International Journal of Engineering

Journal Homepage: www.ije.ir

Flexural and Impact Properties of Stainless Steel based Glass Fibre Reinforced Fibre Metal Laminate under Hygrothermal Conditioning

S. Singh*, S. Angra

Department of Mechanical Engineering, National Institute of Technology Kurukshetra-136119, Haryana, India

PAPER INFO

Paper history:
Received 05 October 2017
Received in revised form 03 November 2017
Accepted 30 November 2017

Keywords:
Fibre Metal Laminate
Strength Degradation
Mechanical Properties
Hygrothermal Conditioning
Moisture Diffusion
Delamination

A B S T R A C T

Fibre metal laminates (FMLs) have appeared as the most suitable materials for shipbuilding, aeronautical and aerospace applications due to their superior mechanical properties over traditional materials. In this paper, degradation in flexural and impact properties of glass fibre/epoxy composite (GF/E composite) and stainless steel glass fibre/epoxy fibre metal laminate (SS FML) due to hygrothermal conditioning has been investigated for marine applications. Hand lay-up process was used for specimen preparation according to ASTM standards. Distilled water and seawater were used for hygrothermal conditioning at 40°C and 70°C for three months. The three point bend test was performed on universal testing machine using a three point bend fixture. The pendulum type impact testing machine was used to perform Izod impact test. Due to the preventive action of outer stainless steel layers against moisture ingestion, the reduction in mechanical properties of SS FML was less as compared to GF/E composite. SS FML and GF/E composite exhibited low moisture absorption rate in seawater at both temperatures as high salt content in seawater reduces the moisture diffusion process into the composite matrix.

***doi**: 10.5829/ije.2018.31.01a.22*

NOMENCLATURE

FMLs	Fibre metal laminates	SW	Seawater
GRP	Glass fibre reinforced composite	J	Joule
GF/E composite	Glass fibre/epoxy composite	NaCl	Sodium chloride
UD	Unidirectional glass fibre	FS	Flexural strength (MPa)
SS FML	Stainless steel glass fibre/epoxy fibre metal laminate	IE	Impact energy (Joule)
GLARE	Glass fibre reinforced aluminium laminate	UC	Unconditioned specimen
CARALL	Carbon fibre reinforced aluminium laminate	HC	Hygrothermally conditioned specimen
FRP	Fibre reinforced plastic	GW	Percentage gain in weight by specimen
DW	Distilled water	ARALL	Aramid fibre reinforced aluminium laminate

1. INTRODUCTION

Fibre/metal laminates (FMLs) have emerged as useful materials for shipbuilding applications, due to excellent fatigue and damage resistance, impact properties, high specific strength, ease of machinability and formability [1, 2].

First fibre metal laminate developed was ARALL (Aramid Fibre Reinforced Aluminium Laminate). It was designed and produced in 1978 by Faculty of Aerospace Engineering at the Delft University of Technology in Netherland. They found that the fatigue crack growth resistance of sheet materials can be improved by laminating and adhesively bonding thin layers of the material, instead of using one thick monolithic sheet [3, 4].

Sarlin et al. [5] performed hygrothermal conditioning in hot and moist environments on FMLs which contained either mild steel EN 10130 DC01 or stainless steel AISI 304 and Glass fibre/epoxy

*Corresponding Author's Email: satnamsingh@nitkkr.ac.in (S. Singh)

Please cite this article as: S. Singh, S. Angra, Flexural and Impact Properties of Stainless Steel based Glass Fibre Reinforced Fibre Metal Laminate under Hygrothermal Conditioning, International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics Vol. 31, No. 1, (January 2018) 164-172

composite to observe their corrosion resistance. It was concluded that both unconditioned and conditioned specimens of FMLs based on stainless steel AISI 304 has higher corrosion resistance and peel strength than mild steel based FMLs. Khalili et al. [6] found that damage tolerance limit, stiffness and impact energy absorption were higher for FML's with outer stainless steel layers instead of FML's with outer aluminium alloy layers and only glass fibre reinforced composite (GRP).

Tensile, flexural and Izod impact strengths of woven coir and woven coir–glass fibre-reinforced polyester composites were evaluated by Jayabal et al. [7] and concluded that woven glass fibre polyester composites have highest value of tensile, flexural and Izod impact strengths. Akil et al. [8] concluded that the flexural strength degradation for polyester/jute fibre based composite laminates was lower for specimens immersed in seawater and higher in distilled water. The rate of moisture ingestion in composite specimens was maximum in distilled water and minimum in seawater.

Mechanical properties and their hygrothermal degradation for FRP (Fibre reinforced plastic) laminates have been investigated by many researchers. However, the effect of hygrothermal conditioning on flexural and Izod impact properties of stainless steel based fibre metal laminate with variation in aqueous environments and temperatures have not been studied before. Therefore, the objective of the present work is to evaluate the degradation of flexural strength and impact energy absorption of stainless steel glass fibre/epoxy fibre metal laminate (SS FML) and glass fibre/epoxy composite (GF/E composite) due to hygrothermal conditioning in two aqueous environments at two different temperatures.

