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Experimental Study on the Mechanical Properties of Polymer Matrix Composite Sandwich Structures

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Abstract: ***In this project the effect of core thickness and facesheet thickness on flexural strength and elastic modulus is investigated for Polyurethane core glass/epoxy sandwiched structures. The face sheets of glass/ epoxy were prepared using hand layup and vacuum bag moulding technique. In order to interpret the effect of variable ANOVA is used. From the results of ANOVA it is found that, the face sheet thickness is most significant variable for flexural strength and for elastic modulus core thickness. The images of the fractured specimens showed, crack propagation starts from the interface between the core material and facesheet and moves towards the center of the core to the lower face of the facesheet.***

Keywords: Glass/Epoxy Polyurethane foam, Flexural Strength, Elastic modulus, ANOVA

1. Introduction

Improving the performance of any structural material for a specific applications like aerospace, marine, automobile and civil engineering is of prime concern to designers. The designers strive to build the structural materials which are light with improved performance. The major factors contributing to the improved performance in these applications have been advanced materials and new structural concepts. New materials such as composites and structural concepts such as sandwich construction have resulted in lighter structural designs with superior performance.

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore that high temperature resins are extensively used in aeronautical applications.

The sandwich structure consists of relatively two thin face sheets of composite material in which a core material is sandwiched. Core materials refer to the central component of a sandwich structure like honeycomb, balsa or foam cores. The purpose of sandwich structure is to achieve a stiff and simultaneously light component. A sandwich structure is designed to make sure that it is capable of taking structural loads throughout its design life. In addition, it should maintain its structural integrity in the in service environments. The structure should satisfy the following criteria.

2. Literature Review

Liviu Marsavine et al. [1] showed the experimental results on the dynamic fracture toughness of polyurethane foam and the effect of impregnation on the fracture toughness. The results of the impact test on this type of foam on un-notched specimens shown impregnation layer decreases the energy absorbed to fracture.

Amir Shahdin et al. [2] fabricated and tested mechanical properties of glass fiber entangled sandwich beams and compared the results with honeycomb and foam sandwich structure. They observed the compression bending of entangled sandwich specimens have relatively low compressive and shear modulus when compared to honeycomb and foam sandwich materials.
Mohammad Mynul Hussain et al. [3] studied compression fatigue performance of fire resistant syntactic foam (Eco core). The failure modes were damage on set, damage progression and final failure. These were characterized by 2%, 5% & 7% changes in compliance. Three modes of failure found to be same for static and fatigue loading.

K.Kanny and H Mahfuz [4] have investigated the effect of frequency on the fatigue behavior of S2 glass fiber vinyl ester reinforced sandwich composites with two different PVC cores. The flexural fatigue test were performed on sandwich beams with core densities of 130 and 260 kg/m^3 at a frequency of 3 and 15 Hz, at a stress ratio R=0.1 and at four different loading levels viz. 90%, 85% and 75% of ultimate load. It was observed that the fatigue strength increased with increase in frequency. In all case failure was dominated by a primary shear crack in the core.

G.S. Langdon et al. [5] reported a preliminary experimental investigation into the response of sandwich panels comprising E glass fibre reinforced vinyl ester facesheets and closed cell PVC foam cores to localized blast loading. A failure progression pattern was identified, with increasing impulse: front facesheet delamination, core compression, back facesheet delamination, fibre fracture, core fragmentation, plastic deformation and debonding of the back facesheet followed by complete core penetration. No back facesheet rupture was observed.

Mojtaba Sadighi et al. [6] did finite element simulation and experimental investigation on the mechanical behavior of three-dimensional woven glass-fiber sandwich composites using FE method. Experimental load–displacement curves were obtained for flat wise compressive, edgewise compressive, shear, three-point bending and four-point bending loads on the specimens with three different core thicknesses in two principal directions of the sandwich panels, called warp and weft.

O.Velecela eta al. [7] studied steady quasistatic compression of GFRP monolithic laminate and sandwich panels made of randomly oriented continuous filament mat/ polyester. The facing/laminate thickness trigger system and aspect ratio on their failure mechanism and their energy absorption capabilities examined. The experimental data showed, high value of energy absorption per unit mass were predominant feature of the thickest monolithic laminate & sandwich panels with thickest facing.

