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Improvement of the Interlaminar Shear Strength on Surface Modified Glass Fibre/Stainless Steel Wire Mesh Reinforced Hybrid Composites

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Abstract : This paper investigates theinterlaminar shear behavior of surface modified glass fiber/ stainless steel wire mesh reinforced epoxy hybrid composites. The glass fiber is treated either by 1N solution of sulfuric acid or sodium hydroxide. The stainless steel wire mesh is also surface treated by either electro dissolution or sand blasting. The hybrid composites are fabricated using epoxy resin reinforced with glass fiber and fine stainless steel wire mesh by hand lay up method. The hybrid composite consisting of acid treated glass fiber and electro dissolved or sand blasted stainless steel wire mesh exhibits superior interlaminar shear property in comparison with the composites made without any surface treatment. The fine modifications identified on the surface texture of the glass fiber and stainless steel wire mesh enhances the bonding between the resin and reinforcement which improves the interlaminar shear strength.
Key words : Interlaminar shear strength, laminate.

1. Introduction

Polymer composites are widly used in automobiles, aerospace, home appliances and packaging industries due to a need of high strength, water proof and resistance to corrosion to avoid environmental attack.Furnitures, fittings and interior decorative items are made with polymer composites due to its low weight, high strength an resistance to moisture properties[1,2].Hybrid composites can be obtained by mixing more than one reinforcement in a matrix. It enhances desired mechanical properties and cost effective to meet design requirements[3]. Fiber reinforced polymer composites majorly used in aerospace and automobile components like cams,gears,brakes,wheels, rollers seals, liners for bearing, bushes and clutches[4].

Interlaminar shear behavior is an important parameter that to be justified before using the laminate in to structural applications. The resistance offered by a layered composite to internal forces that tend to reduce relative motion parallel to and between the layers[5]. Normally the value of interlaminar shear strength is low when compared to longitudinal tensile strength[6]. Various shear test methods were developed. The results obtained from these test are varied . Each test method has its limitation and inaccuracy[7]. The short beam shear test method has been popularly used to explain the resistance to interlaminar failure of FRP composites. This method is easy to perform with simple devices.

It could be noted that limited work has been carried out in the area of hybrid composite laminate especially with stainless steel wire mesh as reinforcement, and the role of surface treatment of glass fiber and stainless steel mesh has not yet been studied. This paper investigates the interlaminar shear strength of epoxy/glass fiber reinforced composite with and without surface treatment of the fabrics by acid and base to produce non hybrid composites and stainless steel wire mesh treated by electro dissolution and sand blasting to produce hybrid composites.

2 Experimental Procedure

2.1 Material selection

EPOXY **-** LY 556 resin, HARDNER – HY 956 was used as matrix. E-glass fiber bidirectional woven cloth of 400GSM with 0.4mm thickness and fine stainless steel (AISI 304) wire mesh with a wire diameter of 151µm with mesh opening size of 282µm were used as reinforcement.

2.2. Treatment of Reinforcements

A 300 x 300mm size of E-Glass fiber was dipped in two solutions, 1 N sodium hydroxide and 1 N sulfuric acid separately for 24 hours. After that these fibers were washed with purified water to clean the surface of the fibers, then dried at room temperature.

Surface treatment was done on Stainless steel wire mesh by Electro dissolution process. A 12V DC power source was connected to the stainless steel wire mesh to make it to anode and copper as cathode. Phosphoric acid was electrolyte. Sand blasting was performed on stainless steel wire mesh with fine (30-50 microns) abrasive sand particles. Wire mesh was sand blasted on both sides to obtain uniform surface treatment .

2.3. Fabrication of Composite laminate

Hybrid and non hybrid composites were fabricated by hand lay-up technique. Glass fiber and stainless steel wire mesh were cut into 300x300mm. The volume ratio of epoxy and glass fiber/Stainless steel wire mesh was 60:40. In the ratio of 10:1 grams the epoxy resin with hardner was mixed. The thickness of the laminate was maintained as 3 ± 1mm. In order to maintain uniform thickness of all the laminates the middle layer of glass fiber was removed when the stainless steel mesh wire was inserted into the stack to make hybrid laminate**.** The glass fiber and stainless steel wire mesh orientation and stacking sequence was shown in Fig-1. Compressive load of 200 KPa was applied on the laminate and allowed to cure for 24 hours at room temperature. Various types of fabricated laminates with their notations are listed in Table-1.

