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Impact of Hygrothermal and Pre-Loading Conditions on Flexural Modulus of GFRP Composites

Sushma Singh[1] and Khushmeet Kumar[2]
[1&2]Mechanical Engineering Department, Baddi University, Baddi (H.P.)-173205

Abstract— Composites due to their extraordinary properties are used in many applications. Especially in ship building applications the use of sandwich and laminate composite is increasing progressively. This is due to the good resistance of composites under accelerated conditions of moisture and temperature for which ships are subjected in their life. This paper presents the experimental results on effect of Hygrothermal and preloading conditions on flexural modulus of GFRP sandwich structure. GFRP structures of two core thicknesses (8mm and 16mm) were submitted to two different exposure environments viz. immersion in water at room temperature and 45 ºC. Also three preloading conditions of 30%, 50% and 70% were applied for two durations of time i.e. 30 and 60 days. The results obtained are analysed for flexural modulus. The results show that the reduction in flexural modulus is more for 16mm core thickness; compared to 8 mm core thickness. It is also observed that the reduction in flexural modulus is directly proportional to exposure time, preloading conditions and exposure temperature. The maximum reduction of 52.95% in flexural modulus is found for 16 mm core thickness with 70% preloading, immersed in water at 45ºC temperature for two month duration.

Index Terms— Composite, Hygrothermal, sandwich, bending test, modulus, preloading, GFRP

1 Introduction

Composites are the materials which are fabricated by combining two or more different material and whose properties may differ from parent materials. Composites are much lighter than other metals in comparison by weight. In case of stiffness & strength, they are much better than the parent materials [1]. Composites are of many types and are classified in different ways. Sandwich structured composites are fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density [2]. Environmental factors such as humidity and temperature can limit the applications of sandwich structure composites by deteriorating the mechanical properties over a period of time. When a fibre-reinforced composite sandwich structure is exposed to a Hygrothermal environment and mechanical loads, changes in material properties are expected [3]. Danawade et al. [4] investigated the flexural strength, flexural modulus and flexural stress at specified strain levels of wood reinforced steel composite tube using three point bending test. Mukherjee and Arwikar [5] studied a set of accelerated aging and natural environment tests to evaluate performance of glass fibre-reinforced polymer (GFRP) reinforcing bar in a tropical environment. Fabricated beams (bars) were immersed in a 60°C water bath for varying durations. The novelty of the experiment was that the environmental exposure was given to the beams while they were subjected to service loads. They found that the change in modulus of elasticity of composite sheet depends on thickness and properties of the damaged epoxy.

Bergeret et al. [6] experimentally studied the effect of accelerated environment on mechanical properties of glass-fibre-reinforced thermoplastic composites. They reported that there is a decrease of 90% to 50% in ultimate stress to failure and impact strength with ageing according to the nature of the matrix. They also found that increasing the ageing temperature results the faster degradation rate. Selzer and Friedrich [7] investigated the effect of moisture on the mechanical properties and the failure behaviour of fibre-reinforced polymer composites. The results show that the absorbed moisture decreases those properties of both epoxy-based composites which were dominated by the matrix or the interface. Kumar et al. [8] conducted an experimental study and found that exposure of moisture and temperature leads to the swelling of the epoxy resin and results the decrease in micro-hardness and other mechanical properties. Correia et al. [9] analysed the effect of immersion and condensation environments on flexural properties of GFRP composites. They reported that immersion and condensation environments had a significant effect on the flexural properties of GFRP profiles. They also found that strength and strain at failure decreases due to moisture and these effects were accelerated by increased temperature.

Also it is found from the literature that composites have a large number of practical applications. Further the past studies on composite material includes the short aging of materials which may be further extended and the present work was carried to study the effect of moisture, heat and loading conditions on flexural modulus of sandwich structure of Glass Fibre Reinforced Polymer (GFRP) woven fabric (E-Glass) and Thermocol (polystyrene) of different thickness for a specified time period.

2 Experimentation

The aim of the experiment was to study the effects of accelerated environmental conditions on strength of sandwich composite. Initially the samples were prepared and each sample was held in experimentation for pre-decided time periods then tested for their flexural strength and deflection.

2.1 Setup

The setup basically consists of following main elements:

- Water Tank
- Heating Elements
- RTD Sensors
- Temperature Controllers
- Solid State Relays

2.2 Specimen Specifications

The sandwich structure facing were made of unidirectional woven glass fibre.

