알루미늄 샌드위치 패널의 구조적 형상 및 진동 특성에 관한 연구*

배동명† · 손정대

부경대학교

A Study on the Structural Shape and Vibrational Characteristics of Aluminum Sandwich Panel

Dong-Myung BAE† and Jung-Dae SON
Pukyong National University

Abstract

Aluminum honeycomb sandwich panel (AHSP) not only have high flexural rigidity and strength per density but also excellence in anti-vibration and anti-noise properties. Their properties are very useful for build airplane and high speed crafts, which need lighter-weighted and more strengthed element. Recently, the AHSP is regarded as a promising strength member of light structures like the hull of high speed crafts.

Generally, the core shape of aluminum sandwich panel (ASP) is the hexagonal shape of honeycomb. But, in this paper, authors proposed the ASP with pyramid core, as the ASP model of new type, and analysed the structural and vibrational characteristics for aluminum pyramid sandwich panel (APSP) as this new ASP type, according to the thickness variation of core and face, the height variation of core. The applied sandwich models have isotropic and symmetrical aluminum faces and pyramid cores. And, the applied boundary conditions are simple, fixed and free support.

Key words : structural shape(구조형상), aluminum pyramid sandwich panel(알루미늄 피라밋 샌드위치 패널), aluminum honeycomb sandwich panel(알루미늄 하니컴 샌드위치 패널), vibrational characteristics(진동특성)

Introduction

The present expansion in the economy and trade scale in accordance with a development in industry and an increase in income have made time more valuable in the passenger and freight transportation.

Due to this, it is necessary to establish a system of speedy marine transportation for the domestic and international passenger and freight transportation. the need for super high speed vessels in inevitable to satisfy the above necessities.

One of the most important element in designing a super high speed vessel is a light weight structure. To accomplish this, the material se-

* This work was supported by Pukyong Research Fund in 2001.
† Corresponding author : dmbae@pknu.ac.kr

lection and the choice of construction method of ship's structure are very important. The compound material (FRP/GRP), aluminum alloy and high tension steel etc. are usually used on material for high speed vessel structure Aluminum alloy as materials is used over 90% for constructing in ship's hull and part structure.

From this point of view, the best material of choice is the Aluminum Honey-comb Sandwich panel (AHSP) structures.

AHSP Structure is composed of one regular hexagonal honeycomb core and two thin face plates. As compared with other materials, it has excellent structural efficiencies such as having the greater strength relative to weight factor, no welding deformation, remarkable insulation characteristics, energy absorption, fire retardant, fatigue resistance, flexibility and high bending strength. AHSP structure is already used in many fields : the aviation-space field, TGV on the high speed railroad train of France, super speed craft and the shelter structure of cruiser in ship's construction field etc., which needs high strength and stiffness.

In this paper, we modified the core shape of AHSP structure, which is composed of a regular hexagonal honeycomb core and two thin face panel and have been applied to many fields. We proposed the Aluminum Pyramid Sandwich Panel (APSP) as a new model. Especially, the core of APSP is constructed with the core shapes like pyramid to be pitched flat panel with two direction. The sandwich panel with the pitched core shape to one direction have been applied to the high speed railroad train of Germany, Japan, and Italy etc.

From the characteristic comparison and check of the strength and stiffness to the AHSP, it has excellent performances as stated above. Authors have performed an analysis for the shelter structure to be established on bridge deck of a Ro-Ro Ferry (Minoan Lines, length 198m and speed 28.4 knots), which plies the Mediterranean coast between Greece and Italy. The AHSP structure was applied to a roof part of this shelter structure.

To confirm the advantages of APSP to be proposed by authors, the APSP was selected as the objects of comparison with the AHSP of roof on the shelter structure. And it was referred to the structural characteristics of APSP, according to the variation of angle and height for pyramid of core truss, and the variation of face and core thickness. For the severe vibration and noise problems which arise from high speed craft, we also studied the response characteristics of natural vibration for APSP and AHSP in this research.