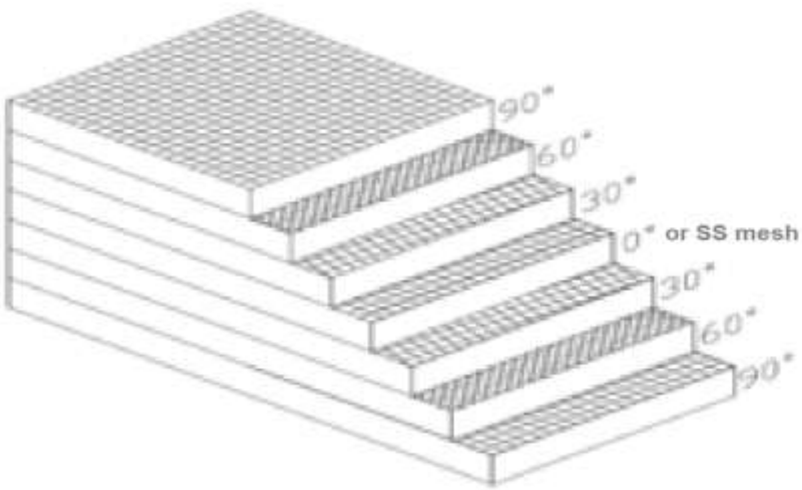

Fig-1 Fiber orientation of Non hybrid and hybrid composite

Table-1 Notations used to represent the composites.

S.No	Laminate Type	Notations used	Explanation
1	Non –hybrid	UGF	Untreated glass fiber
2		AGF	Acid treated glass fiber
3		BGF	Base treated glass fiber
4	Hybrid	UGFUM	Untreated glass fiber untreated mesh
5		AGFSBM	Acid treated glass fiber sand blast mesh
6		BGFSBM	Base treated glass fiber sand blast mesh
7		AGFEDM	Acid treated glass fiber electro dissolved mesh
8		BGFEDM	Base treated glass fiber electro dissolved mesh

2.4 Interlaminar shear test

A short beam test was used to determine the inter-laminar shear strength of the non-hybrid and hybrid polymer composites. The inter-laminar shear test measures the bond strength between the various layers in a laminate. The Inter-laminar shear test was conducted using 5 Ton capacity UTM (FIE make India). Small specimens of nominal size 25 X 5 X 3 mm were used. The inter-laminar shear test was conducted at a crosshead speed of 1 mm/min. The distance between the anvil is 11 mm.These specimens were tested according to ASTM D2344-84. The inter-laminar shear strength(I) was calculated by using the formula

$$I = 0.75P / bt$$

where P is load to fracture (N), b is the width (mm) and t is the thickness (mm). Three specimens of each laminate were tested and the mean value of the three tests were tabulated. The photograph of ILSS specimen mounted on UTM shown in Fig-2.

Fig -2 Photograph of Inter-laminar shear test (ILSS) specimen mounted on UTM.

3. Results and Discussion

3.1 Acid treatment of glass fiber

As an acid comes into contact with E-glass fibers, ionic exchange occurs between the metal cations at the glass surface and the positively charged hydrogen ions present in the acid solution, exhibits leaching of sodium, potassium, calcium, magnesium, boron and aluminium from the extreme layer of the fiber, dissolution of the silica network on fiber surface and eventually complete dissolution of fibers, slight enlargement of fiber diameter/shortening of fiber length as longitudinal stresses relax with formation of axial and helical cracks, reduction of weight, strength and stiffness[8]. Fig-3 shows the SEM images of sulfuric acid treated glass fibers. The SEM image indicates the presence of very fine ring like feature on the surface of the fiber.

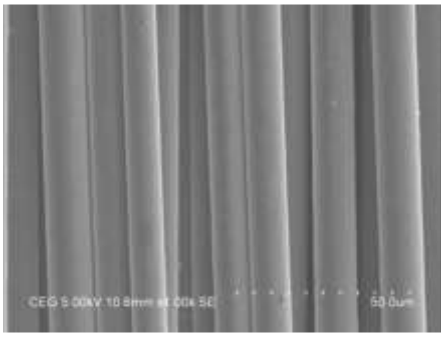

Fig-3 SEM images of sulfuric acid treated glass fiber shows presence of very fine ring like feature on the surface of the fiber.

