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Evaluation of apparent shear modulus of multi-layered PUF cored sandwich beams using novel experimental technique

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Abstract

This experimental investigation was mainly concerned with the evaluation of apparent shear modulus (G_c) of multi-layered polyurethane foam core sandwich beams using a novel experimental technique. Aiming to this goal, some experimental three-point bending tests were conducted on sandwich beams made up of composite face sheets and multi-layered polyurethane foam cores of different layer density. Various core configurations in a stack of three layered core was experimented to study the effect of layer density and core configuration on apparent shear modulus. Prior to actual task, to get more confidence on proposed technique and also to understand the experimental procedure necessary for the present investigation, some samples of single PUF core sandwich beams of known densities were tested to evaluate the shear modulus(G_c) and compared the results with existing results. Series of multi-layered cored beams of different span length and configurations were tested to cater the demand of experimental procedure and to study the effect of layer density and ply order on apparent shear modulus. From the present investigation it is observed that the apparent shear modulus of linearly ordered multi-layered core i.e. core layers arranged in order of lower density to higher density from face sheet of tension side to compression side(configuration-2) could be a better option. Furthermore the apparent shear modulus of linearly ordered multi-layered core sandwich beam was comparatively better than other core configurations and single cored beams of different core densities used for multi-layer construction. However its value was slightly lower than single core made of highest layer density. But upon comparison with modulus/weight, linear multi core model may be a better choice.

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*Keywords:*Novel experimental technique;Multi- layer core;Core configuration;Apparent shear modulus;

1. Introduction

In today's modern living era, the quest for alternate solutions to technically challenge problems is never ending. Many researchers have proposed variety of tailored materials such MMC, FRP, layered and sandwich composites etc, to match the specific requirement. Sandwich composites are preferred structures due to their superior performance, durability and extremely low weight [1,2,3]. A sandwich structure will offer different mechanical properties with the use of different types of materials for their constituents [4]. Various combinations of core and face sheet materials are utilized by researchers worldwide to match the specific requirements. Out of these combinations, composite face sheets and polyurethane foam core are widely used constituents for sandwich construction, because of low weight to strength ratio, cost effectiveness and durability of resulting structures [5]. Traditionally polyurethane foam is used as a single core of constant density. The major drawback of single core construction is the material property mismatch of face sheets and core which causes higher shear stresses at the interface under external load [6]. Various techniques are used to reduce this harmful effect. Out of these, one such technique could be the use of the multi-layered core of different layer density instead of single conventional core of constant density. The multi-layered core can be obtained by perfectly bonded plies of several polyurethane foam layers of different densities. In such case, several combinations of layer arrangements are possible i.e. layers arranged in ascending or descending order of their density between the two face sheets, or randomly arranged order. To rate the performance of these modified structures, it is essential to know some useful physical properties. In view of above fact, the present investigation was mainly focus on evaluation of one such physical property i.e. apparent shear modulus (G_c) of multi-layered polyurethane foam core sandwich beams using a novel experimental technique. In order to get more confidence on this experimental technique, it is verified using bench mark results. The schematic view of a typical multi-layer core sandwich beam chosen for present study is as shown in figure-1.

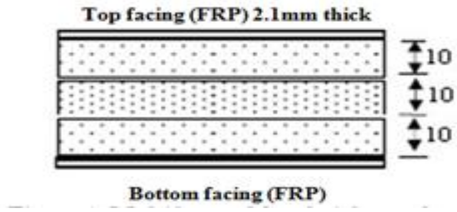


Fig.1. Multi-layer sandwich beam

2. Evaluation of Shear Modulus of Single Core Sandwich Beams

In order to evaluate the shear modulus of single PUF core sandwich beams made up of core of different core densities using the proposed experimental technique some, samples of single cored sandwich panels of known core density were fabricated. Three sets of three specimens each of core density 50Kg/m^3, 100Kg/m^3 and 150Kg/m^3 and span length 150mm, 200mm and 250mm as shown in figure-2 were cut out from these panels and tested under three- point bending using computerized universal testing machine model TUE-C 600 at constant crosshead speed of 2mm/min as shown in figure-3. The load v/s deflection relation was recorded and plotted during the tests. All the specimens were loaded till failure. The close of best two graphs of Load (F) v/s deflection(y) for each span length specimen were considered for investigation as shown in figure-4. The geometric details of specimen tested under 3P- bending are as follows

