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Effect of Aviation Turbine Fuel Exposure on Interlaminar and In-plane Shear Properties of Glass Fiber Reinforced Epoxy Composite

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ABSTRACT

This study investigated the effect of aviation turbine fuel exposure on interlaminar and in-plane shear properties of E-glass/epoxy composite. The two types of test specimens, namely bare and resin-coated specimens with varying thicknesses as per the ASTM standard, were made out of E-glass/epoxy composite to evaluate their interlaminar and in-plane shear properties. These all types of specimens were immersed inside the aviation turbine fuel for two months and then afterward their effect on the reduction of mechanical properties like interlaminar and in-plane shear tests properties were experimentally investigated. Test results show that ATF fuel exposure has reduced the interlaminar shear strength by 10.04 %, 7.83 %, and 6.01 % for bare, with 0.1 mm and 0.2 mm resin coating, respectively. Similarly, in-plane shear strength was reduced by 14.75 %, 11.22 %, and 7.52 % for bare, with 0.1 mm and 0.2 mm resin coating, respectively, and in-plane shear modulus was reduced by 10.87 %, 8.94 %, and 6.52 % for bare, with 0.1 mm and 0.2 mm resin coating conditions as compared to as-received (without ATF exposure) specimens.

SEM micrographs and results too showed that properties were reduced and indicated that the glass/epoxy composite was resistive to fuel ingression. It was observed that bare specimens exhibited a reduction in shear properties due to ATF ingression to the polymeric network and induced internal stresses, which not only degraded the matrix and fiber-matrix adherence but created micro-cracks too in the resin at interfaces. Resin-coated specimens limit fuel ingression, which has led to a reduction in properties.

Keywords: Aviation turbine fuel; Mechanical property; Fuel exposure; E-glass/Epoxy; Inter laminar; In-plane shear

1. INTRODUCTION

The relentless passion of the aerospace industry to augment its performance is constantly driving the way to explore high-performance structural materials, i.e., composite. Composites are becoming the prime material in various industries because of their low weight and improved properties and are being used not only for structural application but ablative purposes too. These are widely used for spacecraft components, hot air balloons, gliders to fighter planes, space shuttles, and commercial aircraft. Increased usage of composite in the aerospace industry was possible because of its advantages like significant weight reduction, drapability, high thermal stability and impact resistance, resistance to fatigue and corrosion, and ease of assembly. Composite materials enable the integration of parts and lead to the replacement of various metallic components by a single monolithic composite component.[1] Rapidly, these key factors of the composite are outweighing the usage of metal in the aerospace industry.[2]

During the storage for a longer span, the long-term performance of the composite is to be ensured. As the structures, which are being made using these composites, need to be in service for a longer time, and it has to be exposed to various types of loading and environmental conditions. In aerospace, the composite drop tanks for fighter aircraft are made out of glass/epoxy composites and are being used to carry aviation turbine fuel. Hence, the glass/epoxy composite's tendency towards the absorption of the fuel will decide its degradation of mechanical properties. This degradation will be detrimental to the structural performance. So, studying the effect of ATF exposure on glass/epoxy composite has become very significant to establish the design margin for the composite structures, which store the fuel.

The interlaminar and in-plane shear properties play an important role in designing structural composites, so degradation of any kind will not only lead to failure but will restrict its usage.

The composite is porous and has the tendency of ATF ingression, to limit the same and to cater to the structure which is being used for storage of the liquids, providing the resin coating has become the must. Keeping that in the mind, bare and resin-coated specimens were tested after giving the ATF exposure separately to a distinct set of specimens, to know the actual effects on Interlaminar Shear Strength (ILSS) and In-Plane Shear Strength (IPSS).

Sandeep V. Gujjar, *et al*.[3] described the effect of different types of resin coating on a mild steel surface to get the ideal one. These resins (epoxy, phenolic, polyurethane, and polyester)

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were applied to the metallic surface using the pneumatic spray method and after this immersion as well a salt spray test using a solution of NaCl was carried out, which was followed by the estimation of the rate of corrosion and evaluation of its mechanical properties and found that epoxy resin coating was extremely effective and exhibited better properties relative to other coatings. Baig, *et al.*[4] aimed to study the recent advancement in the development of epoxy resin coating for tribological application. It was observed that several metallic, polymeric, ceramic, and carbon-based filler suspensions to epoxy resin matrices will improve the tribological performance of the coating.

Kumarasamy, *et al.*[5] illustrated the effect of various types of fuel solutions on tensile and compressive properties of glass/epoxy composite. Once the test specimens were immersed in the respective solution and got saturated, after this it will be followed by its mechanical testing. It was observed that tensile and compressive properties underwent slight degradation because of the formation of micro-crack and voids inside the composite when it is exposed to immersion. Adettunji, *et al.*[6] studied and reported the protective efficiency of epoxy-based coating on the metallic plate in NaOH, HCl, and distilled water media. Test result outcome shows that epoxy resin coating was effective for the metallic plate of mild steel in HCl and distilled water media but ineffective for NaOH media.