Aluminum Sandwich Panel Structure

1. Aluminum Honeycomb Sandwich Panel (AHSP)

The AHSP structure to be shown in Fig.1 and Fig.2 are composed of a heartwood, honeycomb core and two thin face panels of alu-

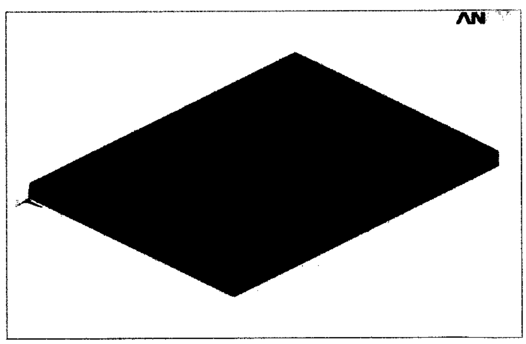


Fig. 1. FEM anylysis model of AHSP.

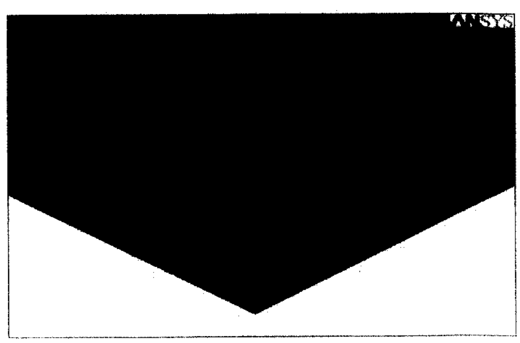


Fig. 2. Zooming of honeycomb core.

minum alloy material. The two face panels adhere to both sides of the honeycomb core with glue. As the two plates are far apart from their neutral axis, the 2nd section moment of inertia is increased. Consequently the structural stiffness is increased as a result, therefore it is the type for more efficient lightweight structure.

2. Aluminum Pyramid Sandwich Panel (APSP)

Fig.3 is the shape of unit cell pyramid, as the unit structure of core part of APSP model shape to be proposed in this paper. In this Fig.3, h and θ means the core height and angle of unit cell pyramid of core on APSP structure. Fig.4 and Fig.5 are the core shape of APSP, which the pyramid cells are continuously constructed with cross-link type, that is, the flat panel is pitched to x and y direction.

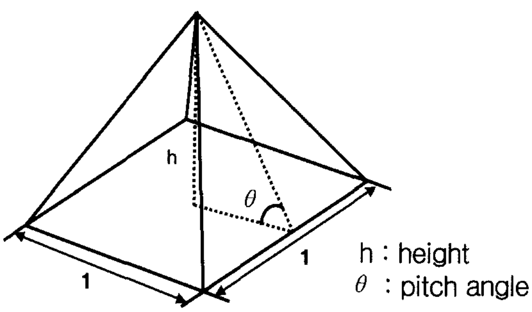


Fig. 3. Unit pyramid cell.

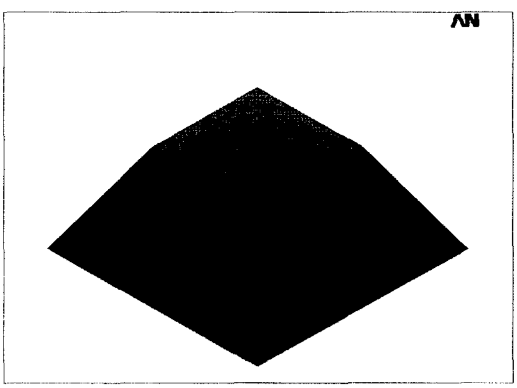


Fig. 4. Connection of five unit cell.

Numerical Analysis

1. Structure of analysis objects

1.1 Aluminum Honeycomb and Pyramid Sandwich Panel (AHSP and APSP)

The AHSP has been applied to a roof part of shelter structure to be established on the bridge deck of the Passenger Ro-Ro Ferry,

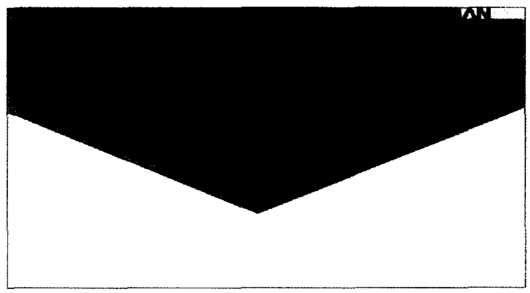


Fig. 5. Continuous core shape of APSP to be constructed with unit pyramid.

