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

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Abstract: *The use of sandwich structures with composite face sheets in commercial aviation is increasing since they offer great energy absorption potential and increase in flexural inertia without significant weight penalties. The purpose of the core is to maintain the distance between the laminates and to sustain shear deformation. By varying the core, the thickness and the material of the face sheet of sandwich structures; it is possible to obtain various properties and desired performance.The main environmental factors for the deterioration of GFRP sandwich composites are temperature, sunshine, water/moisture, alkalinity and load. In this paper an experimental investigation has been carried out to study combined effect of chosen parameters moisture and temperature (Hygrothermal) on magnitude of damage of GFRP sandwich structure composites under loading conditions. The sandwich structure composed of E-glass fibre, polystyrene (Thermocol core) and epoxy resin with different thickness (8mm and 16mm) were prepared and investigated for flexural stress by three point bending test. The effect of different bending pre-loads was also assessed. It has been observed that the sandwich structure with higher core thickness withstand a higher bending load show less flexural stress as compared with low core thickness. It was also found that bending pre-load also affect the degradation. Higher percent bending pre-loads lead to higher degradation in maximum flexure load and flexure stress.*

Keywords: *Sandwich, Composite, Hygrothermal, Three Point Bending Test, Flexural Stress, Preloading*

I. Introduction

Composites are materials which are made up of two or more materials whose properties are different from the parent materials. In practical applications composites have been competing with other materials such as steel, concretes and aluminium in different industries like aircraft, racing cars, ship hulls from last 30-40 years [1]. Composites are much lighter than other metals in comparison by weight. Also the composites have low thermal expansion which is the basic requirement of the high temperature working conditions. In case of stiffness & strength, the composites are ahead of the other materials as shown in Fig. 1.

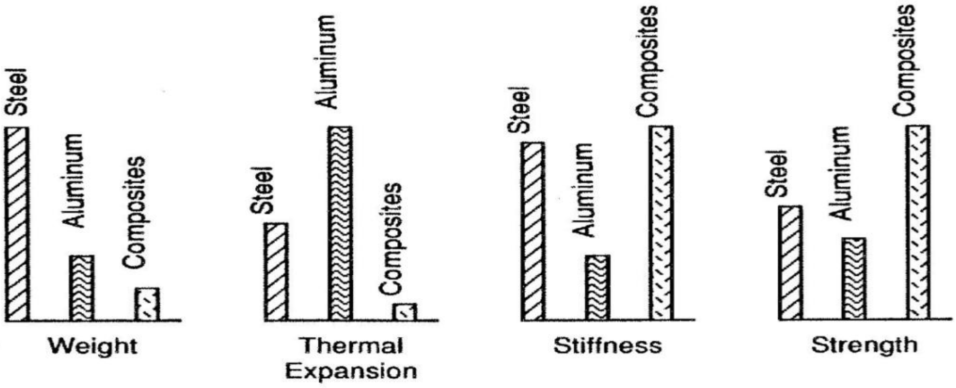


Figure 1 Comparison of performance of composites with other metals [2]

Due to better performance number of application of composite have grown steadily for example composites are extensively used in space technology, production of *Aerospace components* (tails, wings, fuselages, propellers), production of sport goods e.g. *racing car* bodies and *bicycle frames* etc and also used for general industrial and engineering structures [3].

Composites are various types and a sandwich structured composite as shown in Fig. 2 is a special class of composite materials that is 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 [4]. Sandwich structures provide an efficient method to increase bending rigidity without a significant increase in structural weight. Thin-gage face sheets (0.020″ to 0.045″) are bonded to honeycomb (aluminium or Nomex) or syntactic foam cores or polystyrene cores. These structures, based upon a minimum-gage thickness adequate to carry the in-plane loads, can carry out-of-plane loads and remain stable under compression without a significant weight penalty [5].