2. MATERIALS AND METHODS

2. 1. Materials Used In this research, the materials were selected by considering the shipbuilding applications. E-glass fibre [9, 10] UD (SikaWrap-430 G) with fibre fabric thickness of 0.172 mm, density of 2.56 g/cm^3, areal weight of 445 GSM (supplied by Sika India Pvt. Ltd.) and MasterBrace 4500, a two part epoxy resin (supplied by BASF India limited) were used to prepare the glass fibre epoxy composite. Stainless steel AISI 304 sheet (with 0.08% of C, 18 – 20% of Cr, 2% of Mn, 8 - 10.5% of Ni, 0.045% of P, 0.03% of S, 0.75% of Si, 0.10% of N and remaining iron) of thickness 0.4 mm has been used as the outer skin of fibre metal laminate due to its high corrosion resistance [11]. This makes it a convenient material for ship building applications. An epoxy-based adhesive with cured thickness 0.1 mm (supplied by Huntsman Advanced Materials India Pvt. Ltd.) was used to join metal and the composite sheets.

2. 2. Method of GF/E Composite and SS FML Preparation Hand layup process was used to prepare GF/E composite sheet [6, 12]. The epoxy mixture was prepared by mixing its two components in the ratio of 100:40 by weight at room temperature (i.e. resin 100 gm and hardener 40 gm). A mechanical stirrer (REMI lab stirrer) was used to mix resin and hardener for two minutes at 500 rpm. After mixing, the prepared mixture of epoxy was placed in a vacuum degasser unit to remove the air bubbles entrapped in between the layers of mixture. This mixture was spread over the glass fibre sheet (in mould, 50 cm × 25 cm) using a brush. The desired thickness of GF/E composite was produced by adding two more layers of glass fibre sheet. The fibres in all three layers of GF/E sheet were in the same direction. The sheet of GF/E composite laminate was removed from the mould after curing for 24 hours at room temperature. After removal, the epoxy mixture was applied on the other side of GF/E sheet to produce an equivalent surface as on the previous side. The sheet was completely cured in seven days. After curing, the waste edges of the sheet were removed using a shear machine.

SS FML was produced using stainless steel (SS) AISI 304 sheets along with cured GF/E sheets. Sandblasting was used to enhance the surface roughness and adhesion quality of stainless steel sheets. An epoxy-based adhesive was prepared by mixing its two components in the ratio of 100:80 by weight (i.e. resin 100 gm and hardener 80 gm) and applied on both sides of GF/E composite sheet as well as on rough surfaces of SS sheets. The GF/E composite sheet contained adhesive layer over its both surfaces was placed between two SS sheets in a picture frame mould (50 cm x 25 cm) under the pressure of 0.4 MPa [12] on a mechanical press at 50°C for at least 3 hours. The fibres in GF/E composite layers were in the rolling direction of SS sheet as shown in Figure 1. Hot pressurized curing process increases the rate of curing and it also facilitates to maintain a uniform thickness of adhesive film (0.10 mm) between the metal and GF/E sheet. After 3 hours of hot curing, hot plates were shut off and the FML sheet was kept under pressure for next 21 hours. Cured SS FML sheet was removed from mould after 24 hours. The stacking sequences of GF/E composite laminate and SS FML are shown in Figures 1 and 2, respectively. The specimens used for flexural and Izod impact tests are shown in Figure 3.

3. EXPERIMENTATION

3. 1. Hygrothermal Conditioning Hygrothermal conditioning of flexural and impact test specimens

(GF/E composite and SS FML) was performed in two aqueous environments i.e. distilled water (DW) and seawater (SW) at 40°C and 70°C for 90 days. Artificial seawater (pH value of 8.2) was prepared in the laboratory according to ASTM D1141-98. A water bath with four chambers was used to keep the specimens immersed in distilled and seawater. The illustration of the setup is shown in Figure 4.

A higher temperature of 70°C (below the glass transition temperature of epoxy resin and adhesive used) was used to increase the rate of moisture absorption as well as to complete the conditioning process in a short span of time.