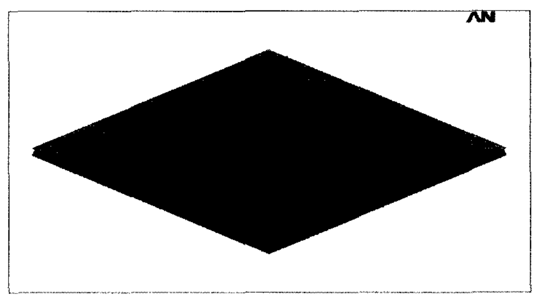


Fig. 6. FEM analysis model of APSP.

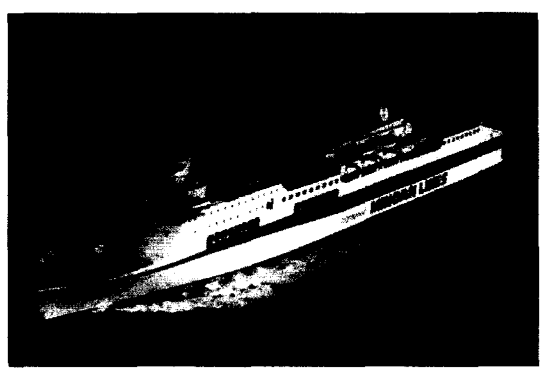


Fig. 7. Passenger Ro-Ro Ferries
198m, 28.25 knots, FL 19k tons.

which plies the Mediterranean coast between Greece and Italy (cf. Fig.7).

The Passenger Ro-Ro Ferry, MINOAN (19Kton Ro-Fax class) and the modelling of the whole shelter structure are shown in Fig.8. The FEM model of length and breadth, 800x1040 mm, for the AHSP struture consists of a sandwich panel of face panel and honeycomb core, and is shown in Fig.1. A magnified part of honeycomb core is shown in Fig.2. And the material properties of the AHSP and APSP structure are listed in Table 1.

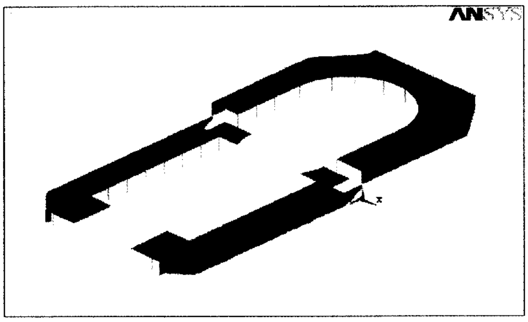
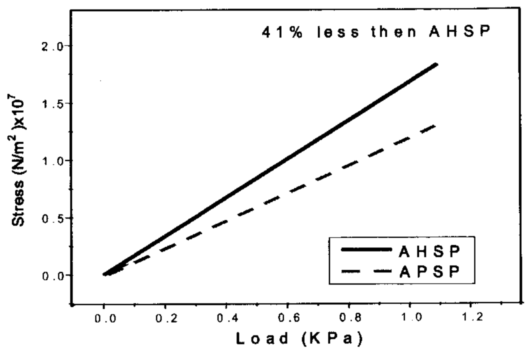


Fig. 8. Shelter structure on the bridge deck of cruiser.

