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Analysis and investigation of honeycomb sandwich panel parameters under Static three-point bending

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ABSTRACT

Investigation of the sandwich structures under bending has an important role to understanding the composite structures stability. Bending behavior of sandwich structures has a wide range of applications in science, engineering and technology. In this study the effects of core shape, cell wall height, wall thickness and skin thickness on critical bending load of honeycomb sandwich panels have been investigated. The other parameters of sandwich panel supposed constant during all analyses. The finite element simulation has been carried out with using of ABAQUS software and results were compared with experimental results. After that design of experiment based on Taguchi method has been carried out for understanding the effect of investigated parameters on maximizing the critical bending load. Eventually, the effect of parameters has been investigated with using of ANOVA.

Introduction

The idea of honeycomb structures Inspired from the nest of bees in the nature and more than 500 types of these structures were built heretofore. Paper honeycomb structure was built 2000 years ago by the Chinese who originated the paper honeycomb structure [1]. The first paper honeycomb structure has been used for packing [1, 2&3].

After that honeycomb structures were built in the shape of a tube which has been used in the horizontal beams of railway. Unique features of honeycomb sandwich structures are high Bending strength and light weight which causes a great demand about these structures. Nowadays, honeycomb sandwich structures have a wide range of applications in many industries such as aerospace industry, shipbuilding, boat building, military and automotive. [1]

Honeycomb sandwich structure has been studied under static three-point bending and impact with different cell sizes by Crupi [4] and maximum force and energy of structure were acquired and the effect of support on force and energy were investigated. Li et al [5] investigated a sandwich panel with pyramidal core and shells made of composite orthotropic materials (carbon fiber) using a theory method and the results were compared with practical results and the compatibility of two method were approved. Other researchers did not consider the effect of honeycomb core shape on stress field in their analysis. Thomsen et al [6] implemented the High-order theory for analyzing sandwich panels. Riber [7] implemented non linear stress analysis of a sandwich panel that subjected to a lateral load. Gaudenzi et al [8] used numerical methods and practical experiments to analyze stress in the sandwich panel cores which made of fiberglass. Lestari et al [9] conducted experiments on sandwich structures with honeycomb core and shells made of FRT and investigated the failure rate on sandwich structures. Kumar et al [10] performed a four-point bending tests on sandwich beam with a core made of compressed cork and skins made of carbon epoxy composite materials and investigated the effect of angle of the carbon fibers (in sandwich beam shells) on the mechanical behavior of the sandwich structure. Mott et al [11] investigated the buckling of a sandwich plate with a rubber core and shells made of fiberglass under hydrostatic pressure, using the finite element method and results of these analyses were compared with the results of practical experiments on two beam sandwich panel with two kinds of rubber core samples.

In this paper the effects of core shape, cell wall height, wall thickness and skin thickness on critical bending load of honeycomb sandwich panels have been investigated. Shape of the core is considered to include circular, hexagonal and square. These shapes are the three most commonly used shape in industry.

Finite element simulation

The finite element model has been performed to analyze the sandwich panel under Static three-point bending and simulation was implemented in ABAQUS/Explicit. Static three-point bending test were carried out on honeycomb Panels (150 ×50×11 mm). In the static three-point bending the structure was held through two supports and then in the longitudinal direction.

The support span distance was 80mm and the distance of each support span from border was 40mm. The honeycomb consists of hexagonal cells with diameter of 6 mm and thickness of 0.06 mm. The skin thickness was 1 mm. Main parameters of the honeycomb sandwich panel, as shown in figure 1.

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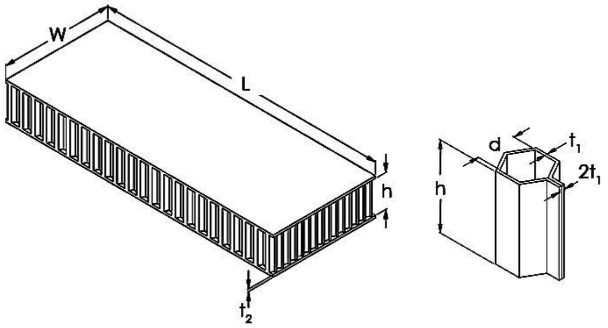

Fig. 1. Main parameters of honeycomb sandwich panel.

