AERO2015P544

The 14th International Conference of Iranian Aerospace Society
Communication and Space Technology, Iranian Research Organization for Science and Technology, Tehran, 3th to 5th of March, 2015.

The 14th International Conference of Iranian Aerospace Society

Flexural Behavior of Stiffened Foam Core Sandwich Panel with One Layer and Different Shape for Stiffener

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Abstract

In this research the study of a new type sandwich panel with glass/epoxy skins and corrugated composite-foam core under transverse loading are considered. Sandwich panels are a type of composites that consist of two outer strong and thin skins and a light and thick core located in between the skins that provide good advantages like high strength/stiffness to weight or mass ratio. Corrugated composite laminate was built using the hand layup method and the experimental technique, VARTM (Vacuum Assisted Resin Transfer Molding) was used to join the skins to the core with higher quality. Single-point bending test load was applied to the samples according to ASTM standard. Finite element analysis was applied for determining maximum deflections of samples, as a second method. Two types of core are considered. First is a simple foam core but in second a corrugated composite laminate with three different shape consist of rectangular, triangular and trapezoidal with one layer for thickness and 2 centimeter for wavelength is improvised. It has been shown that the flexural stiffness of second type sandwich panel was improved with changing the geometric shape of corrugated composite in from triangular to rectangular and trapezoidal. The flexural stiffness to mass ratio was improved respect to sample with simple foam core by adding one layer woven glass-epoxy corrugated composite with three geometric shape to PVC foam core too. Finally the experimental and finite element results were compared. Also the numerical results show a good agreement with experimental results.

Keywords: *Sandwich panel- Stiffened core - Flexural stiffness- Composite skins*

Introduction

Sandwich panels are type composites that consist of two outer skins and a core located between them. The core is made of lightweight materials that provide good shear strength. Composite materials have been utilized in variety of engineering field such as marine, aerospace and automotive industries [1-3].

The idea use of sandwich structures was issued by Stephenson brothers for the first time in 1830. Sandwich structures are different due to their core or skins material and also due to the kind of joint between core and skins. Also corrugated composite are not new idea to the engineering and they have been used over many years in naval, civil, automotive and aerospace applications due to their efficient performance for example low mass to stiffness ratio (in the transverse direction of corrugations), increasing the adaptability of the vehicle to enable optimized performance [4,5].

Rahimi and Rahmani have investigated the effect of wavelength changing of corrugated composite laminate with trapezoidal shape in PVC foam core in flexural behavior of sandwich panels with composite skins experimentally and numerically. They compared this samples with sample with simple PVC foam core. The result showed that the flexural stiffness has increased with decreasing in wavelength; but the flexural stiffness to mass ratio first has increased and then decreased with decreasing in wavelength [6]. Mohammadi and associates have found that the critical compressive axial load and the critical compressive axial load to mass ratio of sandwich beam with trapezoidal corrugated composite laminate in PVC foam core respectively have increased almost 4 and 2 times respect to a sandwich panel with the same skins but only a simple PVC foam core [7].

But we can improvise a corrugated composite laminate in a foam core of a sandwich structure and design a new sandwich structure with improved properties such as higher flexural stiffness to weight ratio. In this research the geometric shape effect of corrugated composite with one layer on flexural stiffness and flexural stiffness to mass ratio of corrugated composite-foam core sandwich panel has been investigated and compared with a simple foam core sandwich panel.

Expriment

We used woven E-glass with surface density 185 gr/m2 and epoxy resin SR1700 with density 1.157 gr/cm3 and viscosity 1700 MPa.s at 20 degree of Celsius and SD2705 hardener with density 1.04 gr/cm3 and viscosity 245 MPa.s at 20 degree of Celsius from Sicomin for skins and corrugated composite laminate. Also we used PVC foam with 1 cm thickness for core. Properties of foam are shown in Table 1.

