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EVALUATION OF FLEXURAL STIFFNESS FOR THE LIGHTWEIGHT POLYMER FOAM CORE SANDWICH STRUCTURES

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Abstract: Composite sandwiches are the multi-layer structural members that can be designed with vast variety of materials to obtain desired physical and mechanical properties. Very high strength to weight ratio, good impact and corrosion resistance, heat and acoustic insulation are the main advantages of the composite sandwich structures. Besides these, depending upon the core and face sheet materials it also provides superior flexural stiffness. However, the evaluation of the flexural stiffness of the sandwich structures is not based on a common standard and the calculations have been carried out according to the sandwich handbooks' formulations which are related to cumulative summation of each layer stiffness. In this study, the flexural stiffness of a sandwich having lightweight polymer foam core (48 kg/m3 PVC) and carbon fiber facings (3K woven plain, 200 g/m2) was evaluated with the aid of ASTM D7250/D7250M – 06 Standard. The composite sandwiches manufactured by vacuum bagging method were tested considering two different loading configurations as indicated in ASTM Standard under three-point bending loading. The span length was first determined as 150 mm and then 200 mm, respectively. The use of ASTM D7250 Standard approach eliminates additional tests for determining the young modulus of the core and facings and directly helps to calculate flexural stiffness considering two different loading configurations.

Index Terms: Sandwich structures, flexural stiffness, three-point bending test, ASTM D7250 Standard.

I. INTRODUCTION

Composite sandwiches are the advanced multi-layer structures that allow to design weight-critical parts especially used in aerospace, aviation, automotive, marine applications, sporting goods, blades for wind-power stations. In addition to very high load carrying capacity, by combining the particular composite constituents, multi-functional designs can also be possible such as obtaining heat and acoustic insulation, providing good impact resistance. Sandwich structures can be defined as a special form of conventional laminated composites typically consist of two thin facings made from stiff and strong material such as light weight alloys or fiber composites bonded to a thick light weight material called core such as foam or honeycomb [1-3]. The facings carry almost all of the bending and in-plane loads and on the contrary, the core material provides a balance for the facings and define the mechanical properties such as flexural stiffness and out-of-plane shear and compressive behavior [4]. Therefore the face sheets need to be stiff and strong in tension and compression to resist the bending and wrinkling loads whereas the core needs to be stiff and strong under shear and extension in the thickness direction to provide resistance to wrinkling and local indentation failure.
Flexural stiffness is a bending characteristics of the sandwich structures that can be defined as the resistance of the structure to deflection under bending loading exerting as out of the plane. The core material in a sandwich transmits the shear loads and holds the top and bottom facings far away from the neutral axis in order to maximize the flexural stiffness of the structure [5].

Flexural stiffness of a sandwich beam represented in below Figure 1 was generally evaluated according to the following procedure and given by Chemamiet al. [6].

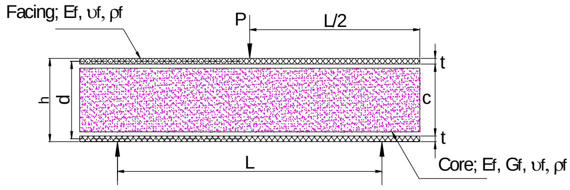


Figure 1: Calculation of flexural stiffness [6]

$$D = \frac{E_f b t^3}{6} + \frac{E_f t b d^2}{2} + \frac{E_c b c^3}{12} = 2D_f + D_o + D_c \quad \text{Eq. (1)}$$

Where;
D is the bending stiffness, E_f and E_c are the Young's modulus of the facings and the core, respectively, b is the width, t and c are the facing and core thicknesses, respectively, and d is the distance between the neutral axis of the facings. $2D_f$ is the rigidity of the facings from the neutral axis, D_o is the contribution to the bending stiffness of the facings from the neutral axis of the sandwich in the core for a symmetrical sandwich, and D_c is the rigidity provided by the core from its neutral axis, respectively. If the total sandwich thickness is highly greater than the facing thickness, then the first and last terms can be neglected [6]. Li and Wang explained the reason of neglecting these terms by making optimal geometric design [7].
Chemami et al. [6] produced two different sandwiches which differentiated by the facings. Similar PVC core materials having a density of 200 kg/m^3 were used while these have four layers of

