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NOVEL METHODOLOGY TO IMPROVE THE FLEXURAL RIGIDITY OF SANDWICH COMPOSITE

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KEYWORDS: Stitching, Winding, Sandwich panel, Tensile strength, bending strength, Flexural Rigidity, strength to weight ratio.

ABSTRACT
Composite sandwich structures fail by various means such as de-bonding, breaking of core etc. which can be minimized by stitching and z-pinning technique, but these techniques have their own limitations. To improve the parameters that the above mentioned methods cannot provide, a new method called as winding on the sandwich panel is introduced. In this paper the comparison of these methods with the new technique used on standardized sandwich panel is portrayed with differences in properties such as Bending strength, flexural rigidity and strength to weight ratio. A 0.8mm diameter glass fibre yarn is used for the winding and stitching techniques on the sandwich panel. The face sheet used is E-glass/epoxy and the core is PVC Divinycell H80 foam. All Tests are carried as per ASTM standards.

INTRODUCTION
Composite Sandwich panel are most widely preferred because of their high strength to weight ratio. Since the process of making the sandwich panel involves bonding of the face sheets (made up of specific material "capable of handling bending loads") with a core material (generally light in weight having high rigidity and "capable of handling shear loads") with a particular adhesive, the panel hence can fail if the layers get separated from each other due to failure called delamination. This delamination failure may be due to (I) voids in between face sheet and core during adhesive application, (II) insufficient usage of adhesive, (III) varying property of the adhesive with varying temperatures etc., There are few methods which can solve this problem such as Stitching and Z-pinning with some limitation in each technique. The idea behind this paper is to introduce another method, which in separate or combination of itself with the other methods give good strength with an allowable acceptance in weight. The method which is discussed here is named as winding (external fastening method). The face sheets are made of GFRP 2 weave silane treated open form E-glass fabric cloth, the core of PVC Divinycell H80 and the winding filament of E-glass yarn. The test specimens made according to the ASTM standard test is used for better comparison results.

PROCEDURE
The complete test procedure is grouped into three phases for convenience-
Phase 1: Determination of properties of the face sheet and core material
Phase 2: Fabrication and testing of the comparative main sandwich panel
Phase 3: Comparison, weight fraction, and failure formulation

PHASE 1
Face sheet: The mechanical properties of the face sheet were found through Tensile and Flexural (bending) test. A laminate was fabricated with 16 layers of E-glass fabric (each contributing to thickness of ~ 0.2mm) using epoxy resin as GY257 and hardener as C2963 in the ratio (10:1) using compression molding process. Ten specimens were cut from the laminate (i.e., 5 for tensile test and 5 for bending test furnishing the ASTM requirements) using water jet cutting method.

Tensile Test: Testing Standard: ASTM, which deals with "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. The objective of this test was to find the in-plane tensile properties of matrix composite face sheet. This standard requires that the minimum length of the specimen should be taken as the gripping length at both ends + two times specimen width + gauge length. The width was taken as required and the cross section being rectangular in shape. The final dimensions were found to be 25mm width and 250 mm length. Aluminum tabs with scribed sides were used for frictional gripping which was also recommended

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by the standard. The Tensile test was carried out in a UTM with wedge type mechanical grips. The CHS (cross head speed) was maintained constant at 5mm/min and the strain was measured using an electrical Extensometer. The tensile strength was calculated using the relation $\sigma_T = P/A$ (where σ_T =Tensile strength (MPa); P = Maximum load (N); A= Average cross sectional area (mm^2)). The Elastic modulus 'E' was found out to be ~20.6 GPa and the tensile strength as ~247 MPa.

Fig.1 Tensile Test

Failure: Most of the specimens failed at the gauge in the middle and one at the grip.

Bending Test: Also called as 3-Point Bending Test. ASTM standard used for testing: ASTM D 790-30 labeled as "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials". The final dimensions were taken as 25 mm wide and 150 mm long. The bending test was conducted in a UTM with the 3-Point Bending Setup with CHS 5mm/min and displacement measured using an electrical extensometer. The Bending strength was calculated using the relation $\sigma_B = (3PL_s)/(2bd^2)$ (Where, σ_B= Bending Strength (MPa); P= Maximum Load (N); L_S= Width (mm); b= Depth (mm); d= Span (mm)).

