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The Flexural Properties of Glass Fabric/Epoxy -Rigid Polyurethane Foam Core Sandwich Composites at Different Span to Depth Ratios and Densities

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Abstract - **The experimental studies for determining the flexural properties of thermo set rigid polyurethane unfilled foam core – glass/epoxy skin sandwich composites, are presented here. Sandwich composites were fabricated in the shape of panels by using glass fabric/epoxy as the skin material and rigid polyurethane foam (PUF) as the core. PUF materials of 125 & 250 kg/m^3 foam densities with 3:1 & 4:1 skin to core weight ratios were fabricated separately using the vacuum bagging technique. The sandwich panels were tested at different span to depth ratios. The flexural properties like the bending strength, flexural rigidity, shear stress, shear deflection and shear strain were evaluated and a detailed analysis made on the influence of foam densities and different span to depth ratios on the fracture behaviour of these sandwich composites in flexure. Due comparisons have been made on the flexural behaviour with other foams also.**

Keywords: Rigid polyurethane foam, Flexural properties, Sandwich composites, Foam Density, Span to depth ratios.

I. Introduction

Increasing performance demands for modern technology applications make it necessary to look for new materials. It is difficult to achieve high and strict performance standards using any one material, hence new materials are fabricated by combining two or more conventional materials. These materials are named as composite materials. A formal definition of composite materials given by **ASM Handbook [1]** is "Macroscopic combination of two or more distinct materials, having a recognizable interface between them".

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Some of the main advantages of **composite materials [2]** are low weight, high strength, modulus, bending stiffness and chemical resistance. Properties of composites can also be tailored according to specific design requirements, directional and spatial properties.

Defining a composite material needs information on three aspects

1. Matrix material: e.g. polymer, metal or ceramic.
2. Reinforcements: e.g. continuous or discontinuous fibers or particles.
3. Structure: e.g. laminated or sandwich.

A *Sandwich Structured Composites*

Sandwich structured composites[3] are a special class of composite materials which have become very popular due to high specific strength and bending stiffness. Sandwich constructions are widely used in many structures, because the concept is very suitable for lightweight structures with high in-plane and flexural stiffness. Low density of these materials makes them especially suitable for use in aeronautical, space and marine applications. Sandwich composites consist of two thin and stiff skin layers attached on either side of a light weight, thick slab known as the core. Thin Aluminium sheets, fibre reinforced epoxy of glass, carbon, natural fibres are commonly used facing materials. Rigid unfilled thermoset polymer foams such as Polyisocyanurate, Polyurethane, Polystyrene, Polyethylene etc. are used as core materials**.** Integral bonding between the skins and core delays the interfacial failure under the applied loads thereby enhancing the flexural properties of sandwich composites**[4,5]**. Major advantage of sandwich structured composites is the possibility of tailoring properties by choosing appropriate constituting materials and their volume fractions.

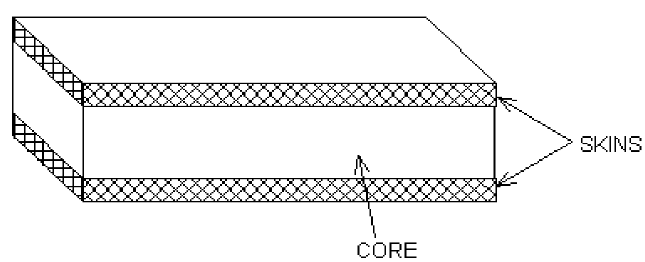

Figure 1:Structure of Sandwich Composite

II. Methodology & Approach

The objective of this paper is to fabricate sandwich panels with 125 and 250 kg/m^3 density foams at 3:1 & 4:1 skin to core weight ratios and analyse the flexural behaviour of the sandwich composite panels with PUF foam as core and Glass fabric reinforced epoxy laminate as face sheet with varying densities of the core and the span to depth ratio of the sandwich[6].