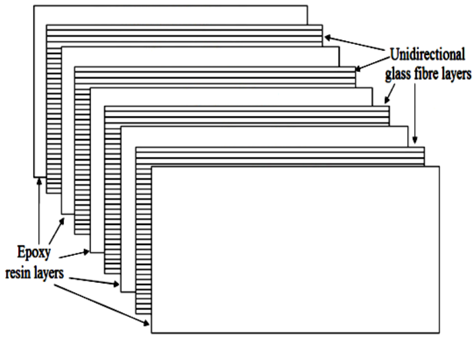

Figure 1. Stacking sequence of GF/E composite

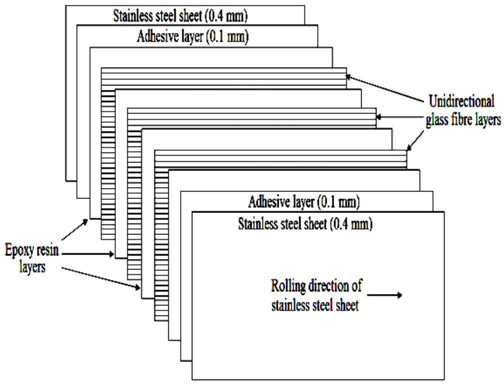

Figure 2. Stacking sequence of SS FML

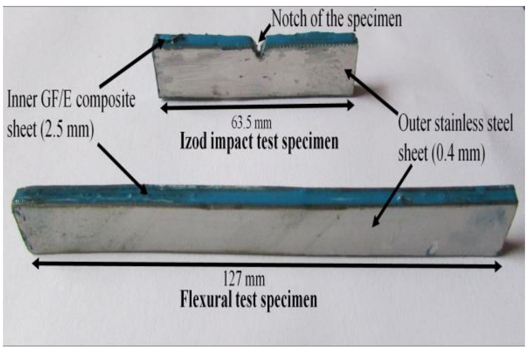

Figure 3. Flexural and Izod impact test specimens of SS FML

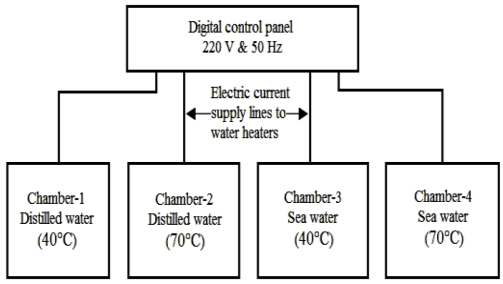

Figure 4. Four chamber water bath illustration

After every ten days, five flexural and impact samples were taken from water bath chambers. The surface moisture of these samples was absorbed by using a soaking paper. The amount of moisture absorbed by samples was recorded on an electronic weighing balance (accuracy of 10^{-4} gm)**.** After that those samples were again dipped into water chambers for further moisture absorption. The average values of percentage weight gain due to moisture absorption were reported.

3. 2. Flexural Test Specimens of GF/E composite and SS FML for flexural test were cut from the prepared sheets and tested on 50 KN (Model name - EZ50) universal testing machine (UTM), manufactured by Lloyd Instruments Ltd, UK according to the ASTM D790-15e2 standard [7, 13]. The machine has minimum load resolution and maximum crosshead travel of 0.1 N and 855 mm respectively. Three point bend test was conducted with standard size fixture on specimens with dimensions 127 mm x 12.7 mm x 3.5 mm. The specimens were tested horizontally on the fixture with a rate of crosshead motion of 1.5 mm/min.

Five flexural specimens of GF/E, and SS FML were taken from water chambers and tested after every ten days (up to 90 days) to evaluate their flexural strength. The flexural stress-strain behaviour of SS FML is shown in Figure 5.

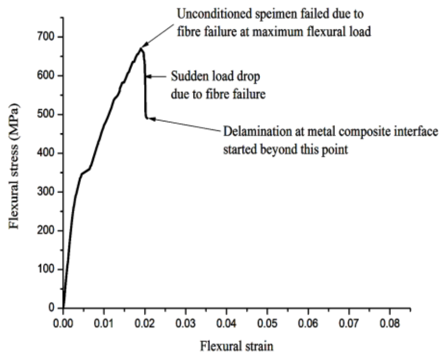

Figure 5. Flexural stress-strain diagram for SS FML

The unconditioned flexural specimen of SS FML failed due to fibre failure. From Figure 5, it is observed that the flexural specimen of SS FML failed without yielding (before 5% strain limit as per ASTM). The flexural stress decreased due to sudden load drop. It is because of the failure of internal glass fibre/epoxy layers. If the load continuously applied even after the failure of glass fibre/epoxy layers, delamination starts at the metal composite interface due to the shear action between metal and composite surfaces.

3. 3. Impact Test Izod impact test was conducted on pendulum type impact testing machine (Model IT-30-D made by Fuel Instrument & Engineers Pvt. Ltd.) having an electronic system consists of a digital indicator and sensor to record the impact energy of the specimen. The capacity of the impact testing machine with a least count of 0.5 J was 300 J. Impact specimens were cut from the prepared sheets of GF/E and SS FML according to the ASTM D256–10e1 standard [7]. These specimens with dimensions 63.5 mm x 12.7 mm x 3.5 mm were tested vertically (edgewise) with the lower part fixed in the fixture. Notch in the specimen was cut using a single tooth notch cutter. The other dimensions of the notch like included angle and the radius of curvature at the apex were 45° and 0.25 mm, respectively. Five specimens were taken from each water bath chamber and tested to evaluate their impact energy absorption. The impact testing machine setup is shown in Figure 6.

4. RESULTS AND DISCUSSION

4. 1. Moisture Absorption Behaviour of SS FML and GF/E Composite Specimens of SS FML and GF/E composite were immersed in two aqueous environments (i.e. Distilled water and seawater) at 40°C and 70°C to study their moisture absorption behaviour. The moisture absorbed by specimens is directly related to weight gain by them. So, the specimens were taken from water chambers after every ten days (up to 90 days) and their weight was recorded using an electronic weighing balance (accuracy of 10^{-4} gm).

