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FLEXURAL PROPERTY EVALUATION OF GFRP-FOAM SANDWICH COMPOSITE - AN EXPERIMENTAL APPROACH

R. Santhanakrishnan, P. K. Dash, A. Joseph Stanley and M. Sabarish
Department of Aerospace Engineering, MIT, Anna University, Chennai, India
E-Mail: rsanthanakrishnan2@gmail.com

ABSTRACT

The paper deals with the fabrication and flexural properties studies of stitched core foam sandwich structures with four different degree stitch orientation, i.e., 90^0, 45^0, $90^0/45^0/90^0$ and $90^0/45^0$. The specimens were fabricated over two bidirectional woven fabric surfaces of glass fiber reinforced composite face sheet which were mechanically connected with vertical threads. A modified lock stitch method was used. The flexural strength and deflection of fabricated specimens were determined through three point bending test (ASTM C 393-62). A significant increase in flexural rigidity was observed when it compared with various degrees of orientation of stitching of the sandwich specimen, and found it is highest for $90^0/45^0/90^0$ stitched sandwich specimens. Also, the results were compared with simply glued sandwich composite and found a significant improvement in flexural strength of stitched composite compared to glued composite.

Keywords: stitched core sandwich, deflection, elastic modulus, flexural rigidity, 3-point bending.

1. INTRODUCTION

The need to study the structural behavior and failure characteristics of sandwich materials and structures has emerged during recent years as a consequence of increased acceptance of this structural concept in several critical weight applications. Substantial amount of structural sandwich composites have been already used in many areas of aircraft, ship hulls, wind turbine blades, offshore oil platforms and bridge decks because of their superior structural capacity to carry transverse loads, superior bending stiffness, low weight, excellent thermal insulation and significant acoustic damping. They typically consist of surfacing plates (skins) and light-weight core combination. The main duty of skins of sandwich composite is to carry the transverse load or bending moment while the core takes care of separating and fixing the skin, carrying the transverse shear load, and providing other structural or functional duties such as impact tolerance, radiation shielding, impact resistance etc. [1].

Out of several structural behaviors, the flexural property determination is essentially required in marine and aeronautical applications to determine the sandwich composite application. Also, the requirement of high stiffness and strength, mainly on flexural loads, together with low specific weight is an essential property on designing this newly developed composite. However, the weakest point of such composite elements consists in the possible debonding, and delamination of the external facings of the sandwich skins, which must possess considerable rigidity and strength, from the central part of the sandwich core. Also, it is required to possess a low specific weight and adequate shear stiffness.

The research carried out in the above context has proved that a sandwich composite material made up of bonded assembly of two thin skin possessing good-strength and tensile properties and a much thick core with low density execute good compressive property [2]. Numbers of research paper have been presented on experimental and numerical investigation on the mechanical behavior of sandwich composite either in the form of a plate or beam for various applications [3-6]. Further the dynamic behavior and failure characteristics are the subject of research [7-9]. Several research papers have emphasized the section wise analysis approximating the properties of face sheet with various materials and credentials of core materials [10-14]. Also, various manufacturing processes have been highlighted to achieve the better sandwich construction with significant tensile, flexure, shear, impact and fatigue strength for long term application [15-20]. However, a lesser number of researches are available in the area of 3-D stitched sandwich composite materials [21-23] and 3-D spacer fabrics.

This paper presents an experimental determination of flexural properties of stitched sandwich beam under three point bending load which has been applied over the number of specimens. Four different stitching orientations like 90^0, 45^0, $90^0/45^0/90^0$, $90^0/45^0$ and glued composite were studied and the results were compared.

2. MATERIALS AND EXPERIMENT

Three-dimensional sandwich composite is a newly developed sandwich structure, the reinforcement of which is integrally woven by advanced textile technique. Two face-sheets are connected by continuous fibers, named pile in the core, providing excellent properties like outstanding integrity, debonding resistance, lightweight, good design ability and so on. In this paper, specimens were fabricated with various stitching orientation with glass fiber reinforced face sheet and Divinycell core and compared with unstitched sandwich composite. Both the fabrication and testing methods are mentioned in following paragraph.