Only a quarter of the panel was modeled due to the symmetry of the problem (Fig 2).

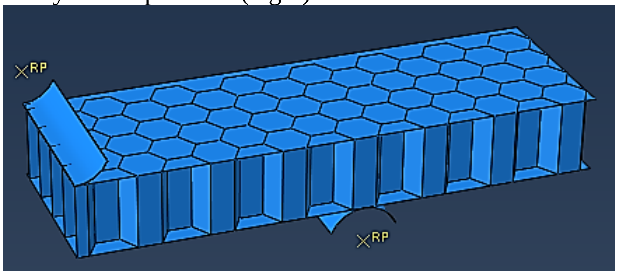

Fig. 2. Defined honeycomb sandwich panel in ABAQUS software

The sandwich plate consisted of two materials. The honeycomb core was made of AA5052 aluminum alloy and the two skins are realized by AA5754 H32 aluminum alloy. Material properties of these alloys were shown in table1.

Table1. Material properties of applied aluminum alloys [12].

Material	AL5750 H32	AL5052 H24
Density(Kg/m^3)	2670	2680
Yield strength(Mpa)	245	195
Ultimate strength(Mpa)	290	230
Poisson's ratio	0.33	0.33
Shear strength(Mpa)	140	115
Young's modulus(GPa)	70	70

The elastic-plastic behavior considered for material definition. The orthotropic elastic-plastic properties were not considered. The isotropic plasticity was selected and in this case the results always were satisfying. The tool and supporters considered as rigid bodies. The supporters were fixed in all directions. The tool can be moved only in one direction. The tool displacement set as 10 millimeters.

Successive mesh sensitivity test were carried out to evaluate the optimized mesh size. Finally, the selected mesh had 9531 4-node shell elements with reduced integration (S4R in ABAQUS): 3294 in the skins and 6237 in the honeycomb core. Stress distribution contour of this simulation was shown in Figure 3.

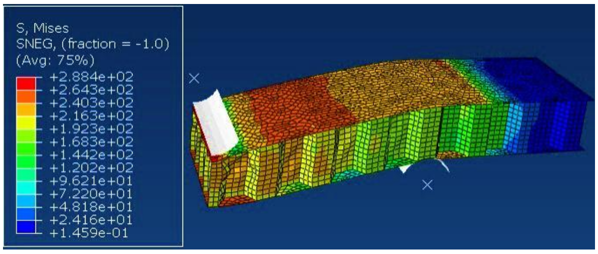

Fig. 3. Stress distribution contour of simulated honeycomb sandwich panel under Static three-point bending.

The numerical results were compared with the experimental Data [4] to validate the finite element simulation. The variable selected to validate the numerical model was the critical bending load.

Force-Displacement graph for both numerical simulation and experimental investigation [4] was shown in the figure 4. Numerical results were close to the experimental ones so that the precision of the model in the prediction of critical bending load was satisfying.

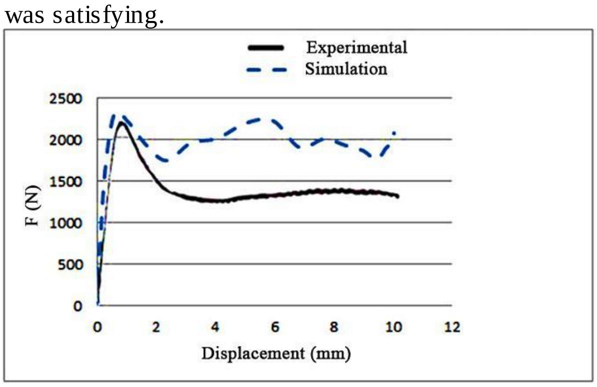

Fig. 4. The Force-Displacement graph for both numerical simulation and experimental investigation [4]

Critical bending load for both numerical and experimental investigation [4] was compared and the error was shown in the table 2.