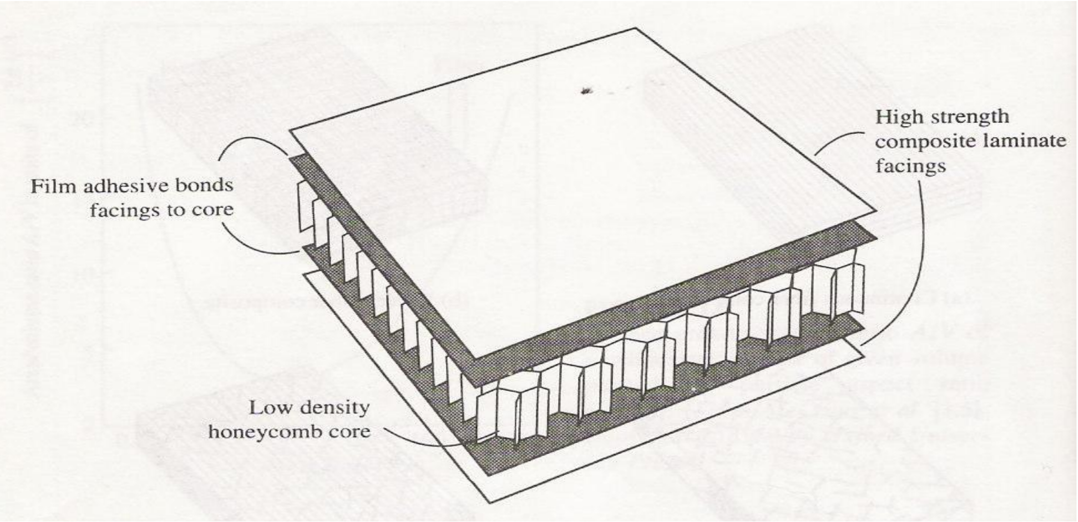


Figure 2 Honeycomb sandwich composite [5]

Greene [6] states that polyester resin is the most widely used resin, while being economical, with ease of use and good chemical resistance. Despite this, epoxy resin shows the best performance out of all resins used in marine industry. 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. These changes in material properties are connected to irreversible material strength degradation. Exposure to water ambience induces environmental effects into both the core and the face sheet of sandwich structure. Effect of exposure to external temperature remains delimited to the outer facing of sandwich structure for a significant time due to the high thermal insulation provided by the core material. The Hygrothermal environment effects induce an essentially one side expansion into the sandwich layup that tend to distort the shape, reduce the strength of the sandwich structure and produces the matrix cracking [7].

II. Literature Review

A vast literature is available on the strength degradation of sandwich composites under exposure to environmental conditions. Some researchers found that the mechanical properties of composite resin degrade after storage in water and temperature as compared to dry condition due to its water absorption. Greene [6] states that as the resins in used in marine industries are exposed in marine environment, degradation from water occurs because of absorption of some moisture because absorption of water adds weight to composites and resin and in long term affect the mechanical properties of composites. Danawade et al. [3] investigated the flexural strength, flexural modulus and flexural stress at specified strain levels of wood reinforced steel composite tube using three point bending test. Sun and Sakino [8] experimentally studied the flexural strength enhancement by reinforced concrete columns with square steel tube. Selzer and Friedrich [9] investigated the effect of moisture on the mechanical properties and the behaviour of fibre-reinforced polymer composite. The result showed that the absorbed moisture decreases those properties of both epoxy-based composite. Pegoretti and Penati [10] studied the effect of Hygrothermal aging at 70 °C in water on the molar mass and thermal properties of recycled poly and its short glass fibre composites and found that under Hygrothermal conditions micro-cracks were more active and leads to more moisture gain.

