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Analysis of Sandwich Composites Using Anova Approach

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Abstract-- ***Sandwich construction finds its widespread application in the field of aerospace and consumer domain. Several types of core materials are used in the manufacture of sandwich composites. This paper provides an overview of the effect of foam core thickness and density of sandwich structure subjected to flatwise and edgewise compression followed by flexural test on PU foam based core material. Further ANOVA approach is used to determine the response surface methodology (RSM) of the specimen tested. Central composite design was adopted to study the RSM. The sandwich structure chosen here is made up of glass epoxy type and different density of 80kg/m^3, 120kg/m^3 and 160kg/m^3 was chosen to study the mechanical properties.***

Keywords: **Sandwich structures, ANOVA, Flat-wise compression, Edgewise compression, Flexural test.**

I. INTRODUCTION

Sandwich composites are widely used in aerospace application because they are light weight and possess high strength to weight ratio. The main advantage of sandwich composite is the ability to provide increased flexural strength without significance increase in weight. With recent advancement in aerospace industry it is important to study mechanical properties characterization of sandwich composites. Recent applications have demonstrated that fiber reinforced sandwich composite can be effectively used in aerospace application and several critical weight applications. A combination of good flexural and compressive strength coupled with low weight is the key factor for aerospace applications which can be easily achieved by using sandwich construction [1].Experimental studies have been carried out to assess the behavior of the sandwich composites when subjected to flat-wise compression, edgewise compression and flexural tests. These studies are useful for phenomenal studies and for analytical comparisons.

Author G. Di Bella studied the effect of manufacturing procedure on unsymmetrical sandwich structure under static load condition and found that samples manufactured using hand layup technique possess lower mechanical properties because of poor adhesion between skin and core whereas samples manufactured using vacuum bagging technique require higher energy values than hand lay up for structural collapse as the air bubbles are removed due to vacuum and resulting product is flawless [2].

Author A.P. Mouritz studied compression, flexure and shears properties of a sandwich composite containing defects and found that I edgewise compression strength decreases rapidly with increase in gauge length. The stiffness and strength of the sandwich composite decrease with increasing impact energy and impact damage are except when the composite is loaded under bending tension [3].

Author Asad Mirzapur, husssain, & mehdi vafayan studied the response of sandwich panels with rigid PU foam cores unserd flexural loading and concluded that the flexural properties of the sandwich structure with a thin layer of the resin on dry faces were even much better than that of the dry faces alone and the specific flexural strength of this sandwich structure increased by 267%. The strength and flexural properties of PU foam alone reduce by increasing the processing temperature from 25^o C to 70^o C [4].

Author Jin Dai, H. Thomas Hahn studied the flexural behavior of sandwich beams fabricated by vacuum assisted resin transfer moulding and found that the core fractured in the thickness direction along the grains and led to face debonding. The normalized shear stress in the core decreased with increase in the span length. The foam core is better in short beams because its high shear strength results in higher load carrying capacity[5].

Response surface methodology

It is a series of mathematical and statistical technique used for modeling and analyzing the problem and has objectives of optimizing the responses [6,7] .it is a sequential experimentation strategy for empirical model building and optimization. By conducting experiments and applying regression analysis, a model of the response to some independent input variables can be obtained. Based on the model of the response to some independent input variables can be obtained. Based on the model of the response, a near optimal point can be deduced. RSM

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is often applied in the characterization and optimization of processes. RSM can determine and represent cause and effect relationships among input control factors that influence the response as a two or three dimension hyper surface. Most of the work in RSM has been focused on the case where there is only one response of interest. In product or process development, however, it is quite common that several response variables are of interest, in this case determination of optimum conditions on the input variables would require simultaneous consideration of all the responses[8]. Hence the present objective of this work is to study the behavior of sandwich composites when subjected to flat wise, edgewise compression and flexural test, by studying the cause effect relationship among the influential factors using RSM. by using regression analysis the response to the variable is obtained and the most significant parameter among the input variables is determined using analysis of variance(ANOVA). The ANOVA is performed to check the requisiteness of the mathematical models.

II. FABRICATION OF COMPOSITE SPECIMEN

Vaccum bag moulding technique is used for the fabrication of glass epoxy sandwich composites. Glass fiber bi-oven cloths of 0.22mm thick are cut to desired size and shape. These cloths are stacked layer by layer for four times to attain a thickness of 1mm. Epoxy resin is used as a bonding agent to bond 8 layers of sheet (top and bottom) in the ratio 10:1 resin 10% : hardner 1%. LY556 resin and HY951 hardner is chosen in the same proportion.

This in turn is bonded with core (PU foam), on both the sides to form sandwich panels. The panels are post cured at 60^{o}C in an oven for 24 hours. The core material chosen has 3 different densities namely 80 kg/m^3, 120kg/m^3 & 160 kg/m^3. Further the core thickness selected were 6mm, 8mm & 10mm. The facings were made of glass fiber.