Table 1: PVC foam properties [8]

PVC	*E(MPa)*	*G(MPa)*	*ν*	*ρ (kg/m³)*
C7075	66	30	0.3	80

For determination tensile modulus of elasticity of glass/epoxy skins in order to use in finite element

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analysis a tensile test according to ASTM –D3039M-00 carried out on five same samples with dimensions 25 cm * 2.5 cm * 2.5 mm and average data have been used for determination tensile modulus of elasticity. These five samples for tensile test were product with VARTM technique. The properties of glass-epoxy that have been used in samples are shown in Table 2.

Table 2: Wove glass-epoxy properties [9]

E_1=E_2(Gpa)	G_{12}=G_{23}(Mpa)	G_{13}(Mpa)	v	$\rho(kg/m^3)$
10.58	4.14	1.1	0.05	1785

For samples production we cut 3 layers of glass woven for each skin of each sample and also cut PVC foam for core of each samples in standard size. According to ASTM-C393 we choose dimensions of samples in 31 cm * 6 cm * 1.1 cm. For improvising corrugated composite laminate in PVC foam core; first we cut slices of foam in rectangular, triangular and trapezoidal shape with 2 centimeter for wavelength and 1 layer of glass woven that wetted with epoxy resin earlier, in it. The mixing ratio of SR1700 epoxy resin and SD2705 hardener by weight is 100 to 22 respectively. The schematic of simple core sample and a combinatorial core with triangular shape and their cross section are depicted in Fig. 1. The parameters that are shown in fig. 1 have been chosen as below;

$L: length = 31 \quad cm$

$b: width = 6 \quad cm$

$d: total \quad thickness = 1.21 \quad cm$

$t_c: core \quad thickness = 1 \quad cm$

$t_s: skin \quad thickness = 0.09 \quad cm$

$t^*: corrugate \quad thickness = 0.03 \quad cm$

$\lambda: corrugate \quad wavelength = 2 \quad cm$

Then with use of VARTM technique the four case samples with two type of core have been product. Which the first has a simple core and the second has a corrugated composite layer with three different geometric shape in core; with 2 centimeter for wavelength of corrugated composite; as shown in Fig. 2(only the triangular shape is shown in this figure). Again according to this standard we product three samples in each type and average data have been used. For testing according to standard of ASTM-C393 single-point loading was applied to the samples under displacement control at rate of 0.5 millimeter per minute. The distance between two supports was 25 centimeter and diameter of load and supports pins were 10 millimeter. The experimental data were transmitted to the computer by the internal displacement and force sensors of the INSTRON 5500R machine as shown in Fig. 3.

Then the load-displacement curves have been obtained. Also for tensile test the INSTRON 5500R with frame 6027 under displacement control at rate of 2 millimeter per minute according to ASTM-D3039M-00 was used. Tensile test product samples and tensile test of sample number 3 are shown in Fig. 4.

Numerical

For numerical analysis in this study we have used ABAQUS 6.10 commercial software. We have modeled half of samples; because of their symmetrical geometry, loading and boundary conditions. We created three parts for sample with simple core which consist of two 3D deformable shells for two skins of sample; and one 3D deformable solid for core. But for sample with corrugated composite-foam core; we should create another part for corrugated laminate with rectangular, triangular and trapezoidal shape. The shell parts consist of composite layup with woven glass-epoxy composite property and 0.3 mm thickness for each layer; also the corrugated shell wavelengths is 2 centimeter. We used standard shell elements S8R with quadratic geometric order for shell parts; because thickness to width ratio of composites that have been used in samples is less than 0.05. Also we used standard 3D stress elements C3D8R with linear geometric order for solid parts. We defined a slender and thin surface with a set of shell elements with 0.5 millimeter for width and 6 centimeter for length in upper skin for applied load modeling and applied a uniform distributed pressure in a general and static step equal the appropriate load at that surface. Boundary condition at one end of model so that the displacement at that end in load direction and in width direction should be zero.

The finite element model of triangle shape corrugated laminate with upper and lower skins is shown in Fig. 5. Also in this figure it is obvious that elements were condensed adjacent the load zone because of stress concentration and maximum stress and deflection occur in this zone.

