

Comparative analysis of the honeycomb and thin-shell space antenna reflectors

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Abstract. Parabolic three-layered reflectors from polymer composite materials with the aluminium honeycomb fillers became widely used in space communication systems in the past decades. There are technological possibilities for creating reflectors in the form of thin-walled ribbed shell with the lower linear density than that of the three-layered structures. The paper presents the results of the temperature and stress-strain analysis for the two types of structures, which could help to select the variant with the best performance characteristics.

1 Introduction

The state-of-the-art space antenna reflectors are essentially parabolic shells with various types of reinforcement that enable the required stiffness. The most frequent design layout is a three-layered shell with the honeycomb reinforcement, less frequent is a thin shell with the reinforcing ribs over the convex surface [1]. The common features for all structures are, firstly, the requirement for the high shape and dimensional stability under condition of varying temperature as a result of the spacecraft entering the Earth shadow and, secondly, low linear density (the mass in relation to the surface area). The design of the reflectors with the honeycomb filler meets the most stringent requirements with the regard to the shape and dimensional stability, while having a relatively small linear density in the range of 3.5-5.0 kg/m² [2]. Sources [3] and [4] presented the results of simulating the thermal and stress-strain behavior of several reflector variants with the concave shell ribbed reinforcement for the geostationary Earth orbit (GEO) conditions, which proved the possibility of the designs with the small linear density and high stiffness [4]. After the analysis of various reinforcement patterns [5], the “five-point star” pattern was singled out, as being superior to the other variants with respect to stiffness and linear density.

This research aims to compare the characteristics of the space antenna reflector layouts with the honeycomb filling and ribbed reinforcement. In order to achieve this aim, the following objectives were fulfilled consecutively:

- Geometric models were developed;
- Thermal physical characteristics of the honeycomb filling were determined;
- Temperature and stress-strain state at GEO was determined.

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2 Geometric models development

The comparative analysis involved building geometric models of the design with the honeycomb filling (Fig. 1) and the ribbed reinforcement (Fig. 2). The shells in the both variants were made from carbon fibre composite.

The temperature and stress-strain simulation was performed using the finite-element method in the Siemens NX PLM software package. The carbon fibre composite was assumed to have the following thermal physical and mechanical properties: thermal conductivity coefficient 1000 J/(kg·K); density 1550 kg/m³; emissivity 0.85; absorptivity 0.735; CLTE $5.27 \cdot 10^{-7}$, Young's modulus 140 GPa, Poisson ratio 0.3.

In the honeycomb filled design each carbon fibre composite shell was 0.6 mm thick, the honeycomb layer was 25 mm thick.



Fig. 1. Three-layered construction with the honeycomb filling.

The ribbed reinforcement design was essentially a smooth parabolic shell 0.4 mm thick with flat ribs, 90 mm high and 0.6 mm thick.



Fig. 2. Ribbed reinforcement design.

3 Honeycomb filler characterization

For the finite-element analysis of the thermal state, the information about the thermal physical and mechanical properties of the honeycomb fillers is essential. The unified reference data for the honeycomb materials are not available, which necessitates conducting thermal physical and mechanical characterization for each design layout.

The mechanical characteristics of the honeycomb materials were determined by means of the e-Xtreme Digimat 6.0. The input data included the AMr-2 alloy properties, in particular, Young's modulus 71 GPa, density 2680 kg/m³; the honeycomb characteristics: hexagonal pattern, 0.015 mm wall thickness, 25 mm filler height. The mechanical properties values for the honeycomb material are given in Tables 1 and 2.

Table 1. Young's modulus of the honeycomb material.

Axis	Young's modulus, MPa
<i>x</i>	0.035
<i>y</i>	0.035
<i>z</i>	484.989

Table 2. Poisson's ratios and shear modulus of the honeycomb material.

Plane	Poisson's ratio	Shear modulus, MPa
<i>xy</i>	0.99	0.0087
<i>yz</i>	0.33	91.1633
<i>zx</i>	0.33	91.1633

The thermal physical properties in the longitudinal direction were determined using a 3D model of the honeycomb elementary cell, with 0.015 mm wall thickness and 25 mm height. Hexagonal polygonal bodies 0.6 mm thick were added above and below it to simulate the carbon fibre shell. After that a finite-element model was created and the boundary conditions were specified in the form of temperature and radiative heat transfer inside the cell.

The Siemens NX Nastran was used to conduct the finite-element analysis for 15 calculating cases simulating various operating temperatures at 20 °C interval: from minus 120 °C to plus 160 °C. The heat flux density through the elementary honeycomb cell was determined in accordance with Fourier law:

$$q = -\lambda_{\text{eff}} \frac{T_1 - T_2}{\delta_{\Sigma}} \quad (1)$$

where q is the heat flux density; λ_{eff} is the effective heat conductivity, T_1 is the temperature on the upper shell surface, T_2 is the temperature on the lower shell surface.

Temperatures T_1 , T_2 for each case were specified with a 2 °C difference. For example, for the 60 °C case the temperature T_1 constituted 59 °C, T_2 – 61 °C. After the heat density flux was determined, the honeycomb material thermal conductivity was estimated

$$\delta_{\Sigma} = \delta_1 + \delta_2 + \delta_3; \quad (2)$$

$$\frac{\delta_{\Sigma}}{\lambda_{\text{eff}}} = \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}. \quad (3)$$

where λ_1 , λ_3 are the shell thermal conductivities; λ_2 is the filler thermal conductivity.