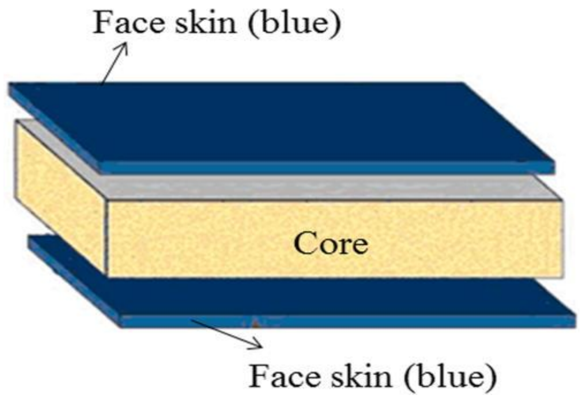

Fig.1: Typical sandwich specimen

III. MECHANICAL TESTS OF SPECIMEN

A. FLATWISE COMPRESSION

The flat-wise compression properties of sandwich composite were measured in conformance with ASTM C365 specifications [9]. The sample cross sectional area for this test is 50 x 50 mm. The specimens were loaded in mecmesin multi-test machine in flat-wise position at a cross head speed of 4mm/min to failure.

B. EDGEWISE COMPRESSION

The edgewise compression properties of sandwich composite was measured in conformance with ASTM C364 specifications [10]. The sample cross sectional area for this test is 50 x 90 mm. The specimen were loaded in mecmesin multi-test machine in edgewise position at a cross head speed of 4mm/min to failure.

C. FLEXURAL TEST

The three point bending test was performed in accordance with ASTM C393 [11]. This provides the properties of sandwich panels subjected to flat-wise flexure. The sample cross section area for this test is 50 x 150 mm. The specimen was loaded in mecmesin multi-test machine between two supports. The span length for the test chosen was 100 mm. and the test was carried out at a cross head speed of 2mm/min.

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IV. ANALYSIS OF VARIANCE (ANOVA)

Design expert 9.0 was used to study the response surface methodology (RSM) using central composite design the experiments were carried out in order to predict the influence of each factor on the response. The variables chosen for this experiment were density and thickness.

Factors	Coding	Factor levels		
		-1	0	+1
Density (kg/m^3)	X1	80	120	160
Thickness (mm)	X2	8	12	16

Table 1. Parameters and their levels

Sl.no	Variables in coded form	
	X1	X2
1	-1	-1
2	+1	-1
3	-1	0
4	0	-1
5	0	0
6	0	0
7	0	0
8	0	0
9	0	+1
10	+1	+1
11	0	0
12	+1	0
13	-1	+1

Table 2.factorial table

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Run	Density (mm)	Thickness (kg/m^3)	Beam deflection(mm)
1	160	12	1.7534
2	120	12	1.6934
3	120	16	1.5691
4	120	12	1.6934
5	120	8	1.8178
6	120	12	1.6934
7	80	16	1.5456
8	80	12	1.6801
9	160	8	1.88
10	160	16	1.6159
11	120	12	1.6934
12	80	8	1.8145
13	120	12	1.6934

Table 3. Analysis of Variance (ANOVA)

Clearly only 13 experiments are required to the entire compression testing parameters using the face centered central composite design. For accurate results each combination of factors was repeated three times.

The competence of the model is checked by ANOVA technique. In this technique if the calculated F ratio value of the developed model does not exceed the standard tabulated value of the F ratio for the desired level of confidence, then the model is said to be competent within the confidence limit. The value of F ratio is important in studying the relative factors effects. If the value of F is high then the effect of that factor is higher compared to error variance. So higher the value of F then more important is that factor in influencing the process response [12].

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Source	Sum of squares	Degree of freedom	Mean square	F value	P valve	Effect
Model	0.11	7	0.016	37398.23	< 0.0001	Significant
A-density	2.542E-003	1	2.542E-003	6017.43	< 0.0001	Significant
B-thickness	0.031	1	0.031	73271.09	< 0.0001	Significant
AB	5.760E-006	1	5.760E-006	13.64	0.0141	Insignificant
A^2	1.277E-003	1	1.277E-003	3023.82	< 0.0001	Significant
B^2	1.971E-006	1	1.971E-006	4.67	0.0832	Insignificant
A^2B	1.044E-004	1	1.044E-004	247.22	< 0.0001	Significant
AB^2	3.853E-006	1	3.853E-006	9.12	0.0294	Insignificant

Table 4. ANOVA for deflection (Before Elimination)

Final Equation in Terms of Actual Factors (without back elimination):

Beam deflection = +2.44148-6.78953E-003*Density-0.058295*Thickness+4.03125E-004* Density*Thickness+3.00345E-005*Density^2+2.65948E-004*Thickness^2-1.38281E-006* Density^2 * Thickness-2.65625E-006* Density * Thickness^2.