Mukherjee and Arwikar [11] 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. Beams were cast with the GFRP reinforcing bars as internal reinforcement. They 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. Bezazi, et al. [12] studied and analysed stiffness degradation and the identification of damage mechanisms during and after fatigue tests of sandwich panels with PVC foam cores. The sandwich panels with cross-ply laminates skins made of glass fibre and epoxy resin were manufactured by vacuum moulding and subjected to three-point bending tests. Two PVC cores of similar type but with differing densities were investigated. The effect of core density and thickness on the damage behaviour was highlighted. It has been demonstrated that the sandwich SD 2, with the higher core density, withstands a higher load and possesses greater rigidity in static tests, combined with an enhanced fatigue resistance, when compared to sandwich SD 1 which has a lower core density. Siriruk et al. [13] experimentally analysed the marine composite sandwich structural materials, comprising of low density PVC foam core and carbon fibre reinforced vinyl ester based resin composite facings, were studied for associated degradation in mechanical behaviour caused by sea water. Steeves and Fleck [14] focuses on the competing collapse mechanisms for simply supported sandwich beams with composite faces and a PVC foam core subjected to three point bending. The mechanical properties of the face sheets and core are measured independently. Depending upon the geometry of the beam and the relative properties of the constituents, collapse is by core shear, face sheet micro buckling or by indentation beneath the middle loading roller. Aviles and Montero [15] studied effect of Hygrothermal condition on sandwich composites. Sandwich specimen composed of E-glass/polyester face sheets bonded to a PVC foam core were exposed to high moisture (95% RH) and immersed in sea-water for extended periods of time. Degradation of mechanical properties of the face sheets, foam core and face/core interface were progressively evaluated using flexural testing of the laminates. Testing reveals substantial flexural stiffness and strength reductions for the laminated composites. Degradation of the interfacial face/core fracture toughness is weak for specimen subjected to elevated moisture and more pronounced for sandwich specimen immersed in sea-water. After 30 days of exposure to high moisture, foam damage is visible in the form of cracks and pits on the cell walls.

Literature indicate that the sandwich composites have a large number of practical applications and various materials were used for the core material of the composite but this work can be extended by using the polystyrene (Thermocol sheet) as a core material as this is light in weight. 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 (i.e. Hygrothermal effect) and loading conditions on sandwich structure of Glass Fibre Reinforced Polymer (GFRP) woven fabric (E Glass) and Thermocol (polystyrene) of different thickness for a specified time period.

III. Experimental Procedure

The experimental setup was prepared where all the necessary inputs were made. The aim of the experiment was to study the effects of environmental parameters on strength of composite sandwich material. Initially the samples were prepared and each sample was held in experimentation for pre-decided time periods then tested for their flexural stress.

A. Setup

Pictorial view of setup for the experimentation is shown in Fig.3. The setup basically consists of following main elements:

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

Figure 3 Work Setup

B. Materials

The sandwich structure facing were made of unidirectional woven glass fibre. Detailed characteristics of the fibres used for this work are reported in Table 1. An epoxy resin combined with the hardener, both supplied by MBrace, was used as matrix. Polystyrene (Thermocol) sheet was used as a core material.

Table 1 : Detail of Commercially Available Fibre Glass Sheet (EU 900 & EU 750) [16]

MBrace G Sheet EU 900 & EU 750 – Unidirectional Glass fibre sheet		
Technical data of fibre	E-Glass, 900 gsm	E-Glass, 750 gsm
Modulus of elasticity	73 kN/mm²	73 kN/mm²
Tensile strength	3400 N/mm²	3400 N/mm²
Total weight of sheet	900 g/m² in main directions	750 g/m² in main directions
Density	2.6 g/cm³	2.6 g/cm³
ε Ultimate %	4.5	4.5
Thickness for static design weight / density	0.342 mm	0.285 mm
Safety factor for static design (manual lamination / woven product)	1.5 (recommended)	1.5 (recommended)

C. Specimen Specification

The following were the specifications of the specimen:

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 (Fig. 4) had been taken according the ASTM Standard C-393 [17]. Fig. 5 shows the actual image of specimen.