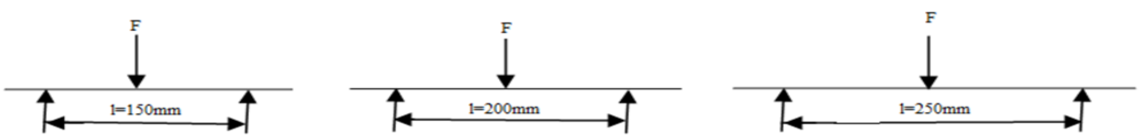


Figure 2 .Specimens of different span lengths under 3P- Bending

Fig.3.(a) Sandwich beam specimens

Fig.3.(b) 3-point bending test setup

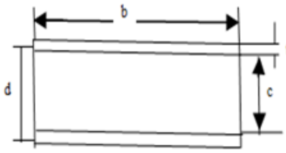
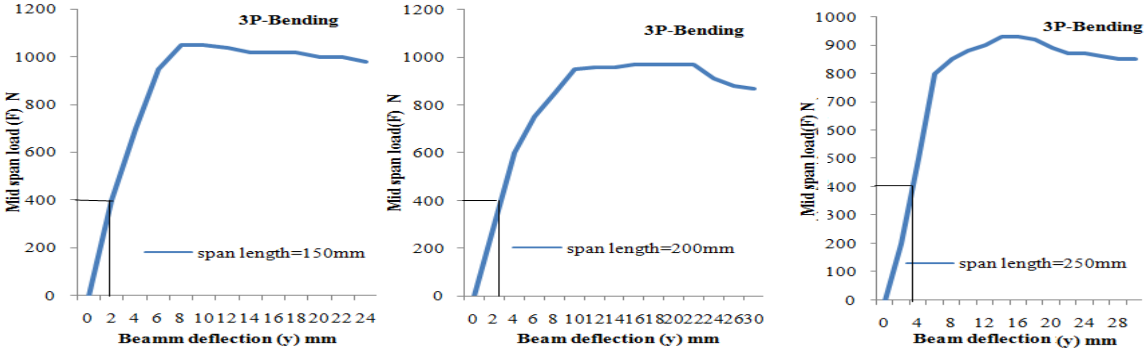


Fig.3.(c) Cross section of beam



(φ_1=175N/mm; l_1=150mm) (φ_2=140N/mm; l_2=200mm) (φ_3=115N/mm; l_3=150mm)

Figure 4. Graphs of load v/s deflection for specimens of various span length made of PUF 50

From the relationship between load and mid-span deflection of a sandwich beam under three point bending in linear elastic region as proposed by Allen H.G [6], we have $y=\{(Fl^3/48\ D)+(Fl/4AG_c)\}$. Expressing this equation in terms of slope($\varphi=\Delta F/\Delta y$) of load(F) v/s deflection(y) curve as follows. $(1/\varphi l)= \{(l^2/48\ D)+(l/4AG_c)\}$(1). By plotting the results of $(1/\varphi l)$ v/s l^2 for various span lengths(l_1,l_2 and $l_3$etc)as shown in figure-5 and graphically extrapolating the curve, a constant value of ordinate at l^2=0 gives the value of factor (β) = $l/4AG_c$ from(eq-1),which is used to calculate the core shear modulus of a sandwich beam. From the above experimental data(figure-4) for a sandwich beam made of PUF50(ρ=50Kg/m^3) core of various span lengths (l_1=150mm, l_2=200mm and l_3= 250mm), a graph of $(1/\varphi l)$ v/s l^2 was plotted as shown in figure-6 similar to a general graph (figure- 5) and upon graphically extrapolating, the factor (β) was obtained as follows(Table-1).