Further it is found that B^2 & AB^2, were found to be insignificant hence backward elimination is carried out to make the ANOVA model significant

Source	Sum of squares	Degree of freedom	Mean square	F value	P valve	Effect
Model	0.11	5	0.022	19505.37	< 0.0001	Significant
A-density	7.148E-003	1	7.148E-003	6304.76	< 0.0001	Significant
B-thickness	0.031	1	0.031	27297.99	< 0.0001	Significant
AB	5.760E-006	1	5.760E-006	5.08	0.0589	Significant
A^2	1.450E-003	1	1.450E-003	1278.66	< 0.0001	Significant
A^2B	1.044E-004	1	1.044E-004	92.11	< 0.0001	Significant

Table 5.ANOVA for Deflection (with back elimination)

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Final Equation in Terms of Actual Factors (with back elimination):

Beam deflection = +2.40345-6.38708E-003* Density-0.051913* Thickness+3.39375E-004 Density*Thickness+2.98333E-005* Density^2-1.38281E-006* Density^2 * Thickness.

Fig 2 shows the behavior of density and core thickness on beam deflection of the sandwich composite. It was found that with increase in thickness of the sandwich specimen the beam deflection reduced to a greater extent. It was found that the beam deflection reduced by 14% when the thickness increased from 8mm to 16mm, for a density of 80 kg/m^3. However with change in density the beam deflection reduced by 3.42%.

From the Fig 3 shows the beam deflection value lies within 1.6mm when the thickness is between 12mm to 16mm and the density ranges from 100 kg/m^3 to 140 kg/m^3. Also the beam deflection appears to rise to 1.8mm when the thickness ranges from 8mm to 11mm and the density ranges from 100kg/m^3 to 160 kg/m^3.

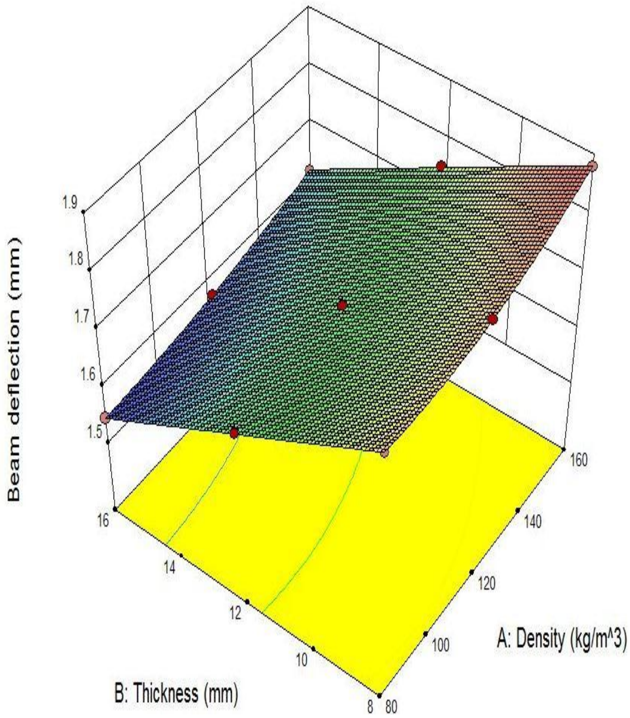

Fig 2. RSM graph shoes effect of density and thickness on beam deflection

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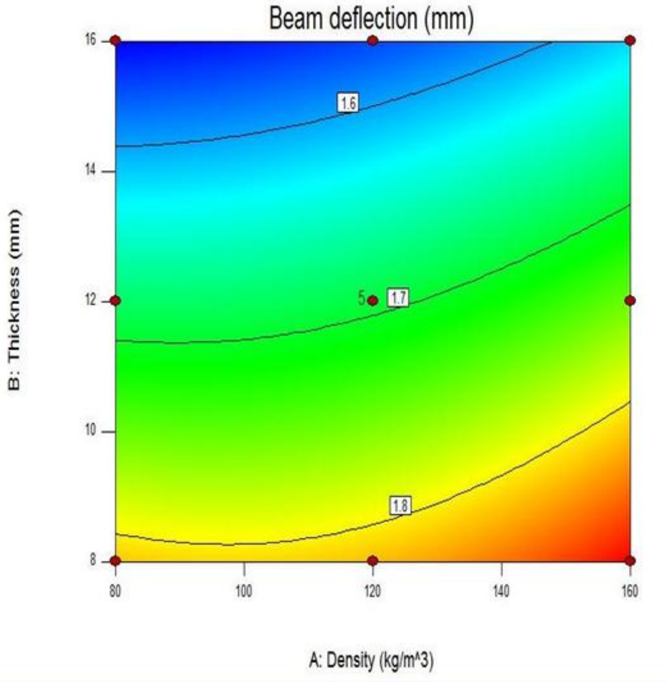

Fig 3. Contour graph shows effect of density and thickness on beam deflection

V. CONCLUSION

The empirical modeling with the help of response surface methodology on the analysis of factors influencing the beam deflection on sandwich panels subjected to flexural test indicated that.

1. With increase in thickness there was a gradual decrease in beam deflection for a range of samples tested.

2. The beam deflection steadily increased with increase in density.

3. The deflection decreased by 14% when the thickness of the sandwich panel increased from 8mm to 16mm.

4. Similar studies were carried out on flat-wise and edgewise compression test for glass and carbon based sandwich structure.

VI. FUTURE ENHANCEMENT

The present study focuses mainly on glass and carbon based sandwich composites. But there is a scope for analyzing these results with a glass carbon based hybrid composites along with tensile test to analyze the laminate strength.

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