unidirectional glass fiber [0_4] and four layers of cross laminated unidirectional glass fiber [$0/90_2/0$], respectively. Then according to the three-point bending tests with 142 mm span length. The sandwich having facings of [$0/90_2/0$] provided more rigidity in bending. Kabir et al. [8] used 6 mm and 12 mm thick aluminum foam cores (220-350 kg/m^3) and 0,32 mm thick aluminum facings to construct sandwich panels and subjected to three-point bending tests. Using the same principle given in Eq. 1, they carried out the tests with 50 mm and 100 mm span lengths, respectively. Increasing the core thickness yielded very high flexural stiffness (approximately 4 times).

Conventional calculations of flexural stiffness requires to determine the young modulus of facing and core material. For this reason, besides bending, additional tests have to be done. Moreover, additional composite manufacturing must be carried out to prepare the particular test specimens. However, ASTM D7250/D7250M – 06 Standard [9] has offered a relatively simple approach to evaluate bending stiffness. The approach can be used based on making bending tests according to two different loading configurations. By using the standard approach, a researcher may save manufacturing time and resources. In this study, low density polymer foam (PVC) core and woven plain carbon fiber fabrics were used to construct sandwich panel. The production was performed via vacuum bagging method. The test specimens having same width and thickness were cut in length considering 150 mm and 200 mm support span lengths, respectively. According to the ASTM C393/C393M-11 Standard [10], three-point bending tests were carried out. After obtaining the force-displacement curves of the specimens, flexural stiffness was practically evaluated by using ASTM D7250 Standard.

II. FABRICATION OF SANDWICH PANELS

Woven plain carbon fiber fabrics having an areal density of 200 g/m^2, and 20 mm thick, 48 kg/m^3 rigid closed cell PVC foam core materials were supplied to manufacture the sandwich panels. The construction of composite sandwiches were made by using polymer matrix, MGS L160 epoxy resin and its hardener H160. The physical and mechanical properties of PVC foams and polymer matrix materials are given in Table 1 and 2.

Table 1
Mechanical properties of PVC foam core materials [11]

Density of 20 mm thick PVC foam core materials (kg/m^3)	48
Compressive strength perpendicular to the plane (MPa)	0,60
Compressive modulus perpendicular to the plane (MPa)	48
Tensile strength in the plane (MPa)	0,95
Tensile modulus in the plane (MPa)	35
Shear strength (MPa)	0,55
Shear modulus (MPa)	16

Table 2
Physical and mechanical properties of matrix materials [12]

Physical and mechanical properties	Epoxy resin	Hardener
Density (gr/cm^3)	1,13-1,17	0,96-1,00
Viscosity (mPa.s)	700-900	10-50
Bending strength (MPa)	110-140	-
Modulus of elasticity (GPa)	3,2-3,5	-
Tensile strength (MPa)	70-80	-
Compressive strength (MPa)	80-100	-

The sandwich specimens were fabricated in a same panel having 345 mm by 475 mm sizes but the specimens were cut to two different lengths, 200 mm and 250 mm, respectively as shown in Figure 2. The group of Sp.1 represents the specimens which were subjected to three-point bending tests at a support span length of 200 mm and the group of Sp.2 has a support span length of 150 mm.