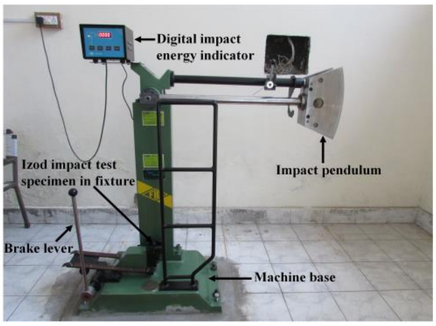

Figure 6. Izod impact test machine setup

Figures 7 and 8 represent the trend of percentage weight gain by the specimens of SS FML and GF/E composite at 40°C and 70°C, respectively.

Table 1 encapsulates the percentage weight gain by SS FML and GF/E composite specimens due to moisture absorption during hygrothermal conditioning. SS FML specimens showed maximum weight gain of 0.44% in distilled water at 70°C and minimum weight gain of 0.32% in seawater at 40°C. GF/E composite specimens exhibited maximum and minimum weight gain of 1.93% and 1.28% in distilled water at 70°C and seawater at 40°C, respectively. The highest weight gain occurred for GF/E composite specimens in distilled water due to the direct and maximum surface exposure [8]. Initially, the curve of percentage weight gain for GF/E composite displayed a linear trend with increase in number of days for both environments as shown in Figures 7 and 8.

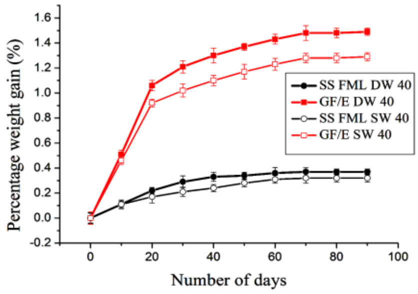

Figure 7. Percentage weight gain by SS FML and GF/E composite at 40°C

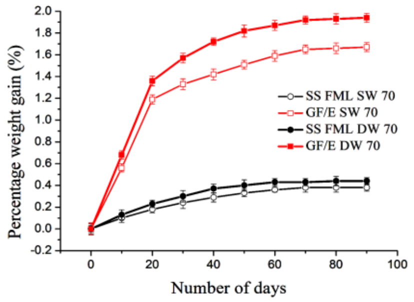

Figure 8. Percentage weight gain by SS FML and GF/E composite at 70°C

TABLE 1. Percentage weight gain (wt.%) by SS FML and GF/E composite in distilled water and Seawater

Type of environment	SS FML	GF/E composite
Seawater (70°C)	0.38	1.67
Seawater (40°C)	0.32	1.28
Distilled water (70°C)	0.44	1.93
Distilled water (40°C)	0.37	1.49

The 65% to 70% of total weight gain happened in first 20 days. After that, the rate of moisture absorption decreases. This is due to the reason that the microscopic cavities in epoxy absorbed maximum amount of moisture, which results in its swelling [8, 14]. After 70 days of immersion, saturation occurred, and GF/E specimens showed nearly constant weight with minor increments. The type of water environment (i.e. seawater or distilled water) has appreciable effect on weight gain by GF/E composite. GF/E specimens gain less weight in seawater at both temperatures due to its high salt content [8].

The SS FML specimens absorbed less water as compared to GF/E composite due to the resistance offered by outer stainless steel layers. The maximum weight gain by SS FML specimens occurred in first 40 days with nearly constant rate of moisture absorption. After that the moisture absorption process slowed down and beyond 60 days of immersion, the specimens displayed nearly constant weight. From Figures 7 and 8, it is observed that the effect of water environment and temperature on moisture absorption by SS FML is very less as compared to GF/E composite. This is due to less exposure area of SS FML for moisture absorption [14]. The outer stainless steel layers restrict the moisture absorption by reducing the effective area of absorption. The moisture can only penetrate through the free edges of SS FML composite layers. The percentage gain in weight (GW) by SS FML and GF/E composite specimens is described as $GW_{DW\ (70°C)} > GW_{SW\ (70°C)} > GW_{DW\ (40°C)} > GW_{SW\ (40°C)}$.

Both GF/E and SS FML absorbed more moisture in distilled water when compared to seawater at both temperatures. This is because of high salt content of seawater (Mainly NaCl), which decelerates the moisture diffusion process into the composite matrix [8]. It is also observed that the temperature of water plays an important role in moisture diffusion process. Higher the temperature, higher will be the rate of moisture diffusion.