A.P. Chakraverty, *et al.*[7] demonstrated the influence of the absorption of moisture on the mechanical properties of glass/epoxy composite under hygrothermal conditioning and hydrothermal immersion. It was found that hygrothermal exposure is more detrimental compared to hydrothermal, but temperature and time of exposure also play an important role irrespective of the type of exposure. Hygrothermal conditioning and hydrothermal immersion reduced ILSS and glass transition temperatures, as the moisture not only induces the matrix plasticization and swelling but will lead to the breakdown of a chemical bond at the interfaces of the fiber and matrix. Groysman[8] this work aimed to study the solutions and corrosion problems in the oil, refining, gas, and petrochemical industry. The phenomena and factors affecting the corrosion were discussed. Further, corrosion control and monitoring methods were illustrated.

Yadav Khagendra Kumar, *et al.*[9] studied the effect of GFRP laminate's flexural properties, after immersing the same in aviation fuel like AVGAS 100 LL and ATF, and the laminate was fabricated using a vacuum infusion technique. It was reported that exposure of both the solutions of aviation fuel to GFRP laminate affected the flexural properties and showed a reduction. The effect was relatively more for ATF immersion on the reduction of flexural properties. Bin Wei, *et al.*[10] illustrated the efficacy of seawater treatment on the reduction of bending and tensile strength of basalt and glass/epoxy composites. It was found that the deterioration of these composites was observed because of the combination of absorption of water and extraction of soluble material, where absorption of water led to matrix swelling and cracking and extraction of soluble material will degrade the interfacial adhesion of fiber and matrix.

Silva, *et al.*[11] focussed on the study of the effects of various environmental conditions on the epoxy's mechanical characteristics.

Chaichanawong, *et al.*[12] exhibited the influence of moisture on the various mechanical properties of glass fiber-reinforced polyamide resin composites, and Akay, *et al.*[13] focussed on the impact of moisture on the mechanical as well as the thermal properties of oven-cured and autoclaved kevlar-49/epoxy laminates. Mahto, *et al.*[14] reported the in-service qualitative assessment of polymeric composites in various environmental conditions, and Tsenoglou, *et al.*[15] discussed the evaluation of relaxation of fiber-matrix interfacial behavior caused by water absorption in composites. Sateesh, *et al.*[16] conducted a study of the environmental impact of GFRP composites and evaluated its effect on the degradation of mechanical parameters. Kootsookos, *et al.*[17] studied the seawater effect or aging over the glass and carbon-based composites.

Khanna, *et al.*[18] analyzed the drilling performance of CFRP composites and carried out experimental trials to establish various cutting parameters under cryogenic and dry cooling conditions. Navneet, *et al.*[19] developed lubrication and cooling technologies to cater to the requirement of machining metal matrix composites and Magnesium. Agrawal, *et al.*[20] reviewed critically the improvement of cryogenic machining setups for composites and alloys.

The researchers like Komorek, *et al.*[21], Mourad, *et al.*[22], Jose-Trujillo, *et al.*[23], Abdurohman, *et al.*[24], and Wood, *et al.*[25] studied and analyzed the effect of seawater on composites.

Nevertheless, most of these studies used seawater or distilled water for immersion to explore the residual strength of epoxy-based laminates. The available data is limited for the glass/epoxy composite, which has undergone ATF exposure. In addition to this detailed study of the E-glass/epoxy laminate made, using prepreg was also not seen, as mostly in research papers it was observed that the composite laminates were fabricated using vacuum infusion technique, resin transfer molding (RTM) process or by wetting the fabric with resin using tabletop process. Hence, this research was carried out for a detailed understanding and enhanced learning of the ATF fuel exposure effect on the mechanical properties of glass/epoxy composite laminates.

Furthermore, investigations were not seen that report a comparative deliberation about the ATF exposure on mechanical properties of glass/epoxy laminates of composite having resin coating of different thicknesses. The different thicknesses, i.e., 0.1 and 0.2 mm resin coating, were given over the test specimens to see the effect of ATF exposure. As the resin coating over the test specimen will not only reduce the degradation of shear properties but keep the ATF penetration to a surficial level too. Furthermore, the possibilities were explored to establish the optimum resin coating thickness, which will restrict the degradation of interlaminar and in-plane shear properties of glass/epoxy composite to the minimum.

This paper aims to evaluate the longer-duration effect of ATF on the mechanical parameters of glass/epoxy composite. A detailed systematic study is conducted to determine and correlate the ATF aging effect on the mechanical properties of the said composite in bare and resin-coated conditions for better understanding and to improve the design of aerospace

components having ATF exposure. The durability of E-glass/epoxy composite under ATF exposure was described in this paper.

2. MATERIAL AND METHODS

2.1 Materials

Glass/epoxy prepregs with the following specifications are taken.

Table 1. Prepreg specifications

Parameter	Specified values
The areal density of prepreg, GSM	450
Volatile content by % weight	<1%
Resin content by % weight	37
Fabric content by % weight	63
The areal density of the fabric, GSM	300
Thickness of prepreg	0.23 mm
Tackiness	Medium tack condition
Glass Type	E-Glass
Resin	Epoxy
The manufacturing process for laminate	Contact hand layup with vacuum bagging
No. of layers	18 for ILSS, 12 for IPSS
Stacking sequence	BD fabric $[0^0]_{18}$ for ILSS, $[\pm 45^0]_{3S}$ for IPSS

2.2 Laminate Preparation

As E-glass epoxy prepreg is being used as a candidate material for laminate fabrication, which is having less than 1% volatile content and a zero-bleeding system, hence porosity levels in the test specimens made by this prepreg will be extremely low. The metallic flat plate was used to stack the required number of layers in the desired direction, and the requisite laminates were made as per respective ASTM standards.