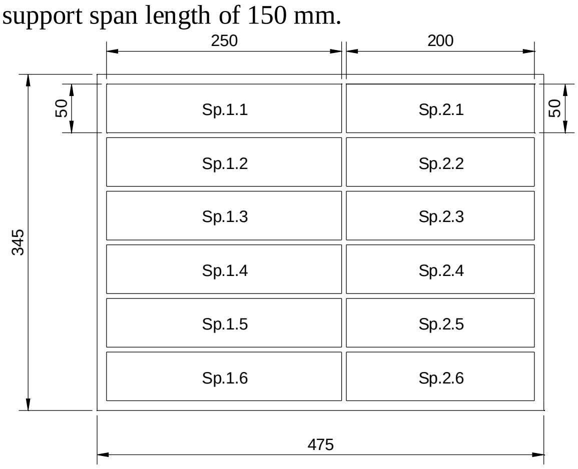


Figure 2: Dimensions and numbers of sandwich specimens

As it is seen from Figure 2, six specimens were tested from each group to obtain accurate results. After determining the specimens' geometry, the composite sandwich panel were manufactured with hand lay-up followed by vacuum bagging method. Firstly, matrix material were prepared considering the total amount of both carbon fiber fabrics and foam core. Epoxy resin and its hardener were mixed at a weight ratio of 4:1 as suggested by the technical data sheet [12]. The important thing during stirring the mixture is preventing the formation of void content since it can adversely affect the structural bonding capability of the laminates. The hand lay-up process was applied by stacking of both carbon fiber fabrics and foam simultaneously. Figure 3 represents the schematic view of the manufacturing process. After lamination of the sandwich constituents, a perforated release film is laid over the sandwich to allow the entrapped air to move away. Then a breather is laid on top of perforated release film to absorb excessive resin from the sandwich. And finally, the sandwich structure was covered with a vacuum bag using a sealant tape. Vacuum was applied for an hour and curing was carried out at room temperature under vacuum atmosphere.

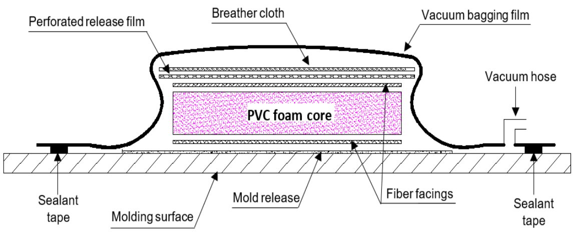


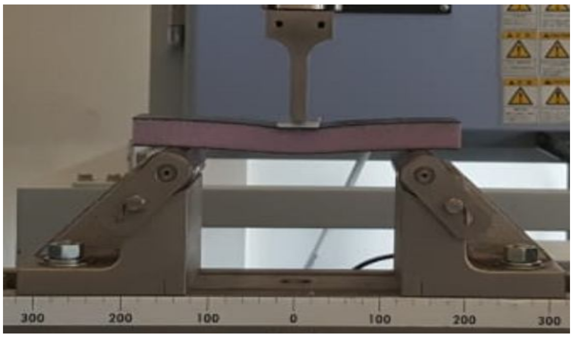
Figure 3: Schematic view of manufacturing process [13]

II. THREE-POINT BENDING TESTS

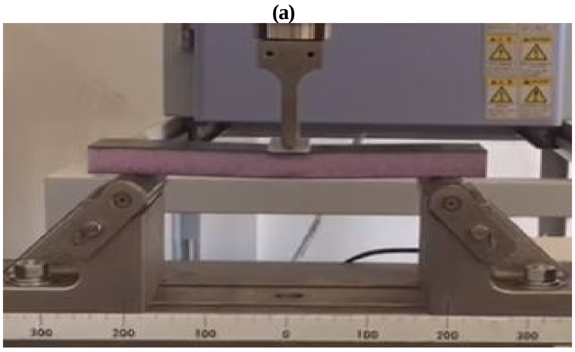
Three-point bending tests were performed according to ASTM C393/C393M-11 standard at ambient conditions by using Shimadzu (AG IS) 100 kN universal testing machine. The cross-head speed was set to 2 mm/min. The test specimens were shown in Figure 4. The support span length were adjusted to 150 mm and 200 mm for the corresponding specimens. 5 mm thick aluminum plate having size of 50mm x 25mm was used between the specimens and loading block in order to prevent the local indentation failure.

IV. RESULTS AND DISCUSSION

Force-displacement curves of the sandwich specimens were obtained and have been given in Figure 5. The minimum five results out of six were presented in the figure. As it is seen from Figure 5, the two groups of specimens have shown similar behavior in linear elastic region. After the maximum force is reached, the nonlinear behavior and failure modes have differed from each other.