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2.1 Preparation of stitched sandwich specimen

Divinycell closed-cell 'H' grade foam core (density = 80kg/m^3, thickness = 10 mm) was used as the core material along with the woven open form glass fabric face sheets of 10 mils thickness. Panels with closed cell foam sandwiched between two layers of bi-directionally woven glass fabric on each side were put for fabrication. Newly developed fixture was used for stitching the sandwich panels with pile orientation on 90^0, 45^0, 90^0/45^0/90^0, and 90^0/45^0 as shown in Figure-1. The multiple needles have constrained motion, i.e., it can move in only one direction along the groove provided in the vertical member. The slots were provided in the horizontal plates for passing the needles the specimen through the specimen. The sandwich contents placed in between the two fixture plates designed for stitching. The gap between the plates and angle of the plates could be adjusted by screw and nut mechanism. The angle was fixed with the help of the graduated scale attached to the vertical member. Above-mentioned modified lock stitched method was adopted for stitching. The stitching pitch was adjusted to 10mm for each specimen preparation. The Glass Yarn G37 1/5 3.8S was used for the stitching of the sandwich panels. A low viscous epoxy resin based on bisphenol constituent and modified with aromatic glycidyl ether called Araldite GY257 with hardner C2963 manufactured by Huntsman, Australia, was used for the fabrication of the panels. The resin and hardener was mixed in a proposition of 100:45 respectively. After stitching, the sandwich panels were prepared using the vacuum infusion process at DIAB Core, Chennai, India. The specimens were allowed to pre cure for 24 hours at room temperature conditions at laboratory, and then kept for 7 days for post cure before taken out for experimental studies. The configuration of sandwich and stitched foam sandwich specimen with pile orientation are shown in Figures 2 and 3, respectively.

2.2 Tension tests

Five coupons of foam were prepared and tested according to ASTM C297 to determine the tensile properties. The coupons were cut such that the properties in the direction perpendicular to rise would be the direction of flexural stresses in the sandwich panel. The prism-shape coupons had a 70 x 70 mm cross-section and a 10 mm thickness. The specimens were adhesively bonded from both sides to specially prepared steel T-sections, using epoxy resin due to low stiffness of the foam. The tests were conducted in Universal Testing Machine with wedge-type mechanical grips and with a displacement rate of 0.5 mm/min. The longitudinal strains were measured by using electrical strain gauge and strain indicator, a product of Rohit Group, Rurky, India. Table-1 shows a summary of the tension test results of the Divinycell closed-cell 'H' grade foam core. The tensile stress - strain curves obtained is almost linear with a slight strain-hardening shown in Figure-4.

Table-1. Summary of the tension test results of the divinycell closed-cell 'H' grade foam core.

Coupon number	**width** (mm)	**Thicknes s** (mm)	**Elastic modulus "Initial slope" E** (Gpa)	**C.V.**	**Tensile strength** (Mpa)	**C.V.**
1	25.78	3.35	19.26	6.92	179	3.58
2	25.71	3.3	21.8		175	
3	25.8	3.37	18.25		179	
4	25.33	3.4	19.34		184	
5	26.2	3.3	18.89		167	

C.V. = Coeffecient of variation

2.3 Tests of skin plate

The face skins were fabricated from weaved E-glass and the araldite GY257 with hardener C2963 epoxy system at the mixture ratio of 100:45. The average thickness of the cured laminate was 3.34 mm. five coupons were prepared according to ASTM D 3039. The coupons were 300 x 25 mm. Tension tests were performed using a Universal testing machine with wedge-type mechanical grips at a rate of loading of 2 mm/min. The longitudinal strain was measured using two electric resistance strain gages, 5 mm long, one on each side of the coupon. Figure-5 shows the tensile stress - strain curves in both directions, which are generally similar, given the near balanced nature of the cross-weave of the fabric. Table-2 shows a summary of the tension test results of the face sheet the stress - strain curve obtained is almost linear.

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Table-2. Summary of the tension test results of the face sheet.