The following specifications of the specimen were used

Length of specimen : 300 mm
Breadth of specimen : 40 mm
Thickness of specimen : t+2h mm (approx.)

Where t is thickness of thermocol sheet and h is thickness of glass fibre sheet. For this experimentation thickness of specimen are 12mm and 20mm for 8mm and 16mm core respectively. Dimensions of the specimen are shown in Figure 1. All the dimensions are taken according the ASTM Standard C-393 [10]. Figure 2 shows the actual image of specimen.

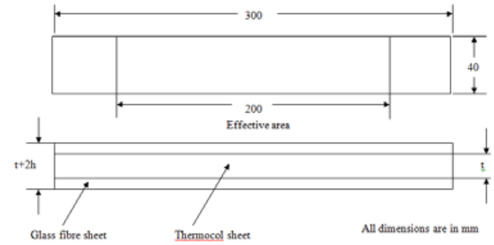


Fig. 1. Dimensions of the Specimen

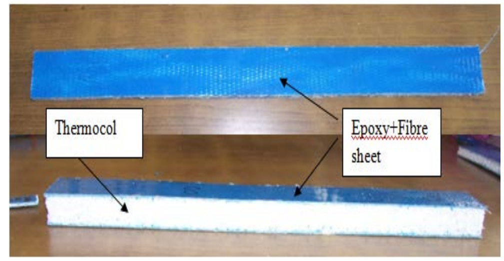


Fig. 2. Actual Image of specimen

2.3 Testing of specimens

Total 24 numbers of samples were prepared for testing at different temperatures and different loading conditions as shown in Table 1.

TABLE 1
SPECIMEN MATRIX DETAILS

Thermocol sandwich core thickness	**Bath Temperature (°C)**	**Holding Time (days)**	**No. of specimen pre stressed at % Load at failure (N)**			**Total Specimen**
			30%	**50%**	**70%**	
16 mm	45	30	1	1	1	3
	Room temperature		1	1	1	3
8 mm	45		1	1	1	3
	Room temperature		1	1	1	3
16 mm	45	60	1	1	1	3
	Room temperature		1	1	1	3
8 mm	45		1	1	1	3
	Room temperature		1	1	1	3
Total pieces at particular load			**8**	**8**	**8**	**24**

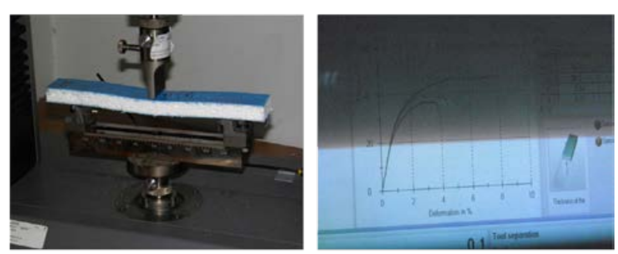
2.4 Three Point Bending Test

The Three Point Bending flexural test provides values for the modulus of elasticity in bending Ef, flexural stress σf, flexural strain εf and the flexural stress-strain response of the material. For rectangular cross section flexural modulus (σf) is given by

$$E_f = \frac{L^3 m}{4bd^3} \quad (1)$$

Where,
L = Support span, (mm)
m= The gradient (i.e., slope) of the initial straight-line portion of the load deflection curve, (N/m)
b = Width of test beam, (mm)
d = Depth of tested beam, (mm)

Universal Testing Machine (UTM) was used for the test on GFRP composite sandwich structure specimen and to calculate maximum flexural modulus and gradient (m). All specimens were tested at a predefined fixed deformation (5%) and peak load to strength as shown in Figure 3.



(a) (b)

Fig. 3. (a) Gripped specimen on the machine (b) Simultaneous display of output as test was conducted

3 Results and Discussions

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All the specimens were tested by three point bending test and based on the test data value of flexural modulus has been calculated using the equation (1). The value of unloaded and un exposed specimen for 8 mm and 16 mm core thickness were found to be 244.34 and 81.75 respectively. The values of flexural modulus at different loading, exposure conditions and time duration are shown in Table 2.

