PREPARATION OF POROUS CORE CFRP SANDWICH PANEL WITH LOW OUT-OF-PLANE DEFORMATION

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Abstract
As a new material suitable for primary mirrors of space telescopes, we focused on porous core CFRP sandwich panels. Previous studies reported that large out-of-plane deformations appeared at edge of ROHACELL (polymethacrylimide based foam) core sandwich panels. In order to improve the surface accuracy, we focused on GRAFOAM (carbon-based foam) core which has a low thermal expansion coefficient. ROHACELL core and GRAFOAM core sandwich panels was manufactured and surface accuracy of those panels were experimentally compared. Experimental results showed that the out-of-plane deformation appeared in the panels with ROHACELL core was suppressed in those with GRAFOAM core.

1. Introduction

As a new material suitable for the primary mirrors of space telescopes, carbon-fiber reinforced plastic (CFRP) sandwich panels have been expected in terms of high specific stiffness, high thermal conductivity and low coefficient of thermal expansion. However, when honeycomb cores are used in the CFRP sandwich panels, dimples occur on surface of the CFRP skins, and degrade the surface accuracy [1]. In order to suppress the dimples, we have examined to apply a porous material as the core in previous studies [2]. Because the porous materials is lightweight and has large bonding area with respect to skins, it should be attractive to achieve dimple-free mirrors.

In previous studies, we have fabricated mirror specimens with honeycomb core and a porous material, ROHACELL [2], and assessed the surface deformation of both specimens. Experimental results revealed that dimple-free sandwich panels were achieved by using ROHACELL core. However, larger out-of-plane deformation was observed in the ROHACELL core sandwich mirrors than the conventional honeycomb core ones because of larger moisture absorption. This is a significant disadvantage to use in space telescopes because the cores will absorb moisture in atmosphere and deform by the dehumidification in a vacuum environment after launch. Therefore, it is necessary to prevent deformation by moisture absorption. In addition, mirrors in space telescopes are exposed severe thermal cycle during operation. Thus, it is also necessary to suppress thermal deformation of mirror.

Based on the above backgrounds, we have aimed to achieve porous core sandwich panels with smaller out-of-plane deformation. In this study, to achieve this purpose, we have focused on the carbon-based porous material with low-expansion by heat and moisture absorption. In this paper, as a first step of the study, we have fabricated sandwich panel specimens with various cores. Then, we have compared the surface deformation of the specimens at after fabrication, after moisture absorption and after re-dry condition. Furthermore, in order to quantitatively evaluate the thermal deformation, we have examined the deformation of panels analytically by analytical simulations based on finite element method (FEM).

2. Measurement of deformation of porous core sandwich panels

2.1 Fabrication of sandwich panel specimens

Unidirectional prepreg (T700S / epoxy # 2592, Toray Co., Ltd.) was used for skins of specimens. Polymethacrylimide foam called ROHACELL (51WF, Evonik Industry) and carbon-based foam GRAFOAM (FPA-10, GRAFTECH Co., Ltd.) were used as core materials. Core thickness was 10 mm. Young's modulus, coefficient of thermal expansion (CTE) and coefficient of moisture expansion (CME) of each core material are shown in Table 1. To fabricate CFRP skin, unidirectional prepregs were cut to size of 140 mm × 140 mm and they were laminated in quasi-isotropic $[45/0/\text{-}45/90]_S$ of 8 plies. After lamination of prepregs, it was cured in hot-press at 80 °C under pressure of 0.58 MPa for 30 min. In addition, it was heated to 130°C under 0.58 MPa and held 120 min. Fabricated skin was divided into four portions with sizes of 70 mm × 70 mm. Then, two sheets of the skins, a core and adhesive were piled and were cured at 120 °C under 0.05 MPa for 90 min in hot-press. An optical flat (OF) plate was used for the mold and Aflex (Asahi Glass Co., Ltd.) was used as ~~a~~ mold-releasing film.

Table 1 Physical properties of core materials.

Core	Density [g/cm^3]	Elastic modulus [GPa]	CTE [10^{-6}/K]	CME [10^{-4}/wt%]
ROHACELL	0.052	0.075	33	5
GRAFOAM	0.16	0.5	2.3	(0.5)

2.2 Measurement condition

Surface deformation of fabricated sandwich panels were measured by a laser displacement sensor (LK-G155, KEYENCE Co., Ltd.) mounted on an automatic XY stage. Measurement area was 60 mm × 60 mm on the fabricated specimen surface, and the scan pitch was set to 2 mm. Measurements were performed at room temperature.