The estimation of the thermal efficiency in the transverse direction employed the layout similar to that for the longitudinal direction. The thermal load conditions were identical to the estimation of the longitudinal thermal conductivity.

The thermal conductivity of the honeycomb filler in the longitudinal and transverse directions is presented in Fig. 3.

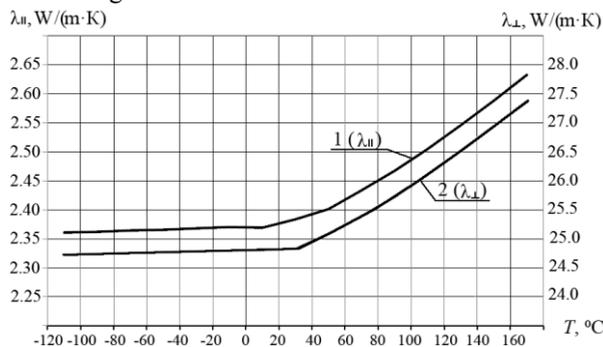


Fig. 3. Thermal efficiency of the honeycomb material as a function of temperature, longitudinal (1) and transverse (2) directions.

4 Determining the stress-strain behavior of the honeycomb filler structure

The temperature gradient was determined by means of Space Systems Thermal solver from the Siemens NX software package. The research involved analyzing 24 moments of operation in the GEO. The largest gradient coincided with the moment when the reflector axis of rotation was at 150° relative to the Earth-Sun axis. The thermal calculation data were used as the reference data for stress-strain calculation. The simulation results are presented in Fig. 4.

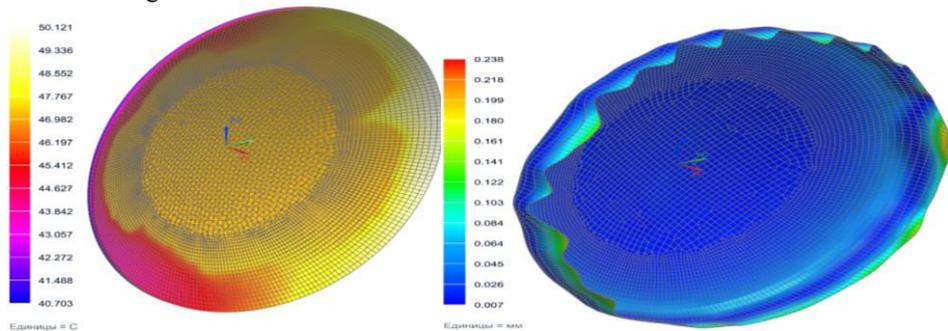


Fig. 4. Thermal (left) and stress-strain (right) behavior of the three-layered structure at the moment, when the reflector axis of rotation was at 150° angle the Earth-Sun axis at GEO.

5 Determining the stress-strain behavior of the ribbed reinforcement structure

To estimate the stress-strain behavior of the ribbed reinforcement structure, 24 moments of the work at GEO were analyzed. The largest temperature gradient coincided with the moment when the reflector axis of rotation was at 120° relative to the Earth-Sun axis. The thermal calculation data were used as the reference data for stress-strain calculation. The simulation results are presented in Fig. 5.

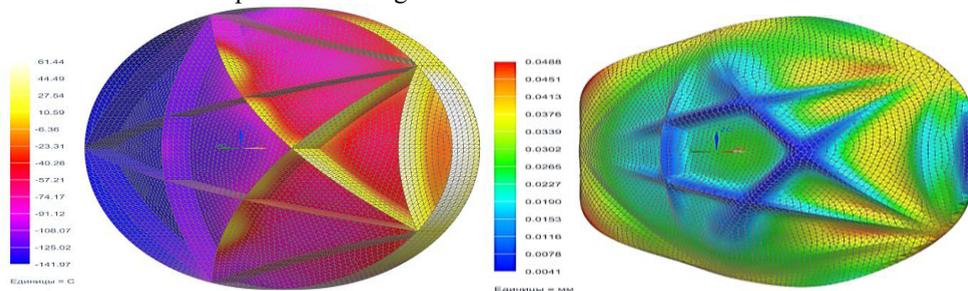


Fig. 5. Thermal (left) and stress-strain (right) behavior of the ribbed reinforcement structure at the moment, when the reflector axis of rotation was at 120° angle to the Earth-Sun axis at GEO.

6 Analysis

Table 3 presents the comparison of the design layout characteristics under investigation.

Table 3. Comparative characteristics of the design layouts.

Layout	Temperature gradient, °C	Maximum displacement, mm	Mass, kg
Three-layered structure	9.42	0.238	2.6
Ribbed reinforcement structure	184.54	0.049	1.224

As is evident from Table 3 the honeycomb filler structure is characterized by a more uniform distribution and a lower temperature gradient. The three-layered structure had 0.238 maximum displacement, while the mean displacement across the surface is in the range of 0.04 to 0.06 mm. The maximum displacement for the ribbed reinforcement structure constituted 0.049. However, the ribbed reinforcement layout has a clear advantage with the mass twice as low as that of the honeycomb filler layout. Therefore, the ribbed reinforcement layout is selected for the further development.

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