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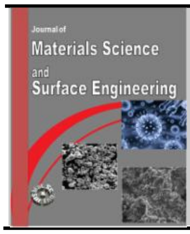

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Studies On Shear Flow Of Foam Core-Glass/ Epoxy Skin Sandwich Composites In Flexure

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Abstract

Studies on understanding shear flow by varying geometry and skin to core weight ratio of sandwich composites help understand the crux of failure patterns. Glass epoxy skin foam core sandwich composites used in high end structural aerospace applications exhibit various types of failures occurring over time. The current study focuses on understanding the shear flow patterns of failure in glass epoxy foam core sandwich composites on flexural load application. The shift in the neutral axes exists in case of bending. Ratio of stresses in foam, from compressive and tensile tests gives the necessary 'r' ratio.. Low density Polyurethane (PUF) and Polyisocyanurate (PIR) foams of 125kg/cum are chosen to fabricate the sandwich panels with glass epoxy skin by maintaining a constant skin to core weight ratio of 4:1 with various thicknesses of 10mm, 25mm, 50mm. Foam tensile test specimens are fabricated, and tested, compression test properties are used, and, the shift in neutral axes understood by a new novel design approach for the tensile test specimens .

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Introduction

Sandwich composites, and their popularity in structural design, due to their ability to substantially decrease weight while maintaining mechanical performance, necessitate the need to understand the behavioural patterns in failures as well. The weight reduction results in higher payloads and decreased fuel consumption with a positive impact on cost and decreased impact on the environment.

Geometries of the sandwich panel composite materials also enable designers to engineer with extreme precision to their loading requirements [1]. The core is one of the variables in a sandwich composite that enables modifications to be made due to the wide range of mechanical properties it provides and understanding the subsequent causes of failure [2-3], aides in design A lower weight in a container or vessel construction enables higher payloads, resulting in reduced emissions and, cost. Sandwich composites provide vital strength and speed for the sports equipment segment. In industry, a lightweight solution can result in faster and smaller robots. Obviously, anything that moves consumes energy, and the heavier it is, the more energy it consumes [4]. The constituent components of the sandwich are bonded using epoxy adhesives with the basic underlying concept that face sheets carry the bending stress and the cores carry the shear stress. The bending stiffness of the sandwich is very much higher than a solid structure having the same total weight and the same material as the facings.

Rodrigo Silva et al. [5] studied the sandwich composite plate effects of the transverse shear deformation are often significant. For this reason, the results of the first-order shear deformation theory (FSDT) can be severely affected by the choice of the shear correction factor (k), especially in sandwich plates with low shear modulus core. The objective of this study was to validate the first-order shear deformation theory (FSDT) in the elastic analysis of sandwich plate structures.

R.Vijayalakshmi Rao et al.[6] made an attempt to study the flexural and fatigue behaviour of E-glass/ Vinyl ester/Polyurethane foam sandwich composites.

In the case when a beam is subjected to bending stress causing deflection, the material on the outside is put to tension and that on the inside is put to compression. So, the transition point between tension and compression does not contribute to either mode of stress, adding little or nothing to the mechanical performance [7]. Hence the usage of thick core material improves structural performance

Theoretical Explanation

The general design considerations that a structural designer is consider is to make sandwich structures to maximize stiffness at very low weights ie face sheets should be thick enough to withstand tensile and compressive stresses induced by mechanical loads in mixed mode failure ie bending. The overall structure is to show high flexural and shear rigidity to avoid high deflections under heavy loads. The face sheets are to have sufficient stiffness to provide higher fundamental frequency. The cores are to have sufficient shear modulus to prevent buckling of the sandwich under load. The flexural specimens were tested at span to depth ratio of mainly 16:1 to understand the shear flow and shift in neutral axis in the flexural specimens.

The mechanical properties for the sandwich panels are to be calculated for the above conditions. Ratio between ultimate compressive stress and tensile stresses helps achieve the corresponding C/D ratio, Eqs .1 & 2

$$r = \frac{\sigma_{tu}}{\sigma_{cu}} \qquad (1)$$

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$$\frac{C}{D} = \frac{1-2r+(r*r)}{2*(1+r)*(1+r)} \qquad (2)$$

The shearing stress τ, multiplied by thickness t, gives a quantity Q known as the shear flow, which represents the longitudinal force per unit length transmitted across a section at a level y1 from the neutral axis.

$$Q = \tau * t \qquad (3)$$

The shear flow values are calculated based on max shear stress in core multiplied by thickness.

Fabrication

The study investigates flexural properties, on sandwich structures, focusing on the effects induced by different core thickness arrangements with skin to core weight ratio of 4:1 for polyurethane (PUF)and polyisocyanurate (PIR) foams (Table 1). The panels were fabricated by vacuum bagging techique at room temperature and atmospheric pressure,Fig.(1).