A. Selection of Appropriate Constituent Materials

E-Glass fabric: 280 & 100 GSM, plain weave, Epoxy: GY257 Hardener: ARADUR 140, Foam: Thermoset unfilled rigid Polyurethane foam

TABLE I. MATERIAL PROPERTIES OF CORE

Properties	PUF-125 kg/m^3	PUF-250 kg/m^3
Elastic Modulus, E (MPa)	11	42.93
Poisson's Ratio	0.312	0.325

Table II. MATERIAL PROPERTIES OF CORE

Properties	Glass Fabric	Epoxy Resin	Skin
Elastic Modulus, E (MPa)	35000	1500	11550
Poisson's Ratio	0.27	0.35	0.32

B. Fabrication Process of Sandwich Composites

Fabrication process for the rigid foam sandwich composite panels is to be carried out by using the vacuum bagging technique. This technique allows the application of one atmospheric pressure on the sandwich panels and infuses the resin into the fabric.

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Figure 2: Vacuum bagging of sandwich panels for 3:1 & 4:1 skin to core ratios

For 3:1 & 4:1 skin to core weight ratios of 125 & 250 kg/m^3 foams, we have calculated the number of layers required on each side. A volume fraction of 0.3 was taken between the resin and glass fabric**[7].** Therefore, we need to cut out 280 gsm & 100 gsm glass fabric with required dimensions. The mixture of resin and hardener in the appropriate ratio is applied on each glass fabric layer and the layers arranged accordingly.Layers are rolled for proper adhesion between them, after each layer is laid. The whole sample is then inserted into a vacuum bag which is sealed at both ends. The vacuum pump is switched on for half an hour. The atmospheric air pressure then acts on the panel as the bag is evacuated. The composite is kept within the bag for a day for complete curing of the resin.

C. Testing of Sandwich Composite Panels

Flexural tests were carried out based on the appropriate ASTM standards for testing the sandwich composite panels and analyze the fracture behaviour & mechanical properties of the panel**[**8,9]. These Flexure tests are carried out in an INSTRON machine.

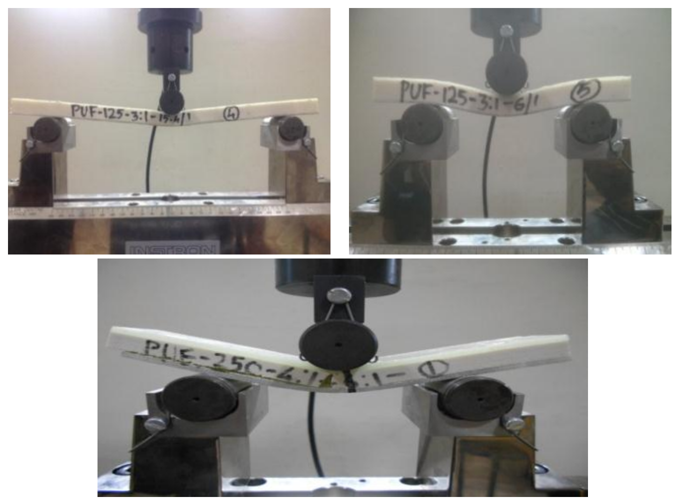

Figure 3: Specimens under three point bending test of 15.4:1 , 12:1 & 6:1 span to depth ratio

Sandwich panels with core densities of 125 kg/m^3 and 250 kg/m^3 are considered for the testing. For each density of core used, panels with skin to core weight ratio 3:1 and 4:1 are also tested for the flexural properties. Specimens with span to depth ratios of 6:1, 12:1 and 16:1 are tested using Three-point bending test method in Instron UTM machine and load versus deflection graphs were plotted. The flexural properties such as flexural rigidity, Bending stress, Bending stiffness, maximum Shear stress in core, shear strain etc were found from the evaluations made from various studies[4].In their previous studies, Hemnath and Padmanabhan have consolidated the various equations [9,10,11,**]**.

III. Results & Discussion

Table 3: Mechanical properties of 125 kg/m^3 density foam at 3:1 skin-core weight ratio with different span to depth ratios

Properties/span to depth ratio	15.4:1	12:1	6:1
Maximum Bending Stress Range (N/mm^2) (Average)	14.38-21.92 (17.16)	16.65-19.65 (17.93)	10.09-11.87 (10.82)
Flexural Rigidity per width Range (N-mm^2/mm)×10^6 (Average)	3.88-4.52 (4.23)	4.07-5.43 (4.59)	3.66-4.15 (3.97)
Bending Stiffness Per unit width Range (N/mm) (Average)	0.95-1.40 (1.06)	1.44-2.23 (1.81)	1.29-2.01 (1.55)
Shear Strength in Core, At y=0 mm distance Range (N/mm^2) (Average)	0.21-0.32 (0.24)	0.32-0.35 (0.33)	0.35-0.42 (0.38)
Bending Strength per unit width Range (N-mm/mm) (Average)	229-347 (262.37)	271-299 (287.78)	142-173 (159.39)