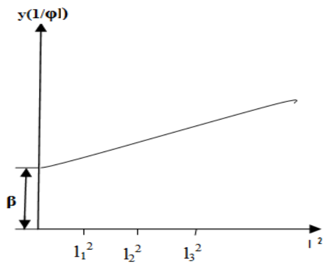


Fig. 5: General graph of $(1/\varphi l)$ v/s (l^2)
(Graphical extrapolation for β)

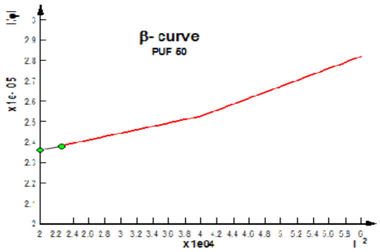


Fig.6. Graph of $(1/\varphi l)$ v/s l^2 forPUF50 sandwich beam
(For l^2=0;β= 2.37x10^{-05})

Table 1.Evaluation of shear modulus of PUF50 sandwich beam.

A=bd	φ= ΔF/Δy	$(1/\varphi l)=\{(l^2/48D)+(l/4AG_c)\}$	$\beta=(1/\varphi l)\ _{l^2=0} = l/(4AG_c)$	$G_c= l/(4A\ \beta)$= 6.76
(mm^2)	(N/mm)	(N^{-1})	2.37x10^{-05}(Figure-7)	MPa

By following similar experimental procedure the shear modulus of single PUF cored beams of various densities are evaluated as follow.

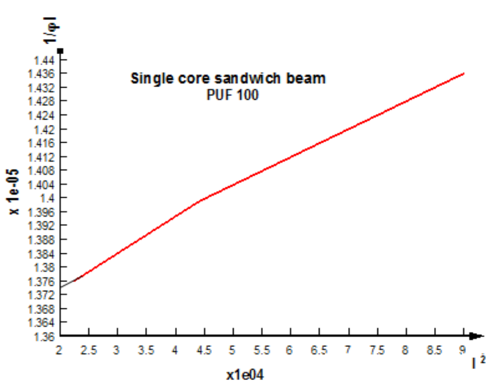


Fig 7.(a)PUF 100 sandwich beam

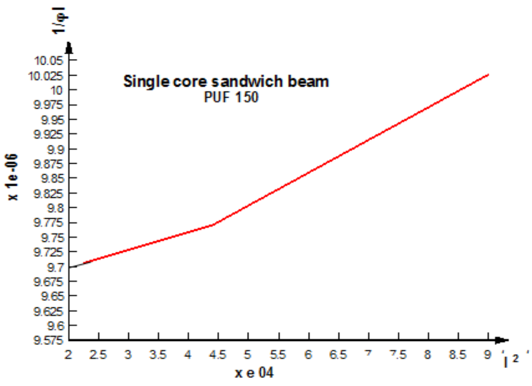


Fig 7.(b)PUF 150 sandwich beam

Fig 7. Graphical extrapolation of graph of y(1/φl) v/s x(l^2) for sandwich beams of different core densities

Table 2. Shear modulus of various single PUF cored sandwich beams.

Sandwich beam	PUF 50	PUF100	PUF150
β - factor	β= $2.37\text{x}10^{-05}$	β= $1.374\text{x}10^{-05}$	β= $0.96\text{x}10^{-05}$
Shear modulus(G_c)	6.67MPa	11.66MPa	16.52MPa

3. Apparent Shear Modulus of Multi-Layered cored Sandwich Beams

In this section an attempt was made to evaluate experimentally the apparent shear modulus of multi-layered PUF core sandwich beams by following similar procedure as discuss in previous section. For this study, series of multi-layered core sandwich beams of various core configurations as shown in figure-9 were fabricated with a stack of three polyurethane foam layers of density 50Kg/m^3,100Kg/m^3 and 150Kg/m^3 and tested. The thickness of all the core layers and face sheet were remain constant throughout the study. Experimental set up for 3P-bending of various multilayer cored sandwich beams is as shown in figure-9.