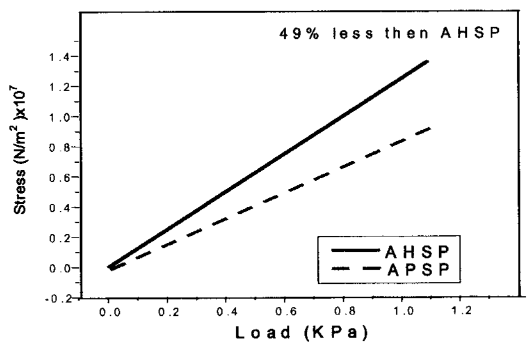
Table 1. Material properties of AHSP and APSP

	Items	AHSP	APSP
Core	Material	A5052H19	
	Cell Size (mm)	8.66	-
	Pitch Angle (deg.)	-	60
	Height (mm)	15	15
	Density (kg/mm^3)	2680	2680
	Thickness (mm)	0.1	
	Young's Modulus (Gpa)	70	
	Poisson's ratio	0.33	
Face	Material	A6063-T5	
	Thickness (mm)	1.0	
	Young's Modulus(Gpa)	69	
	Poisson's ratio	0.33	

In this paper, to study the characteristics for the APSP structure, it was referred to the AHSP and APSP structure, of which the unit cells of core are a regular hexagonal honeycomb shape and a pyramid shape. The load condition is the uniform distributed load of 1.092KPa. And the boundary conditions of two cases are considered, that is, the cantilever which one edge is fixed and the 4 edges are simply supported. Under these load and boundary conditions, it was referred and compared to the maximum stresses and deflections for AHSP and APSP structure. And the structural characteristics were studied, according to the variation of angle and height of pyramid for the core of APSP and the variation on thickness of the face and core panel of APSP.



(a) Stress values under cantilever



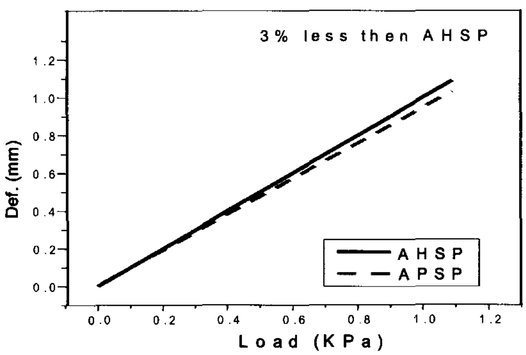
(b) Stress values under 4 edges S.S

Fig. 9. Max. stress values of AHSP and APSP on two boundary conditions.

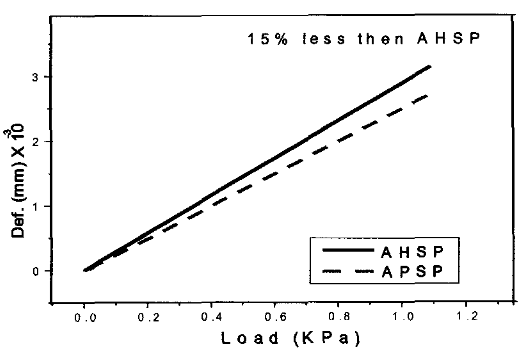
2. Comparison of Stress and Deflection

For the distributed load of 1.092KPa and two cases of boundary condition, the cantilever which one edge is fixed and the 4 edges are simply suppported, the maximum stress values of AHSP and APSP are shown in Fig. 9. That is, the maximum stress values of APSP is about 41% and 49%, less than AHSP.

And, under two boundary conditions, the maximum deflection values of AHSP and APSP are shown in Fig. 10. That is, the maximum deflection values of APSP is about 3% and 15% less than AHSP. It means that the APSP is more excellent than the AHSP in the structural stiffness.



(a) Deflection values under Cantilever



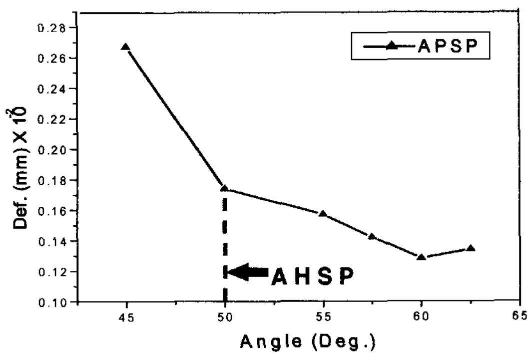
(b) Deflection values under 4edges. S.S

Fig. 10. Max. deflection values of AHSP and APSP on 2B.C.