3.2 Base treatment of glass fiber

As an alkali comes into contact with E-glass fiber, the chemical attack involves in a breakup of the silica network by hydroxide ions and eventual dissolution of the E-glass. The glass fibers drastically reduce strength and weight when they are in contact with strong alkalis. Immersion in weak alkaline solutions at room temperature results in strength reductions of 30% within 14 days. The dissolution of SiO_2 network determines the rate of degradation of alkalis. The loss of mass is proportional to time[8]. Fig-4 shows the SEM image of sodium hydroxide treated glass fibres. The presence of innumerous fine leach pits along with few severely leached regions are seen.

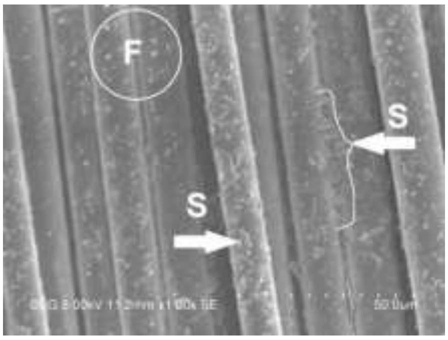

Fig-4 SEM image of sodium hydroxide treated glass fiber shows High magnification view of a representative region of fine leach pits(F) and severe leaching(S).

3.3 Electro dissolution treatment of SS mesh

Electrodissolution treatment is an electrochemical process[9]. During this process, the removal of metal happens on the metal surface. As a result, Fig-5 shows the surface of the metal wire with microscopically fine pits. These micropits facilitate the bonding between the resin and the wire mesh.

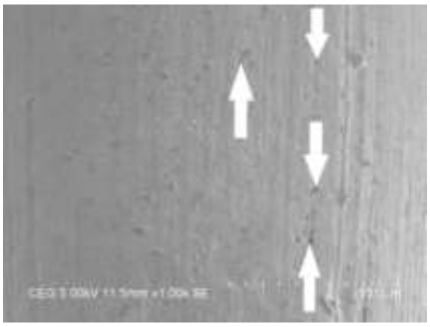

Fig-5 SEM image of the surface of the electro dissolution treated stainless steel wire mesh shows presence of numerous micro pits.

3.4 Sand blasting of SS mesh

In this process abrasive particles are forced on the surface of the material under high pressure to convert smooth surface into rough surface and cleaning of surface by removing surface contaminants[10]. Due to the erosive action caused by the sharp edges of hard silica particles irregular pits of size ranging between few microns and fifty microns (Fig-6) are formed on the surface of the stainless steel mesh.

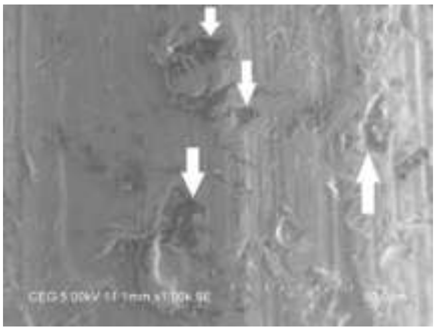

Fig-6 SEM image of the surface of the sand blasted stainless steel wire mesh shows Close up view of erosion pits of various size and shape.

3.5 Inter-laminar shear strength

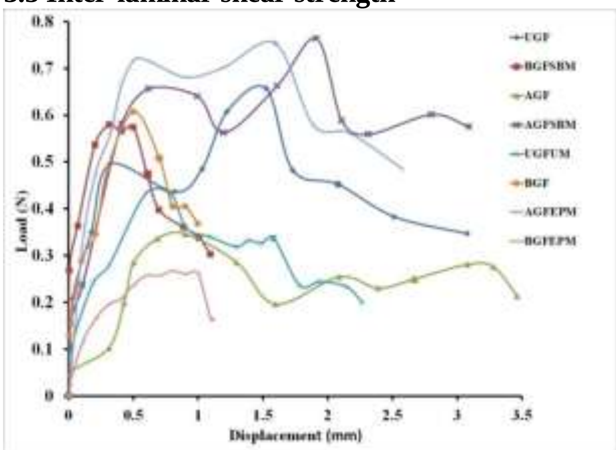

Fig -7 Inter-laminar shear strength values of composite laminates.

