

## Research Article

## Mechanical Characterization of Stitched Foam Sandwich Panel by Varying Thread TPI

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### Abstract

*The paper deals with the fabrication and flexural properties studies of stitched core foam sandwich structures by varying thread TPI (Twist Per Inch). 10 mil silane treated open form E – glass fabric was used as a face sheet. Divinycell foam H-80 was used as a core material. The perforated foam was placed in between the face sheets and hand stitch method was used for stitching the face sheet and the foam by glass yarn (37 1/5) of 3, 3.8, 5.3. The panels were fabricated under Vacuum bag moulding process. The flexural strength and flexural deflection of fabricated specimens were determined through three point bending test (ASTM C 393-62). A significant increase in flexural rigidity of foam was observed in the panel stitched with thread of 3 TPI when compared with other layers.*

**Keywords:** Flexural, Open Form, Perforated, hand stitch and Glass Yarn

### 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 (Ahn, D.G., Nam, et al 2009).

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.

Many research papers 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<sup>(3-6)</sup>. Further the dynamic behavior and failure characteristics are the subject of research (Bezazi.A et al 1999) (Chang.S et al 2004) (Corigliano.A 2007). Several research papers have emphasized the section wise analysis approximating the properties of face sheet with various materials and credentials of core materials. 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<sup>(15-20)</sup>

### 2. Materials and Experiment

This paper presents an experimental determination of flexural properties of stitched sandwich beam stitched with different thread TPI under three point bending load which has been applied over the number of specimens. The stitching orientation on 90° with different thread TPI is carried out and glued composite were studied and the results were compared.

Stitched foam sandwich composite is a newly developed sandwich structure, the reinforcement of which

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is integrally woven by advanced textile technique. Two face-sheets are connected by continuous fibers, named pile

**Table 1** Summaries of the tension test results of the Divinycell closed-cell H grade foam core:

Coupon number	Cross sectional area (mm <sup>2</sup> )	Thickness (mm)	Elastic modulus "Initial slope" E(MPa)	Mean (MPa)	S.D. (MPa)	C.V.	Tensile strength (MPa)	Mean (MPa)	S.D. (MPa)	C.V.
1	625	10	78	80.4	3.04	3.78	1.68	1.66	0.02	1.24
2	625	10	80				1.69			
3	625	10	83				1.64			
4	625	10	77				1.66			
5	625	10	84				1.65			

Note : S.D. = Standard deviaton C.V. = Coeffecient of variation

**Table 2** Summary of the tension test results of the face sheet

Coupon number	width (mm)	Thickness (mm)	Elastic modulus "Initial slope" E(Gpa)	Mean (Gpa)	S.D. (Gpa)	C.V.	Tensile strength (MPa)	Mean (MPa)	S.D. (MPa)	C.V.
1	25.7	3.3	19.26	19.5	1.35	6.92	179	177	6.34	3.58
2	25.7	3.3	21.8				175			
3	25.7	3.3	18.25				179			
4	25.7	3.3	19.34				184			
5	25.7	3.3	18.89				167			

Note: S.D. = Standard deviaton; C.V. = Coeffecient of variation

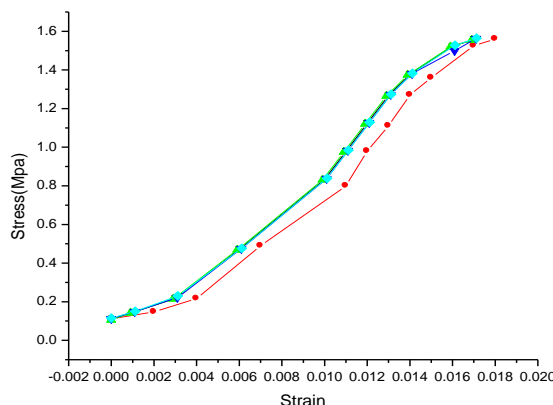
in the core, providing excellent properties like outstanding integrity, debonding resistance, lightweight, good designability and so on. Diagonal hand stich method was adopted for stitching the sandwich panel. The face sheet thickness was varied and flexural test were carried out and the results were compared with unstitched specimen. Both the fabrication and testing methods are mentioned in following paragraph.