The laminates were prepared using the E-glass/epoxy prepregs, which were having the mechanical properties mentioned in Table 2, and by the autoclave curing process. The required number of layers in the desired direction is laid up on the metallic mold and the laminates were made as per respective ASTM standards. These laminates are cured in an autoclave under vacuum and pressure. A vacuum level of 600 torr was maintained for initial 30 minutes, which was followed by maintaining 150 Torr for the remaining period of curing. It was cured at 135 ^{0}C and a pressure of 3750.31 Torr was maintained during curing. The laminates were tested by ultrasonic for delamination and other defects, as shown in Fig. 1.

The bare specimens were cut directly out of the laminates and for making the resin-coated specimens, laminates were coated with a brush with a known amount of epoxy resin, i.e., AY103 epoxy resin and HY951 hardener (100:10), as per their laminate size to get the requisite thickness. The uniformity of coating thickness was obtained by using the wiper/doctor blade. These blades were used to remove excess resin. After drying the coated resin at room temperature, the resin-coated specimens were cut from laminates, and after cutting; the specimen in the thickness direction was also coated with resin.

Table 2. Mechanical properties

Parameter	Specified values	ASTM Standard
Laminate density	1.85 g/cc	ASTM-D-792
Fiber volume fraction	63%	ASTM-D-2584
Tensile strength	380 MPa	ASTM-D-3039
Tensile modulus	24 GPa	ASTM-D-3039
Flexural strength	670 MPa	ASTM-D-790

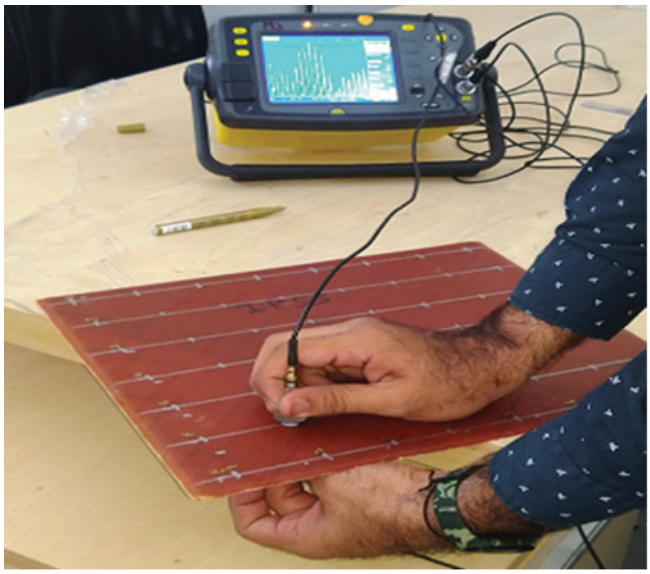

Figure 1. Test laminate undergoing UT test.

2.3 Specimen Preparation

The interlaminar shear test specimens of desired size meeting the ASTM D 2344 were made. Similarly, in-plane shear test specimens were also made as per ASTM D 3518 standard. The specimens from laminate were cut using the diamond cutter to give edges without fuzzing and delamination. As specimens are to be checked for % of fuel ingression in definite intervals till they got saturated, traveler coupons were also cut and prepared.

The specimens altogether were made for three different types namely bare, 0.1 mm, and 0.2 mm resin-coated, to know how the resin coating affects the rate of fuel absorption.

2.4 Exposure to Aviation Turbine Fuel (ATF)

At the outset, the prepared specimens can have some degree of moisture ingression from the environment that has to be dried

up inside a hot oven by executing a de-moisturization cycle at 110 ^{0}C for 1 hr. After the completion of this cycle, all the specimens and traveler coupons were initially weighted before giving ATF exposure. After this, it was immersed inside the container, which contains the ATF. The weight changes of the traveler coupons were daily measured to determine the amount of ATF ingression. The traveler coupon was periodically taken out and its surface was dried using tissue paper and weighed again using the electronic weighing balance of 0.1 mg accuracy, to know the rate and amount of ATF absorption till the saturation stage comes. The weighing frequency was initially fast, up to one week, and it was slowed down as the process continued. Conditioning was continued for up to about two months. The ATF ingression of the respective specimens was calculated using the initial weight and weight of the specimens after this exposure at a given time. As the specimens, which were immersed in ATF exposure were categorized under bare, 0.1 mm, and 0.2 mm resin coating, for each category of specimens, three samples each were used for bare, 0.1 mm and 0.2 mm resin coated and the average weight gain was determined. It was observed that bare specimens were undergoing a high rate of ATF absorption, and 0.2 mm resin-coated specimens show a lower rate of absorption.

The % of ATF gain or loss, relative to dry weight, is computed and is depicted as a dry weight percentage

$$\text{ATF absorption} = \frac{W_t - W_0}{W_0} \text{x} 100$$

where W_0 is the dry specimen weight (before immersion) and W_t is the wet specimen weight at the time "t" (after ATF immersion)

3. MECHANICAL CHARACTERIZATION

To correlate the test result after ATF exposure, the specified property (as-received) of the glass/epoxy composite before exposure is to be established. The test specimens for evaluating all mechanical parameters were made accordingly as per respective ASTM standards which were followed by a de-moisturization cycle and after this, these specimens underwent respective tests to establish as-received properties.