3. FEM analysis of deformation of porous core sandwich panels

For the analyses, commercial finite element analysis software ANSYS Ver.13 (ANSYS Inc.) was used. Schematic illustration of analytical model of the sandwich panel is shown in Fig. 1, and Fig. 2 shows meshed FEM model. Model size is 70 mm × 70 mm, and skins were laminated in quasi-isotropic $[45/0/\text{-}45/90]_S$ of 8 plies. Thickness of skin and the core is 1 mm and 10 mm, respectively. Adhesives were also installed between skin and core. In in-plane direction, the model was meshed into fourteen elements with hexahedral quadratic element. In the thickness direction, each ply of the skin and adhesive have one element, and the core was meshed into four parts. The total number of elements was 4312. Displacement of X and Y-direction were restrained at point A (see Fig.2). And displacement of X, Y and Z-direction and Y-direction were fixed at point B and C, respectively. By these restrictions, rigid motion and rotational motion in all directions were restricted and only the out-of-plane deformation was allowed. In this analysis, in order to simulate the thermal deformation observed after fabrication of the specimen (after cooling from 125 °C to 25 °C), a temperature change of -100 °C was given as a load to all nodes of the model. Table 2 shows material properties used in the analysis.

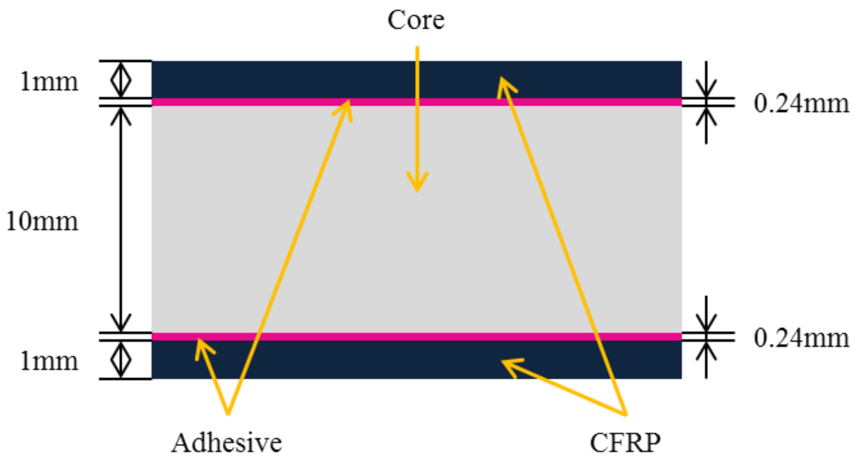

Figure 1 Schematic illustration of analytical model of the sandwich panel.

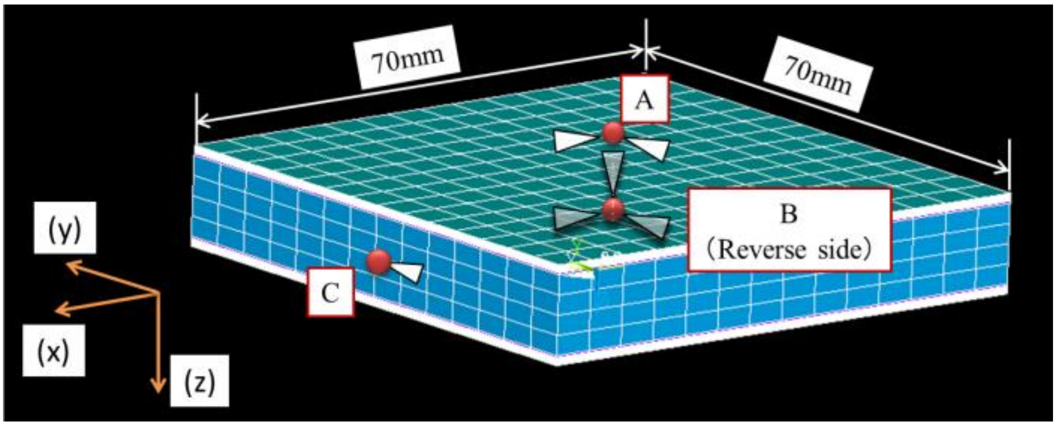

Figure.2 FEM model.

Table 2 Material properties used in analyses.