Results and Discussion

The load-displacement relations among the results have been chosen. The samples have been labeled for better management of data and result as SS for simple core sample and A, B, C for samples with combinatorial core with rectangular, triangular and trapezoidal shape for corrugated composite layer, respectively. These relations for every three samples with same core are shown in Fig. 6 for sandwich sample with simple core and in Fig. 7, 8 and 9 for corrugated composite-foam core sandwich samples with rectangular, triangular and trapezoidal geometry shape for corrugated composite layer in foam core respectively.

As shown in these figures every three sample that have same core; have similar behavior under transverse loading. In simple core samples the load-displacement curve grows up in an elastic manner until failure of upper skin. Then after failure in upper skin; simple core samples can't carry load more. The second type sandwich samples with corrugated composite-foam core have an elastic zone until failure in upper skin due to comparison stresses too. But second type samples with corrugated composite-foam core after first failure in upper skin; carry some load because of corrugated composite in foam core. This ability will improve with changing of corrugated composite shape from rectangular to triangular and trapezoidal; respectively. The result like maximum load and deflection relative with it; of each three samples are shown for simple core samples in table 3 and for corrugated composite-foam core samples with rectangular, triangular and trapezoidal shape in table 4, 5 and 6 respectively.

Table 3: flexural test result of SS samples

	P_m	δ_m *(mm)*	*M* *(gr)*	*D* $(N*m^2)$	*D/M* $(N*m^2/gr)$
SS1	635.4	9.16	61	22.58	0.3701
SS2	564.94	8.74	60	21.04	0.3506
SS3	539.4	6.08	62	29.4	0.4741
average	579.9	7.99	61	24.34	0.3982
standard deviation	49.71	1.67	1	4.44	0.0663

Table 4: flexural test result of A samples

	P_m	δ_m *(mm)*	*M* *(gr)*	*D* $(N*m^2)$	*D/M* $(N*m^2/gr)$
A1	1077.24	9.41	88	39.78	0.4520
A2	1235.55	9.82	92	39.62	0.4306
A3	1080.7	10.66	87	35.89	0.4125
average	1131.16	9.96	89	38.43	0.4317
standard deviation	90.41	0.637	2.64	2.2	0.01977

Table 5: flexural test result of B samples

	P_m	δ_m *(mm)*	*M* *(gr)*	*D* $(N*m^2)$	*D/M* $(N*m^2/gr)$
B1	1214.1	11.41	85	38.103	0.4482
B2	1270.77	11.91	84	38.182	0.4545
B3	1319.59	13.16	87	33.91	0.3897
average	1268.15	12.16	85.33	36.73	0.4308
standard deviation	52.79	0.901	1.52	2.44	0.03573

Table 6: flexural test result of C samples

	P_m	δ_m *(mm)*	*M* *(gr)*	*D* $(N*m^2)$	*D/M* $(N*m^2/gr)$
C1	1627.7	12.66	85	45.59	0.5363
C2	1489.2	12	85	43.49	0.5116
C3	1424.55	11.58	83	42.95	0.5174
average	1513.81	12.08	84.33	44.01	0.5217
standard deviation	103.78	0.544	1.15	1.39	0.01291

Maximum stresses in sandwich structures occur in skins that are tensile in upper skin and compression in lower skin. Composites in compression are more weak than in tensile. In other words strength of composites in tensile is greater than their strength in compression typically. Thus all samples fail in upper skin due to compression at first; as shown in Fig. 10. Samples with trapezoidal and triangular shape for corrugated composite in foam core have maximum and minimum increasing in flexural stiffness among all samples with corrugated composite-foam core respect to samples with simple core respectively. These increasing are 80.81% and 50.9% respectively. Moreover the flexural stiffness to mass ratio of corrugated composite-foam core samples has been improved in all cases. Again samples C and B have maximum and minimum increasing in flexural stiffness to mass ratio respect to samples with simple core respectively. These increasing are 31.01% and 8.18% respectively.