The Inter laminar shear test was conducted to find the bond strength between the fiber and resin in the laminated composites. The interface/interphase depend on both glass fiber and the epoxy. The enhanced mechanical properties of laminate is depends on the behavior of interface/interphase.

A typical load displacement diagram for both hybrid and non-hybrid laminate are shown in Fig-7. The response of each hybrid and non-hybrid laminate shows nearly linearity for the elastic limit in the initial loading stage. This trend is continuous until to reach an apparent elastic limit. After this point the curve showed a decreasing load. The AGFEDM, AGFSBM, UGF composite laminate showed a significant decrease in load just beyond the peak load. The AGFEDM hybrid laminate achieved the highest peak load among all the hybrid and non-hybrid laminate. The UGF non-hybrid laminate reached a peak load slightly less than the hybrid ones. For hybrid laminate AGFEDM laminate exhibits an interlaminar shear strength of 32MPa and BGFEDM exhibits interlaminar shear strength of 15MPa. Non-hybrid laminate UGF exhibits ILSS value of 26MPa and AGF exhibits 14 MPa.

3.6 Failure modes of short beam shear specimens

The delamination of the laminate happens by inter laminar shear stress. The failure specimens were examined after testing to identify induced damage on both hybrid and non-hybrid laminate.

In short beam shear test the maximum shear stress occurs in the area where other stress may exist unlike homogeneous beam theory, in which the maximum value of shear stress occurs at the neutral plane, where normal stress are zero[11]. The failure modes like fiber rupture, micro buckling and inter laminar shear cracking were identified on the tested specimens[12]. These inter laminar shear failure could not happen only in the mid plane of the laminate. From the load displacement curve for all SBS test specimens shows similarity such as knee or drop. To correlate these failure modes it is difficult with load displacement curve so a detailed failure modes are described as following figures 8a-8h.

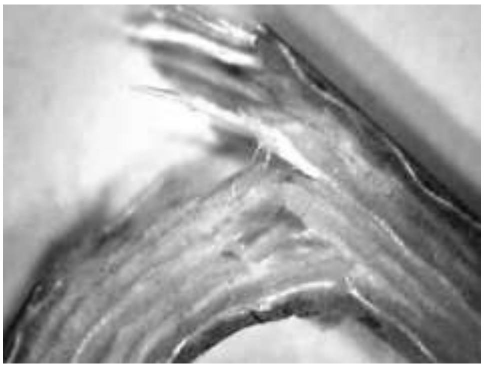

Fig- 8a Microscopic image of UGF laminate

In UGF SBS composite specimen the failure takes place in the form of localized material damage beneath the loading nose. It is caused by high stress concentration under the loading nose resulting in matrix crack and first layer of the glass fiber damage. The tensile stress generated at the bottom layer due to bending moment. This is enough to cause transverse tensile cracks. The delamination was present on the three layers of the bottom of the laminate. During SBS test top layer undergoes compression and bottomlayer become tension[13].In the bottom layer fiber undergone fracture through the resin and showed good elongation.

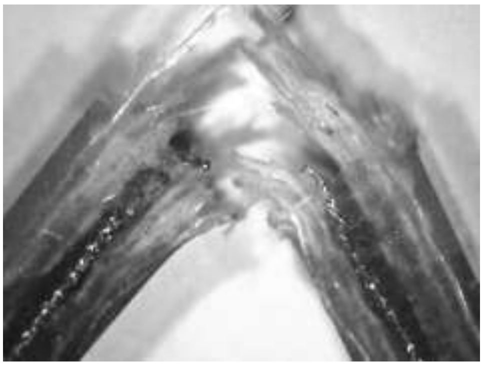

Fig-8b Microscopic image of BGFSBM laminate

In BGFSBM shows the characteristic delamination where in the complete layers of the laminate had fractured. The sand blasted steel wire located in the middle layer of the laminate undergone fracture. One of the bottom layer showed resistance to tensile stress. The top layer does not show much elongation and fractured. Glass fiber was much more affected by alkaline treatment. It reduces the load bearing capacity of the glass fiber.