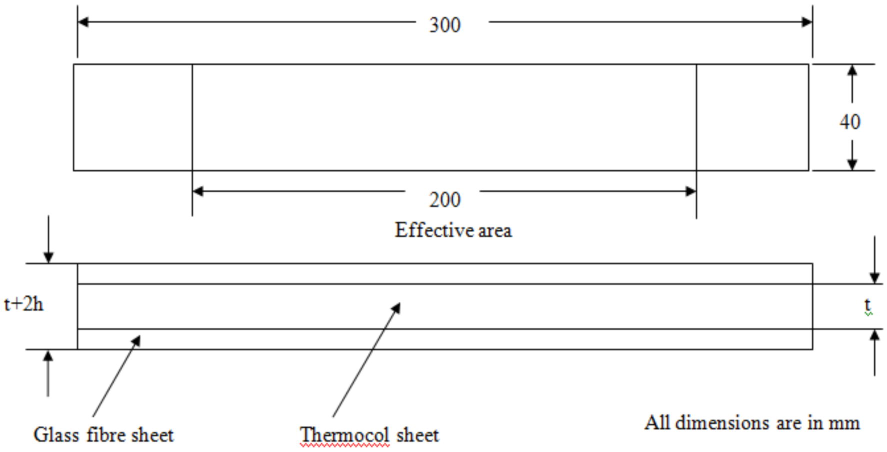


Figure 4 Dimensions of the Specimen

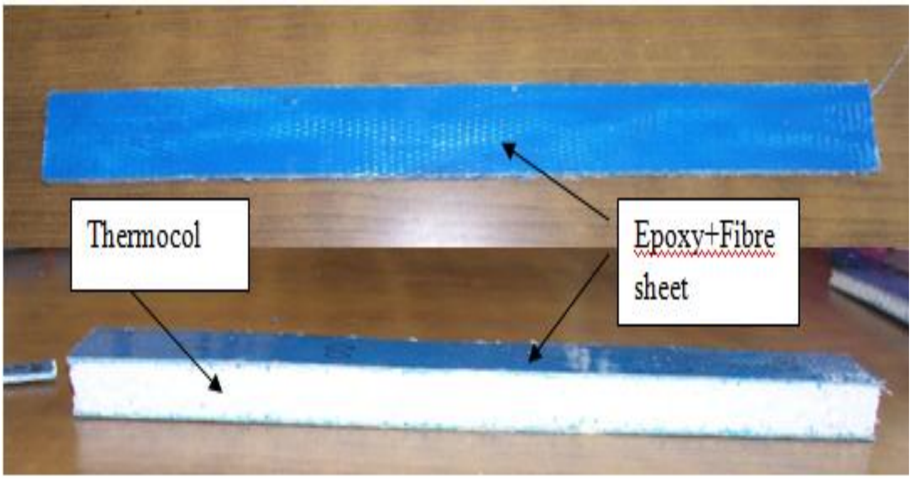


Figure 5 Actual Image of specimen

D. Testing of samples

24 numbers of samples were prepared for testing at different temperatures and different loading conditions as shown in Table 2.

Table 2 : 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**

Three Point Bending Test

The Three Point Bending flexural test provides values for the modulus of elasticity in bending E_f, flexural stress σ_f, flexural strain ε_f and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing.

For rectangular cross section flexural stress (σ_f) is given by

$$\sigma_f = \frac{3PL}{2bd^2} \qquad (1)$$

Where-

σ_f = Stress in outer fibres at midpoint, (MPa)

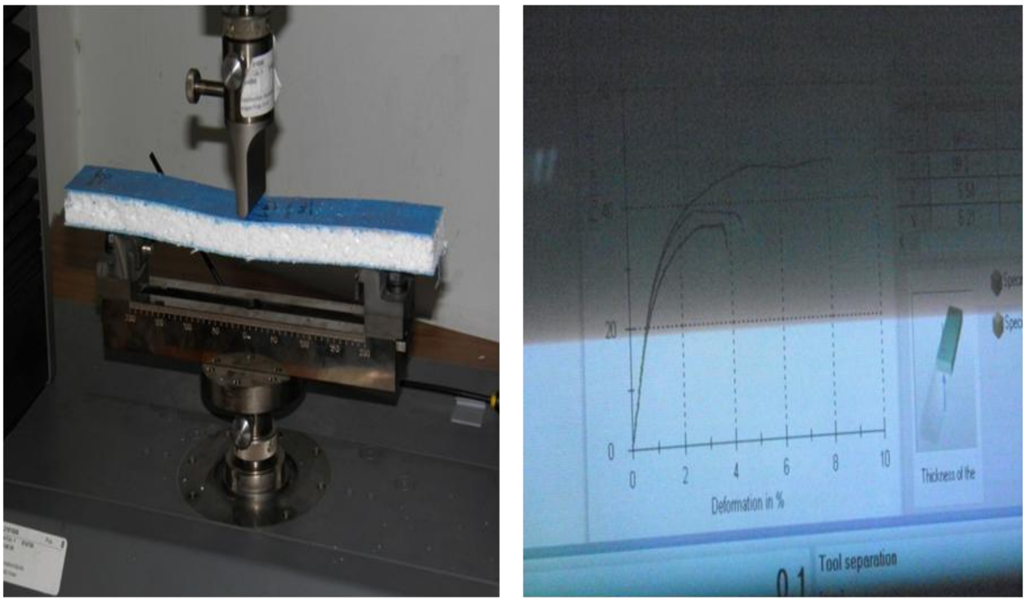
P = load at a given point on the load deflection curve, (N)