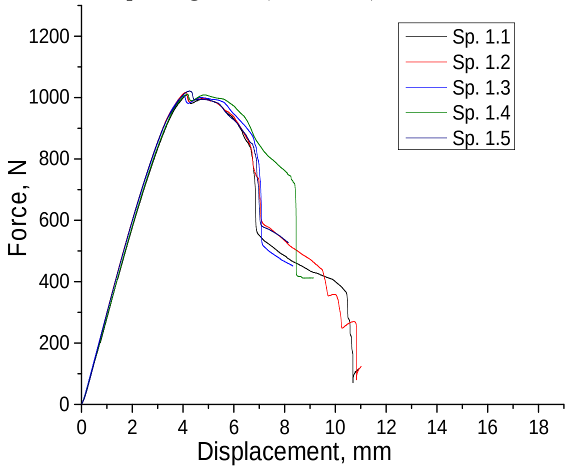


(a)

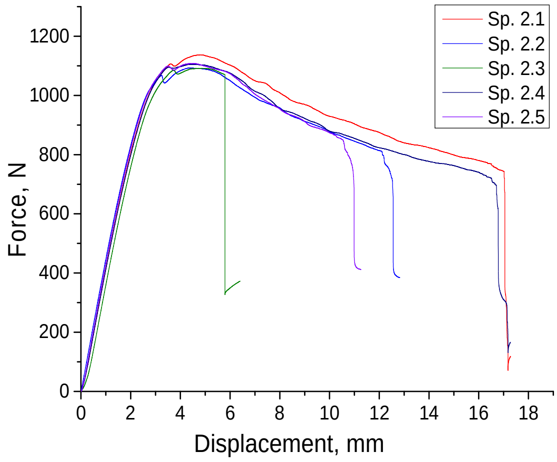


(b)

Figure 4: Application of the bending tests considering the support span lengths of; a) 150 mm, b) 200 mm



(a)



(b)

Figure 5: Force-displacement curves of the sandwiches at a span length of; a) 200 mm, b) 150 mm

In Figure 5a, unlike to the Figure 5b, drop in the force is faster. Because, the failure mode in long beam specimens is firstly expected to be face yielding rather than core shear. On the contrary, relatively short beam specimens have primarily shown a bit core crushing failure [9]. Therefore, the specimens in Figure 5b have not shown a sudden drop in the force after the maximum point was reached.

Maximum load carrying capacity of the sandwich specimens has been determined from the force-displacement curves and recorded in Table 3 and 4.

Table 3
Load carrying capacity of the sandwich specimens tested at a span length of 150 mm

3 Point Mid-spanLoading, S=200 mm	
Specimen	Pmax, N
1	1008,113
2	1017,204
3	1006,364
4	1010,846
5	1021,289
Avarage	1012,763

Table 4
Load carrying capacity of the sandwich specimens tested at a span length of 200 mm

3 Point Mid-spanLoading, S=150 mm	
Specimen	Pmax, N
1	1137,558
2	1092,99
3	1091,877
4	1105,26
5	1108,058
Avarage	1107,149

The force-displacement curves of the specimens in each group have been fitted well to each other. Thus, the results of maximum load carrying capacity are obtained very similar. The second group of sandwich specimens tested at a span length of 150 mm can carry approximately 100 N higher bending loads than that of 200 mm span length.

In order to evaluate the flexural stiffness of the produced sandwich structure, the average of the force-displacement curves were used for the each group. ASTM D7250/D7250M – 06 Standard suggests to useEq (2) to calculate the flexural stiffness.

$$D = \frac{P_1 S_1^3 (1 - S_2^2 / S_1^2)}{48\Delta_1 (1 - P_1 S_1 \Delta_2 / P_2 S_2 \Delta_1)} \quad \text{Eq. (2)}$$

Where;

- D= flexural stiffness, N-mm^2
- P= total applied force, N
- Δ_1= beam mid-span deflection corresponding to P_1 (configuration #1), mm
- Δ_2= beam mid-span deflection corresponding to P_2 (configuration #2), mm
- S_1= support span length (configuration #1), mm
- S_2= support span length (configuration #2), mm

When determining the P_1 and P_2 together with their $\Delta_1$and Δ_2, the linear region of the force-displacement curve must be identified for both two different loading conditions. The values can fall into up to 10% offset of the linear line to satisfy the linearity assumption, as seen in Figure 6 [9]. Percent (%) offset has been calculated as [(C-B)/(C-A)]/600.