A different set of specimens was made for interlaminar and in-plane shear properties requirements as per respective ASTM standards, to cater to the need for ATF exposure to bare, 0.1 mm, and 0.2 mm resin-coated specimens, and all were dried-up up inside the hot oven at 110 ^{0}C for 1 hour to remove the initially absorbed moisture ingression from the environment.

The ATF exposure for two months was given to E-glass/epoxy composite, and afterward, it has undergone the following tests, to know the degradation of mechanical properties.

3.1 Interlaminar Shear Strength (ILSS) Test

Interlaminar shear strength (ILSS) test samples of different types were immersed in ATF and the samples were given two months of exposure to this ingression, the test was conducted using a servo mechanical universal testing machine as per ASTM D 2344 standard.[25] The dimensions of the specimens were maintained as per ASTM requirements, i.e., 40 mm long X 12 mm wide X 4.14 mm thick. The interlaminar shear strength (ILSS) is determined using a fixture of the three-point test as shown in Fig. 2. The material direction, which will undergo investigation, shall be oriented along the lengthwise dimension of the test specimen. The span/depth ratio of the test pieces shall be kept low enough for minimizing the effect of bending deformation, resulting in shear failure rather than bending.

Figure 2. Test specimen undergoing interlaminar shear strength test.

The interlaminar shear properties before (as-received) and after ATF exposure are as follows.

3.2 In-plane Shear Strength (IPSS) Test

In-plane shear test samples of different types were immersed in ATF and the samples got exposed for two months with this ingression, afterward test was conducted using a servo mechanical testing machine according to ASTM D 3518 standard[26] as shown in Fig. 3. The dimensions of the specimens were maintained as per ASTM requirements, i.e., 250 mm long X 25 mm wide X 2.76 mm thick.

The laminate was prepared using the stacking sequence of +45^0/-45^0. The significance of choosing this stacking sequence is such that the laminate is specially orthotropic, and the coupling effect generated due to bending stretching and the anisotropic effects of in-plane bending are avoided.

This test calculates the in-plane shear strength (IPSS) and

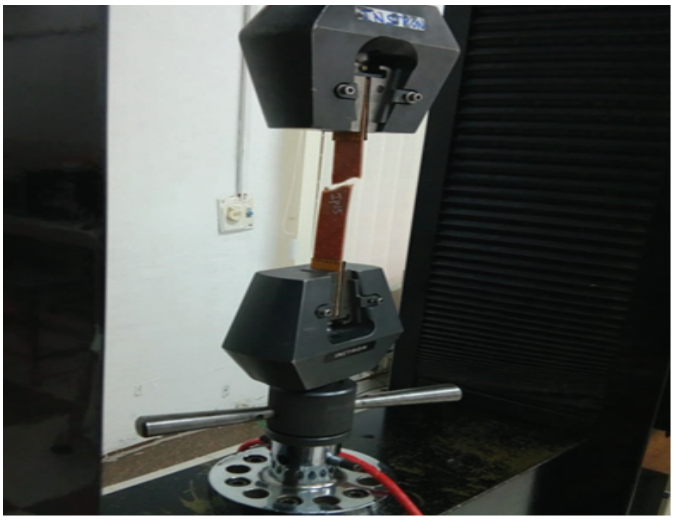

Figure 3. Test specimen undergoing in-plane shear strength Test

modulus. A uniaxial tension test on $+45^0/-45^0$ test specimens was conducted to evaluate the in-plane shear properties. The test specimen will undergo that kind of load which will only generate a pure shear stress state and the corresponding strain is recorded.

Rosette strain gauges are used on testing specimens to record strains along the direction of loading and perpendicular to the loading direction. The in-plane shear modulus is determined from the curve of stress-strain.

4. RESULT AND DISCUSSIONS

Slight reductions in interlaminar shear strength (ILSS) and in-plane shear strength (IPSS) were observed compared to as-received specimens, but it was not significant as the glass fibers are chemically resistant. This slight reduction of properties is happening because of the formation of micro cracks and voids, generated out of stresses induced internally because of ATF penetration to the matrix network. In addition to this, penetration of fuel is weakening the interfacial properties of matrix and reinforcement, which is further leading to properties degradation.

4.1 Interlaminar Shear Properties

Interlaminar shear strength (ILSS) of as-received (without ATF exposure) glass/epoxy test specimens was determined and obtained a mean value of 68.21 MPa. After this, interlaminar shear strength was evaluated experimentally for distinct types of glass/epoxy specimens namely bare and specimens with the 0.1 and 0.2 mm thick epoxy resin coating, which has undergone ATF exposure. The interlaminar test specimens were tested experimentally for bare and with 0.1 mm and 0.2 mm resin-coated conditions, and a correlation of data was made with the as-received specimen property. It was observed that interlaminar strength was reduced by 10.04 %, 7.83 %, and 6.01 % for bare, with 0.1 mm and 0.2 mm resin coating, respectively, as depicted in Fig. 4.