*2.1 Preparation of stitched sandwich specimen*

Divinycell closed-cell H grade foam core (density = 80kg/m<sup>3</sup>, 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. By using vertical pillar drilling machine foam is drilled at an angle of 90° with pitch distance 15mm. Foam is placed in between face sheet. Panels are stitched 90° over the face sheet is shown in Fig.1. 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 hardener C2963 manufactured by Huntsman, Australia, was used for the



**Fig. 1** Diagonal Stitching



**Fig. 2** Stress –Strain Diagram of Divinycell closed-cell H grade foam core under Tensile Testing.

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 bag moulding process at Reinforced Plastics ,Bangalore, 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.

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

**Table 3:** Flexural rigidity of sandwich panels

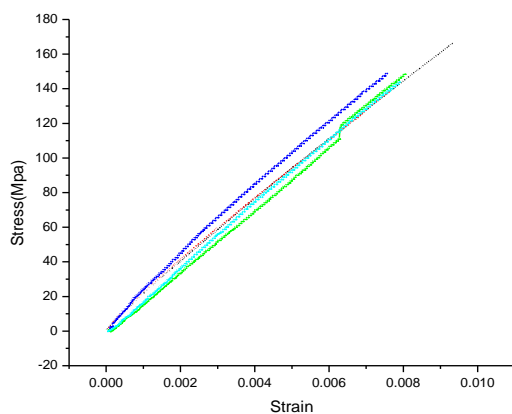
S.No	Face Sheet Thickness (mil)	Span Length (mm)	Breadth (mm)	Flexural Rigidity (Mean) N-mm <sup>2</sup>	S.D	C.V	Critical Load (Mean)N	Normal Stress $\sigma_t = \frac{M}{bt_r d}$ (N/mm <sup>2</sup> )	Shear Stress $\tau_c = \frac{P}{bd}$ (N/mm <sup>2</sup> )
1	20 (Unstitched)	130	30	1855729.3	0.2736	1.4 * 10 <sup>-7</sup>	201.80	52.55	0.646
2	20 (Stitched by 3 TPI)	130	30	2087414.314	0.3489	1.6 * 10 <sup>-7</sup>	226.91	59.09	0.727
3	20 (Stitched by 3.8 TPI)	130	30	4066978.504	0.27	6.8 * 10 <sup>-8</sup>	339.31	84.5	1.067
4	20 (Stitched by 5.3 TPI)	130	30	8248437.4	0.214	2.5 * 10 <sup>-8</sup>	365.01	88.01	1.12

Note : S.D. = Standard deviaton; C.V. = Coefficient of variation

displacement rate of 0.5 mm/min. The longitudinal strain were measured by using electrical strain gauge and strain indicator. 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 Fig.2.

2.2 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 an 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. Fig. 3 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.



**Fig. 3** Stress-Strain Diagram of Tensile Test of GFRP Skin

The sandwich panels were tested in a 3-point bending test as per ASTM standard C393-62. The support span dimension a<sub>1</sub> was calculated from Eq.(1)

$$a_1 = \frac{2Ff}{S} \tag{1}$$

The allowable facing stress F (182MPa) for the E glass fabric was found out by 3-point bending test using ASTMD790M. The f represent facing sheet thickness (0.4 mm). The allowable core shear stress S (1.15 MPa) was taken from the manufactures data sheet <sup>(21)</sup>. The 3-point bending test was conducted with a cross head speed of 1.5mm/min using KALPAK universal testing machine. The sandwich panel width was 30 mm and thickness was 10.8 mm, 11.2 and 11.6mm for 20 mil, 30 mil and 40 mil panels respectively. The span lengths were calculated as

per ASTM standards. 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 Eq.(2).