Coupon number	**width** (mm)	**Thickness** (mm)	**Elastic modulus "Initial slope" E** (Gpa)	**C.V.**	**Tensile strength** (Mpa)	**C.V.**
1	25.78	3.35	19.26	6.92	179	3.58
2	25.71	3.3	21.8		175	
3	25.8	3.37	18.25		179	
4	25.33	3.4	19.34		184	
5	26.2	3.3	18.89		167	

C.V. = Coefficient of variation

2.4 Flexural test procedure

The sandwich panels were tested in a 3-point bending test as per ASTM standard C393-63. The support span dimension a_1 was calculated from Equation (1).

$$a_1 = 2fF/S \quad (1)$$

The allowable facing stress F (182Mpa) for the E glass fabric was found out by 3-point bending test using ASTMD790M, f represents facing sheet thickness (0.4 mm). The allowable core shear stress S (1.15 Mpa) was taken from the manufacture's data sheet (24). The 3-point bending test was conducted with a cross head speed of 2mm/min using KALPAK universal testing machine as shown in Figure-6. The sandwich panel width was 35 mm for 10.4 mm thickness. The support span used was 100 mm and the specimen length was 180 mm as per standard.

The theoretical flexural rigidity (D) value was found out using the sum of flexural rigidities of the constituent parts about the centroidal axis of the sandwich beam shown in Equation (2).

$$D = E_f \frac{bf^3}{6} + E_f \frac{fbd^2}{2} + E_c \frac{bc^3}{12} \quad (2)$$

where, E_f stands for modulus of facing (bending), E_c is modulus of core, b is width of sandwich beam, 'f' is facing thickness, 'c' is core thickness and 'd' stands for distance between the facing centroids. The moduli of the core (80.4 Mpa) and facings (19.5 Gpa) were determined using ASTM C 297 and ASTMD3039. Five specimens of each type of sandwich composite were tested in three point bending test and average results were presented in Table-3.

Table-3. Properties of sandwich composite tested under 3- point bending (standard deviation in parenthesis).

Specimens	P_{cr} (N)	**Flexural stiffness** (MN-mm^2) (Exp)	σ_f (Mpa)	τ_c **Mpa**
Unstitched	313(2.4)	7.12(4.4)	96.73(4.4)	0.859
Stitched 45^o Orientation	357(3.6)	7.85(3.9)	110.33(3.6)	0.980
Stitched 90^o Orientation	339(3.6)	8.27(3.9)	104.77(3.6)	0.9313
Stitched 90^o/45^0 Orientation	376(2.8)	7.92 (4.4)	116.20(3.9)	1.032
Stitched 90^o/45^o/90^o orientation	411(3.5)	8.95(4.5)	127.02(3.4)	1.129

3. RESULTS AND DISCUSSIONS

The results are presented in Table-3 for sandwich beam during flexural testing are analyzed in lines of following parameters as:

a) Effect of flexural stiffness
b) Effect of stress
c) Effect of stitching orientation

The material properties are explained in previous sections that the two face sheet is made up of bidirectional glass fiber reinforced composite with constant thickness of 0.4mm and 44% fiber volume fraction.

3.1 Effect of flexural stiffness

The flexural stiffness of sandwich composite is an essential determining factor for application of the material on design. Generally, the compositions of sandwich material have higher elastic modulus of face sheet compare to elastic modulus of face core. Here, it is approximately 243 times higher as observed from experiment. In addition, the thickness of the face sheet (i.e., only 0.4mm) is quite small compare to the thickness of core material (i.e., 10 mm). It has been observed that the 90^0/45^0/90^o stitched sandwich panel has highest flexural rigidity compared to all other sandwich tested.

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3.2 Effect of stress

The stresses have major role on the material behavior and durability. The stress has significant role on the material stability. According to sandwich beam theory, the maximum normal stress on the face is: $\sigma_f = \frac{M}{bt_f d}$ and it has been found that the stress is varying from 96.73 Mpa for unstitched specimen to 127.02 Mpa for $90^0/45^0/90^0$ stitched specimen. Similarly, the shear stress in the core is $\tau_C = \frac{P}{bd}$ and it has been found that the stress is varying from 0.859 Mpa for unstitched specimen to 1.129 Mpa for $90^0/45^0/90^0$ stitched specimen. This variation is attributed to the type of pile support provided by threads and their orientation which received sufficient stiffness by absorbing resin materials. Summing up, it can be ensured that both faces carried bending moments in form of tensile and compressive stress while the core carried the transverse force in form of shear stress. The compression is sizably repelled by the stitched piles during bending.