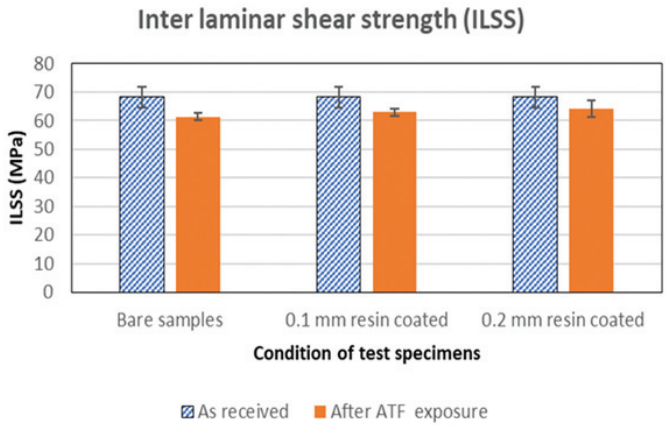

Figure 4. Comparison chart of interlaminar shear properties for as-received specimens with bare and resin-coated specimens after ATF exposure.

Table 3. Effect of ATF exposure on interlaminar shear strength of glass/epoxy composite

Sample condition	Average interlaminar shear strength (in MPa)	
	As-received	After ATF exposure
Bare samples	68.21	61.36
0.1 mm resin coated		62.87
0.2 mm resin coated		64.11

The interlaminar shear strength before (as-received) and after ATF exposure are as follows.

4.2 In-plane Shear Properties

In-plane shear properties of as-received (without ATF exposure) glass/epoxy test specimens were determined, obtaining a mean value of in-plane shear strength and shear modulus of 99.12 MPa and 4.14 GPa, respectively. The in-plane shear specimens were tested experimentally for bare and with 0.1 mm and 0.2 mm resin-coated conditions, and a correlation of data was made with the as-received specimen property. It was noticed that in-plane shear strength was reduced by 14.75 %, 11.22 %, and 7.52 % for bare, with 0.1 mm and 0.2 mm resin coating, respectively as shown in Fig. 5, and 10.87 %, 8.94 %, and 6.52 % degradation in terms of in-plane shear modulus for bare, with 0.1 mm and 0.2 mm resin coating conditions respectively, as depicted in Fig. 6.

The in-plane shear properties before (as-received) and after ATF exposure are as follows.

Error bars as shown in Fig. 4, 5, and 6 were evaluated by using the standard error on the standard deviation of the mean value of the measurements.

The effect of ATF ingression in terms of degradation of interlaminar and in-plane shear properties was notable. To compare and assess the damage mechanisms originated in the fiber-matrix interface for different types of test specimens, before and after the ATF exposure, the fractured surface of the tested interlaminar, and fractured fibers of the tested in-plane shear specimens were investigated by using Scanning Electron microscope (SEM). The fractured surfaces of Interlaminar Shear Strength (ILSS) test specimens and fractured fibers of in-plane shear test specimens were investigated using a SEM. It was observed that fractured surfaces of bare ILSS test specimens underwent ATF exposure and exhibits matrix cracking under different magnifications, as shown in Fig. 8 and 9. The test specimens, which were coated with 0.1 and 0.2 mm resin coating also underwent SEM examinations and found that ATF exposure only degraded the resin coating on the surface and generated the crack, but it restricted the ATF ingression to test specimens. The size of the surface crack of the 0.1 mm

Table 4. Effect of ATF exposure on in-plane properties of glass/epoxy composite

Sample condition	Average in-plane shear strength (in MPa)		Average in-plane shear modulus (in GPa)	
	As-received	After ATF exposure	As-received	After ATF exposure
Bare samples	99.12	84.5	4.14	3.69
0.1 mm resin coated		88.0		3.77
0.2 mm resin coated		91.67		3.87

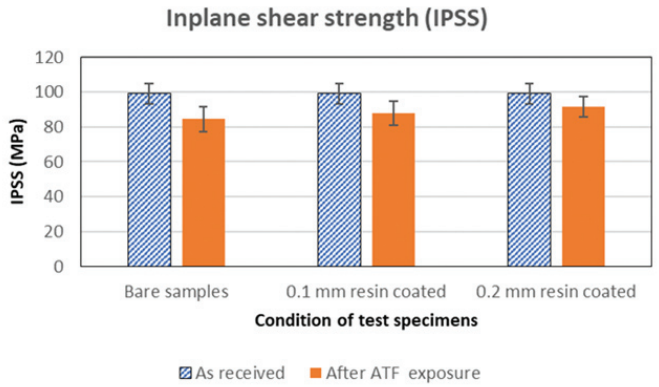

Figure 5. Comparison chart of in-plane shear strength for as-received specimens with bare and resin-coated after ATF exposure.