The Bending strength obtained from the test was ~149MPa and the corresponding E was ~16.7GPa.

Fig.2 Tensile Test

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Mode of failure: The specimens failed by a crack formation which initiated on the surface under tension.
Core: The properties are calculated by the manufacturer itself according to several ASTM standards. Here we are interested in the shear strength only which is 1.15MPa for Divinycell H80 using the ASTM C 273 standard. This core can operate at temperatures between -200^{0}C to +70^{0}C and is preferable to use with skins having a temperature up to +85^{0}C (*reference courtesy DIAB group)

PHASE 2

This test is to determine the type of sandwich construction which has the advantages such as High bending strength, High Flexural Rigidity, High Performance in Preventing delamination. The types of sandwich construction used for comparing with each other are:

I. 0^0 and 90^0 winded Sandwich Panel
II. Crisscross Stitching and 90^0 Winded Sandwich Panel
III. Plain Sandwich Panel
IV. Only Crisscross Stitched Sandwich Panel
V. Only 90^0 Winded Sandwich panel.

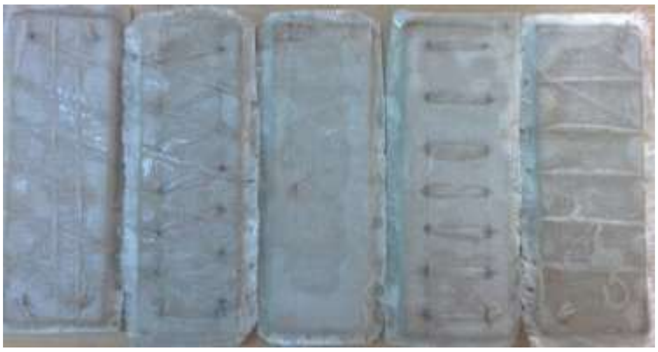

Fig. 3 Types of Sandwich panels as named above

The common characteristics which are made to be constant for better comparison are (a) Same ASTM method is employed for testing that is to test the bending strength using 3- Point Bending Test;(b) Face sheet is made up of two layers of E-glass weave fabric i.e., Four layers are used in single specimen; (c) The core is common which is made up of PVC H80; (d) The same method of fabrication is used that is Hand layup; (e) Same Epoxy Resin LY556 and Hardener HY951; (f) The E glass filament used for winding is common; (g) Same Dimensions such as (Thickness = 10 mm; Length= 150 mm; Breadth= 50mm)

A. FABRICATION PROCESS

The specimen is fabricated as follows

- The core is cut according to the dimensions (150mm length and 50mm width)
- Holes are drilled at places where the E- glass fibre filament is supposed to pass specially for specimens related to winding and stitching through the core
- E- glass fabric sheets (4 nos. i.e., two above and two below) are then cut according to the dimensions +10mm extra on all sides
- A temporary stitch is provided to hold all the layers
- The E -glass filament is made to pass through the holes drilled earlier accordingly as per requirements
- A simple hand layup method is employed using the given resin and the specimen is allowed to be cured under a load for one day followed by grinding the excess face sheets
- The material is then tested for its flexural properties
-

B. TESTING OF THE SPECIMENS

"ASTM D790-30 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials" is used for testing. As the standard states the test specimen should have a rectangular cross section. The final dimensions were taken as 50mm wide and 150 mm long. The bending test was conducted in a UTM with the 3-Point Bending Setup with CHS 5mm/min and displacement measured using

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an electrical extensometer. The Bending strength was calculated using $\sigma_B = (3PL_s)/(2bd^2)$ (Where, σ_B= Bending Strength (MPa); P= Maximum Load (N); L_S= length (mm); b= breadth (mm); d= depth (mm)) and the flexural rigidity using $EI = PL^3/48\delta$ (where δ is the displacement and L is the span length)