3. Objectives

It is found that the flexural strength of sandwiched polymer matrix composites are depending on the foam density, composition of the facesheet and the bond strength between the core and facesheet. So, there is scope for further investigation on the sandwich structures. Hence, the objective set for this project is to study the effect of core thickness and facesheet thickness on the flexural strength and elastic modulus of glass/epoxy polyurethane sandwiched polymer matrix composite at fixed density of core i.e 300 kg/m^3.

4. Methodology

Diagram 4.1 below shows the steps involved in this experiment.

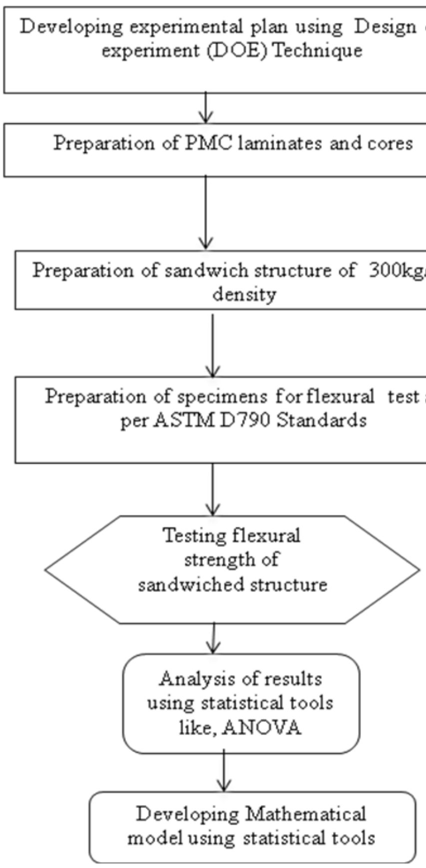


Figure 4.1: Flow chart of research methodology

5. Selection of Material

The materials and their properties selected for making the face sheet and core material are shown in Table 5.1

Table 5.1: Properties of Materials

Reinforcement	*Matrix material*	*Hardener*	*Core material*
E-glass of 300 GSM Bidirectional woven roving	Epoxy resin (LY556) [Araldite]	Hardner HY 951 [Aradur]	Polyurethane Core 1.Methyl di-isosynate (MDI) 2.Polyether Polyol(PEP) At 60:40
Density of fiber $\rho_{f} =$ 2.54 g/cc	Density of Epoxy resin at 25^0 C $\rho_{m} =$ 1.15-1.20 g/cc	At 20^0 C 1:1 in water Boiling point > 200^{0}C, Density= 1 g/cc	Density of Polyurethane core 300 kg/m^3

5.1 Development of Experimental Plan

In this project the parameters selected for the study are facesheet thickness and the core thickness at constant density of core at 300 kg/m^3.The list of parameters and their levels are shown in table 5.2

Table 5.2: Selected parameters and their levels

Parameters	*Levels*		
	1	2	3
Facesheet thickness, mm	2	4	6
Core thickness, mm	10	20	30

Using design of experiment (DOE) approach, the minimum number of experiments to be conducted are 5. For this the nearest orthogonal array is L9. The Experimental plan according to L9 array is shown in table 5.3

Table5.3: Experimental Plan

Experiment No.	*Face sheet thickness, mm*	*Core thickness, mm*
1	2	10
2	2	20
3	2	30
4	4	10
5	4	20
6	4	30
7	6	10
8	6	20
9	6	30

On the basis of above selected parameters and Experimental plan specimens are prepared and Sandwich structures are then cut to the size 250 x 30mm as per ASTM standard D790 as shown in figure 5.1