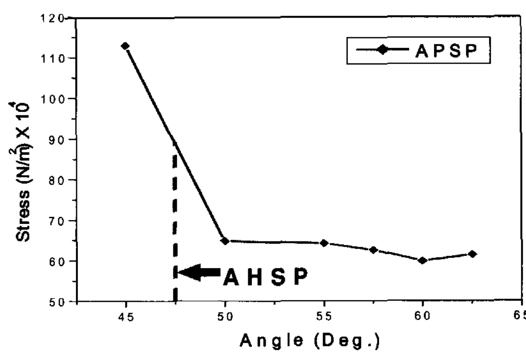
3. Comparison of stress and deflection according to the variation of angle and height for unit cell of core, APSP

According to the variation of angle, that is, 45°, 50°, 55°, 57.5°, 60°, and 62.5° of the unit cell truss for the core of APSP, which the length and breadth ratio is unit, the results of analysis for deflection and stress values are as followings.

From Fig.11,the deflection and stress value are the least at the angle of unit cell, 60°. Also, under conditions that another all variables are same, the deflection and stress values of AHSP is similar to its values at the angle, 50° and 47.5° of unit cell for the core of APSP.



(a) Deflection values for variation of angle



(b) Stress values for variation of angle

Fig. 11. Stress and deflection values according to the variation of pyramid angle on core of APSP.

For the equivalent comparison of deflection and stress values by the variation of angle of unit cell for the core of APSP, the values which divided deflection and stress into mass are shown in Table 2.

Table 2. Values to the divided deflection and stress into mass

APSP	(Def./mass)×(10^{-6})	(Stress./mass)×(10^{-6})
50°	4.4048	1.6406
55°	3.9006	1.5957
57.5°	3.5956	1.5843
60°	3.3636	1.5727
52.5°	3.2712	1.4992
65°	3.1220	1.4365
67.5°	2.9044	1.3778
70°	2.7080	1.2778
AHSP	4.4189	2.2526

And the values of equivalent deflection of AHSP are similar to its values at the pitched angle, 50° of APSP.

4. Variation of Height of Core

When the piramid angle of core for APSP is 60° and the length and breadth ratio is unity, the deflection and stress values are analysed to the core height, 5 cases of 6.35, 7.94, 9.53, 11.11, 12.70 mm, which the values between 6.35mm and 12.70mm is divided into 4 equal parts. The equivalent values, which divided deflection and stress values into mass is shown in Table 3. From the comparision of result of analysis for AHSP and APSP, it may be referred that the APSP is more profitable than the AHSP in the lightweighter.

Table 3. Equivalent stress and deflection values according to variation of core height

Thickness of APSP(mm)	Equiv. Def (10^{-3}mm)	Equiv. Stress (10^{8}kg/m^{2})	Rem.
6.35	12.332	70.800	
7.94	10.900	61.380	
9.53	9.900	55.700	
11.11	8.737	47.600	
12.70	8.097	43.714	
AHSP Th.12.70	9.900	60.500	

Where, Equiv. Def. and Stress : Def./mass and Stress/mass

5. Variation of Face and Core Thickness

The length and breadth scale of APSP are 1000mm, respectively and the 4 edges of this panel are fixed and the normal uniformly distributed load of 1 KPa is applied to this panel.

According to the variation of thickness of face and core, the structural characteristics of APSP is studied as followings.

When the face thickness varies from 0.1mm to 3.0mm under the core thickness, 0.1mm, the maximum deflection and stress values are listed in Table 4. That is, under the core thickness, 0.1mm, the maximum deflection and stress values decrease a little step by step, according to the increase of face thickness in the range, 1.5~3.0mm. But in the cases, which the face thickness are reduced to 0.5mm and 0.1mm, about 1.85 and 7.7 times deflection values as large as, and about 1.60 and 6.5 times stress values as large as its values of the face thickness, 1.0mm, are shown in Table 4.