$$D = E_f \frac{bf^3}{6} + E_f \frac{fba^2}{2} + E_c \frac{bc^3}{12} \tag{2}$$

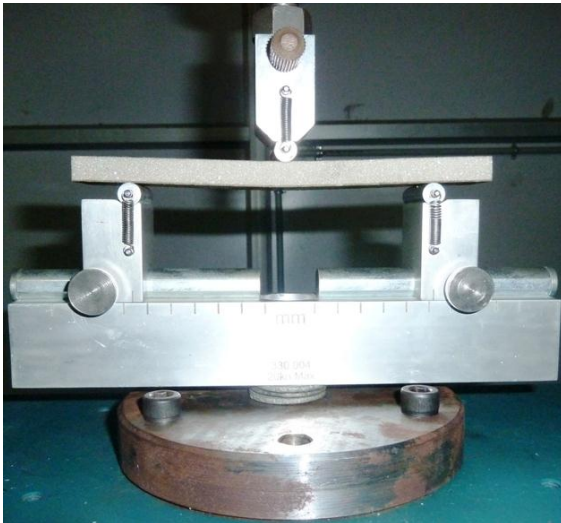
where, E<sub>f</sub> stands for modulus of facing (bending), E<sub>c</sub> is modulus of core, b is width of sandwich beam, f is facing thickness, c is core thickness and d stands for distance between the facing centroids. The moduli of the core (80.4 MPa) and facings (19.5 GPa) were determined using ASTM C 297 and ASTMD3039.

3. Results and Discussion

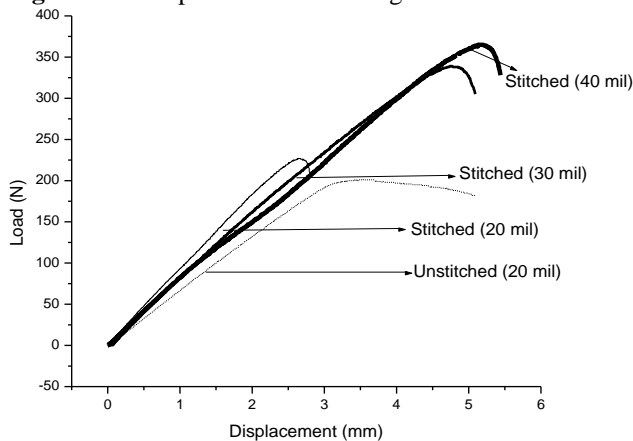
The flexural stiffness was found out by means of overhanging beam 3 point bending test as per ASTM 393-62 as shown in Fig.4. The test results is shown in Fig.5

and the corresponding values is shown in Table-3. During flexural testing the following observations are found out.

1. Effect of stitching
2. Effect of thread TPI
3. Effect of stress



**Fig. 4** Test Setup of 3-Point Bending



**Fig.5** Load Vs Displacement curves of sandwich specimens

### 3.1 Effect of stitching

Unstitched and stitched sandwich panels of face sheet 20 mil thickness was tested and the results were shown in Fig.6 and in Table.3. From the results it is observed that the percentage of increase in flexural rigidity is 12%. The critical load of unstitched panel is 201.80 N, whereas for stitched panel is 226.9 N. For unstitched panel it is observed that after reaching the critical load, the panel shrinks to take load, only displacement is observed. For stitched panel once the critical load is reached there is a sharp drop in curve has been found. The material properties are explained in previous sections that the face sheet is made up of bidirectional glass fiber reinforced composite with constant thickness of 10 mil and 44% fiber volume fraction.

### 3.2 Effect of thread TPI

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. The flexural rigidity of panel stitched with 3.8 TPI is increased by 48% while comparing with the panel stitched with 5.3 TPI and has an ultimate load of 339.31N. The maximum flexural rigidity is obtained in the panel stitched with 3 TPI which shows an increase of 50% greater than 30 mil thickness panel and reached the critical load of 365.01 N is observed from the experiment. It has been observed that the panel stitched with 3TPI thread has highest flexural rigidity compared to all other sandwich panels.

### 3.3 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 52.55 MPa for unstitched specimen to 59.09 MPa for stitched specimen with 20 mil thickness. The bending stress for 40 mil thickness is 32 % greater than 20 mil stitched sandwich 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 0.646 MPa for unstitched specimen to 0.727 MPa for stitched specimen with 20 mil thickness. The shear stress for 40 mil thickness is 35% greater than 20 mil thickness stitched specimen. This variation is attributed to the type of pile support provided by threads received sufficient stiffness by absorbing resin materials and face sheet thickness. 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.

## 4. Conclusion

The present paper focussed 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 plié and face sheet thickness. Based on experimental and numerical analysis the following concluding remarks revealed.

- 1) The stitched sandwich composite increased the sizable load carrying ability of the sandwich in compared to unstitched sandwich composite.

- 2) Decreasing thread TPI greatly increases the flexural rigidity.
- 3) 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.
- 4) 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.

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