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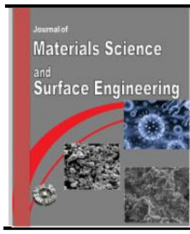

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Flexural Behaviour of Sandwich Composite Panels Fabricated Through Different Vacuum Bagging Techniques

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Abstract

The experimental investigation here focuses on the fabrication of sandwich panels using a single hot vacuum bag, modified vacuum bag, multiple bag and a single hot vacuum bag with platen compression techniques. The present vacuum bagging system cannot be used to prepare sandwich structures when the pressure needs to exceed one bar for bonding considerations. In order to avoid this issue, a new methodology that follows a modified and then a multiple bag technique is proposed to fabricate sandwich panels with high temperature curing of epoxies. Sandwich composites with glass fabric-epoxy face sheet as skin material and a low density thermoset unfilled rigid foam–Polyisocynurate (PIR-100kg/cu.m), as core material, are considered here. Specimens are tested for flexure for varied spans and at a constant skin to core weight ratio. The flexural strength, rigidity and shear properties are evaluated from the observations to find the influence of the core and span to depth ratios on the respective properties of the sandwich composites.

The work had been presented at an international conference ***Fatigue Durability India 2015****, 28-30th May 2015, JN TATA AUDITORIUM, Indian Institute of Science, Bangalore.*

Introduction

A composite material can be defined [1] as a combination of two or more materials that results in better properties than those of the individual constituents. The two main constituents of a composite material are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness which may be harder, stronger, and stiffer than the matrix. A sandwich-structured composites [2] are a special class of composite materials , fabricated by attaching two thin but stiff skins to a lightweight, but thick core. These materials have increasingly been used in a variety of industrial applications such as [3] marine, automobile industry, aeronautics, and aerospace as it is convenient for designers to design for specific requirements with precision and work with the desired characteristics, due to high strength to weight ratios. Polyisocyanurate (PIR) [5] foams represent the system of choice to produce Glass fabric-faced sandwich panels, providing energy efficiency and compliance to severe fire safety requirements.

The manufacturing techniques are also seen to contribute [6] toward performance of the composite. Vishakh *et. al*. [2] and Surya Teja Varma [4] have investigated the flexural properties of foam core glass epoxy sandwich composites, followed room temperature vacuum bagging technique. Menta [6] developed a non-autoclave vacuum bag process using atmospheric pressure alone that eliminates the need for external pressure normally supplied by an autoclave or a press is an attractive method for composite fabrication. In order to protect against bag or seal failure, part lay-ups are sometimes 'double bagged'. Double bagging [7] [8]involves placing a first, inner bag over the lay-up which is then sealed to the tool base. A second, outer bag is placed over the inner bag and is also sealed to the tool base. The various flexural properties of sandwich specimens such as flexural strength, flexural strength per unit width, bending strength per unit width, bending stress, shear strain were obtained under 3 point bending [9][10] to find the sandwich beam flexural and shear stiffness.

Experimental

Approach of Investigation

The present investigation deals about fabrication of sandwich panels using four different techniques. A Thermo set rigid unfilled polyisocynurate foam (PIR) of density 100kg/m^3 is used as core and glass /epoxy as the skin material. The skin to core weight ratio is maintained at 4:1 with volume fraction of 0.3 in the skin for the fibre, and the beams were tested for flexure.

Table 1: Materials Considered For Fabrication

Material	Name
Skin Reinforcement	E - Glass Fabric-Plain Weave
Core	PIR-100 kg/m^3
Resin	LY556
Hardener	EH200

Table 2: Material Properties of Core

Properties	PIR-100
Elastic Modulus(M Pa)	14.6 MPa
Poisson's Ratio	0.29

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Table 3: Material Properties of Skin

Properties	GlassFabric	Epoxy Resin	Skin
Elastic Modulus, E (M Pa)	35	2	11900

Fabrication Process

The fabrication process was carried out by four different types of techniques such as single hot vacuum bagging , modified vacuum bag, multiple bag and single hot vacuum bag with platen compression. .In single hot vacuum bag technique initially a vacuum bag prepared using general vacuum bagging method, Later the vacuum bag is kept inside the oven for high temperature curing. The vacuum bag is evacuated for 30 min and hot curing is carried at 100^0 c for 30 min.