Table. 4. Max. deflection and stress values under the core thickness. 0.1 mm

Thickness of Face(mm)	Mass (kg)	Max. Def (mm)	Max. Stress (Mpa)	Rem.
0.1	0.405	0.9160	25.90	
0.5	0.945	0.2200	6.28	
1.0	1.620	0.1190	4.01	
1.5	2.295	0.0836	3.35	
2.0	2.970	0.0656	2.81	
2.5	3.645	0.0546	2.45	
3.0	4.320	0.0472	2.28	

When the face thickness varies from 0.1mm to 3.0mm under the core thickness 1.0mm, its values are listed in Table 5. And, the decreasing tendency of the maximum deflection and stress values, according to the increase of face thickness in the range, 1.5~3.0mm, is similar to the case of core thickness, 0.1mm. But in the cases, which the face thickness are reduced to 0.5 and 0.1mm, about 1.65 and 3.88 times deflection values as large as, and about 1.45 and 1.58 times stress values as large as it's values of the face thickness, 1.0mm, are shown in Table 5.

Table 5. Max. deflection and stress values under the core thickness, 1.0 mm

Thickness of Face(mm)	Mass (Kg)	Max. Def (mm)	Max. Stress (Mpa)	Rem.
0.1	2.835	0.3400	15.60	
0.5	3.375	0.1450	3.85	
1.0	4.050	0.0877	2.66	
1.5	4.725	0.0631	2.11	
2.0	5.400	0.0493	1.76	
2.5	6.075	0.0405	1.50	
3.0	6.750	0.0344	1.31	

When the core thickness varies from 0.1mm to 3.0mm under the face thickness of, 1.0mm, the maximum deflection and stress values are shown in Table 6. Also, from Table 6, according to the increment of core thickness in the range, 1.5~3.0mm, the maximum deflection and stress values decrease a little with nearly lineality under the face thickness, 1.0mm. And Fig.12 and Fig.13 represent max. deflection and stress according to the variation of core and face thickness.

Table 6. Max. deflection and stress values under the face thickness, 1.0 mm

Thickness of Face(mm)	Mass (Kg)	Max. Def (mm)	Max. Stress (Mpa)	Rem.
0.1	1.62	0.1190	4.01	
0.5	2.70	0.0991	3.09	
1.0	4.05	0.0877	2.66	
1.5	5.40	0.0789	2.36	
2.0	6.75	0.0714	2.11	
2.5	8.10	0.0649	1.90	
3.0	9.45	0.0593	1.72	

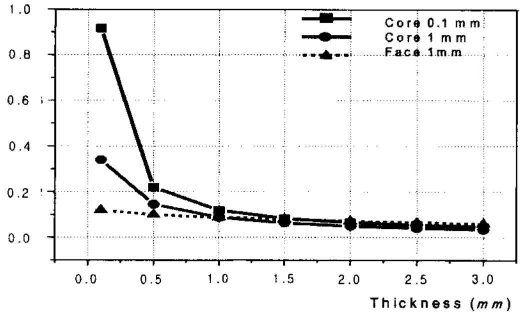


Fig. 12. Max. Deflection to the variation of core and face thickness.

6. Analysis of Free Vibration

The natural frequencies of APSP and AHSP is shown in Table 7. Because the stiffness ratio to mass of APSP is larger than that of AHSP, the natural frequencies of APSP are somewhat larger than that of AHSP. And the natural modes of APSP and AHSP represent in Fig.14~21.

Table 7. Comparison of natural frequencies

	Natural Frequencies (Hz)			
	(1,1) mode	(1,2) mode	(2,1) mode	(2,2) mode
APSP	336.16	548.74	729.81	897.72
AHSP	328.26	531.85	703.23	860.53

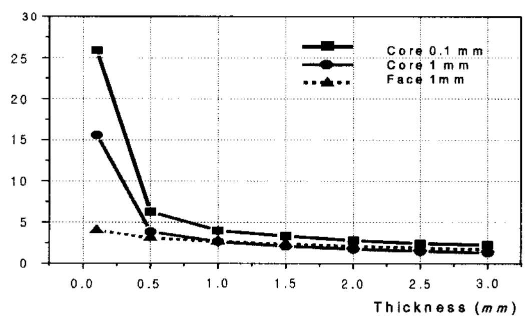


Fig. 13. Max. Stress to the variation of core and face thickness.