4. 2. Effects of Hygrothermal Conditioning on Flexural Strength of SS FML and GF/E Composite

The flexural strength (FS) and impact energy (IE) absorbed by the unconditioned and hygrothermally conditioned specimens of the SS FML and GF/E composite are tabulated in Tables 2 and 3. Figures 9 and 10 show response of SS FML and GF/E composite specimens, under flexural loading before and after hygrothermal conditioning. To maintain the uniformity in comparison, the thickness of both SS FML and GF/E composite sheets were kept same. The flexural strength of unconditioned specimens of SS FML was less as compared to unconditioned GF/E composite specimens. It happened due to weak interfacial bonding between the SS sheets and composite surfaces of SS FML and also due to the high fibre volume fraction (HFVF) of GF/E composite. The degradation rate of FS for conditioned GF/E composite specimen was high for 50 days and after that it maintained nearly a constant rate of degradation [14]. On the contrary, deterioration in FS for conditioned specimen of SS FML was less compared to GF/E composite specimen due to the shielding effect of outer stainless steel layers against moisture ingestion. For first 30 days, the rate of degradation in FS of SS FML was high and after 30 days, degradation in FS was very inadequate due to saturation against moisture ingestion [14, 15].

After hygrothermal conditioning, both SS FML and GF/E composite specimens displayed a notable reduction in FS. It is because of the plasticization effect of absorbed water molecules into the gaps of composite layers. The absorbed water molecules act as plasticizer which makes the composite structure more flexible than before [8, 14]. Degradation of FS for both GF/E composite and SS FML was maximum in distilled water at 70°C due to the highest moisture absorption. The FS degradation of GF/E composite and SS FML in seawater and distilled water can be expressed in order as $FS_{DW\ (70°C)} > FS_{SW\ (70°C)} > FS_{DW\ (40°C)} > FS_{SW\ (40°C)}$.

The epoxy matrix is plasticized and swells due to the penetration of water molecules in to the microscopic gaps between individual layers. The absorbed water molecules degrade the epoxy matrix which results in the generation of residual stresses in the composite laminates [15]. It is observed that the GF/E composite and SS FML specimens swallowed more moisture at high temperature (70°C) instead of low temperature (40°C). The high temperature hygrothermal conditioning makes the matrix phase of composite laminate more soft and weak.

Due to weakening and softening of matrix phase, microscopic cracks developed in it, which resulted in the reduction of FS [8, 16]. These changes in matrix phase also weaken the interfacial bond between composite surface and metal layers of SS FML. Ultimately, SS FML failed due to delamination of metal layer from the composite surface. GF/E composite specimen failed in bending due to softening of matrix phase, which results in the delamination in between the layers of GF/E composite. The moisture absorbed by the epoxy matrix also deteriorates the glass fibres of GF/E composite layers which results in the breakage of glass fibres as well as failure of epoxy/fibre interface.

4. 3. Effect of Hygrothermal Conditioning on Impact Energy Absorption of SS FML and GF/E Composite

Tables 2 and 3 describe the values of impact energy (IE) absorption for both conditioned and unconditioned specimen of GF/E and SS FML.

TABLE 2. Flexural and impact properties of GF/E composite and SS FML at 40°C

Material	Specimen type	Seawater 40°C				Distilled water 40°C			
		FS MPa	Loss %	IE Joule	Loss %	FS MPa	Loss %	IE Joule	Loss %
GF/E	UC [a]	924.37	19.61	29.40	18.71	924.37	22.14	29.40	22.79
	HC [b]	743.09		23.90		719.75		22.70	
SS FML	UC [a]	797.73	13.70	24.70	14.57	797.73	15.21	24.70	18.62
	HC [b]	688.44		21.10		676.38		20.10	

[a] Unconditioned specimen
[b] Hygrothermally conditioned specimen in distilled and seawater at 40°C

TABLE 3. Flexural and impact properties of GF/E composite and SS FML at 70°C

Material	Specimen type	Seawater 70°C				Distilled water 70°C			
		FS MPa	Loss %	IE Joule	Loss %	FS MPa	Loss %	IE Joule	Loss %
GF/E	UC [a]	924.37	23.00	29.40	26.19	924.37	27.84	29.40	32.65
	HC [b]	711.76		21.70		667.05		19.80	
SS FML	UC [a]	797.73	15.88	24.70	21.46	797.73	19.00	24.70	26.72
	HC [b]	671.02		19.40		646.17		18.10	

[a] Unconditioned specimen
[b] Hygrothermally conditioned specimen in distilled and seawater at 70°C

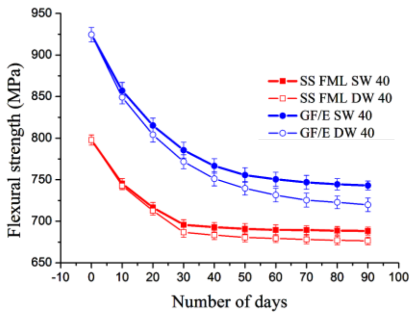

Figure 9. Degradation in flexural strength at 40°C in two aqueous environments during hygrothermal conditioning

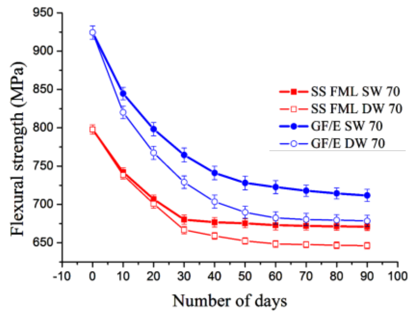

Figure 10. Degradation in flexural strength at 70°C in two aqueous environments during hygrothermal conditioning

Due to hygrothermal conditioning, degradation in IE was observed for both SS FML and GF/E composites.