Table 4: Mechanical properties of 125 kg/m^3 density foam at 4:1 skin-core weight ratio with different span to depth ratios

Properties/span to depth ratio	15.4:1	12:1	6:1
Maximum Bending Stress Range (N/mm^2) (Average)	19.99-23.13 (21.88)	19.73-30.58 (22.98)	9.15-13.11 (11.94)
Flexural Rigidity per unit width Range (N-mm^2/mm) ×10^6 (Average)	4.55-5.46 (5.20)	4.92-6.37 (5.63)	5.46-6.40 (6.06)
Bending Stiffness Per unit width Range (N/mm) (Average)	1.43-1.60 (1.54)	1.59-4.09 (2.7)	1.65-2.84 (2.22)
Shear Strength in Core, At y=0 mm distance Range (N/mm^2) (Average)	0.26-0.31 (0.29)	0.32-0.54 (0.39)	0.32-0.46 (0.42)
Bending Strength per unit width Range (N-mm/mm) (Average)	350-405 (379.22)	330-599 (421.19)	176-257 (227.18)

Table 5: Mechanical properties of 250 kg/m^3 density foam at 3:1 skin-core weight ratio with different span to depth ratios

Properties/span to depth ratio	15.4:1	12:1	6:1
Maximum Bending Stress Range (N/mm^2) (Average)	107.74-119.73 (113.27)	91.11-113.16 (101.98)	68.49-76.87 (72.67)
Flexural Rigidity per unit width Range (N-mm^2/mm) ×10^6 (Average)	2.19-3.28 (2.63)	2.15-2.56 (2.34)	1.79-2.05 (1.95)
Bending Stiffness Per unit width Range (N/mm) (Average)	5.30-6.54 (5.78)	6.33-8.95 (7.88)	6.04-9.66 (7.76)
Shear Strength in Core, At y=0 mm distance Range (N/mm^2) (Average)	1.27-1.40 (1.33)	1.41-1.65 (1.53)	1.90-2.19 (2.03)
Bending Strength per unit width Range (N-mm/mm) (Average)	1187-1406 (1272.98)	988.04-1121 (1064.43)	615-737 (673.20)

Table 6: Mechanical properties of 250 kg/m^3 density foam at 4:1 skin-core weight ratio with different span to depth ratios

Properties/span to depth ratio	15.4:1	12:1	6:1
Maximum Bending Stress Range (N/mm^2) (Average)	90.34-101.15 (95.72)	83.17-107 (90.86)	64.26-79.61 (73.37)
Flexural Rigidity per unit width Range (N-mm^2/mm) ×10^6 (Average)	4.23-5.03 (4.57)	3.9-4.23 (4.11)	3.41-3.78 (3.58)
Bending Stiffness Per unit width Range (N/mm) (Average)	2.9-4.07 (3.93)	6-7.20 (6.32)	11.58-19.5 (16.5)
Shear Strength in Core, At y=0 mm distance Range (N/mm^2) (Average)	1.12-1.33 (1.22)	1.33-1.73 (1.45)	1.93-2.45 (2.21)
Bending Strength per unit width Range (N-mm/mm) (Average)	1379.6-1713 (1533.35)	1318-1642 (1363.83)	879-1134 (1010.48)