Figure 5.1: Sandwich samples of different facesheet and core thickness

Material	*Flexural strength in N/mm² (σ)*	*Elastic modulus in Gpa (E)*
Sandwich Structure (2mm Face sheet & 10mm core thickness)	137.49	8.077
Sandwich Structure (2mm Face sheet & 20mm core thickness)	110.84	14.97
Sandwich Structure (2mm Face sheet & 30mm core thickness)	80.96	19.169
Sandwich Structure (4mm Face sheet & 10mm core thickness)	186.15	14.345
Sandwich Structure (4mm Face sheet & 20mm core thickness)	149.23	21.662
Sandwich Structure (4mm Face sheet & 30mm core thickness)	65.26	31.728
Sandwich Structure (6mm Face sheet & 10mm core thickness)	192.5	20.022
Sandwich Structure (6mm Face sheet & 20mm core thickness)	183.22	25.156
Sandwich Structure (6mm Face sheet & 30mm core thickness)	160.31	31.128

6. Results and Graphs

Flexural strength of the polyurethane core sandwiched glass/epoxy laminate samples of size 250 x 30 mm were tested according to ASTM standard D790. In this test, the specimens were loaded in a three point bending fixture of computer controlled UTM of 10 kN capacity at Raghavendra Spectro Metallurgical Laboratory, Bangalore.

6.1 Flexural Strength

In this mode a large span thickness ratio (L/D) is used. The distance between the two supports was maintained according to the standard. The data is recorded during the 3-point bend test to evaluate the flexural strength using below equation 1 [8]:

$$\sigma = \frac{3FL}{2BD^2} \qquad \text{eqn(1)}$$

Where,

σ = Flexural strength, F= Load at fracture point in N, B= width of rectangular section, D= thickness of rectangular section.

6.2 Elastic Modulus

The Elastic modulus is used as an indication of a material's stiffness. A flexural load involves the ability of the material to bend. Elastic modulus is calculated using below equation 2:

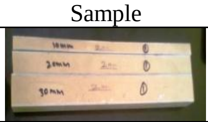
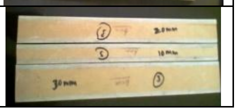
$$E = \frac{ML^3}{4bd^3} \qquad \text{eqn(2)}$$

Where,

E=Elastic modulus in Gpa, L=Length of support span in mm,b=Width of beam tested in mm, M=Slope of the tangent to the initial straight line portion of the load deflection curve calculated as M= (Y1-Y2/X1-X2).

Using the above equations flexural strength & elastic modulus can be calculated as shown in table 6.1.

Table 6.1: Flexural strength, Elastic modulus and Flexural stain of specimens

Sandwich structure	Sample
Face sheet of 2 mm thick and core materials of 10, 20 & 30 mm	
Face sheet of 4 mm thick and core materials of 10, 20 & 30 mm	
Face sheet of 6 mm thick and core materials of 10, 20 & 30 mm	

6.3 Effect of Core Thickness and Facesheet Thickness on the Flexural Strength

The effect of PU core thickness and facesheet thickness on the flexural strength of PU/glass/epoxy sandwich structure is shown in figure 6.1 & 6.2. From the graph 6.1 it is observed that, the flexural strength decreases with increase in core thickness. That is, flexural strength is inversely proportional to the core thickness.

Form graph 6.2 the flexural strength increases with increase in facesheet thickness. In general the flexural strength can be related as

$$\sigma \ \alpha \ \frac{T_f}{T_c}$$

Where

T_f thickness of facesheet and T_c is thickness of core material.

The maximum value of flexural strength is found to be 192.5 Mpa for 6 mm facesheet and 10 mm core thickness.