TABLE 2
FLEXURAL MODULUS OF SPECIMENS

Core Thickness	Loading	Room temperature		45°C	
		Flexural modulus after 1 month	Flexural modulus after 2 month	Flexural modulus after 1 month	Flexural modulus after 2 month
8 mm	Without loading	242.38	192.89	223.45	165.98
	30%loading	239.86	153.56	212.43	147.98
	50%loading	200.04	130.34	178.43	122.03
	70%loading	180.34	118.84	149.50	99.98
16 mm	Without loading	74.20	68.35	71.89	67.78
	30%loading	72.76	64.13	66.23	59.42
	50%loading	65.95	53.43	57.51	42.45
	70%loading	56.21	40.22	52.23	35.06

It was observed from the Table 3 that the value of flexural modulus decreases with increase in exposure time and exposure temperature for all preloading conditions. For a thorough analysis the results are plotted for 8 mm and 16 mm core thickness as shown in Figures 4 and 5.

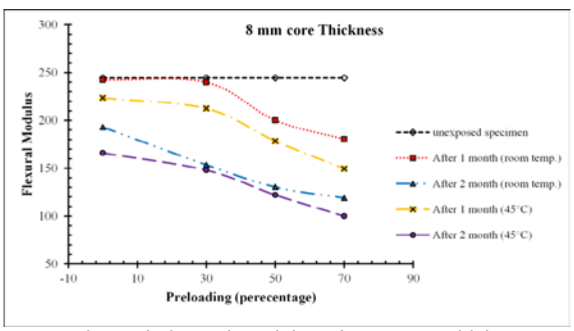

Fig. 4. Comparison of Flexural modulus of 8mm core thickness specimen at different preloading and exposure conditions.

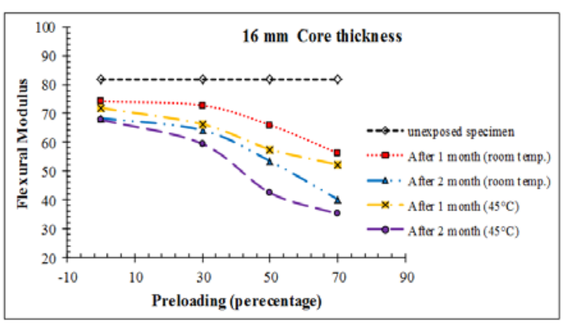

Fig. 5. Comparison of Flexural modulus of 16mm core thickness specimen at different preloading and exposure conditions.

It is seen from Figures 4 and 5 that the flexural modulus decreases with time of exposure i.e. decrease is more for time of exposure of 2 month; compared to 1month exposure time. Further after two months drop in flexural modulus is less; compared to 1 month specimen in both the core thickness specimen. Reason for decrease in flexural modulus may be softening of epoxy due to hygrothermal load. Softening of matrix leads to lose stiffness of samples which results in decrease in flexure modulus. It is also seen that there is considerable decrease occurs in flexure modulus for different preloading samples of both core thicknesses. The decrease in flexural modulus is found in the sequence of preloading 70% > 50% > 30% > Unloaded specimen; compared to unexposed specimen.

The trend in percentage decrease in flexural stress is given in Table 3. The flexural stress reduction is more for 16 mm core thickness; compared to 8 mm core thickness specimens which were exposed in water at 45°C temperature for 2 months. The maximum reduction of 57.11% in flexural modulus is found for 16 mm core thickness with 70% preloading immersed in water at temperature of 45°C for 2 months.

TABLE 3
PERCENTAGE DECREASE IN FLEXURAL MODULUS

Core Thickness	Loading	Decrease in Flexural modulus (%)			
		Room temperature		45°C	
		After 1 Month	After 2 Month	After 1 Month	After 2 Month
8 mm	Without loading	00.80	21.06	08.55	32.07
	30%loading	01.83	37.15	13.06	39.44
	50%loading	18.13	46.66	26.97	50.06
	70%loading	26.19	51.36	38.81	59.08
16 mm	Without loading	09.24	16.39	12.06	17.09
	30%loading	11.00	21.55	18.98	27.31
	50%loading	19.33	34.64	29.65	48.07
	70%loading	31.24	50.80	36.11	57.11

4 Conclusions

The decrease in flexure modulus was considerably high in both the core thicknesses for all specimens. Difference in reduction of flexure modulus between first and second month specimen was comparatively less. The decrease in flexure modulus was more in 16 mm core thickness specimen; compared to 8mm core thickness specimens. The maximum decrease in flexural modulus in 16mm core thickness in first month was 36.11 % and in second month was 57.11 %, whereas for 8mm core thickness specimen it was found 31.24% in first month and in second month was 50.80%. So it is concluded that the Hygrothermal thermal conditions (water and temperature) reduces the strength of GFRP sandwich composite with respect to time.

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