A. Plots for Mechanical Properties of 125 kg/m³ density foam at different Skin-Core Weight ratios

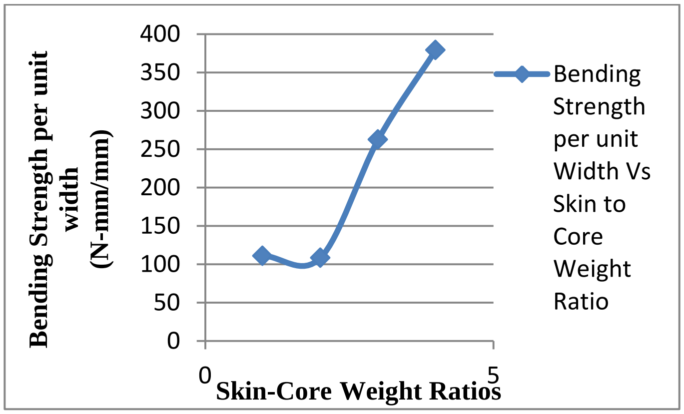

Figure 4: Bending Strength per width Vs Skin-Core Ratios

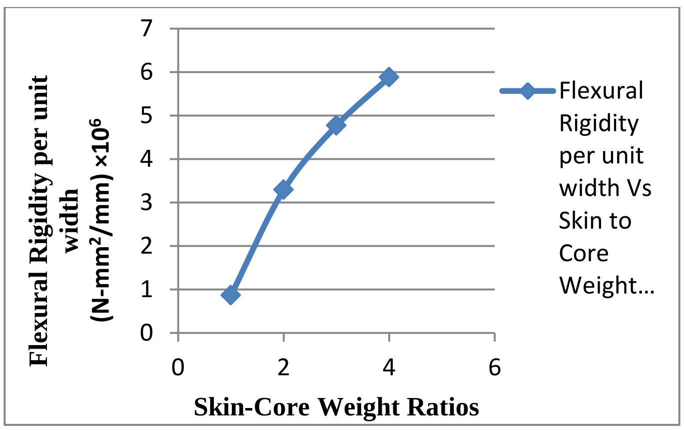

Figure 5: Flexural Rigidity per width Vs Skin-Core Ratios

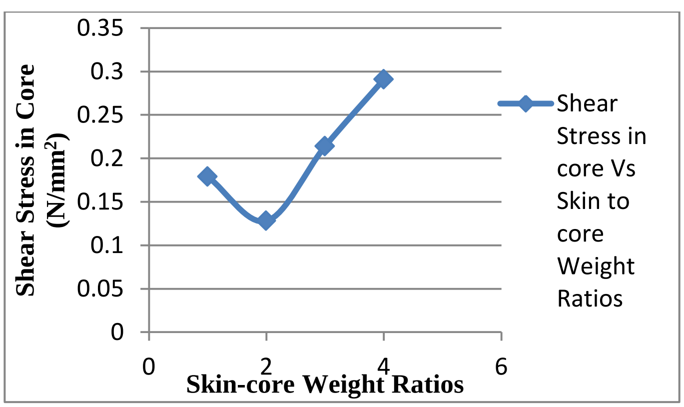

Figure 6: Shear Stress in core Vs Skin to core Weight Ratios

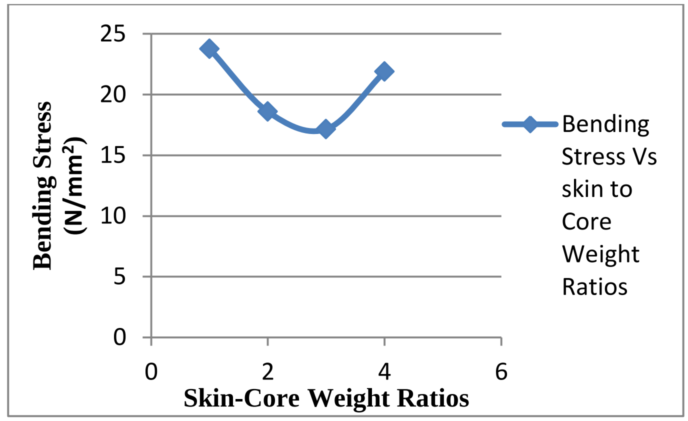

Figure 7: Bending Stress Vs skin to Core Weight Ratios

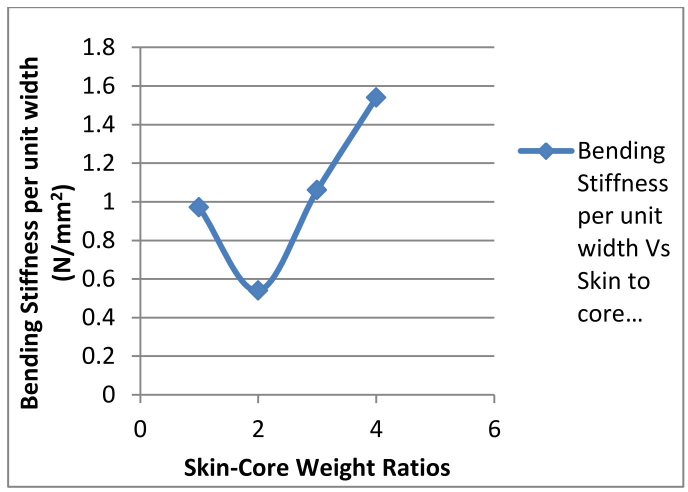

Figure 8: Bending Stiffness per width Vs Skin-Core Ratios

B. Observations

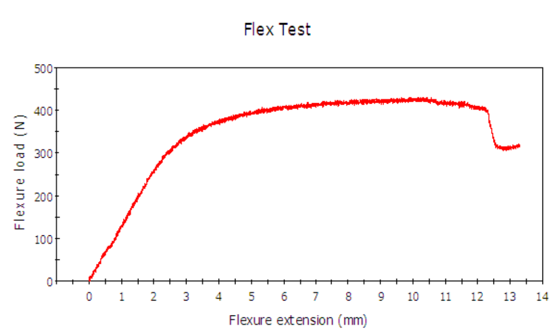

Fig 9:Load Vs Deflection plot

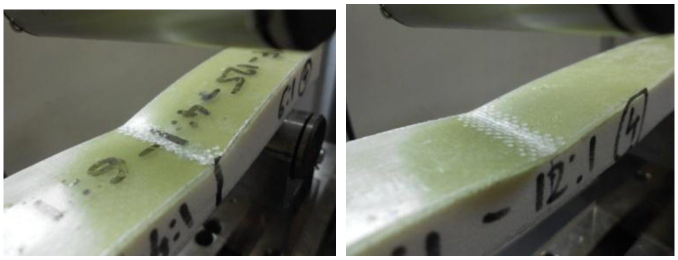

Fig 10: Skin and Core localized damage in 3:1 & 4:1 skin-core ratio of 125 kg/m^3 density foam specimen

The above figures shows the failure modes of 3:1 & 4:1 skin to core weight ratios of 125 kg/m^3 rigid foam density sandwich composite panels. In a 125 kg/m^3 density foam, the result shows that the tested specimen failed due to local skin wrinkling. This failure occurs due to the presence of voids on the compressive side of the panel. . The experiment shows that failure occurs mainly through face sheet shear and compressive core crushing.

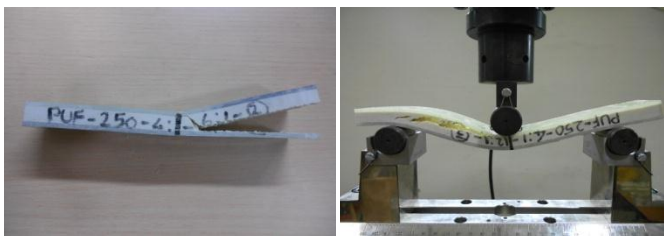

Fig 11: Skin and Core localized damage in 3:1 & 4:1 skin-core ratio of 250 kg/m^3 density foam specimen