The maximum degradation in IE of conditioned specimen of GF/E (32.65%) and SS FML (26.72%) occurred in distilled water at 70°C. The IE degradation for SS FML was less as compared to GF/E composite due to the shielding effect of SS layers. The outer SS layers reduced the area for moisture ingression. The IE reduction for SS FML and GF/E in both aqueous environments can be described as $IE_{DW\ (70°C)} > IE_{SW\ (70°C)} > IE_{DW\ (40°C)} > IE_{SW\ (40°C)}$.

Initially, the degradation in IE was higher for both SS FML and GF/E composite due to the high moisture absorption rate. Figures 11 and 12 represent IE reduction behaviour of GF/E and SS FML at 40°C and 70°C, respectively. It is observed that the IE of SS FML reduces due to hygrothermal conditioning with a constant rate of degradation up to 60 days. After that SS FML illustrate nearly a uniform value of impact energy absorption (with minor decrement). On the contrary, impact energy absorption of GF/E composite decreased with a higher rate of degradation for 70 days and thereafter it represents a lower degradation rate till 90 days. The degradation of IE absorption for GF/E composite and SS FML was more in distilled water at both temperatures as compared to seawater [7,8].

The failure modes for unconditioned and

conditioned specimen of SS FML after flexural test and Izod impact test are illustrated in Figures 13, 14 and 15. Unconditioned flexural specimens of SS FML failed due to fibre breakage followed by the delamination at metal composite interface with further increase in load. While the hygrothermally conditioned flexural specimen failed due to the delamination at metal composite interface as well as in between the composite layers. The delamination between SS layer and composite surface occurred due to the weak interfacial bond in them.

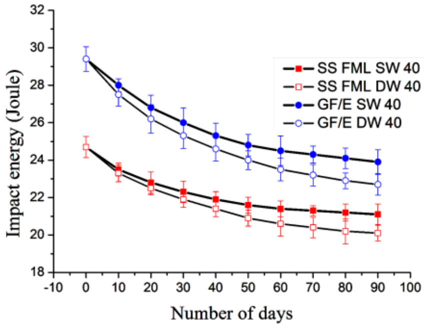

Figure 11. Impact energy reduction in two aqueous environments at 40°C during hygrothermal conditioning

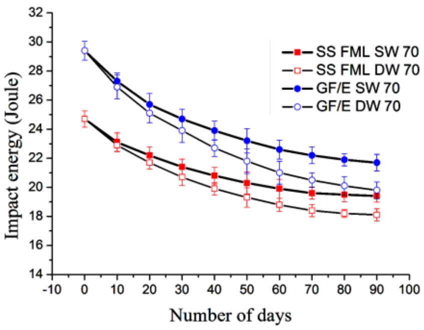

Figure 12. Impact energy reduction in two aqueous environments at 70°C during hygrothermal conditioning

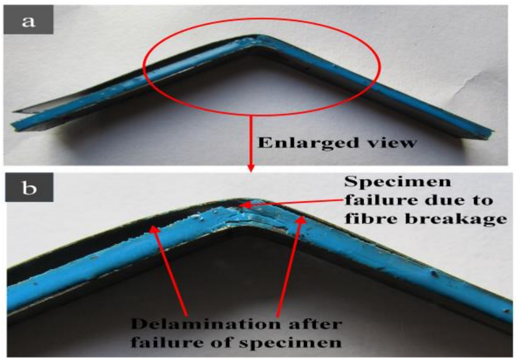

Figure 13. (a) Unconditioned flexural specimen failure, (b) Unconditioned flexural specimen failure (Enlarged view)

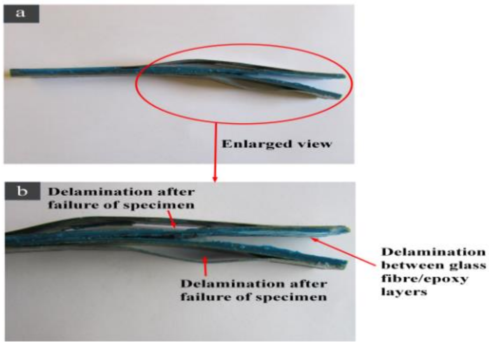

Figure 14. (a) Conditioned flexural specimen failure, (b) Conditioned flexural specimen failure (Enlarged view)

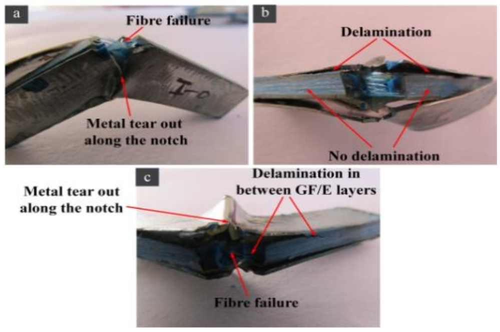

Figure 15. (a) Unconditioned failed impact specimen showing fibre failure, (b) Unconditioned failed impact specimen with no delamination in GF/E layers, (c) Conditioned failed impact specimen with fibre failure as well as delamination in GF/E layers