According to ASTM-C393 standard in long samples bending effect is very greater than shear effect. So in absence of shear effect; the flexural stiffness of samples has been calculated; experimentally & numerically as shown in Eq. (1) and has been compared with each other as shown in table 7. D, E, P, δ, I and L are flexural stiffness, tensile modulus of elasticity, load, deflection, first momentum of inertia and length of samples respectively. Also the flexural to mass ratio of samples has been calculated experimentally and numerically and then has been compared with each other in table 8.

$$D = EI = \frac{PL^3}{48\delta} \tag{1}$$

Table 7: comparison of flexural stiffness of samples

	D $(N*m^2)$ *experimental*	*Increase of D (%) experimental*	*D* $(N*m^2)$ *numerical*	*Increase of D (%) numerical*
SS	24.34	-	23.91	-
A	38.43	55.78	41.07	61.82
B	36.73	50.9	37.15	46.37
C	44.01	80.81	41.23	62.45

Table 8: comparison of flexural stiffness to mass ratio of samples

	D/mass $(N*m^2/gr)$ *experimental*	*Increase of D/mass (%) experimental*	*D/mass* $(N*m^2/gr)$ *numerical*	*Increase of D/mass (%) numerical*
SS	0.3982	-	0.4147	-
A	0.4317	8.41	0.4688	13.04
B	0.4308	8.18	0.4519	8.97
C	0.5217	31.01	0.4908	28.35

The comparison between load-displacement curves of samples has been shown in Fig. 11. As it is clear the slope of all curves of all samples with corrugated composite-foam core with three different geometry improved with respect to simple core samples.

Conclusion

As visible in fig. 11 simple sample has almost 5 mm deflection with 500 N transverse loading while the corrugated composite-foam core sample with rectangular, triangular and trapezoidal shape for corrugated composite layer has almost 11, 13 and 12 mm deflection with 1100, 1300 and 1600 N transverse loading respectively. This means that the corrugated – foam core sample with rectangular, triangular and trapezoidal shape for corrugated composite layer is stiffener 2, 2 and 3 times more than simple sample in transverse loading respectively. The flexural to mass ratio of samples with a corrugated composite-foam core with three geometric shape for corrugate have been improved in all cases with respect to a sample with simple PVC foam core. Also as have been shown in table.7 and table.8 the numerical results show a good agreement with experimental results and this means that software can predict the structural flexural behavior almost well.