L = Support span, (mm)

b = Width of test beam, (mm)

d = Depth of tested beam, (mm)

Universal Testing Machine was used for the performing flexural test on GFRP composite sandwich structure specimen and to calculate maximum flexural stress and maximum applied force. All specimens were tested at a predefined fixed deformation (5%) and peak load to find different stress and strength as shown in Fig.6.



(a) (b)

Figure 6(a) Gripped specimen on the machine (b) Simultaneous display of output as test was conducted

IV. Result And Discussion

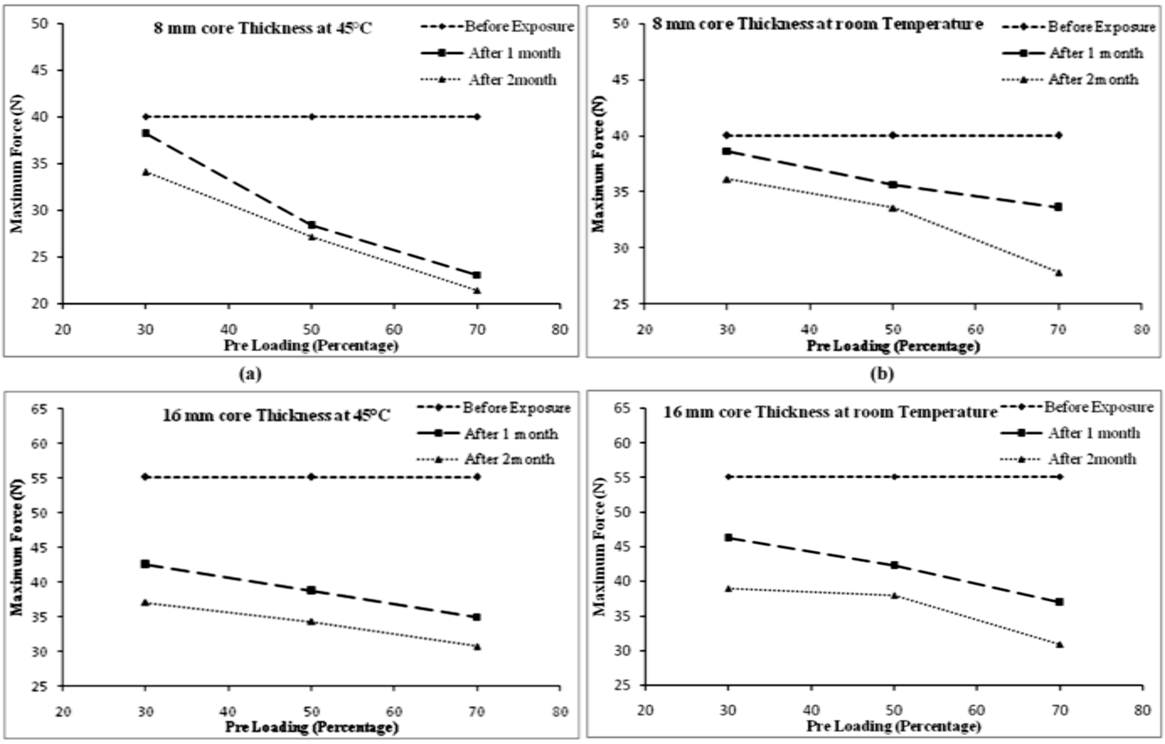
A. Maximum Flexural Load Before and After Exposure

The results after testing the specimen for maximum flexural load at different loading conditions with respect to time are shown in Table 3.