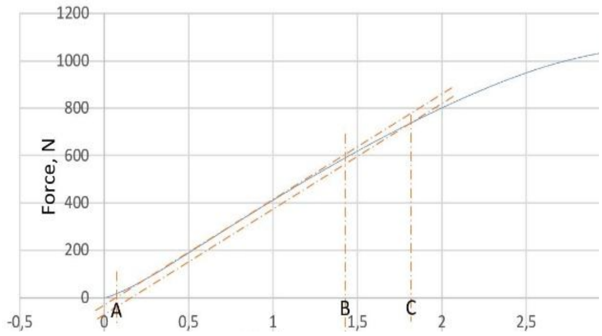


Figure 6:% offset calculation method

Table 5 show the values obtained from the average force-displacement curves of the two loading configuration.

Table 5
Force and displacement values for the loading configuration

Loading condition	Force	Displacement
S = 150 mm	595,175 N	1,4429 mm
S = 200 mm	603,994 N	2,0601 mm

According to the Eq. (2) and using the P_1, P_2, Δ_1, and Δ_2, the flexural stiffness has been evaluated as 408,97 Nm^2.

CONCLUSION

Flexural stiffness is one of the most important bending characteristics for the sandwich structures which particularly serves as load-carrying member. Since a sandwich structure can be constructed by a vast variety of constituents, flexural stiffness becomes significant indicator during the comparison of sandwich structural efficiency. In this study, the evaluation of the flexural stiffness of a sandwich structure having a very lightweight foam core with carbon/epoxy facings was carried out. In the conventional calculations, a designer/constructor firstly needs to determine the young modulus of both facings and core material then flexural stiffness can be obtained. However, additional tests require the use of different test standards and specimen geometry which also cause waste of time and resources. The approach given in that standard allows researchers to calculate flexural stiffness without making any additional tests.

REFERENCES

[1] R. F. Gibson, “Principles of Composite Material Mechanics,”*3rd Ed. CRC Press*,2012.
[2] L. A.Carlsson, , G. A.“Kardomateas,Structural and FailureMechanics of SandwichComposites,”*Solıdmechanıcs and ItsApplıcatıons,* Springer,Vol.121,2011.
[3] J. R. Vinson, “The Behavior of Sandwich Structures of Isotropic and Composite Materials,”*Technomic Publishing Company, Inc.*,1999.
[4] I.M. Daniel, E. E. Gdoutos, K. A. Wang, J.L. Abot, “Failure Modes of Composite Sandwich Beams,”*International Journal of Damage Mechanics*, Vol. 11, 309-334, 2002.
[5] N.Sharma, R. F.Gibson, E. OAyorinde, “Fatigue of Foam and HoneycombCoreCompositeSandwichStructures,”*A Tutorial, Journal of SandwichStructures and Materials*, Vol.8 (4), pp. 263-319. DOI: 10.1177/1099636206063337, 2006.
[6] A.Chemami, K.Bey, J.Gilgert, ZAzari, “Behaviour of compositesandwichfoam-laminatedglass/epoxy under solicitationstatic and fatigue,”*Composites: Part B*, Vol.43, pp. 1178–1184, DOI: 10.1016/j.compositesb.2011.11.051, 2012.
[7] T.Li, LWang, “Bending behavior of sandwich composite structures with tunable 3D-printed core materials,”*Composite Structures*Vol. 175, pp. 46–57. DOI: 10.1016/j.compstruct.2017.05.001, 2017.
[8] K.Kabir, T.Vodenitcharova, MHoffman, “Response of aluminiumfoam-coredsandwichpanels to bending load,”

Composites: Part B, Vol. 64, pp. 24–32. DOI: 10.1016/j.compositesb.2014.04.003, 2014.

[9] ASTM D7250D7250M – 06. Standard Practice forDeterminingSandwichBeamFlexural and ShearStiffness," *USA: Annual Book of ASTM Standards*, ASTM International, 2006

[10] ASTM C393/C393M-11. "Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure,"*USA: Annual Book of ASTM Standards*, ASTM International, 2011

[11] A. B. Banova, Airex C70 Universal Structural Foam Data Sheet, 2011.

[12] Hexion Specialty Chemicals, Technical Information, Epoxy Resins, Germany, 2006.

[13] C. Uzay, N. Geren, M. H. Boztepe, M. Bayramoglu,"Bending Behavior of Sandwich Structures Having Low Density PVC Foam Cores and ±45° Carbon/Epoxy Facings,"*International Advanced Researches & Engineering Congress-2017*, , Osmaniye/TURKEY,16-18 November 2017.

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