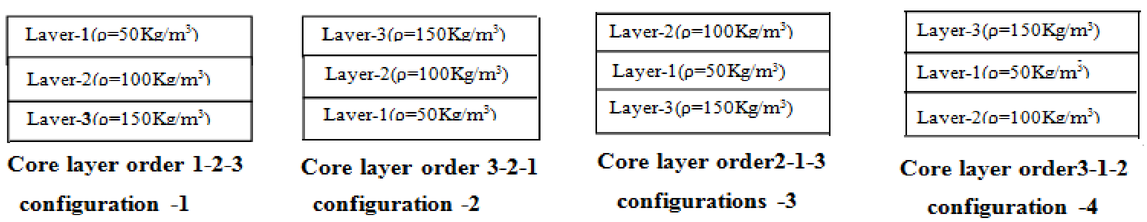


Fig.8. Various multi-layered core configurations used for present investigation

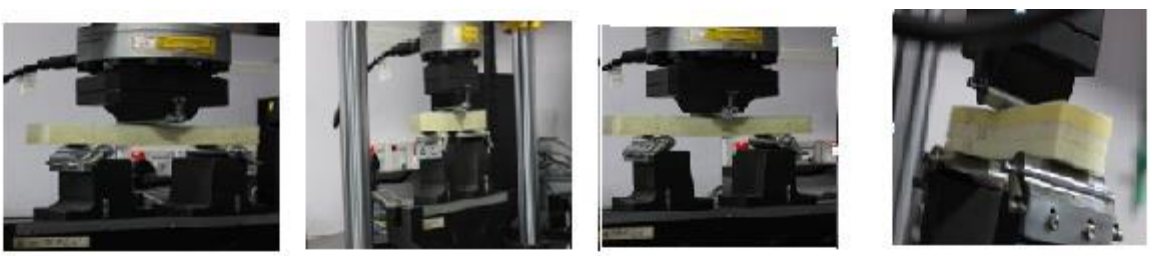


Fig 9. Experimental set up for 3P-bending of various multilayer cored sandwich beams

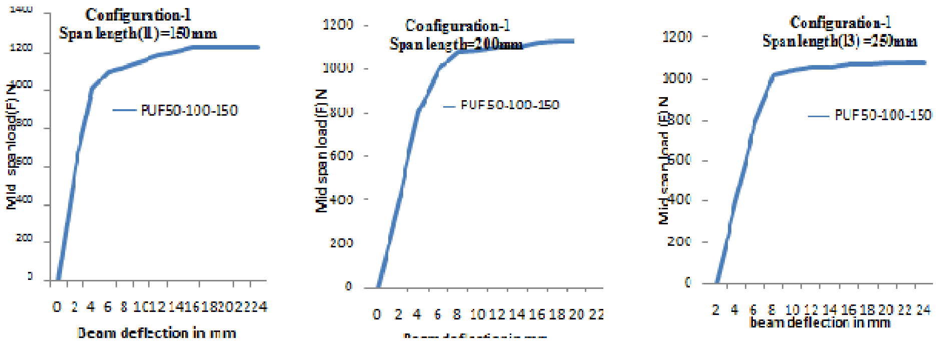


Figure 10. Graphs of load v/s deflection for specimens of various span lengths of PUF 50-100-150(configuration-1)