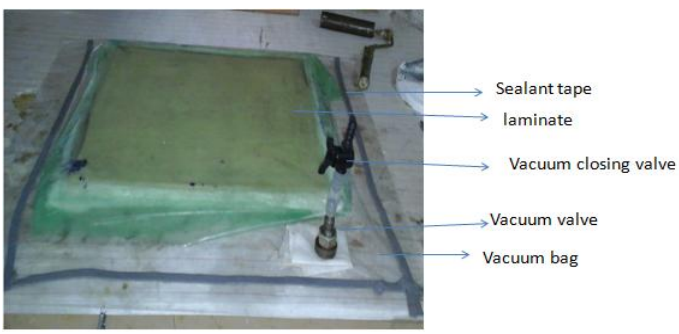

Figure 1: Sandwich panel inside the vacuum bag before high temperature curing

In the modified and multiple bag techniques, more than a single bag were used. The number of the bags was varied in the two techniques. In the compression platen technique, after vacuum bagging , the vacuum bag setup is compressed between two M.S plates and clamped with c-clamps.The entire setup was kept inside the oven for high temperature curing at the same temperature and duration..

Figure 2: Platen compressed vacuum bag inside oven

Testing Of Sandwich Composite Specimens

Three point bending tests were carried out for sandwich beam specimens machined out of all the panels made through all the four abovementioned techniques based on the appropriate ASTM standards for testing the sandwich composite panels [10,11] and analyze the fracture behaviour & mechanical properties of the panels with the aid of an Instron UTM.

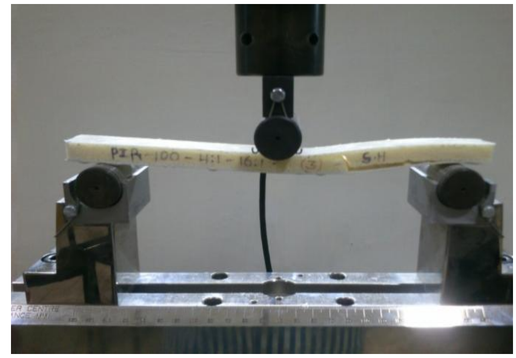

Figure 3: A specimen under 3 point bending with 16:1 span to depth ratio made by single hot bag

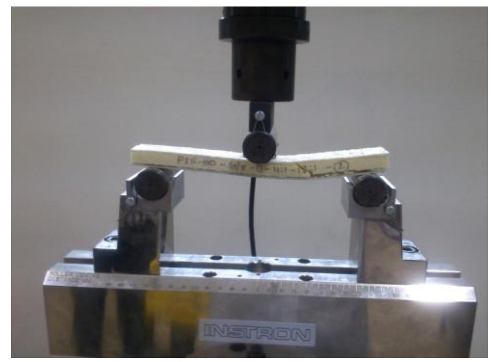

Figure 4: A specimen under 3 point bending with 12:1 span to depth ratio made by dual bag

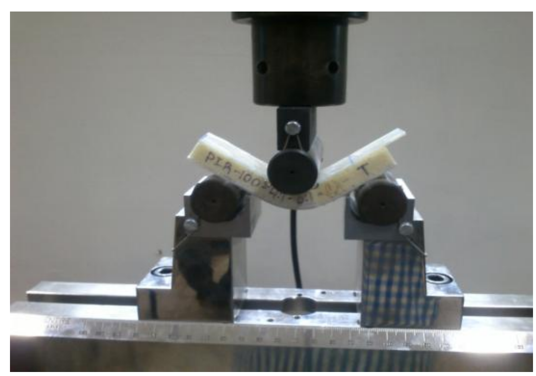

Figure 5: A specimen under 3 point bending with 6:1 span to depth ratio made by triple bag