Table 3 : Maximum flexural load of different loaded specimens

Core thickness	**Loading**	**Average Initial maximum force in (N)**	**Maximum flexural load**			
			Water at room temperature (N)		**Water at 45°C (N)**	
			1 month	**2 month**	**1month**	**2month**
8 mm	30%loading	40.00011	38.60891	36.13763	38.19859	34.10930
	50%loading	40.00011	35.62849	33.58777	28.37029	27.20790
	70%loading	40.00011	33.64071	27.82941	23.10035	21.48920
16 mm	30%loading	55.16891	46.23962	38.99432	42.54316	37.06240
	50%loading	55.16891	42.27462	37.99456	38.76243	34.28530
	70%loading	55.16891	36.96240	30.93794	34.89654	30.72360

The drop in maximum flexure load is increasing with increase in bending preloads in both core thickness specimen. Table 3 and Fig. 7 (a,b,c,d) showing that decrease in maximum force in 70% bending pre-load in both the core thickness specimen is much higher than other bending pre-loaded specimen.



(a) (b) (c) (d)

Figure 7 Comparison of maximum force at different loading after 1 and 2 month exposure a) 8 mm core thickness at 45°C b) 8 mm core thickness at room temperature c) 16 mm core thickness at 45°C d) 16 mm core thickness at room temperature

The plots in Fig.7 show that maximum flexural load is more in 16mm core thickness as compared to 8mm core thickness specimen. It is also observed that the maximum flexure load is decreasing in both the core thickness specimen but drop in maximum flexure load in 16 mm core thickness specimen is more when compared with 8mm core thickness specimen immerged in water at both the temperatures (45°C and room temperature) with some exceptions.

The drop in maximum flexure load is increasing with respect to time period. Fig. 7 (a,b,c,d) shows that decrease in maximum flexure load for each bending pre-load specimen of each core thickness is more in 2 month as compared to 1 month. Average drop in force in 8mm core after 1 and 2 month is 5N and 8.25N respectively whereas average drop in force for 16mm core after 1 and 2 month is 13.33N and 19.33N respectively.

Reason for the degradation in maximum force may be hygrothermal load becauce all the specimen were kept in water at 45°C for a specified time period, this results in softening of epoxy and degrdation in maximum force.

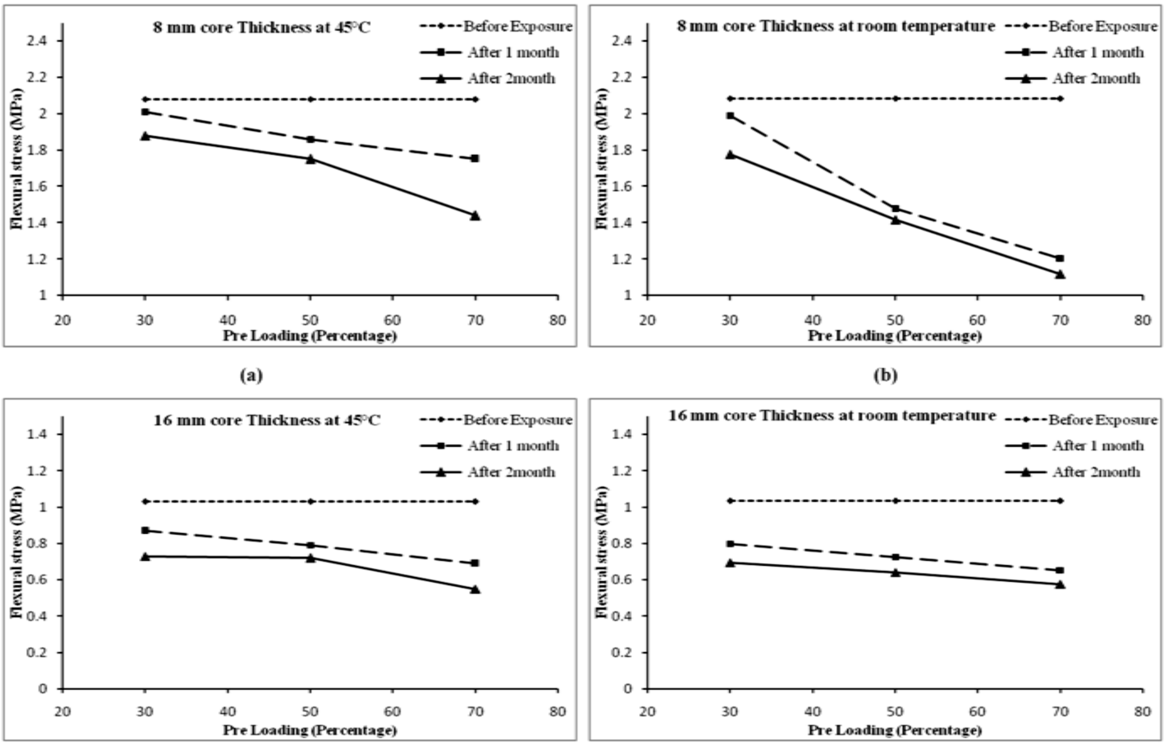
B. Results Of Ultimate Flexural Stress (U.F.S.)