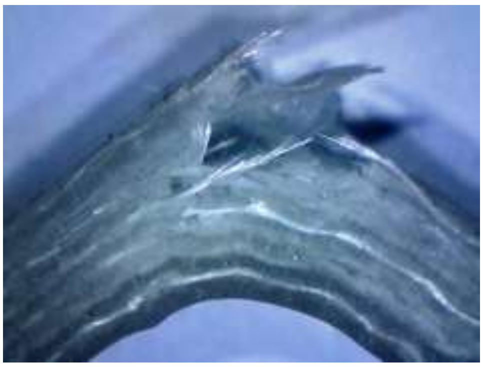

Fig-8c Microscopic image of AGF laminate

In AGF shows the typical bottom layer delamination due to high elongation and tensile stress. This laminate shows resistance to delamination for five layers from top. The bottom layer subjected to tensile stress showed not only fiber elongation the resin also showed good elongation.

Fig-8d Microscopic image of AGFSBM laminate

In AGFSBM shows better bonding between seven layers of acid treated glass fiber and sand blasted steel wire mesh. The complete resistance to delamination can be observed. Some transverse tensile cracks are identified only at the bottom layer of the laminate due to high tensile stress. The remaining layers showed good resistance to delamination.

Fig-8e Microscopic image of UGFUM laminate

In UGFUM shows the good resistance to delamination for all seven layers of the laminate. Transverse compressive cracks were identified at the top layer and the transverse tensile cracks identified at the bottom layer of the laminate. No delamination was identified above and below the neutral layer of the laminate. It produces the inter laminar shear strength value of 17MPa.

Fig-8f Microscopic image of BGF laminate

BGF shows the delamination above and below the neutral layer of the laminate. This is because of alkaline treatment of the glass fiber. Beneath the loading nose no cracks were identified. Transverse tensile cracks are identified at the bottom most layer of the laminate. It produces the ILSS value of 24MPa.

Fig-8g Microscopic image of AGFEPM laminate

In AGFEDM shows good resistance to delamination of the laminate. Transverse tensile cracks are identified bottom most layer of the laminate due to high tensile stress and elongation induced on the glass fiber. Better bonding was identified between acid treated glass fiber and electro dissolved stainless steel wire mesh. It produces ILSS value of 32MPa.

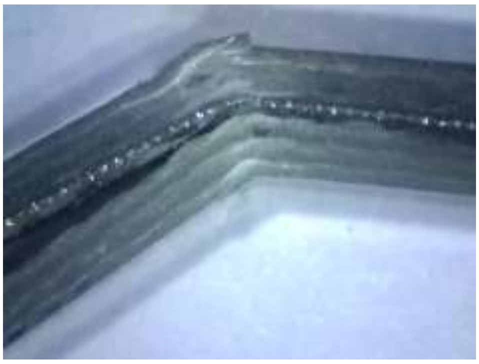

Fig-8h 4.25 Microscopic image of BGFEPM laminate

In BGFEDM shows the resistance to delamination for first three layers from the top beneath the loading nose. After that horizontal split happens at the fourth layer(separation between glass fiber and stainless steel wire mesh). Some tensile cracks are identified at bottom layer. This could be happens due to alkaline treatment of the glass fiber. At the roller supports some micro damages are identified[14].

Surface treatment of stainless steel wire mesh either electro dissolution treatment or sand blasting modifies surface of the stainless steel wire mesh by forming micro pits and erosion pits. It is interesting to note that the interlaminar shear strength of electro dissolved mesh hybrid composite is higher than sand blasted mesh hybrid comosite and this could be attributed to the enhanced interlocking behavior of comparitively smaller size microscopic corrsive pits than the erosive pits formed by sand blasting[15].

It could be stated that presence of irregular corrosive pits enhanceinterlaminar shear strength. Surface modification of glass fiber by acid and stainless steel wire mesh by either electro dissolution treatment or sand blasting could result in improvement of bonding strength.From Fig-7 it was observed that the interlaminar shear strength value of AGFEDM, AGFSBM was 128% and 114% higher than AGF laminate. BGFSBM was 64% higher than AGF but less by 7% of BGFEDM.