The above figures shows the failure modes of 3:1 & 4:1 skin to core weight ratios of 250 kg/m^3 rigid foam density sandwich composite panels. In a 250 kg/m^3 density foam, the result shows that the tested specimen failed due to skin failure on tensile and compressive sides and cohesive and adhesive failure due to de-bonding. This failure occurs due to the presence of voids on the compressive side of the panel. The experiment shows that failure occurs mainly through face sheet shear ,core shear failure and compressive core crushing.

IV. Conclusion

The properties for the 125 & 250 kg/m^3 rigid foam density sandwich panels at different span ratio were calculated and obtained from three-point bending test in Instron machine. The bending test results show that with an increase in span ratio, the load decreases and the mechanical properties for 12:1 span to depth ratio is higher than the 15.4:1 & 6:1 span ratio. The experiment shows that failure occurs mainly through face sheet shear and compressive core crushing in 125 kg/m^3 density foam and cohesive and adhesive failure due to de-bonding and skin failure on tensile and compressive sides in 250 kg/m^3 density foam. In 125 kg/m^3 density foam, parameters like flexural rigidity, bending strength and centre deflection are higher in 12:1 span ratio, whereas in 250 kg/m^3 density foam, parameters like flexural rigidity, bending strength and centre deflection are higher in 15:1 span ratio. Attempts at design optimization for maximum strength and stiffness have been discussed earlier by some investigators[8]. Influence of span to depth ratio and density on the flexural rigidity and bending strength was analysed and understood from the graphs .

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