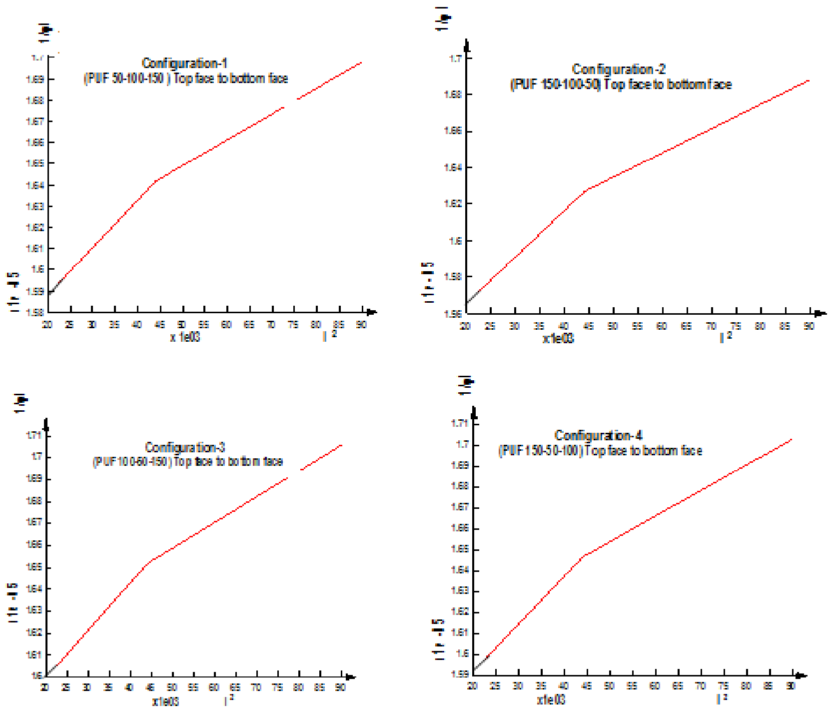


Fig.11. Graphical extrapolation of graph of y(1/φl) v/sx(l^2)for various multi- layer sandwich beams

Table 3. Shear modulus of various multi-layered PUF cored sandwich beams.
L_1 -PUF 50 L_2 - PUF 100 L_3 - PUF 150 (Top face to bottom face)

Configuration-1	Configuration-2	Configuration-3	Configuration-4
Layer order L_1-L_2 -L_3 A=1560mm^2 β=1.588x10^{-5}(Fig-11a) G_C = 8.53MPa	Layer order L_3-L_2 -L_1 A=1560mm^2 β=1.565x10^{-5} (Fig-11b) G_C= 10.3MPa	Layer order L_2-L_1 -L_3 A=1560mm^2 β=1.59x10^{-5}(Fig-11c) G_C= 9.5MPa	Layer order L_3-L_1 -L_2 A=1560mm^2 β=1.595x10^{-5}(Fig-11d) G_C= 10MPa

4. Results and discussion

The need of multi- layer core for sandwich construction serve many purposes such as to minimize the shear stress at the interface of face sheet and core, to improve the beam strength and to reduce the harmful effects of material properties mismatch etc. To rate the performance of these modified structures, it is essential to know some useful beam properties. In view of above fact, the present investigation was mainly focus on evaluation of one such beam property i.e. apparent shear modulus (G_c) of multi-layer polyurethane foam cored sandwich beams using a novel experimental technique. Many experimental techniques [9] and numerical methods are available to evaluate this property and these techniques need the results of both 3P-point and 4P-bending tests. However the proposed technique needs only the results of multi specimen 3P-bending test for different span length. This method of evaluation includes the average effect of slope of load (F) v/s deflection(y) and graphical extrapolation that may leads to more accurate results compared to actual results. For effective investigation, series of multi-layered core beams made up of composite face sheets (Bi-woven E-glass/epoxy resin) and three layered polyurethane foam core of layer thickness 10mm each and different layered density(50Kg/m^3, 100Kg/m^3 and 150Kg/m^3), layer configurations and span length were tested in order to study the effect of layer density and its order on apparent shear modulus. Efforts were made to identify the best layer configuration that maximizes the apparent shear modulus. The various multi-layered core configurations chosen for present study is as shown in figure-8**.** Prior to actual task, to get more confidence on proposed technique and also to understand the experimental procedure necessary for the present investigation, some samples of single PUF core sandwich beams of known core densities were tested and shear modulus(G_c) was evaluated. The results so obtained were compared with the existing data as shown fig.12

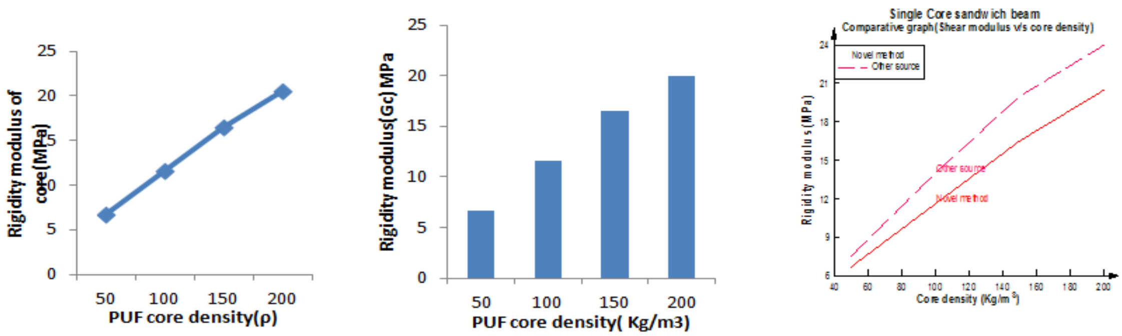


Fig.12. Graphs of rigidity modulus (G_c) v/s core density for various single PUF cored sandwich beams