Table.2 Comparisons of ILSS strength of composites

S.No	Laminate Type	Notations used	ILSS (MPa)	(%)Increased in strength
1.	Non-Hybrid	UGF	26	85.71
2.		AGF	14	Base
3.		BGF	24	71.42
4.	Hybrid	UGFUM	17	21.42
5.		AGFSBM	30	114.28
6.		BGFSBM	23	64.28
7.		AGFEDM	32	128.57
8.		BGFEDM	15	7.14

4 Conclusions

In this study interlaminar shear behavior of hybrid and non hybrid composites were studied. The major conclusions are

1. Theinterlaminar shear strength values of acid treated glass fiber and Electro dissolved/sand blasted stainless steel wire mesh hybrid laminate are superior to other combinations of hybrid and non hybrid laminates.
2. The non hybrid laminate made with acid treated glass fiber enhances smoother surface which does not helps to bond between interface and produces low value of interlaminar shear strength.
3. During surface treatment glass fiber was much more affected by the base treatment than the acid treatment.
4. The alkaline treatment results localized surface leaching and reduces the shear load carrying capacity of fiber.
5. Overall, the study showed that the reinforcement of glass fiber with stainless steel wire mesh made a new material with properties superior to glass fiber reinforced polymer composites, under varying load conditions.

References

1. Antaryami Mishra., Strength and corrosion testing of jute/glass-epoxy hybrid composite laminates, Plastic and polymer Technology, 2013,2:48-54.
2. Nayeem Ahmed.M., Vijayakumar, P., Shivanand, H.K., Syed BasithMuzammil., A study of hybrid polymer composite materials on different matrix material by varying its thickness, International Journal of Mechanical Engineering and Technology, 2013, 4 :274-286.
3. Sayer,M., Bektas, N.B., Callioglu, Impact behavior of hybrid composite plates, Journal of Applied Polymer Science, 2010,118:580-587.
4. Petrucci.R., Santulli,C, Puglia, D., Sarasini, F., Torre, L., Kenny, J.M., Mechanical characterization of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured by vaccum infusion, Materials and Design, 2013, 49:728-735.
5. Shindo, Y, Wang, R, Horiguchi k, Analytical and experimental studies of short beam interlaminar shear strength of G-10CR glass- cloth/epoxy laminates at cryogenic temperatures, ASME,2001,123:112-118.
6. Kasen M.B, Current status of interlaminar shear testing of composite material at cryogenic temperatures, AdvCryogEng, 1990, 36 : 787-792.
7. Han,L, The shear properties of angle ply laminates, MSc thesis, Chemical Engineering Department, Toronto University, 1998.
8. Maxwell. A. S, Broughton. W. R, Dean. G and Sims. G. D., 2005, " Review of accelerated ageing methods and lifetime prediction techniques for polymeric materials", National Physical Laboratory, pp. 1-84.
9. Davidbcochrane, Guide to stainless steel finishes, Euro inox, 1 (2005) 1-20.
10. M.K.CarolLee, Hand book for Abrasive Blasting Operations, (2013).

11. Ahmed ,K.S, Vijayarangan,S.,Tensile, Flexural and interlaminar shear properties of wovwn jute and jute-glass fabric reinforced polyester composites, Journal of Material process technology, 2008, 207:330-335.
12. Mallick.P.K., Fiber reinforced composites-materials, Manufacturing ang design, New York, Marcel dekker Incorporation., 1993.
13. Walter.T.R., Subhash,G, Sankar, B.V, Yen C.F; Monotonic and cyclic short beam shear response of 3D woven composites, Composites science and Technology, 2010, 70., :2190-2197.
14. Pavlidou,S, Papaspyrides, CD., The effect of hygrothermal history on water absorption and interlaminar shear strength of glass/ polyester composites with different interfacial strength, Composites : Part-A, 2003, 34, , 1117- 1124.
15. N.Karunagaran, A.Rajadurai, Effect of surface treatment on mechanical properties of glass fiber/stainless steel wire mesh reinforced epoxy hybrid composites, Journal of Mechanical Science and Technology,2016, 30, 6 : 2475-2482.

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