Figures and Drawings

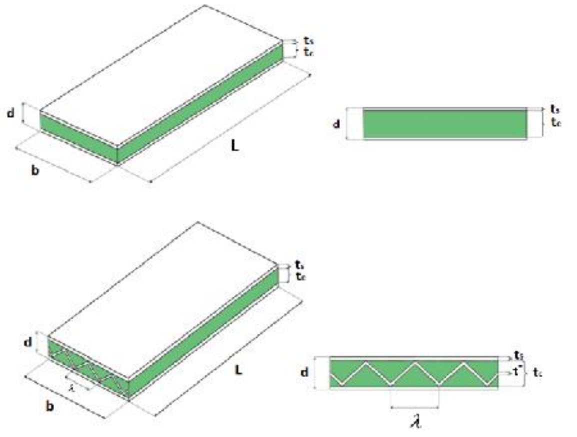

Fig. 1: Schematic of two type samples and their cross section

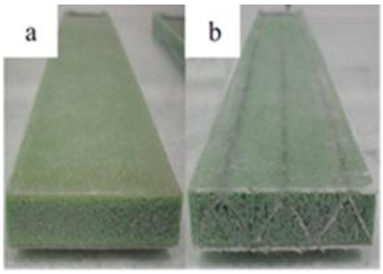

Fig. 2: Samples with (a) simple core, (b) corrugated-foam core

Fig. 3: Single-point bending test with INSTRON 5500R

Fig. 4: Tensile test samples and tensile test of sample 3#

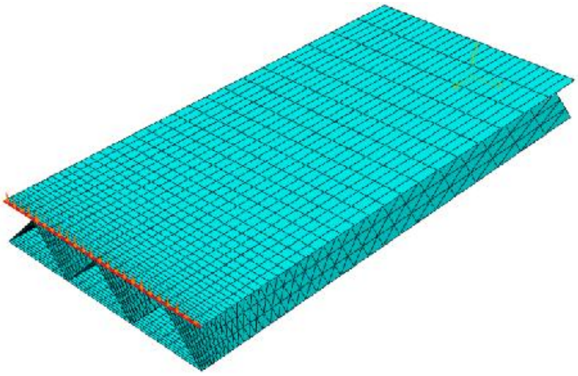

Fig. 5: Finite element model of triangle shape corrugated laminate with skins

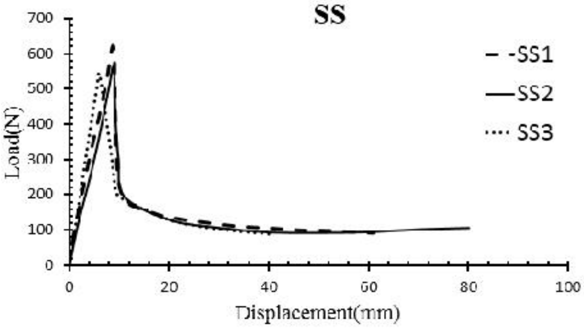

Fig. 6: Load-displacement curve of SS samples

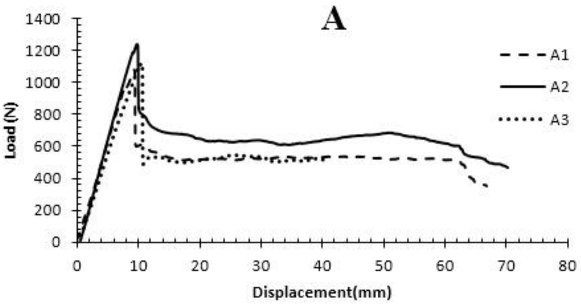

Fig. 7: Load-displacement curve of A samples

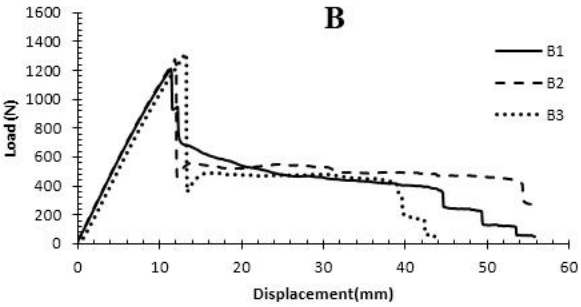

Fig. 8: Load-displacement curve of B samples

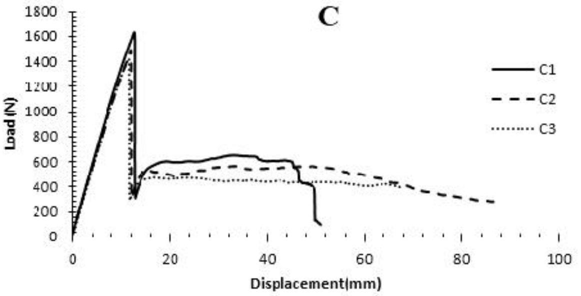

Fig. 9: Load-displacement curve of C samples

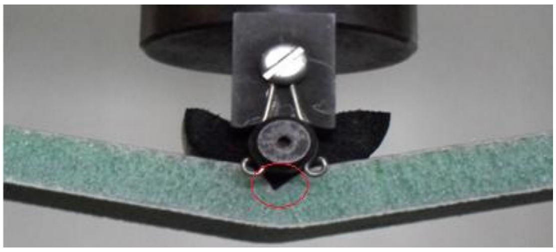

Fig. 10: Failure in upper skin of SS sample

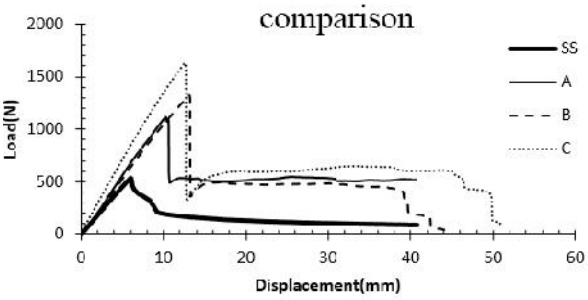

Fig. 11: Comparison in load-displacement curves for samples

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