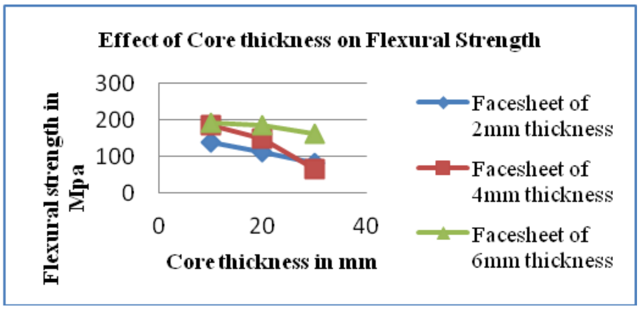


Figure 6.1: Effect of core thickness on flexural strength

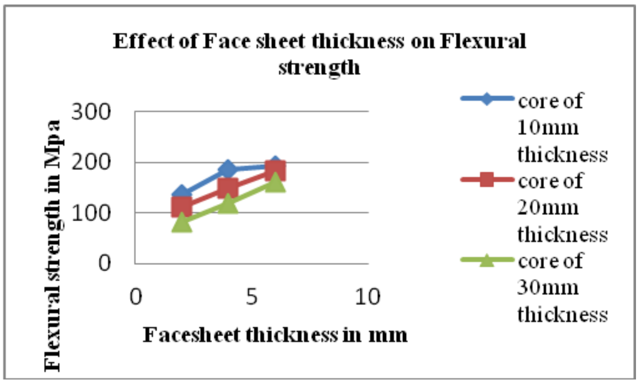


Figure 6.2: Effect of facesheet thickness on flexural strength

6.3 Effect of Core Thickness and Facesheet Thickness on the Elastic Modulus

The effect of PU core thickness and facesheet thickness on the Elastic modulus of PU/glass/epoxy sandwich structure is shown in figure 6.3 & 6.4. From the graph 6.3 it is observed that, the elastic modulus increases with increase in core thickness. That is, elastic modulus is directly proportional to the core thickness. Form graph 6.4 the elastic modulus increases with increase in facesheet thickness. In general the elastic modulus can be related as σ α T_f and σ α T_c. The maximum value of elastic modulus is found to be 31.728 Gpa for 4 mm facesheet and 30 mm core thickness.

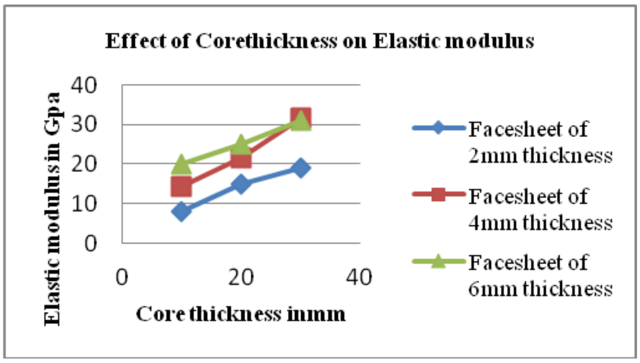


Figure 6.3: Effect of core thickness on elastic modulus

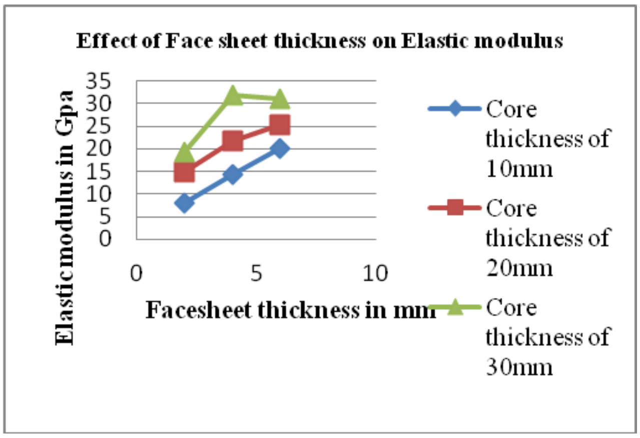


Figure 6.4: Effect of Face sheet thickness on elastic modulus

7. Conclusion and Future Work

7.1 Conclusion

From the experimental results of flexural strength of PU core sandwiched glass/epoxy composite structure following conclusions are drawn.

1. The most significant factor for flexural strength is facesheet thickness contributing 61.53% of influence and for elastic modulus is core thickness contributing 49.2% of influence.
2. The maximum value of flexural strength can be achieved for the sandwich structure having greater facesheet thickness lower core thickness values. In this project the maximum value of flexural strength achieved is 192.5Mpa.
3. The maximum elastic modulus can be achieved for the greater thickness of core and in this project 31.72 Gpa elastic modulus is achieved for 30 mm core thick sandwich structure.
4. During the flexural loading, the complete load is first taken by the facesheet and gradually transferred to the core material.

7.2 Future Work

The project can be continued to study with different composition of facesheet materials and core materials. The mechanical properties such as tensile and fatigue can be studied for different orientation of the fibers for facesheet thickness.

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