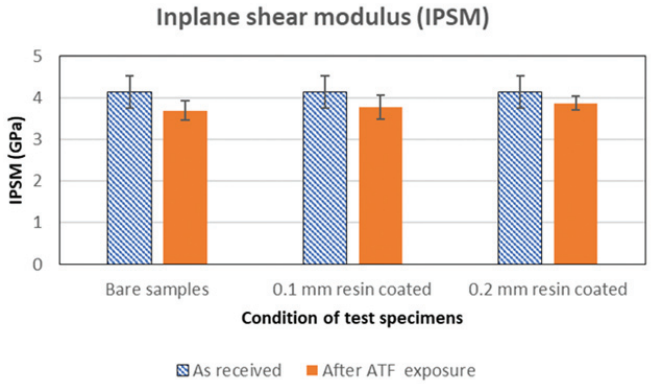

Figure 6. Comparison chart of in-plane shear modulus for as-received specimens with bare and resin-coated after ATF exposure.

resin-coated substrate was more than the 0.2 mm resin-coated one, as shown in Fig.10 and 11.

Similarly, fractured fibers of in-plane shear test specimens were examined before (Fig.12) and after ATF exposure, and it was noticed that bare-tested specimens exhibited maximum degradation compared to resin-coated ones. SEM micrographs revealed that bare specimens underwent matrix cracking, crumbling, and debonding on the matrix fiber interface as shown in Fig.13, whereas the resin-coated tested specimens were limiting the ATF ingression, which gave a relatively lower reduction, as depicted in Fig.14 and 15.

Followings are the observations:

- The tested specimens (bare condition), underwent ATF exposure, exhibiting some reduction of interlaminar and in-plane shear strength compared to as-received. It was observed from SEM's images, that for tested specimens (bare condition), the ATF ingresses the polymer chain and generates internal stresses[18,21] and it will not only degrade the fiber matrix adherence[7] but will create micro-cracks too in the resin at interfaces. SEM Micrographs of fractured surfaces of the test specimens show that it was not clean, and fiber-matrix degradation was one of the reasons. Primarily, this is responsible for the reduction of interlaminar and in-plane shear strength.
- Moreover, specimens with 0.1 mm and 0.2 mm resin-coated exhibited comparable slight decrement of the interlaminar and in-plane shear properties and not allowed notable ingression of fuel molecules inside the polymeric network. In addition, 0.2 mm resin-coated were comparably more impermeable to fuel ingression than 0.1 mm resin-coated specimens, and ATF ingression was restricted to the top surface and prevented its ingression to fiber-matrix interfaces, which has further led to only a slight reduction in the properties.
- A slight reduction was observed in terms of in-plane shear modulus too, and this reduction is due to the increased cross-linkage force in the polymeric chain between the matrix and the fiber. The brittleness was exhibited for tested specimens, and it is due to the ATF molecule which ingresses into the polymeric network and restricted its mobility. Hence, the composite will slightly lose its elasticity. A behavior similar to this was reported by Kumarasamy and Genanu[5,28].
- Resin coat application is found to help in minimizing the degradation of properties after ATF exposure. The plot of normalized ILSS strength parameter $\Delta L/L$ (where ΔL is the difference of average ILSS strength values before and after ATF exposure and L is the ILSS strength value before exposure) for bare and resin-coated specimens is shown in Fig. 7. Normalized ILSS strength parameters were correlated with coating thickness and were plotted in the form of the curve to establish the optimum coating thickness. It is visible from the plot the specimen resin coated with 0.5 mm thickness will exhibit minimum reduction.

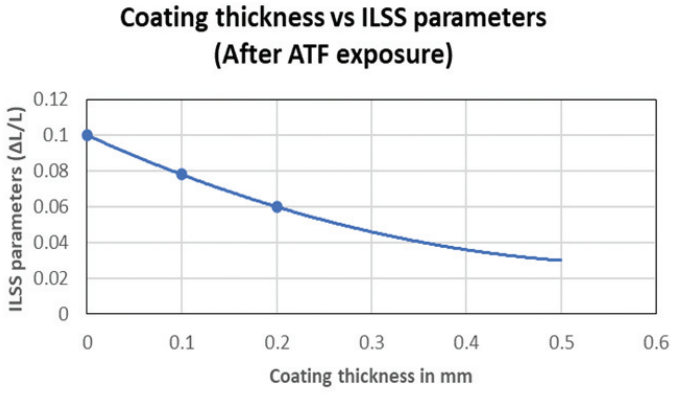

Figure 7. Coating thickness vs ILSS parameters (after ATF exposure).

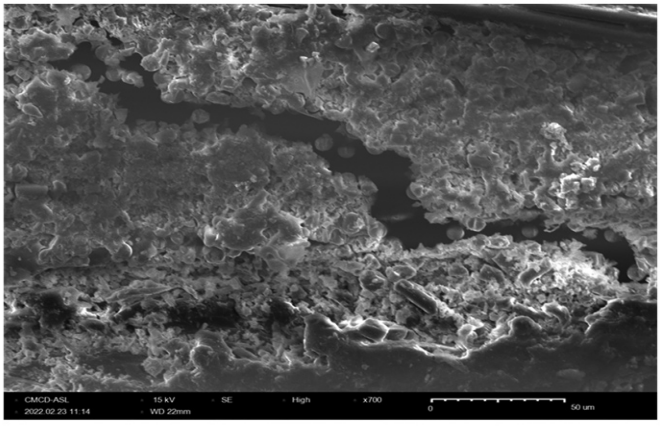

Figure 8.SEM Micrograph of ATF exposed tested samples of ILSS (without resin coating).