3.3 Effect of stitching orientation

Four different stitching orientations for sandwich panel has shown a significant variance in deflection values as well as bending load tolerance as shown in Figure-7. It has been found that the specimens have $90^o/45^o/95^o$stitching orientation produced highest bending load as shown in Table-3 in comparison to other stitched and unstitched conditions. The lowest value is observed for the unstitched sandwich panel and it is about 23.86% less compared to $90^o/45^o/90^o$ stitched panel. This is attributed to additional support provided by threads in form of piles. In addition, these piles contributions are depended on orientation. In case of $90^o/45^o/90^o$ oriented piles there are two 90^o piles and in between one 45^o pile shown in Figure-3(d), this leads to the higher flexural strength and higher shear strength. For other orientation like $90^o/45^o$, 45^o and 90^o it has been observed that there is less load carrying capability compared to $90^o/45^o/90^o$ oriented plies.

4. CONCLUSIONS

The present paper focused on the mechanical experimental characterization and numerical simulation of Divinycell closed - cell 'H' grade foam/glass fibre composite sandwich conceived as a lightweight material for various engineering applications. The experimental campaign confirmed the remarkable potentialities of the innovative sandwich structure with core and skins interconnected by transverse stitched plies. Based on experimental and numerical analysis the following concluding remarks revealed.

a) The stitched sandwich composite increased the sizable load carrying ability of the sandwich in compared to unstitched sandwich composite.
b) As experimented with various oriented stitching, it is found that the $90^o/45^o/90^o$ stitched plies have highest flexural load bearing compared to other orientation.
c) The failure mode of the sandwich has distinct into two different categories as the face sheets failed by compressive and tensile load where as the core failure occurred due to shear failure.
d) The use of foam to fill the sandwich core appears to increase the sandwich stiffness and strength quite remarkably with respect to lighter but weaker solutions: at the same time it furnishes a drastic weight saving with respect to a fully laminated glass fibre reinforced plate.
e) As a main point of remark from the experimental studies, it emerges the considerable weakness of the sandwich extra-skins in real engineering applications could then be quite relevant this should be at least partially eliminated or reduced by improving the production technology on this specific aspect.

In lieu of these considerations and with the aim of obtaining better performance under loading, several design advancements have been sought after. These include better choice of core material, introduction of soft inter-layers (e.g. polyurea layer) between the core and the skin, design modification during fabrication etc. A better agreement between experimental results and numerical simulations could be obtained by adopting more sophisticated constitutive modeling and relevant computational techniques. In particular for the simulation of damage processes and strain localization in the core use could be made of ad-hoc formulated damage models, while the phenomenon of extra-skin delamination could be captured by making use of suitable interface models. Also the possible rate dependency of the sandwich mechanical behavior should be checked and possibly simulated by means of suitable models.

a) Fixture without specimen

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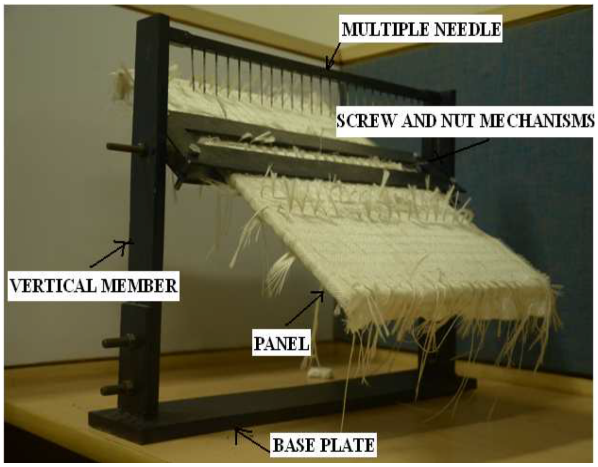

b) Fixture with specimen

Figure-1. Configuration of the fixture used for stitching.