The results after testing the specimen for ultimate flexural stress at different loading conditions with respect to time are shown in Table 4.

Table 4 : Ultimate flexural stress of different loaded specimens

Core Thickness	**Loading**	**Initial flexural stress (MPa)**	**Room temperature**		**45°C**	
			Flexural stress after 1month (MPa)	**Flexural stress after 2month (MPa)**	**Flexural stress after 1month (MPa)**	**Flexural stress after 2month (MPa)**
8 mm	30%loading	2.08	1.99	1.78	2.01	1.88
	50%loading	2.08	1.48	1.42	1.86	1.75
	70%loading	2.08	1.20	1.12	1.75	1.44
16 mm	30%loading	1.03	0.80	0.69	0.87	0.73
	50%loading	1.03	0.73	0.64	0.79	0.72
	70%loading	1.03	0.65	0.58	0.69	0.55

It was observed from the table 4 and Fig. 8 (a, b, c, d) that flexural stress in both the core thicknesses and each bending pre-load specimen is decreasing with increasing time. Decrease in flexure stress after 2 month of exposure is more as compared to 1 month and before exposure values.



(a) (b)

(c) (d)

Figure 8 Comparison of Ultimate Flexural Stress at different loading after 1 and 2 month exposure a) 8 mm core thickness at 45°C b) 8 mm core thickness at room temperature c) 16 mm core thickness at 45°C d) 16 mm core thickness at room temperature

The above Fig. 8 (a, b, c, d) show that the flexural stress of 16mm core thickness specimen is less as compared to 8mm core thickness specimen. It was also observed that there was marginal decrease in flexural stress of the specimen immersed in water at 45°C and room temperature for one month compared to that of Initial value. Further after two months drop in flexural stress was less as compared to 1 month specimen in both the core thickness specimen.

It was also observed from Fig. 8 (a, b, c, d) that decrease in stress in 70% bending pre-load specimen was more as compared to 30% and 50% bending pre-load specimen in both core thicknesses. Flexural stress was decreasing due to decrease in maximum applied force. Average decrease in flexural stress in 70% bending pre - load in 8mm core thickness was 16MPa whereas in 50% and 30% bending pre -load it was 11MPa and