Table 1: Matreials used for sandwich panels

Glass Fabric	Foam	Resin	Hardener
E-Glass , 280-600 gsm	PUF & PIR - 125 kg/m^3	GY 257	Aradur 140

Figure 1: PUF 125 - 4:1-50mm, Vacuum bagging technique for fabrication of sandwich composites

Tensile Test Specimens

Chava Uday et al [8] had studied on double lap shear and peel properties of sandwich composites which focused on investigation of adhesively bonded joints of glass/epoxy skin-rigid unfilled thermoset foam core material sandwich composite structures to study their shear failure properties. This understanding aided in designing specimens for tensile test of foams, Fig 2.

The tensile specimens are fabricated from PIR & PUF 125 kg/m^3 density material with 10 mm thickness. The dimensions of the tensile specimen standards are considered from ASTM [9] for a dog bone shaped specimen. As the foams would get crushed between the grips of the tensile fixture, the design is modified to suit the requirements by taking long specimens with end grooves provided (as shown in Fig 4).

Figure 2: Tensile Test Specimens with GFRP attachment s to be held at grips

Testing and Evaluation

Compressive and tensile tests (Figs 3 &4) are performed to acquire the ratio between the ultimate compressive and tensile stress, and, flexural tests are performed for a static mechanical characterisation of the sandwich structure to acquire important parameters for comparison (Tables 2 & 3).

Figure 3: Compression Test Setup

Figure 4: Tensile Testing of Foam

Table 2: Material Properties of Foam Core from Compression Test

Foam	PUF 125 kg/m^3	PIR 125 kg/m^3
Young's Modulus of Elasticity, E_1, MPa	16.69	26.75
Poisson's Ratio	0.295	0.3207
Compressive Stress, N/mm^2	0.627	1.16

Table 3: Material Properties of Foam Core from Tensile Test

Foam	PUF 125 kg/m^3	PIR 125 kg/m^3
Young's Modulus of Elasticity, E_1, MPa	6.733	5.129
Poisson's Ratio	0.205	0.06
Tensile Stress, N/mm^2	1.7	1.32

Flexure Test was conducted according to ASTM standards[9,10] maintaining a cross head feed rate of 2mm/min.

Subsequently evaluations were done based on studies performed by Hemnath et al.[11] on flexure. The tests were conducted for the two foams of three thicknesses, 10mm (Fig.5), 25 mm & 50mm (Fig.6).

Evaluations For "r" Ratio And C/D Ratio

For, PIR-125 :
$r = 1.32 / 1.16 = 1.272$;
$C/D = 0.007174$

For, PUF-125:

$r = 1.7 / 0.627 = 2.694$; $C/D = 0.1051$

By observing all the specimens, PUF 125 is seen to be more elastic compared to PIR125 due to high load bearing capacity in tensile test.

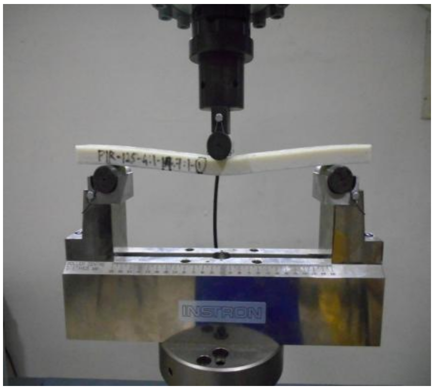

Figure 5: Flexure Test of PIR -125- 10 mm thick specimen

Figure 6: Flexure test of PUF 125-50mm thick

Results and Discussion :

The results for the maximum bending stress, flexural rigidity per unit width, shear strength in core, normal stress, shear deflection, bending shape factor for stiffness and shear strain at maximum load are evaluated and tabulated in Table.4.

Table 4: Mechanical properties of PUF &PIR125 at 4:1skin to weight ratio with thickness 10mm,25mm,50mm

	Type of foam					
	PIR 125			PUF 125		
	Foam thickness(mm)			Foam thickness(mm)		
	10	25	50	10	25	50
Max bending stress	40.21	47.92	56.8	21.88	23.96	33.19
Flexural Rigidity per unit width*10^6, (N-mm^2/mm)	6.38	20.81	77.7	5.20	20.79	139
Shear Strength in Core(N/mm^2)	0.286	0.394	0.39	0.29	0.196	0.176
Normal Stress(N/mm^2)	20.398	47.68	56.69	21.45	23.84	18.78
Bending Shape Factor for Stiffness	3.815	7.183	11.42	3.97	7.183	7.99
Shear deflection	3.62	13.14	20.82	10.29	13.11	21.69
Shear strain at max load	0.0383	0.053	0.048	0.11	0.0579	0.0050

Table 5: Comparison For C/D Ratio In Tensile Foam Specimen

RATIO TYPE	PIR-125	PUF-125
R ratio	1.272	2.694
C/D	0.007174	0.1051

From Table.5 we observe that the shift in neutral axis from the centriodal axis is about 0.72 percent of foam thickness & 'r' ratio is 1.272 in PIR 125; and, in PUF 125 shift in neutral axis is 10.5 percent of foam thickness& 'r' ratio is 2.694.