After successful evaluation of shear properties of single PUF cored sandwich beams made up of different core densities using the proposed technique and comparison with existing results, the same experimental technique was used to evaluate the apparent shear modulus of multi-layered core sandwich beams of various core configurations. The multi-layered core was fabricated by perfectly bonded plies of several polyurethane foam layers of different densities and configurations(order of layers). A three layered core of layer thickness 10mm each and density of each layer varied from 50Kg/m^3 to 150Kg/m^{3}from top face to bottom face of the beam in different orders were fabricated and tested to identify the best layer combination, aiming to achieve better shearing performance under flexural loading. A photo copy of multi-layered PUF core sandwich beams tested under 3P-bending is as shown in figure-9. The apparent shear modulus of all multi-layer configurations were evaluated by extrapolating the graphs of y(1/φl) v/s x(l^2). The comparative results are as shown in fig.13. The analysis of graphs (fig.13) shows that the apparent shear modulus of core configuration-2 of layer order L_3-L_2-L_1(150-100-50) stand better among various core configurations. Furthermore upon comparison with single core beams, the shear modulus of multi-layer core beam of configuration-2 is better. However its value is slightly lower than PUF150. But upon comparison with modulus/weight configuration-2 stand better.

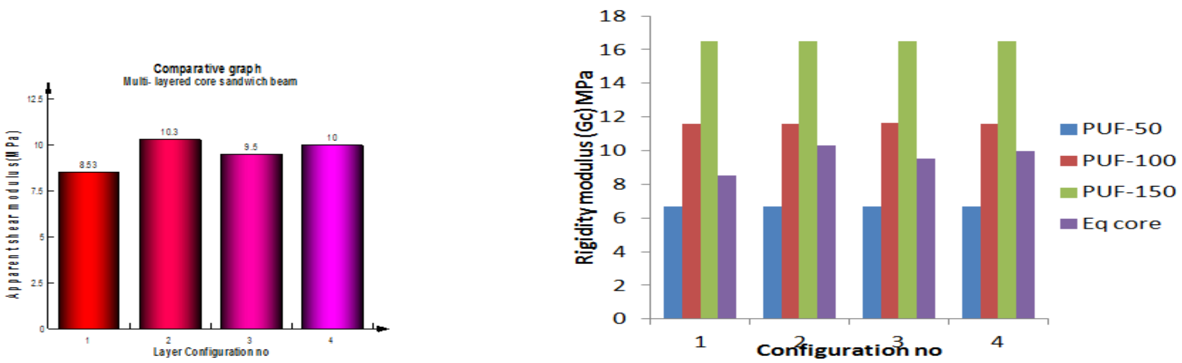


Fig.13. Comparison of apparent shear modulus of various multilayer core configurations

From the present investigation it is evident that the performance of multi-layer core configuration-2(linearly variable model) i.e. core layers arranged in order of lower density to higher density from bottom layer to top layer, that means denser layer adjacent to face sheet under compression & softer layer adjacent to face sheet under tension could be the most suitable solution to the problem of replacement of conventional single layer core sandwich beams with multilayer PUF cores. Because maximum profit in mechanical properties can be achieved with the use of multilayer cores.

5. Conclusion

A novel experimental technique was used to evaluate the shear modulus of polyurethane foam cored sandwich beams. This method of evaluation could be more accurate than existing techniques, because this method allows an average of multi specimen test results and graphical extrapolation. Using this technique the shear modulus of PUF cored sandwich beams of different core densities were evaluated. Furthermore this technique was used to determine the apparent shear modulus of multi-layer cored beams of various configurations. Effect of layer order (layer density) on apparent shear modulus in a stack of three layers core was studied with great care.

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