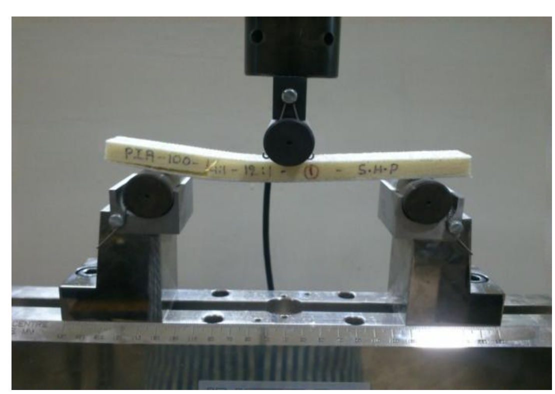

Figure 6: A specimen under 3 point bending with 12:1 Span to depth ratio made by plated compression

Sandwich panels with a core density of 100kg/m^3 are machined for the testing. Skin to core weight ratio is considered as 4:1. The sandwich specimens were tested for the flexural properties. Specimens with span to depth ratios of 6:1, 12:1 and 16:1 are tested using a three-point bending test fixture in an Instron UTM machine and load *versus* deflection graphs were plotted. The flexural properties such as flexural rigidity, bending stress, bending stiffness, shear strain etc. were found similar to those obtained from the evaluations made from an earlier study [12].

Evaluations

Flexural properties are evaluated from the experimental values obtained from the three-point bending test. Following are the different important flexural properties of sandwich composite that can be evaluated from the flexural test. The following equations [11] are considered for the evaluating the various flexural properties.

Flexural Rigidity, D (Nmm^2) :

$$D = hbt^3 + E_f(2tb)\left[\frac{d+t}{2}\right]^2 + \frac{E_c bc^3}{12}$$

Flexural Rigidity per unit width, (Nmm^2/mm)= D/b

Bending Stiffness, N/mm = $\frac{W}{\delta}$

Bending Stiffness per unit width, N/mm^2 = $\frac{W}{\delta.b}$

Bending Stress, σ_b, (N/mm^2)= $\sigma_b = \frac{Mh}{btd^2}$

Bending strength, B (N.mm)= $B = \frac{Wa}{8}$

Bending strength per unit width, (N.mm/mm) = $\frac{W.a}{8.b}$

Shear Strain $\gamma = \left(\frac{Q}{bdG_c}\right)$

where

c = Thickness of the core, mm

b = Width of the panel, mm

t = Thickness of Skin, mm

d = Distance between centroidal axes of two skins, mm

h = Height of the panel, mm

W= Max load in N

δ = Deflection corresponding to maximum load, mm

a = Span of the specimen, mm

Results & Discussion

Table 4: Mechanical Properties Of Sandwich Panel Made By Single Hot Vacuum Bag Technique

Mechanical properties	Span to depth ratios		
	16:1	12:1	6:1
Bending Strength per unit width, (Nmm/mm)	204.9323	181.395	92.4018
Flexural Rigidity per unit width $\times 10^6$, ($N\text{-}mm^2$/mm)	1.154	1.226	1.226
Maximum Bending Stress (N/mm^2)	32.65132	27.64641	14.08297
Bending Stiffness per unit width (N/mm)/mm	39.2698	52.07201	101.8793
Shear Strain at maximum load	0.064541	0.077097	0.07655

Table 5: Mechanical Properties Of Sandwich Panel Made By Modifed Bag Technique

Mechanical properties	Span to depth ratios		
	16:1	12:1	6:1
Bending Strength per unit width (Nmm/mm)	245.163	227.955	227.953
Flexural Rigidity($N\text{-}mm^2$/mm) per unit width$\times 10^6$	2.132	2.739	2.539
Maximum Bending Stress (N/mm^2)	19.864	12.66481	6.47477
Bending Stiffness per unit width(N/mm)/mm	1.51034	1.944	3.889773
Shear Strain at maximum load	0.06896	0.059928	0.078861