The components of SS FML (Epoxy, Glass fibre fabric, bonding adhesive and SS layer) exhibited different moisture absorption and thermal expansion coefficient (TEC) during hygrothermal conditioning [8]. Due to the difference in moisture absorption and TEC by the components of SS FML, residual stresses are produced. These stresses generate micro-cracks at the SS layer and composite surface interface. Due to micro-cracking at the SS layer and composite surface interface, delamination starts and finally SS FML specimen fails without the failure of the inner composite sheet. With further increase in flexural load, delamination occurred in between the layers of GF/E composite.

Both unconditioned and conditioned SS FML impact specimens failed due to fibre breakage, delamination at metal composite interface and in between the GF/E layers. Tearing of outer SS layers also occurred along the notch line due to the impact force. Unconditioned and conditioned impact specimens of GF/E composite followed the similar failure patterns as of SS FML.

5. CONCLUSIONS

- The failure of unconditioned flexural specimens of SS FML and GF/E composite take place due to the breakage of glass fibres. The unconditioned impact specimens of SS FML and GF/E composite fail due to fracture in GF/E sheet along the notch. Tearing of outer SS layers in SS FML impact specimens occur along the notch.

- Hygrothermally conditioned flexural specimens of SS FML and GF/E composite fail due to delamination in between the glass fibre/epoxy layers. The metal composite interface in SS FML samples fail due to delamination.
- During Izod impact test, the conditioned SS FML and GF/E composite specimens illustrate fibre fracture and delamination in between glass fibre/epoxy layers. In conditioned SS FML, delamination occurs at metal composite interface and tearing of metal takes place along the notch.
- The maximum moisture absorbs by SS FML (0.44%) in distilled water at 70°C was less than that of GF/E composite (1.93%) due to the shielding effect of SS layers against moisture absorption.
- The flexural strength (FS) of conditioned specimens of GF/E composite in distilled water (DW) and seawater (SW) has been reduced in order as $FS_{DW\ (70°C)}$ (27.84%) > $FS_{SW\ (70°C)}$ (23.00%) > $FS_{DW\ (40°C)}$ (22.14%) > $FS_{SW\ (40°C)}$ (19.61%) and the impact energy (IE) has been reduced as $IE_{DW\ (70°C)}$ (32.65%) > $IE_{SW\ (70°C)}$ (26.19%) > $IE_{DW\ (40°C)}$ (22.79%) > $IE_{SW\ (40°C)}$ (18.71%). Degradation in both FS and IE of GF/E composite are maximum in distilled water at 70°C due to the highest moisture absorption.
- The FS and IE degradation of conditioned specimens of SS FML in two aqueous environments follows the similar trend as GF/E composite. The flexural strength of SS FML has been reduced as $FS_{DW\ (70°C)}$ (19.00%) > $FS_{SW\ (70°C)}$ (15.88%) > $FS_{DW\ (40°C)}$ (15.21%) > $FS_{SW\ (40°C)}$ (13.70%) and the impact energy has been reduced as $IE_{DW\ (70°C)}$ (26.72%) > $IE_{SW\ (70°C)}$ (21.46%) > $IE_{DW\ (40°C)}$ (18.62%) > $IE_{SW\ (40°C)}$ (14.57%). The reduction in FS and IE of SS FML was less as compared to GF/E due to the preventive action of SS layers against moisture absorption.

6. ACKNOWLEDGEMENTS

The authors are grateful to their parent institution, National institute of technology, Kurukshetra, Haryana, India for the financial support and for the continuous encouragement.

