hand layup method, Oven Cured

Figure 11: Comparison of ILSS (Mpa) & Impact strength (Joules)

Epoxy 4 plied + 15% Epoxy Cyanate blended epoxy + 0% Glass filled Cyanate Blended Epoxy + 10% Glass filled
Cyanate Blended Epoxy + 20% Glass filled Cyanate Blended Epoxy, 30% Glass filled Cyanate blended Epoxy, 1200
GSM, Uni Directional, 4 plied & cross plied, Compression moulding, Oven cured

Figure 12: Comparison of ILSS (Mpa) & Impact strength (Joules)

Epoxy 4 plied + 15% Epoxy cyanate Blended epoxy + 0% Glass filled Cyanate Blended Epoxy + 10% Glass filled
Cyanate Blended Epoxy + 20% Glass filled Cyanate Blended Epoxy, 30% Glass filled Cyanate blended Epoxy, 1200
GSM, Uni Directional, 3 plied & cross plied, Compression moulding, Oven cured

Figure 13: Comparison of ILSS (Mpa) & Impact strength (Joules)

15% Epoxy + 3% Glass filled Cyanate Blended Epoxy + 5% Glass filled Cyanate Blended Epoxy + 7% Glass filled Cyanate Blended Epoxy, 1200 GSM, Uni Directional, 4 plied & cross plied, Compression moulding, Oven cured

Figure 6 captures the role played by higher gsm 1200 unidirectional fiber under room curing conditions in establishing it as the better reinforcement fiber among the all other types of fibers.

Figure 7 captures the further enhancement in the value of 1200 gsm fiber when being used under oven curing conditions

Figure 8 compares the laminate thickness and filler concentrations on the ILSS and Impact strength.

Figure 9 provides the details about the reinforcing capabilities of glass microspheres and fumed silica particles.

Figure 10 relates the significance of thinner to thicker laminates in controlling the properties.

4. RESULTS & DISCUSSIONS

It was observed that the impact strength was found to be better for 4 plied hybrid laminates with 1200 gsm filled with fillers cured through oven curing. Impact strength depends on mainly matrix behavior, its adhesion tendency with respect to the matrix and to some extent the fiber surface chemistry. The addition of particulate fillers adds up to the reinforcement enabling better surface matrix interface off the principle x-y plane. Weave style and fiber orientation across the section will also add up to the matrix interface strengthening. It was observed that the stiffer and tougher 4 plied oven cured laminate with a maximum impact strength of 10 Joule with an ILSS strength measured at 30 Mpa. Behaviour of the dispersed particles beyond the optimum addition was found to have a detrimental effect on the laminate structural strengths due to its influence on bringing down the net cross section besides nucleating the micro cracks in the vicinity of the debonded dispersed fillers. Better impact strength was also found out of the natural tendency of the cyante blended epoxy to get toughened out of increased cross linked density due to oven curing. Matrix Rheology is less significant in deciding ILSS than impact strength. The matrix rheological behavior in resisting the deformation could be enhanced by adding the reinforcement in terms of fillers concentration. The roles of two different types of filler here predicts the positive influence of micro spheres concentration till its optimum value of 10% at which it gains 25Joules against the impact load and in fumed silica, rather a very less concentration of 3% itself is good enough to offer an impact strength of 29.2 Joules. This is due to the thixotropic tendency of fumed silica and its inability to get cured when added in larger concentrations. The latter's better performance is owing to the agglomeration besides its grouping to pin down the cracks and the wide dispersed tendency of fumed silica in the matrix, enabling it to offer better stiffness to the matrix, under impact (1)

The ILSS of a laminated PMC depends on matrix phase additions like fillers, the matrix mixing procedure, the glass fiber finish chemistry, and its slenderness' ratios, concentration and the matrix Rheology, though not so significant like that in impact. If the ability to improve the fiber matrix adhesion could be achieved, then the rate of transverse crack growth across the z plane could be reduced and further it could also bring down the possibility of failure by delamination between the plies out of debonding at the interfaces. By adding fillers off the principle plane of x-y direction, matrix gets tougher by the added reinforcement and in turn they inhibit the growth of transverse cracks across the section.(1). The three ways to reduce the number of ply failures in the z-direction are to increase the resin-to-resin bond strength which is enhanced by toughening during oven curing, to increase the strength of resin to-glass interface by using 1200 gsm thick fiber with a superior fiber chemistry, and to minimize the differences in the thermal properties of the laminate by adding different fillers exhibiting different

Although a cross-ply lay-up within the laminate has been interlinear shear loaded, damage and failure could only be found within the transverse plies, as shown in the fractured images. Over their thickness, fiber/matrix-deboning proved to be pronounced near the ply boundaries of the transverse plies, where exceptionally high shear strains could be found. De bonding was found to be near the ply boundaries of Cross plies across the section with localized larger stress concentrations. (2)

Transverse crack damage was generally the first observed damage. The second type of damage was longitudinal cracking and/or delamination was found to be more in 5 plied thicker laminates, as shown in the images.(3) For these failures, the main factor appears to be the increase in stress due to the reduction in net cross-section. Failure of specimens with high levels of distributed voids was also consistent with failure being controlled mainly by the reduction in net section. It is suggested that the commonly observed decrease in inter laminar shear strength with voids is due to a combination of the reduction of cross-sectional area due to distributed voids and initiation of failure from larger discrete voids. Voids thus reduce the net section area and besides that initiate cracks from larger discrete voids. (4) Presence of blisters, de bonding and de laminations across the plies were seen in the fractured sections of the different laminates, as shown in the images. The varying pattern of failure by ILSS mode, further substantiates the prominent reason behind them, like increased void content either due to faulty filler concentrations in case of hybrid composites or because of poor interfacial bond strength between reinforcements and the matrix. The onset of de lamination and fractures was found faster in the specimens with un optimized filler concentrations (5). On the interdependence of the curing and the fillers volume fraction in influencing the toughness and hence the impact strength , an irregular response pattern was observed.(13)

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