Table 6: Mechanical properties of sandwich panel made by multiple bag technique

Mechanical properties	Span to depth ratios		
	16:1	12:1	6:1
Bending Strength per unit width, (Nmm/mm)	295.47	227.9553	110.5864
Flexural Rigidity per unit width$\times 10^6$, ($N\text{-}mm^2$/mm)	2.141	2.686	1.794
Maximum Bending Stress (N/mm^2)	30.56	17.697	13.196
Bending Stiffness per unit width(N/mm)/mm	1.4273	1.948489	3.8523
Shear Strain at maximum load	0.0784	0.06702	0.08545

Table7 : Mechanical properties of sandwich panel made by platen compression technique

Mechanical properties	Span to depth ratios		
	16:1	12:1	6:1
Bending Strength per unit width, (Nmm/mm)	35.558	209.207	78.4598
Flexural Rigidity per unit width$\times 10^6$, ($N\text{-}mm^2$/mm)	0.668	0.924	0.883
Maximum Bending Stress-N/mm^2	8.57005	39.299	15.25249
Bending Stiffness per unit width (N/mm)/mm	1.42299	1.90364	3.80521
Shear Strain at maximum load	0.01245	0.09204	0.06966

Table 8: Comparison of Mechanical Properties with Various Techniques

Mechanical properties	Type of Technique			
	Single Hot Bag	Modified Bag	Multiple Bag	Platen Compression
Bending Strength per unit width, (Nmm/mm)	159.57	233.69	211.3	107.73
Flexural Rigidity per unit width$\times 10^6$, (Nmm^2/mm)	1.202	2.47	2.207	0.825
Maximum Bending Stress(N/mm^2)	24.79	12.99	20.48	21.01
Bending Stiffness per unit width(N/mm)/mm	2.404	2.44	2.403	2.377
Shear Strain at maximum load	0.072	0.0672	0.076	0.0578

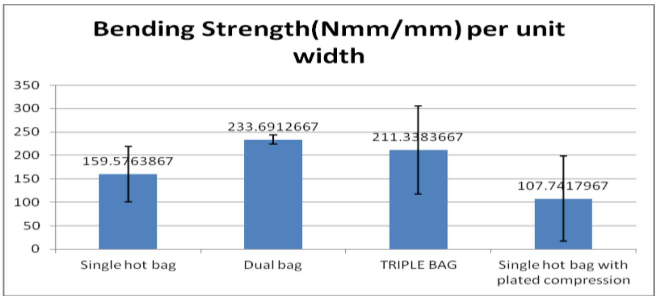

Figure 7: Type of technique Vs Bending strength per unit width

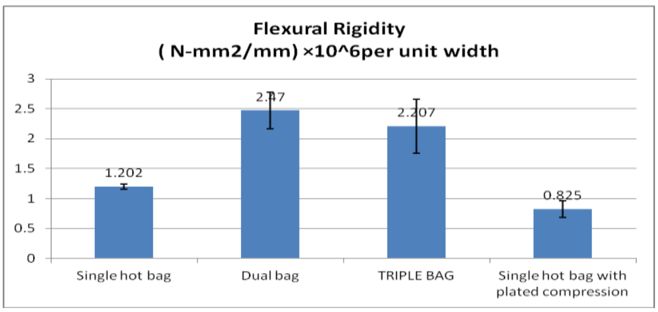

Figure 8: Type of technique Vs Flexural rigidity per unit width (N-mm^2/mm) ×10^6