Figure-2. Configuration of sandwich specimen.

Figure-3(a). 90^{o} pile.

Figure-3(b). 45^{o} pile.

Figure-3(C). $90^{o}/45^{o}$ pile.

Figure-3(d). $90^{o}/45^{o}/90^{o}$ pile.

Figure-3. Configuration of Stitched foam sandwich specimen with pile orientation.

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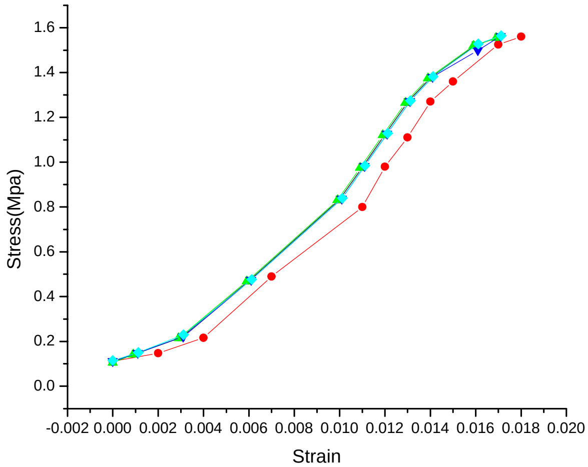

Figure-4. Stress-strain diagram of Divinycell closed-cell 'H' grade foam core under tensile testing.

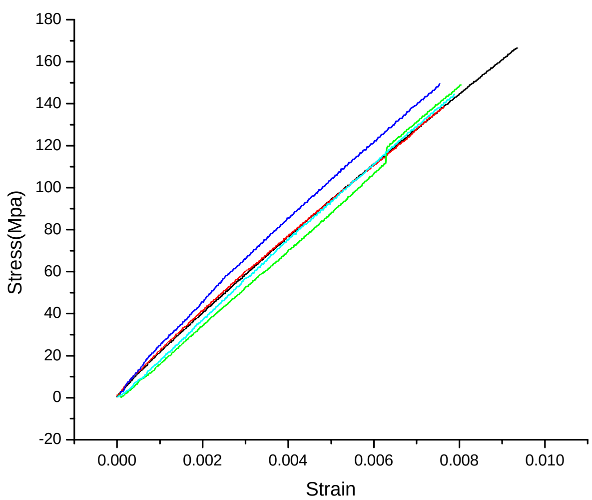

Figure-5. Stress-strain diagram of tensile test of GFRP skin.

Figure-6. Test setup of 3-point bending.

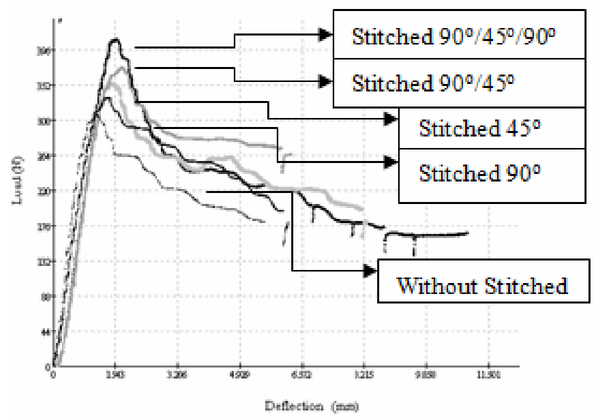

Figure-7. Load vs. deflection (comparison) curve.

REFERENCES

[1] Ahn D.G., Nam G. H., Jung C. G. and Yang D. Y. 2009. Experimental determination of elastic properties of the core in a thin sandwich plate with a metallic truss core. Int. Jr. of Preci. Engg. and Manu. 10(5): 107-113.

[2] Allen H.G. 1969. Analysis and design of structural sandwich panels. Oxford: Pergamon Press.

[3] Altenbach H. 1998. Theories for laminated and sandwich plates-a review. Mechanics of Composite Materials. 34(3): 243-252.

[4] ASTM C 393-62. Standard test method for flexural properties of sandwich construction. ASTM International, PA, USA.