Table 2. Comparing experimental [4] and simulation results

Error	Critical Bending Load(FEM)	Critical Bending Load(Experimental)
3.7%	2302 N	2230 N

Design of experiments

Design of experiment (DOE) is one of the most useful tools for modeling and analyzing the influence of process parameters. Performing this method, the influence of all parameters in the process can optimally understood. [13]

The Qualitek-4 software has been used for design of experiment based on Taguchi method and the analysis of variance (ANOVA).

Optimization based on Taguchi approach has been used to achieve more efficiency honeycomb sandwich panel parameters. All parameters such as material definition, support span distance, dimensions of honeycomb panels and cell diameter were supposed constant and the effects of core shape, cell wall height, wall thickness and skin thickness were investigated. As was shown in the table3, for three of these parameters 4 levels of variations have been set and for the other one considered 3 levels of variations.

Table 3. Levels of independent sandwich panel parameters according to Taguchi approach.

parameters	Level 1	Level 2	Level 3	Level 4
Cell wall height	8mm	9mm	10mm	11mm
Wall thickness	0.04mm	0.06mm	0.8mm	0.1mm
Skin thickness	0.5mm	1mm	1.5mm	2mm
Core shape	Square	Hexagonal	Circular	

Clearly obvious from Table 3 that the appropriate Taguchi orthogonal array with notation L_{16} must be chosen. Sixteen experiments performed with using of numerical simulation and results are reported in table 4.

Results and discussion

The ANOVA has been carried out and obtained from results that the maximum influence percent on the critical bending load belonged to skin thickness.

The influence percent of cell wall height, wall thickness, skin thickness, core shape on the critical bending load reported as 2.97, 17.85, 50.55 and 13.69 respectively. The error reported about 15 percent and can be considered in an appropriate range. The obtained ANOVA results were reported in Table 5.

The optimum condition for gaining the maximum critical bending load has been calculated and was reported in the table 6.

Using MINITAB software, mean effect plot and contour plot of critical bending load versus investigated parameters were generated.

The mean effect plot for critical bending load was shown in figure 5.The cell wall height effect on the critical bending load was large – While increasing cell wall height, the critical bending load will increase and there is a striking point in critical bending load between 10 mm and 11 mm.

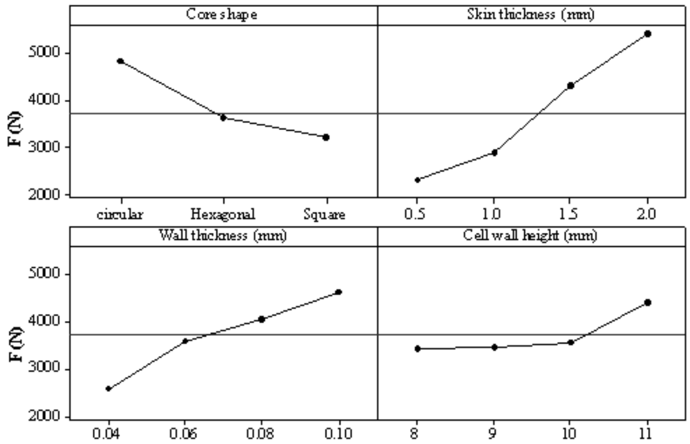

Fig. 5. The mean effects plot for critical bending load (F)

Similarly with increasing wall thickness and skin thickness the critical bending load was increased. As was obtained from mean effects plot, the best core shape for maximizing the critical bending load was circular.

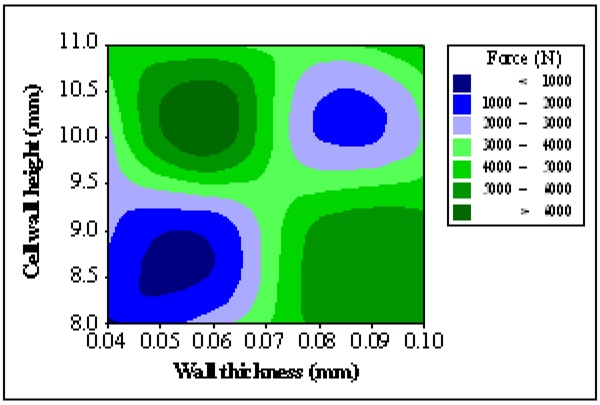

Fig. 6. Contour plot of critical bending load (F) versus cell wall height, wall thickness

As it is obtained from contour plot of critical bending load versus cell wall height and skin thickness, the maximum force occurred when cell wall height was between 8 to 9.2 and 9.8 to 10.5 and respectively for wall thickness this range was between 0.078 to 9.2mm and 0.05 to 0.065.