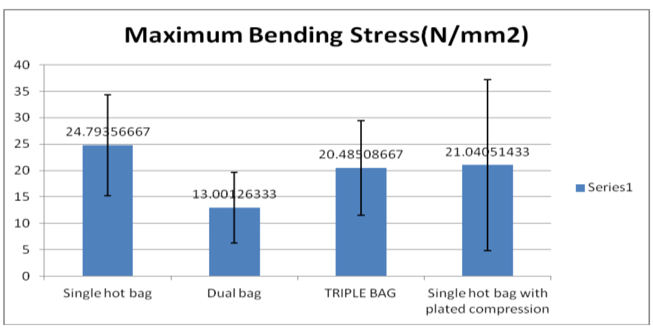

Figure 9: Type of technique Vs Bending stress

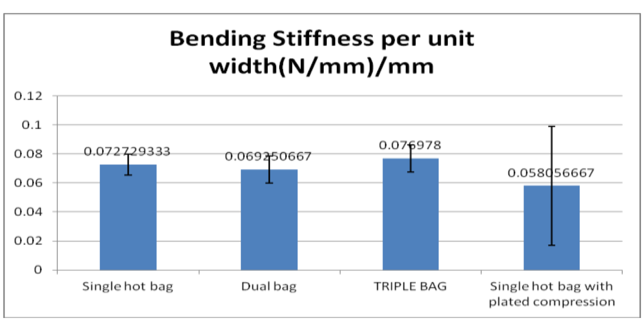

Figure 10: Type of technique Vs Bending Stiffness per unit width (N/mm)/mm

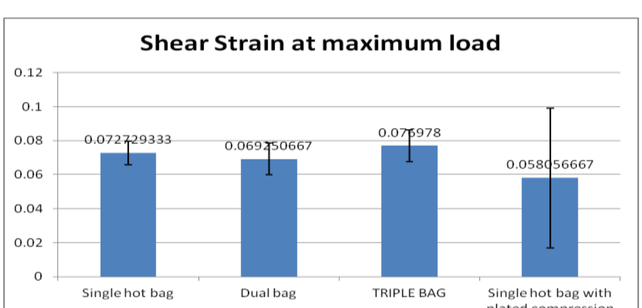

Figure 11: Type of technique Vs Shear strain at max load

Types Of Failure Observed

The specimens tested were observed for the failures and the various failure modes including core shear failure and interface delaminations were observed. The major failure observed was core shear failure leading to interface failure in the longer span specimens.

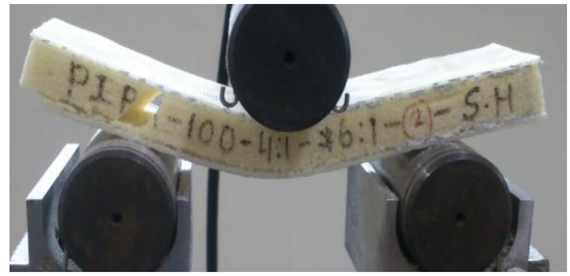

Figure 12: Core crushing failure leading to interface failure.

The above figure shows core shear failures in PIR-100, G/E 4:1weight ratio fabricated by the single hot vacuum bag technique. It has been observed that for all short span specimens, firstly the interface delamination occurs which leads to core failure. Core shear failure also occurred in the short span specimens which lead to an interface failure. This failure occurs mainly due to debonding of the core with the skin.

Figure 13: Core shear failure leading to interface failure

The above figure shows a core shear failure in PIR -100, G/E 4:1 weight ratio fabricated by the single hot vacuum bag with platen compression technique. Initially core shear failure occurs in the specimen that leads to an interface failure between skin and core.

The figure below shows failure of a beam fabricated with the platen compression technique. Initially, the skin and core compression failure occurs in the specimen which leads to an interface delamination. This occurs mainly due to the presence of defects in the compressive side of the panel.

Figure 14: Laminate and core compression failure which leads to interface delamination

Conclusions

Sandwich panels having PIR -100 kg/m^3 as core material and glass fabric (100 and 440 GSM) with epoxy were fabricated with a single hot vacuum bag, modified bag, multiple bag and single hot vacuum bag with platen compression. The sandwich specimens were tested for flexure at various span to depth ratios (16:1,12:1,6:1) using a three point bending test set up in the Instron machine. Sandwich specimens tested from the modified and multiple bag technique panels, show higher bending strength per unit width and, flexural rigidity per unit width, than the other two techniques. Single hot vacuum bag specimens show higher bending stress. More shear strain is observed in the specimens made by the multiple bag technique. The experiments show that the failure of the platen compression technique samples occurs instantaneously compared to other three techniques. Samples fabricated from the multiple bag technique show high bending stiffness per unit width.

In general, the bending stiffness is high for 16:1 span and the shear deflection also is more in 16:1 span to depth ratio samples. Bending stiffness per unit width is high for 16:1 samples. Samples made from the multiple bag technique show higher bending strength per unit width for the 6:1 span samples.

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