[5] Azarmi F., Coyle T. W. and Mostaghimi J. 2009. Flexural properties of sandwich beams consisting of air plasma sprayed alloy 625 and nickel alloy foam. Jr. of Mat. Sci. 44: 2836-2843.

[6] Berthelot J.-M. 1999. Composite materials mechanical behavior and structural analysis. Springer, New York.

[7] Bezazi A., Mahi A. El., Berthelot J. M. and Bezzazi B. 2007. Experimental analysis of behaviour and damage of sandwich composite materials in three-point bending. Part 1. Static tests and stiffness degradation at failure studies. Strength of Materials. 39(2): 170-177.

[8] Chang S., Hong D. and Chiang F. P. 2004. Macro and micro deformations in a sandwich foam core. Jr. of Composites: Part B. 35: 503-509.

[9] Corigliano A., Rizzi E. and Papa E. 2000. Experimental characterization and numerical simulations of a syntactic-foam/glass-fibre composite

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sandwich. Composites Science and Technology. 60: 2169-2180.

[10]Dawood M., Taylor E. and Rizkalla S. 2010. Two way bending behavior of 3-D GFRP sandwich panels with through-thickness fiber insertions. Jr. of Comp. Structs. 92: 950-963.

[11]Fan X. and Xiao-qing W. 2010. Study on impact properties of through-thickness stitched foam sandwich composites. Jr. of Comp. Structs. 92: 412-421.

[12]Feng G., Li G., Liu Z., Niu H. and Li C. 2010. Numerically simulating the sandwich plate system structures. Jr. of Marine Sci. Appl. 9: 286-291.

[13]Frisch-Fay R. 1962. Flexible Bars. Butterworth, Washington, DC, USA.

[14]Gdoutos E.E., Daniel I.M., Wang K.A. and Abot J. L. 2001. Nonlinear Behavior of Composite Sandwich Beams in Three-point Bending. Experimental Mechanics. 41(2): 182-189.

[15]Grediac M. and Dufort L. 2002. Experimental Evidence of Parasitic Effects in the Shear Test on Sandwich Beams. Jr. of Experimental Mechanics. 42(2): 186-193.

[16]Hai F., Weiqing L., Weidong L. and Li W. 2010. Flexural properties of grooved perforation sandwich composites. Jr. of Wuhan University of Technology-Mater. Sci. Ed. 25(4): 583-587.

[17]Islam M. M. and Aravinthan T. 2010. Behaviour of structural fibre composite sandwich panels under point load and uniformly distributed load. Jr. of Comp. Structs. 93: 206-215.

[18]Ivañez I., Santiuste C. and Sanchez-Saez S. 2010. FEM analysis of dynamic flexural behavior of composite sandwich beams with foam core. Jr. of Composite Structures. 92: 2285-2291.

[19]Kim J. H., Lee Y. S., Park B. J. and Kim D. H. 1999. Evaluation of durability and strength of stitched foam-cored sandwich structures. Jr. of Comp. Structs. 47: 543-550.

[20]Li M., Wang S., Zhang Z. and Wu B. 2009. Effect of structure on the mechanical behaviours of three-dimensional spacer fabric composites. Jr. of Appl. Compos Mater. 16: 1-14.

[21]Manalo A. C., Aravinthan T., Karunasena W. and Islam M. M. 2010. Flexural behaviour of structural fibre composite sandwich beams in flat wise and edgewise positions. Jr. of Comp. Structs. 92: 984-995.

[22]Polyakov V. A., Zlfigun I. G., Shhtsa R. P. and Klfitrov V. V. 1998. A refined model for three points bending of sandwich panels. 2. Transverse stresses. Jr. of Mechanics of Comp. Mat. 34(1): 50-69.

[23]QianCheng Z., AiPing C., Chang Qing C. and Tian Jian L. U. 2009. Ultralight X-type lattice sandwich structure (II): Micromechanics modeling and finite element analysis. Jr. of Sci. China Ser. E-Tech. Sci. 52(9): 2670-2680.

[24]Technical data for Divinicell H grade. Available from:http://www.diabgroup.com.