Table 6: Shear Flow in PIR -125 & PUF -125(4:1 skin-core weight ratio)

	Shear Flow (N/mm)	
Sample Thickness(mm)	PIR-125	PUF-125
10	2.86	2.9
25	9.75	4.9
50	19.5	8.8

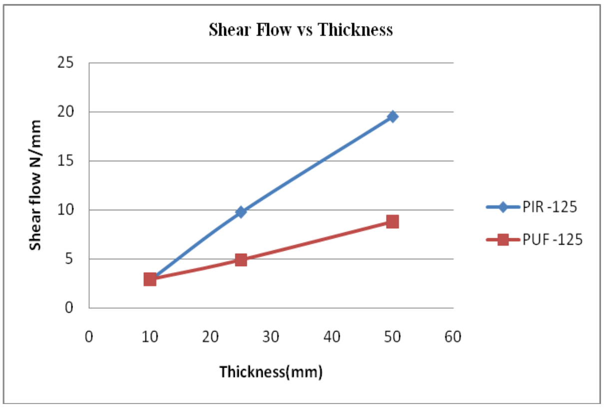

Figure 7: Shear Flow vs Flexural Rigidity / unit width

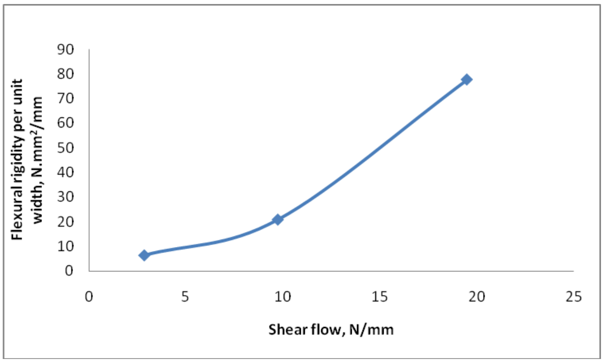

Figure 8: Shear Flow vs Flexural Rigidity / unit width for PIR 125

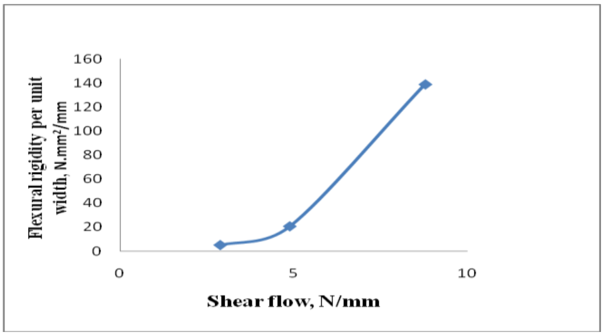

Figure 9: Shear Flow vs Flexural Rigidity / unit width for PUF 125

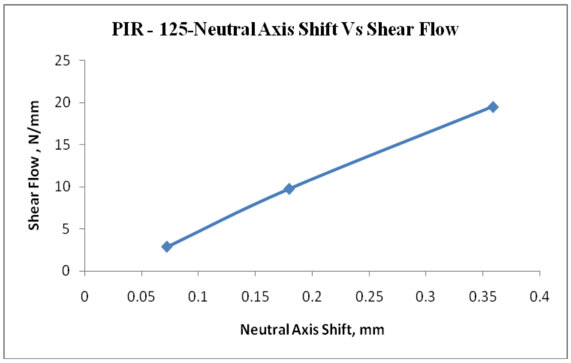

Figure 10: Shift in Neutral Axis vs Shear Flow with increase in thickness (10 to 50mm) -PIR 125

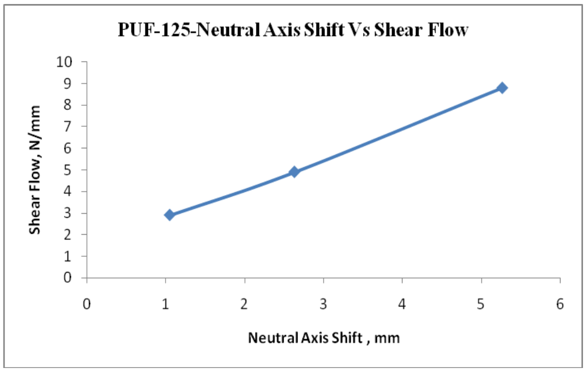

Figure 11: Shift in Neutral Axis vs Shear Flow with increase in thickness (10 to50mm) - PUF 125

Conclusions

It is seen that for PIR-125 the shift in neutral axis from the centroidal axis is 0.71 percent of foam thickness & r ratio is 1.272 which can be understood in case of flexure in foam core sandwich beams. For PUF-125 the shift in neutral axis from the centriodal axis is 10.51 percent of foam thickness & r ratio is 2.694. By observing all the specimens PUF 125 is seen to be more elastic compared to PIR 125 because PUF . The flexural rigidity also is seen to increase with thickness and shear flow.

From shear flow the shift in neutral axes plots, we observed that with increase in thickness 10mm, 25mm, 50mm. shear flow increases, so the shift in neutral axis also increases in both PUF125 & PIR125 is observed. If the thickness of sample is high shear flow is high and the shear properties of PUF are seen to show better performance than PIR which is considered more stiff than PUF.

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