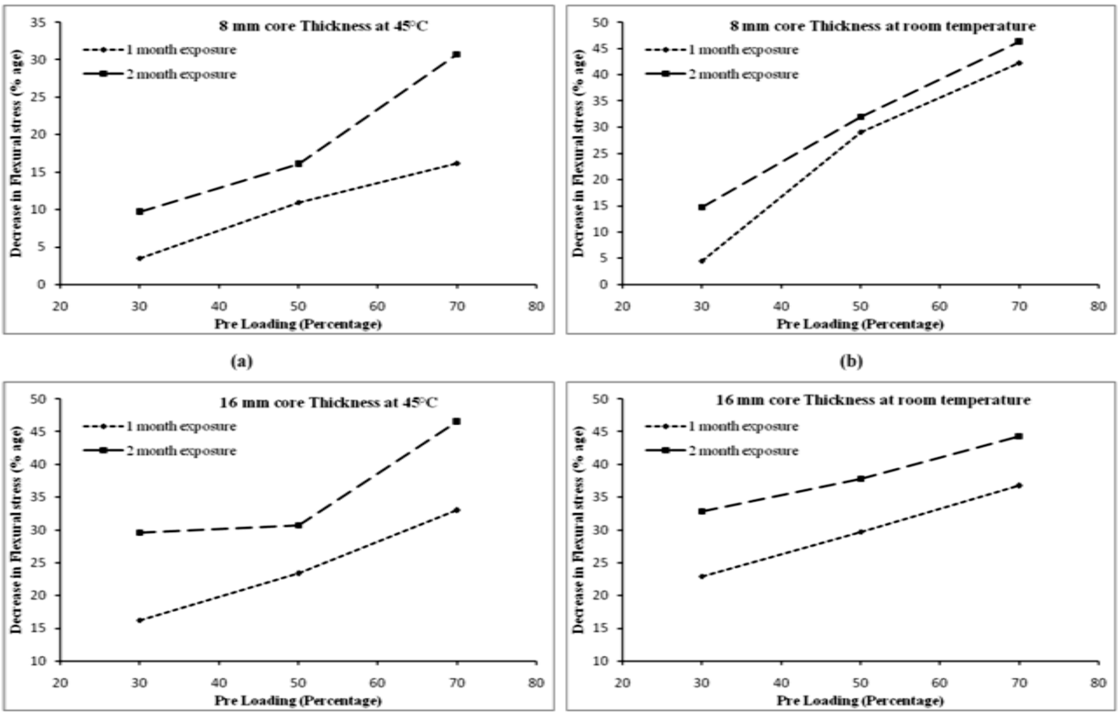
3.35MPa. In 16mm core thickness average decrease in flexural stress for 70% loading was 33.5MPa whereas for 50% and 30% bending pre-load it was 23.23MPa and 15.86MPa.

C. Decrease in Flexural Stress

The results of percentage decrease in ultimate flexural stress at different loading conditions with respect to time are shown in Table 5 and Fig.9.

Table 5 : Percentage Decrease in Ultimate flexural stress of different loaded specimens

Core Thickness	**Loading**	**Room temperature**		**45°C**	
		Decrease in Flexural stress (%)			
		after 1 month	**after 2 month**	**after 1 month**	**after 2 month**
8 mm	30%loading	4.50	14.73	3.48	9.66
	50%loading	29.07	31.98	10.93	16.03
	70%loading	42.25	46.28	16.18	30.75
16 mm	30%loading	22.89	32.82	16.19	29.61
	50%loading	29.74	37.85	23.37	30.73
	70%loading	36.75	44.31	33.01	46.49



(a) (b) (c) (d)

Figure 9 Comparison of percentage dectrease in Ultimate Flexural Stress at different loading after 1 and 2 month exposure a) 8 mm core thickness at 45°C b) 8 mm core thickness at room temperature c) 16 mm core thickness at 45°C d) 16 mm core thickness at room temperature

The trend in percentage decrease in flexural stress is shown in Fig.9. The flexural stress reduction is more in 16mm core thickness samples as compared to 8mm core thickness samples and also in 2 month when compared to 1 month.

It was also noticed that strength reduction in samples preloaded at 70% is more as compared to other samples. Maximum decrease in stress for 8mm core thickness samples was 30% of the ininitial ultimate stress in two months whereas for 16mm core thickness samples it was 46.49%.

V. Conclusion

The decrease in flexural stress was considerably large (about 15.9 % in 8 mm core and 34.9 % in 16 mm core after 1 month and about 30 % in 8 mm core thickness specimen and about 46.49 % in 16 mm core thickness specimen after 2 month) in almost all the specimen immersed in water tank at 45°C as compared to the initial unexposed specimen’s flexural stress. This reduction trend was on higher side in specimen subjected to bending pre-loads at 50 % and 70 % of Ultimate Flexural Load.

Decrease in flexural stress in the specimen immersed in the water tank (at room temperature) in both the month was less than the specimen immersed in the water tank (at 45°C). The reason for decrease in ultimate flexural stress and change in percentage flexural stress seems to be the continuous degradation done by Hygrothermal load which affected the matrix and fibre strength.

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