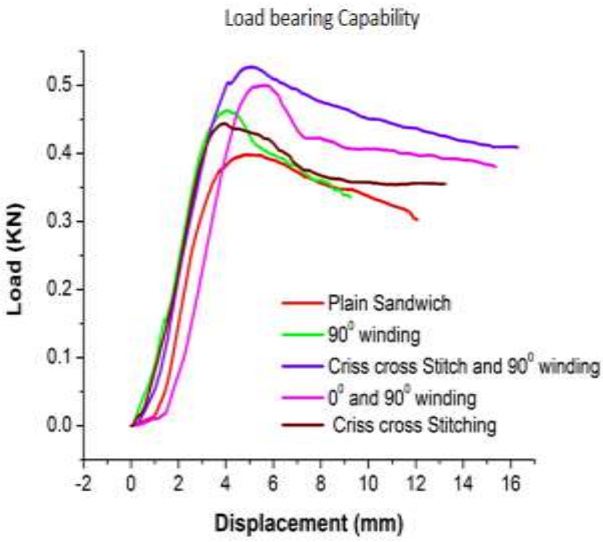

Fig.4ComparisonGraph

TABLE 1
SUMMARY OF THE FLEXURAL TEST RESULTS OF THE PANELS

S.No	Specimen Type	Bending Strength (MPa)	Flexural Rigidity EI (Nmm^2)
1	Plain Sandwich Panel	10.2	1701.05
2	90^0 winding Sandwich Panel	12.612	3809.52
3	Crisscross Stitching and 90^0winding Sandwich Panel	14.74	4379.06
4	0^0 and 90^0 winding Sandwich Panel	13.14	3672.8
5	Crisscross stitching Sandwich Panel	11.96	3378.9

C. STRENGTH TO WEIGHT RATIO
The strength to weight ratio is calculated by dividing bending strength by Average Weight of the specimen. (Average weight is taken for the five specimens belonging to the same group). The increase in weight percentage is calculated with respect to the Weight of the Plain sandwich panel. The following table shows the strength to weight ratio and the increase in weight (%) of the Panels

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TABLE 2
SUMMARY OF THE FLEXURAL TEST RESULTS OF THE PANELS

S.No	Specimen Type	Average Weight (grams)	Strength to Weight Ratio (MPa/grams)	Increased Weight (%)
1	Plain Sandwich Panel	0.92	10.94	NA
2	90^0 winding Sandwich Panel	0.96	12.29	4.35
3	Crisscross Stitching and 90^0winding Sandwich Panel	1.04	14.186	13.04
4	0^0 and 90^0 winding Sandwich Panel	1.02	13.71	10.87
5	Crisscross stitching Sandwich Panel	0.98	12.162	6.52

D. COMPARISON

A comparison of these five types of sandwich panels is shown below in terms of Load bearing capacity which is directly proportional to bending strength of the panel.

As seen from above graph that the bending Strength decreases in the following trend

1. Crisscross stitch and 90^0 Winding
2. 0^0 and 90^0 winding
3. 90^0 winding
4. Crisscross stitching
5. Plain Sandwich

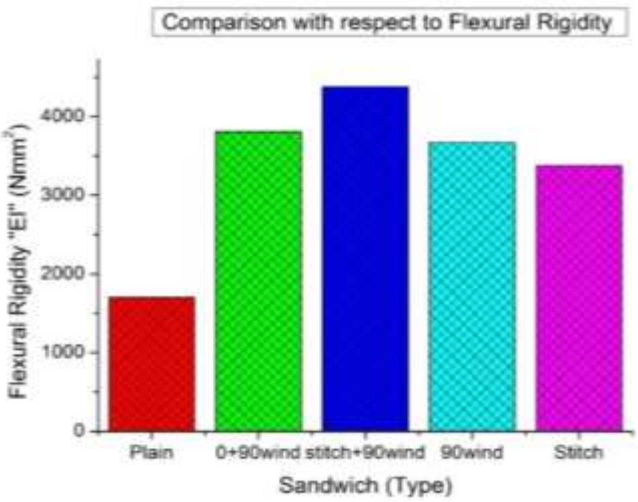

Fig. 5 Flexural rigidity bar chart

The Strength to weight ratio and the increase in weight (%) of different panels can be compared from the following bar charts-