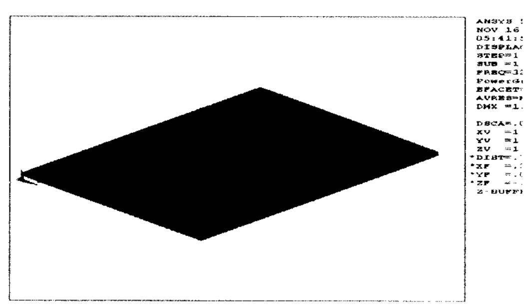


Fig. 14. Natural (1,1)mode of AHSP.

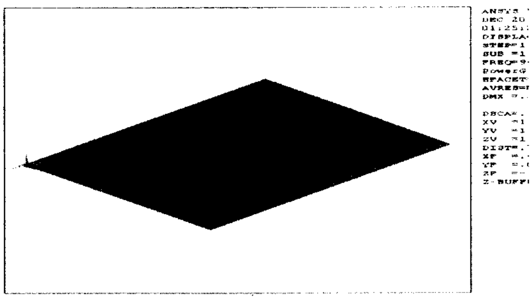


Fig. 15. Natural (1,1)mode of EASP.

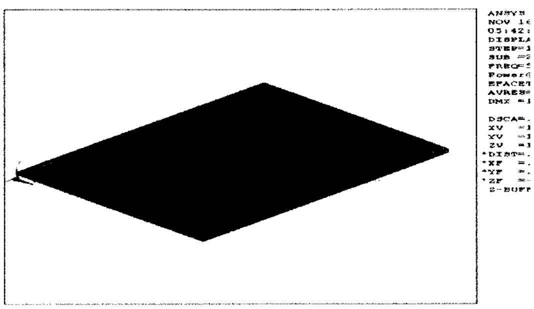


Fig. 16. Natural (1,2)mode of AHSP.

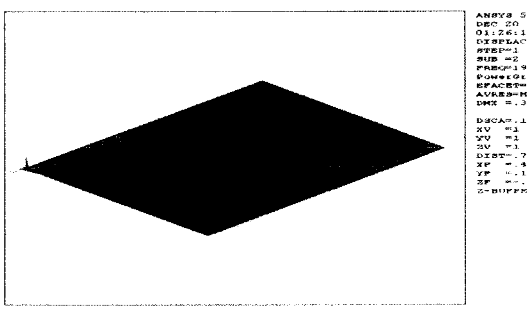


Fig. 17. Natural (1,2)mode of EASP.

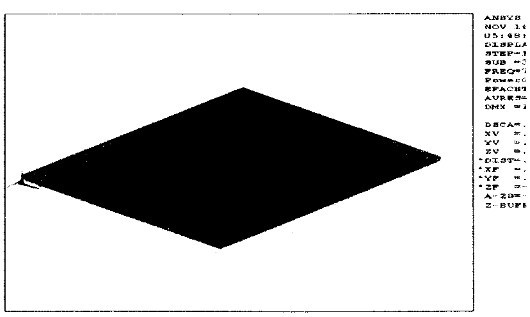


Fig. 18. Natural (2,1)mode of AHSP.

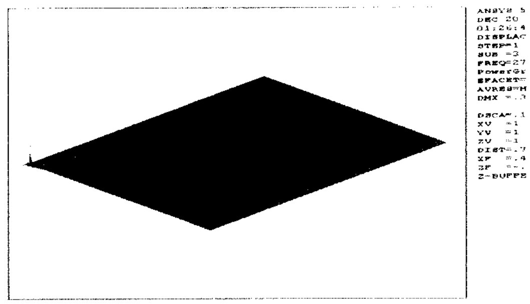


Fig. 19. Natural (2,1)mode of EASP.