7. REFERENCES

1. Kulkarni, R., Chawla, K., Vaidya, U., Koopman, M. and Eberhardt, A., "Characterization of long fiber thermoplastic/metal laminates", ***Journal of Materials Science***, Vol. 43, No. 13, (2008), 4391-4398.
2. Rajabi, A. and Kadkhodayan, M., "An investigation into the deep drawing of fiber-metal laminates based on glass fiber reinforced polypropylene", ***International Journal of Engineering Transactions C: Aspects***, Vol. 27, No. 3, (2014) 349-358.
3. Sinmazçelik, T., Avcu, E., Bora, M.Ö. and Çoban, O., "A review: Fibre metal laminates, background, bonding types and applied test methods", ***Materials & Design***, Vol. 32, No. 7, (2011), 3671-3685.
4. Sherman, D. and Leckie, F., "Alumina carbon/epoxy laminates under cyclic loading", ***Journal of Materials Science***, Vol. 32, No. 23, (1997), 6263-6268.
5. Sarlin, E., Hoikkanen, M., Frisk, L., Vuorinen, J., Vippola, M. and Lepisto, T., "Ageing of corrosion resistant steel/rubber/composite hybrid structures", ***International Journal of Adhesion and Adhesives***, Vol. 49, (2014), 26-32.
6. Khalili, S., Mittal, R. and Kalibar, S.G., "A study of the mechanical properties of steel/aluminium/grp laminates", ***Materials Science and Engineering: A***, Vol. 412, No. 1, (2005), 137-140.
7. Jayabal, S., Natarajan, U. and Murugan, M., "Mechanical property evaluation of woven coir and woven coir–glass fiber-reinforced polyester composites", ***Journal of Composite Materials***, Vol. 45, No. 22, (2011), 2279-2285.
8. Akil, H.M., Cheng, L.W., Ishak, Z.M., Bakar, A.A. and Rahman, M.A., "Water absorption study on pultruded jute fibre reinforced unsaturated polyester composites", ***Composites Science and Technology***, Vol. 69, No. 11, (2009), 1942-1948.
9. Rath, B., Deo, S. and Ramtekkar, G., "Durable glass fiber reinforced concrete with supplimentary cementitious materials", ***International Journal of Engineering-Transactions A: Basics***, Vol. 30, No. 7, (2017), 964-970.
10. Dabiry, Y., Sheikhi, M.M. and Nikoi, R., "An experimental study on the tensile behaviors of ultrasonic welded t-joints for polyamide composite", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 29, No., (2016), 1783-1790.
11. Pärnänen, T., Kanerva, M., Sarlin, E. and Saarela, O., "Debonding and impact damage in stainless steel fibre metal laminates prior to metal fracture", ***Composite Structures***, Vol. 119, (2015), 777-786.
12. Lee, B.-E., Park, E.-T., Kim, J., Kang, B.-S. and Song, W.-J., "Analytical evaluation on uniaxial tensile deformation behavior of fiber metal laminate based on srpp and its experimental confirmation", ***Composites Part B: Engineering***, Vol. 67, (2014), 154-159.
13. Manikandan, V. and Uthayakumar, M., "Effect of redmud particulates on mechanical properties of bfrp composites", ***International Journal of Engineering-Transactions B: Applications***, Vol. 27, No. 11, (2014), 1741.
14. Naceri, A., "Moisture diffusion properties of fabric composite (glass fiber/epoxy resin)", ***International Journal of Engineering-Transactions B: Applications***, Vol. 22, No. 2, (2008), 205-210p.
15. Botelho, E., Pardini, L. and Rezende, M., "Hygrothermal effects on damping behavior of metal/glass fiber/epoxy hybrid composites", ***Materials Science and Engineering: A***, Vol. 399, No. 1, (2005), 190-198.
16. Botelho, E., Almeida, R., Pardini, L. and Rezende, M., "Elastic properties of hygrothermally conditioned glare laminate", ***International Journal of Engineering Science***, Vol. 45, No. 1, (2007), 163-172.

Flexural and Impact Properties of Stainless Steel based Glass Fibre Reinforced Fibre Metal Laminate under Hygrothermal Conditioning

S. Singh, S. Angra

Department of Mechanical Engineering, National Institute of Technology Kurukshetra-136119, Haryana, India

PAPER INFO

Paper history:
Received 05 October 2017
Received in revised form 03 November 2017
Accepted 30 November 2017

Keywords:
Fibre Metal Laminate
Strength Degradation
Mechanical Properties
Hygrothermal Conditioning
Moisture Diffusion
Delamination

چکیده

ورقه های فلزی فیبری (FMLs) به دلیل خواص مکانیکی عالی آنها نسبت به مواد سنتی به عنوان یکی از مناسب ترین مواد برای ساخت و ساز کشتی، هواپیما و هوا فضا ظاهر شده اند. در این مقاله، تخریب خواص خمشی و ضربه ای کامپوزیت فیبر شیشه ای/ اپوکسی (کامپوزیتGF/E) و ورقه فلزی فیبر اپوکسی/ فیبر شیشه ای فولاد ضد زنگ (SS FML)به علت تهویه هوای هیروترمال برای کاربردهای دریایی مورد بررسی قرار گرفته است. فرایند دست کردن برای تهیه نمونه بر اساس استاندارد ASTM استفاده شده است. آب مقطر و آب دریا برای تهویه هیروترمال در دمای ۴۰ درجه سانتیگراد و ۷۰ درجه سانتیگراد برای سه ماه استفاده شد. آزمون خمش سه نقطه ای بر روی دستگاه تست جهانی با استفاده از سه پایه خمش نصب شد. برای انجام آزمون ضربه ایزود، دستگاه تست ضربه ای آونگ استفاده شد. با توجه به عملکرد پیشگیرانه لایه های بیرونی فولاد ضد زنگ در برابر رطوبت، کاهش خواص مکانیکی SS FML نسبت به ترکیبات GF/E کمتر بود. ترکیبات SS FML و GF/E میزان جذب رطوبت کم آب در دریا را در هر دو درجه حرارت نشان می دهد همانگونه که محتوای زیاد نمک در آب، فرایند انتشار رطوبت را در ماتریس کامپوزیت کاهش می دهد.

***doi**: 10.5829/ije.2018.31.01a.22*