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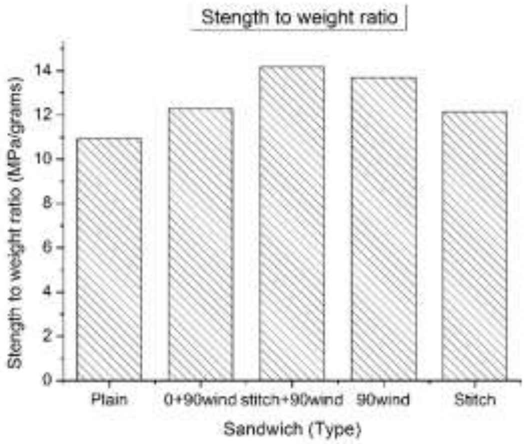

Fig. 6 Strength to Weight Ratio

The panel with stitching and 90^0 Winding has the highest strength to weight ratio and then the others follow in the trend shown in the chart. Here the second place is taken by 90^0winding, which also give good strength for its light weight characteristics.

E. FAILURES OCCURRING IN SANDWICH PANEL AFTER TESTING

Here only local crushing of core is found. This is because of the less thickness of the face material. This can be stopped by increasing the thickness of the face sheet or in this case increasing the number of layers of the E-glass fabric cloth.

Also the delamination of the Plain type of sandwich Panel occurs, but this is not seen in other types of sandwiches. Hence the methods such as the Stitching and the Winding greatly affect in the role of minimising the delamination characteristics.

Another type of failure observed excluding the Plain type of sandwich Panel is that the holes drilled in the core can decrease the bending strength and the flexural rigidity. This is because of artificial formation of cell type of core which minimises the rigidity modulus of the core. This type of Failure cannot be removed totally in the case of stitching method but it can be relieved in the case of winding i.e., the winding can be provided without the use of drilling holes.

The local crushing of core followed by failure of sandwich panel during bending test is shown in the following figure.

CONCLUSION

It is seen from the tests that the sandwich with stitching and 90 winding has the maximum bending strength and flexural rigidity. This is because the delamination is prevented by the stitching and the winding. Also the E-glass filaments used for these methods are aligned at angles such that they take tension and provide additional stiffness.

When compared between pure stitching and pure winding the winding is more effective. From both the windings the 0 and 90-degree winding has high stiffness and strength.

The panel which is efficient in handling high load with light weight capability is the 90^0winding panel. The increase in weight percent of the panel with respect to the Plain sandwich structure is very less when compared with all the other four panels. This is depicted by the following bar chart-

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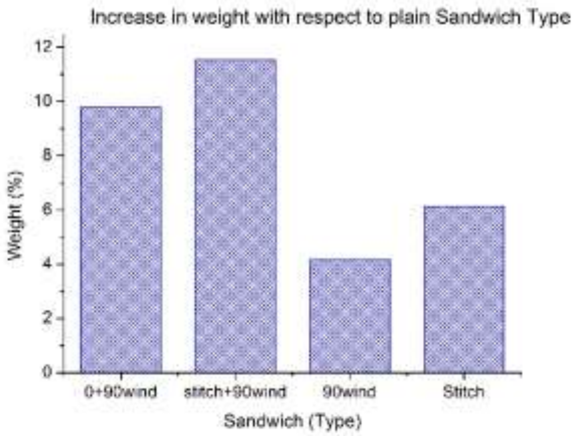

Fig. 7 Increase in weight with respect to plain Sandwich Type

The Bending strength, stiffness and the flexural rigidity can be increased more by

1. Increasing the number of turns of winding.
2. Using hybrid composites i.e., using different materials for face sheet and winding filament.
3. By varying the diameter of the winding filament.
4. Using a process which efficiently makes impregnation of resin into face sheet and fibre filament thus making them strong. This can be done by using the method called vacuum infusion technique.
5. The filaments used for windings should not allowed to be loose i.e., the filament must be fabricated with the sandwich with the right amount of tension and the filament must be in contact with the face sheets to improve strength and decrease wear.
6. Increasing the number of holes or the size of the holes may impose a serious threazzt to the sandwich structure. Hence holes must be minimised to conserve the rigidity of the core. This point is concerned when producing more stitches in the composite sandwich. Therefore, the method of stitching in the sandwich construction should not be over used.
7. Increasing the thickness of the face sheet materials.

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