		Young's modulus [GPa]	Shearing modulus [GPa]	Poisson's raito	CTE [$\times10^{-6}$/K]
Core	ROHACELL	0.075	-	0.33	33
	GRAFOAM	0.075	-	0.33	2.3
Adhesive		3	-	0.3	60
CFRP (Unidirectional)		E_x=346	G_{xy}=4.2	ν_{xy}=0.33	α_x=-0.3
		E_y=5.3	G_{yz}=1.89	ν_{yz}=0.4	α_y=40
		E_z=5.3	G_{xz}=4.2	ν_{xz}=0.33	α_z=40

4. Results and discussions

4.1 Surface deformation of sandwich panels

Measuring results of surface deformation of each sandwich panel specimen were shown in Fig. 3, and root mean square (RMS) values of out-of-plane deformation were shown in Table 3. It is found from Fig. 3 that the surface shape of ROHACELL core sandwich panel after holding humidity environment shows convex shape. This is because the specimen with ROHACELL core was significantly expanded in the fiber direction of the outermost layer by moisture absorption during holding in high-humidity condition [2]. On the other hand, edge effect was not observed for the GRAFOAM core sandwich panel. As seen in Table 3, deformation in the GRAFOAM core specimen was smaller than in the ROHACELL core specimen. It is considered that the deformation was suppressed because GRAFOAM have high elastic modulus and low CTE and CME than those of ROHACELL. From the above results, it was suggested that application of a carbon-based core is effective to fabricate high accuracy panel.

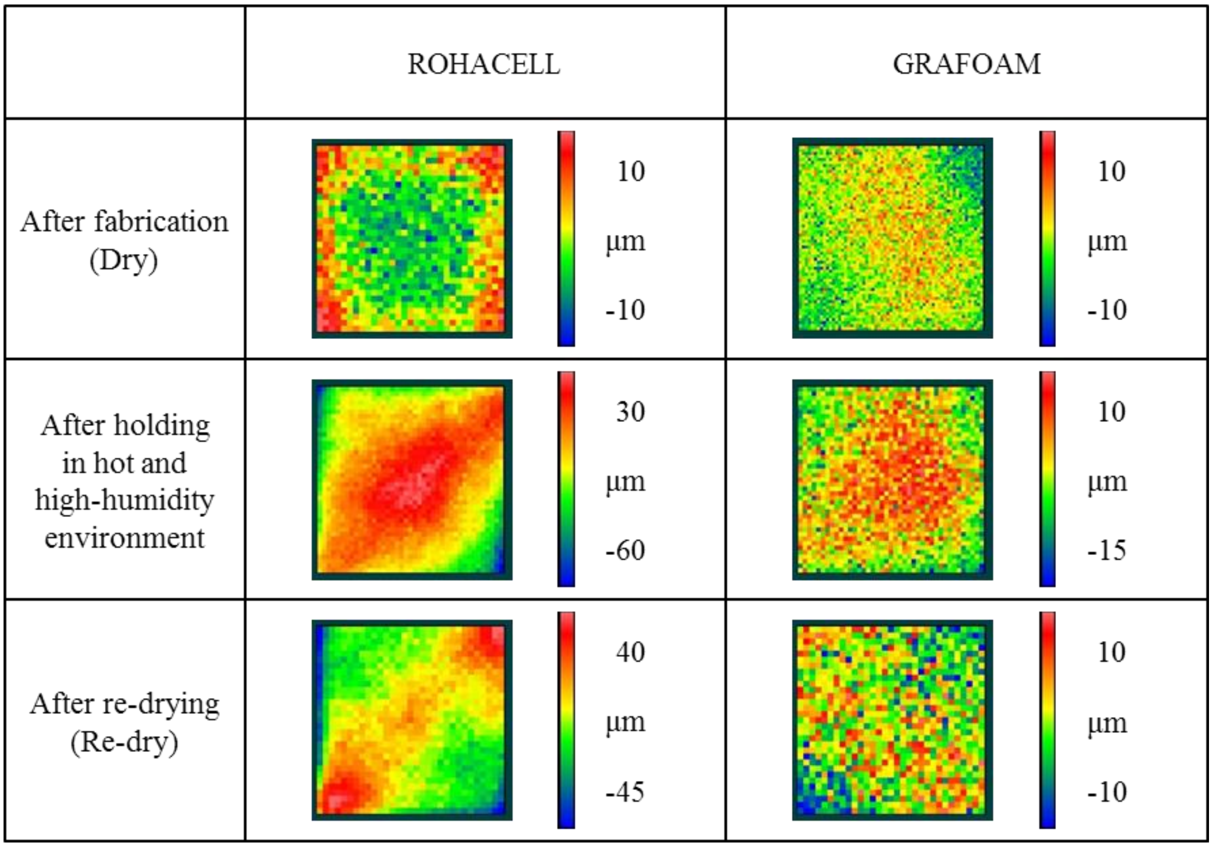

Figure 3 Measurement results of the surface shape of sandwich panels.