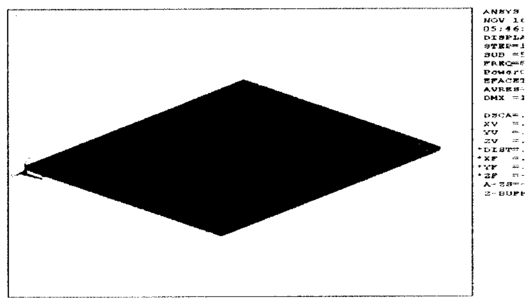


Fig. 20. Natural (2,2) mode of AHSP.

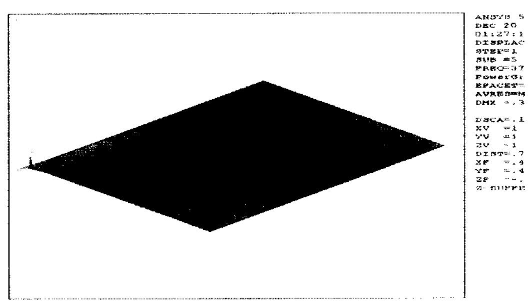


Fig. 21. Natural (2,2) mode of EASP.

Conclusions

In this paper, we studied the structural characteristics of AHSP and APSP, Which the shape of core is continuous pyramid structure and authors proposed. The results are as follows.

1. The APSP structure model is more excellant in strength and stiffness as compared with AHSP.

2. The pitched angle of core cell of APSP with 60° is ensured good quality.
3. From the study of structural charac-teristics by the variation for core height of APSP, which it is similar to the strength of AHSP, it's core height may be decreased to about 3mm. Therefore, the mass of panel can too be reduced.
4. On the variation of the face and core thickness, when the thickness of face and core are more than 1mm, the increase of the face thickness is more efficient. When they are less than 1mm, the increase of the core thickness is more efficient.
5. When another all conditions are same, the natural frequencies of APSP are higher than those of AHSP. It means that the APSP is greater and more excellent than the AHSP in stiffness.
6. Finally, it is provided the useful basic data on APSP for lightweight of aluminum sandwich panel structure. It is thought that the more studies on the optimum shape of core and the economic mass production of APSP are necessary.

요 약

본 연구에서는 실선에 적용된 알루미늄 하니콤 샌드위치 판(AHSP)을 저자가 제안한 심재의 형상이 피라미드인 알루미늄 샌드위치 판의 구조적 특성 및 진동특성을 검토해 보았다. 알루미늄 피라미드 샌드위치 판(APSP)의 기초 자료로 쓰일 수 있게 심재의 각도변화, 높이변화 및 면재와 심재의 두께변화에 따른 구조적 특성을 검토한 결과, APSP가 강도 및 강성에서 우수함을 보였으며, 질량대비 큰 강성때문에 고유진동수도 다소 크게 평가되었다.

References

J. Zhang and M. F. Ashby (1992) : The Out-of-Plane Properties of Honeycomb, Int. J. Mech. Sci., 3.

J. Zhang and M. F. Ashby (1992) : Buckling of Honeycomb under In-Plane Biaxial Stresses, Int. J. Mech. Sci., 34.

M. Grediac (1993) :A Finite Element Study of the Transverse Shear in Honeycomb Cores, Int. J. Solids and Structures, 30.

V. E. Kryutchenko (1995) : Analysis of the Anisotropic Properties of Honeycomb Sandwich Plates, Mech. Composite Mat., 34.

D. M. Bae (2000) : Strength Analysis of Shelter Structure and Joint part of Open Deck for Cruiser, Minoan Line, PKNU, 산업과학기술연구소.

T. Satto, R. D. Parbery, S. Okuno, and S. Kawano (1997) : Parameter Identification for Aluminum Honeycomb Sandwich Panels based on orthotropic Timoshenko Beam Theory, J. of Sound and Vibration, 271-287.

D. Zenkert, "The Handbook of Sandwich Construction, 79-90.

R. W. Clough & J. Penzien (1994) : Dynam-ics of Structures, McGraw-Hill, Inc.

2004년 7월 15일 접수
2004년 9월 4일 수리