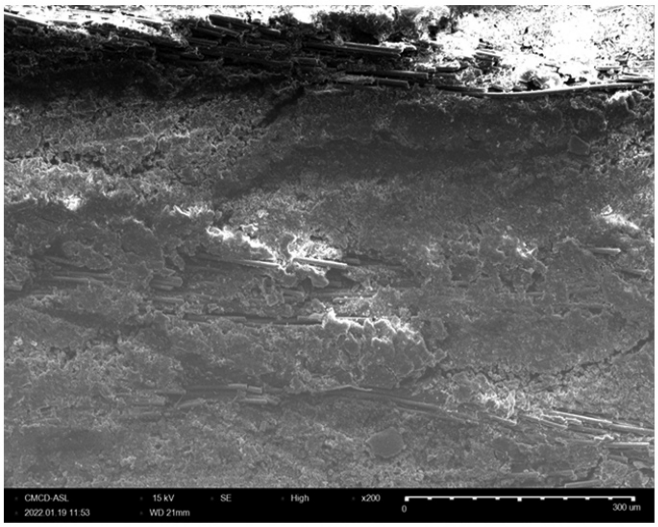

Figure 9. SEM Micrograph of ATF exposed tested samples of ILSS (without resin coating).

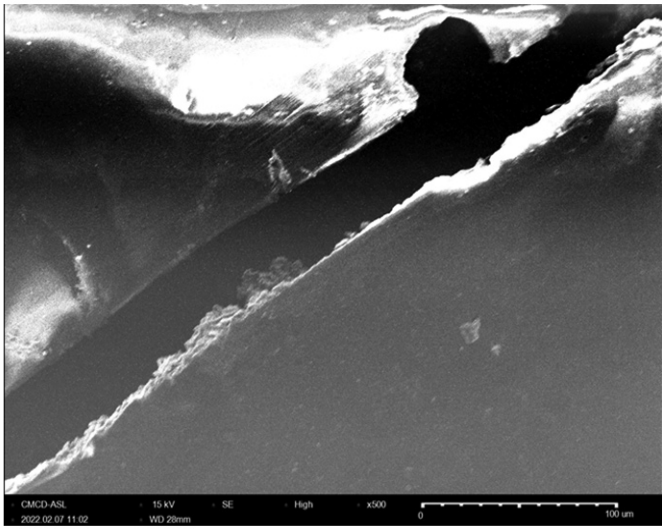

Figure 10. SEM Micrograph of ATF exposed tested samples of ILSS (with 0.1mm resin coating).

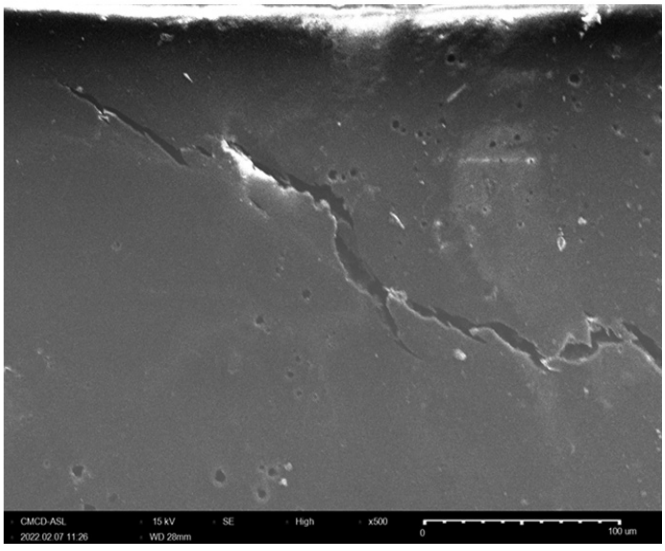

Figure 11. SEM Micrograph of ATF exposed tested samples of ILSS (with 0.2mm resin coating).

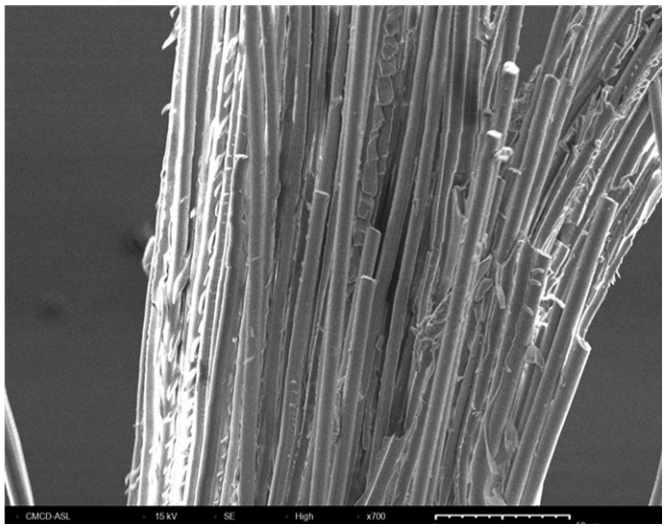

Figure 12. SEM Micrograph of fractured fibers of tested samples of IPSS (without any exposure).