Table 3 Out-of-plane deformations of sandwich panels with each core.

Core	**Out-of-plane deformation, RMS [μm]**		
	After fabrication	**After holding in hot and humidity environment**	**After re-dry**
ROHACELL	3.948	15.47	14.50
GRAFOAM	2.900	4.459	4.136

4.2 Comparison of thermal deformations observed in experimental and analytical results

Analytical results of the thermal deformation occurred after fabrication are shown in Fig. 4, and RMS values of out-of-plane deformations ware shown in Table 4. From Fig. 4 and Table 4, FEM results indicated that ROHACELL core showed the convex shape at edge by the edge effect, and that the deformation was suppressed by using the GRAFOAM. Though the edge effect was appeared in the analytical result for the GRAFOAM core panel, it was not observed in the experimental measurement. In the panels with GRAFOAM core, the influence of orientation error in the skins occurred during preparation could be larger than that of the moisture deformation of core. Therefore, in the experiments, the influence of the deformation of core should not be appeared clearly.

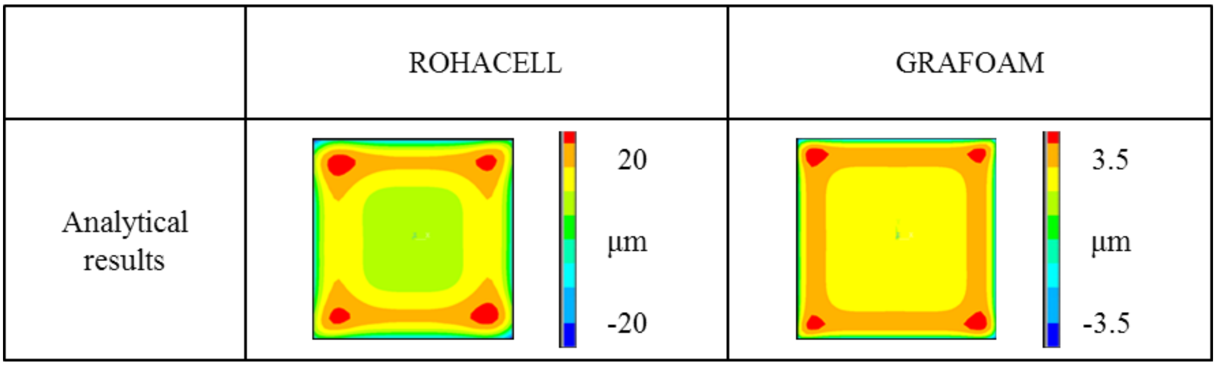

Figure.4 Analytical results of sandwich panels.

Table 4 Surface deformation values obtained by FEM (after fabrication).

Core	**Out-of-plane deformation, RMS [μm]**
ROHACELL	3.03
GRAFOAM	0.530

5. Conclusions

In order to suppress the out-of-plane deformations appeared ROHACELL core sandwich mirror, we examined to use GRAFOAM core with higher elastic modulus and lower CTE and CME as core. We fabricated sandwich panel specimens with both core and evaluated the moisture and thermal deformation through experiments and analyses. Experimental and analytical results showed that both the thermal and moisture deformation observed in ROHACELL core sandwich panels was suppressed in GRAFOAM core sandwich panels because of its higher elastic modulus, and lower CTE and CME than ROHACELL. These results indicate that use of the carbon-based core, such as GRAFOAM, are effective for fabrication of the highly accurate sandwich panel because out-of-plane deformation is suppressed. However, there is a possibility that the weight of sandwich panels become a problem because the density of the carbon-based foam is larger than Polymethacrylimide foam. Therefore, the optimal design which is taking into account weight will be future issues.

References

[1] S Utsunomiya. Development of CFRP mirrors for low-temperature application of space telescopes. Proc. of SPIE, volume 8450, R1-R7, 2012.

[2] S Honda. Effect of moisture absorption characteristics on deformation of foam core CFRP sandwich mirrors. Proc. of JCCM-4, 3C-01, 2013.

[3] J Koyanagi. Time and temperature dependence of surface accuracy on CFRP sandwich mirror.