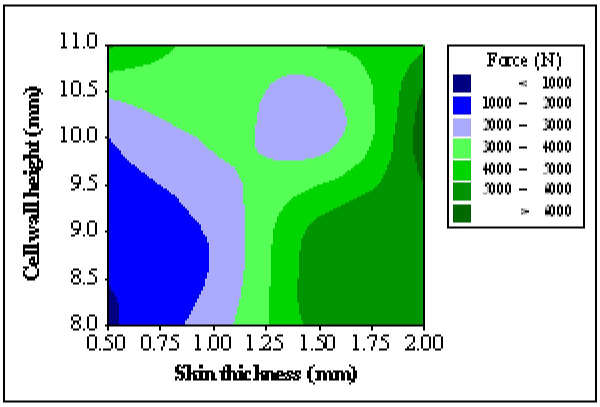

Fig. 7. Contour plot of critical bending load (F) versus cell wall height, skin thickness.

As shown in the contour plot of critical bending load versus cell wall height and skin thickness the maximum force occurred when the cell wall height was between 9.5 and 10.6 and the skin thickness was at its maximum value.

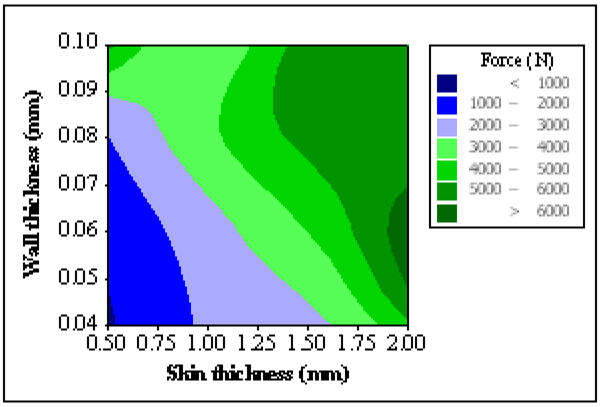

Fig. 8. Contour plot of critical bending load (F) versus wall thickness, skin thickness

As it is obtained from the contour plot of critical bending load versus wall thickness and skin thickness the maximum force occurred when the wall thickness was between 0.05 and 0.07 and the skin thickness was at its maximum value.

Conclusion

In this study the effects of core shape, cell wall height, wall thickness and skin thickness on critical bending load of honeycomb sandwich panels have been investigated. Using of Experiment design based on Taguchi method, sixteen experiments designed and were simulated in the ABAQUS software. Qualitek-4 software has been used for calculating DOE and ANOVA results. As it is obtained from results the critical bending load raised with increasing the cell wall height, wall thickness and skin thickness. The ANOVA has been carried out and the results were shown that the influence percent of skin thickness on the critical bending load was about 50. The influence of wall thickness and core shape reported as 17.85 and 14.92 respectively. The effect of cell wall height in comparison with other parameters was negligible and its influence percent reported about 3. Three type of core shape have been investigated and acquired that the circular shape was the best core shape for increasing the critical bending load. The optimum condition for maximum critical bending load was acquired and in this state the cell wall height, wall thickness, skin thickness and core shape considered as 11, 0.1,2 and circular respectively.