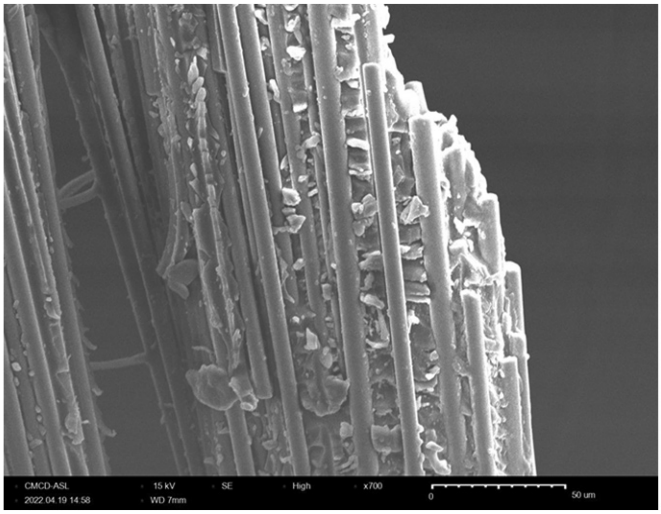

Figure 13. SEM Micrograph of fractured fibers of tested samples of IPSS (without resin coating & after ATF exposure).

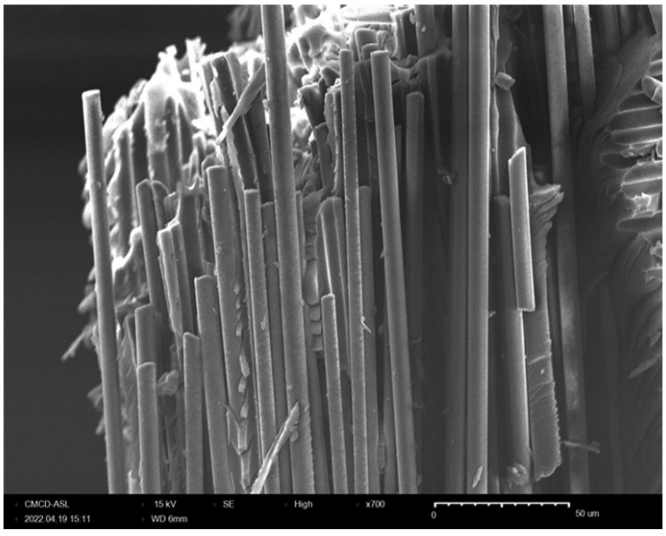

Figure 14. SEM Micrograph of fractured fibers of tested samples of IPSS (with 0.1 mm resin coating & after ATF exposure).

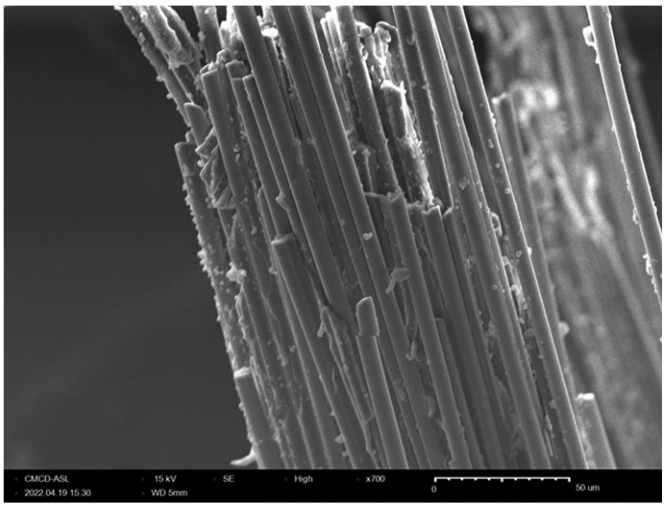

Figure 15. SEM Micrograph of fractured fibers of tested samples of IPSS (with 0.2 mm resin coating & after ATF exposure).

5. CONCLUSION

This paper investigated the ATF exposure effect on mechanical properties of E-glass/epoxy composite and discussed two varieties of specimens, namely bare and resin coated. The following main conclusion was observed:

- The test specimens of Inter laminar and in-plane shear properties have shown a significant reduction of properties w.r.t ATF exposure. But test specimens for in-plane exhibited a 14.75 % reduction in comparison to 10.04% of interlaminar.
- ATF exposure has reduced the in-plane shear modulus of the bare and resin-coated test specimens. For bare specimens, it was reduced to 10.87 % and for 0.2 mm coating thickness, restricted to 6.52 %.
- As the exposure was given for three conditions, namely bare, 0.1 mm, and 0.2 mm resin coating, it was observed that the test specimens which were resin coated with 0.2 mm coating exhibited lower degradation compared to the other two conditions.
- It was explicitly visible that bare and 0.1 mm resin-coated testing specimens got saturated comparably faster than 0.2 mm resin-coated ones. The rate of absorption of the ATF penetrations was less for 0.2 mm resin-coated specimens. It was expected as the resin coating was not allowing the ingression as, after the application of the same, porosity will be reduced. Application of resin coating to the test specimen of E-glass/epoxy composite is limiting the ATF ingression to the surface and restricting its detrimental effect on matrix interface degradation.
- These property degradations were majorly due to resin plasticization and fiber-matrix interface degradation. As the fuel penetrates, it creates internal stresses in the cross-linked network, which will further lead to reduced mechanical properties.
- The plot of coating thickness with normalized ILSS parameters exhibits that 0.5 mm resin coating will be as good as virgin samples. Thus, a minimum 0.5 mm resin coat is recommended.

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