Table 4. Four-level orthogonal array, L_{16} with simulation results

	Cell wall height(mm)	Wall thickness(mm)	Skin thickness(mm)	Core shape	Force(FEM)(N)
T-1	8	0.04	0.5	Square	869.35
T-2	8	0.06	1	Hexagonal	2557.21
T-3	8	0.08	1.5	Circular	5297.51
T-4	8	0.1	2	Square	4995.98
T-5	9	0.04	1	Circular	2153.40
T-6	9	0.06	0.5	Square	1226.23
T-7	9	0.08	2	Square	5249.52
T-8	9	0.1	1.5	Hexagonal	5284.40
T-9	10	0.04	1.5	Square	2640.84
T-10	10	0.06	2	Circular	6612.80
T-11	10	0.08	0.5	Hexagonal	1954.97
T-12	10	0.1	1	Square	3112.01
T-13	11	0.04	2	Hexagonal	4723.83
T-14	11	0.06	1.5	Square	3988.59
T-15	11	0.08	1	Square	3739.88
T-16	11	0.1	0.5	Circular	5213.16

Table 5. The analysis of variance (ANOVA) for the modified linear model, critical bending load versus cell wall height, wall thickness, skin thickness and core shape

	DOF	Sum of Sqrs	Variance	F-Ratio	Pure Sum	Influence Percent
Cell wall height	3	2587195.904	862398.634	1.997	1292180.747	2.978
Wall thickness	3	9040107.854	3013369.284	6.98	7745092.697	17.853
Skin thickness	3	23224943.066	7741647.688	17.934	21929927.91	50.55
Core shape	2	6802894.407	3401447.203	7.879	5939550.97	13.691
Error	4	1726686.875	431671.718			14.928
Total	15	43381828.109				100%

Table 6. The optimum condition for maximizing the critical bending load

parameters	Level description	Level	Contribution
Cell wall height	11mm	4	690.135
Wall thickness	0.1mm	4	925.157
Skin thickness	2mm	4	1669.302
Core shape	Circle	3	1092.987
Total contribution from all factors			4377.581
Current grand averageof performance			3726.23
Expected result at optimum condition			8103.811

References

[1]. Bitzer T, Honeycomb Technology, Materials, Design, Manufacturing, Application and Testing, Chapman and Hall, New York, 1997, 1-199.

[2]. Gibson L.J. and Ashby M.F., Cellular Solids: Structure and Properties, 2nd ed., Cambridge University, UK, 1997, 1-173.

[3]. The Handbook of Sandwich Construction, Zenkert D. (Ed.), Engineering Materials Advisory Services, UK, 1997, 1-44.

[4]. Crupi. V, Epasto. G, Guglielmino. E. "Collapse modes in aluminium honeycomb sandwich panels under bending and impact loading". International Journal of Impact Engineering 43 (2012) 6e15. 2012.

[5]. Ming Li, Linzhi Wu, Li Ma, JianXiong, Zhengxi Guan. "Torsion of carbon fiber composite pyramidal core sandwich plates", Composite Structures 93, 2004 pp. 2358-2367.

[6]. Ole Thybo Thomsen. "High-order theory for the analysis of multi-layer plate assemblies and its application for the analysis of sandwich panels with terminating plies", Composite Structures 50, 2000, pp. 227-238.

[7]. Hans JmgenRiber. "Non-linear analytical solutions for laterally loaded sandwich plates", Composite Stmctures, Vol. 39, 1997, No. 1-2 ,pp, 63-83.

[8]. Gaudenzi. P, Pascucci. A, Barboni. R. "Analysis of a glass-fiber sandwich panel for car body constructions", Composite Structures, Vol. 38, 1997, No, 1-4, pp, 421-433.

[9]. Wahyu Lestari, Pizhong Qiao. "Damage detection of fiber-reinforced polymer honeycomb sandwich beams", Composite Structures 67 , 2005, pp, 365-373.

[10]. Sathis Kumar. S, Milwich. M, Deopura. B.L, Plank. H. "Finite element analysis of Carbon composite sandwich material with agglomerated Cork core", Procedia Engineering 10, 2011, pp. 478-483.

[11]. Peter H.Mott, Jodi M.Smallhorn, Ken W.Campbell, Howard L.Schrader, Craig L.Cartwright, Darren G.Finck. "Comparison of buckling of an arched, rubbercore sandwich composite panel to finite element modeling", Applied Science and Manufacturing 42, 2011, pp. 843-848.

[12]. ASM Handbook," properties and selection: nonferrous alloy and special-purpose materials" , 2003, Volume 2.

[13]. Montgomery. D.C, Design and analysis of experiments, Fifth Edition, John Wiley & Sons, Inc., New York, 2003.