Experimental studies on the mechanical properties of a woven composite material for space antenna reflector

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Abstract. In this paper the results of mechanical tests of a biaxial woven composite are presented. This material was used for a new design of deployable precision space antenna reflector of large aperture. The experiments included standard tensile tests at low, normal and high temperatures, compression and shear tests. An additional nonstandard bending test was performed to determine the smallest radius of curvature that a specimen could withstand without fracture. The experiments showed the perspectives for the use of the studied composite in the reflector structure. The determined mechanical properties can be used for numerical modeling of the reflector behavior.

1. Introduction

To meet the growing demands on signal quality of space antennas it is necessary to use large precision reflectors with high surface accuracy. In traditional design of deployable space antennas, the reflector is represented by a metallized mesh which requires additional tension to ensure the surface accuracy. To eliminate disadvantages of mesh reflectors, a new concept of the large 4 m diameter reflector was considered by JSC Information Satellite Systems Reshetnev [1]. According to this concept shown in figure 1 the reflector consists of rigid spokes and a thick flexible composite shell of corresponding parabolic shape. For placement in a launch vehicle, the reflector is folded into the transportation position by turning the spokes closer together and bending the composite shell in a compact form. Thus, the composite shell material needs to have an appropriate stiffness and strength to ensure the shape stability in deployed position after large bending deformations.

![Figure 1. The space antenna reflector.](image-url)
2. Composite shell material and testing methods

A biaxial carbon fiber woven composite was considered as a material having the desired properties. To fabricate the reflector shell from this material the out-of-autoclave method was used. The resulting composite shell shown in figure 2 consisted of few layers of carbon-epoxy fabric with plain weave style and the orientation angle equal to $0^\circ$. The average thickness of the composite shell was 0.5 mm.

Figure 2. The specimen of composite shell material.

According to this structure, the mechanical properties of the composite shell material are equal in longitudinal and transversal directions. Due to the small thickness, the shell is in a state of plane stress. In this case the elastic properties of the reflector material can be characterized by Young’s modulus, Poisson’s ratio and shear modulus.

To determine the elastic and strength properties, a series of experiments were carried out on specimens of the composite shell. The experiments included standard tensile tests, compression and shear testing. The tensile tests were carried out at the temperature range from -150 to +125 °C which corresponded to the operation temperature of the reflector. The testing procedures were mostly based on commonly used national standards. At least 5 specimens were tested for each type of experiment.

To determine the smallest radius of curvature that the composite shell material can withstand in process of folding the reflector an additional nonstandard bending tests were performed. The standard three-point and four-point bending tests were not applicable because the thickness of the composite shell is too small and it can be bended to very small radius [2,3]. To perform a test the specimen was taped to the edges of two flat plates mounted on a testing machine as shown in figure 3. The plates were moved closer together making the specimen to bend between them. When the plates were sufficiently close, the specimen failed reaching the failure curvature. The radius of curvature was calculated as half of the distance between two plates.

Figure 3. The bending loading scheme (a) and bending test (b).
To carry out the entire test program, three universal testing machines were used. The tension at normal and high temperatures, compression and bending tests were carried out using the Zwick/Roell Z100 electromechanical testing machine equipped with a contact extensometer and a thermal chamber. The tensile tests at low temperatures were carried out on the modified United Smart 1 SFM-300KN testing machine with an environmental chamber. The measurement of Poisson’s ration and shear tests were performed on the Tinius Olsen 100ST equipped with a video extensometer and a three-rail shear test fixture.

3. Results and discussion
During the tests, the loading diagrams were recorded and processed to determine the corresponding mechanical properties. The minimum radius of curvature $R_{\text{min}}$ was determined as the intersection point of two linear parts of the bending diagram shown in figure 4. This point corresponds to the transition of the specimen from elastic deformation to fracture.

The experimental results are presented in table 1. As the results show, Young’s modulus and tensile strength do not have pronounced temperature dependence. Thus, it can be assumed that the reflector fabricated from the studied material is capable of stable operation under considered temperature conditions. The minimum radius of curvature limits the reflector shape in the folded position that should be taken into account both in the modeling and full-scale experiment of folding the reflector. The obtained mechanical properties can be used for refined numerical calculations of the surface accuracy of the reflector under mechanical and thermal loading [4].

| Testing temperature (°C) | Young’s modulus (MPa) | Tensile strength (MPa) | Poisson’s ration | Compressive strength (MPa) | Shear modulus (MPa) | Shear strength (MPa) | Minimum radius of curvature (mm) |
|--------------------------|-----------------------|-----------------------|-----------------|---------------------------|---------------------|---------------------|---------------------------------|
| -150                     | 66773                 | 809                   | –               | –                         | –                   | –                   | –                               |
| +23                      | 64452                 | 853                   | 0.08            | 171                       | 6151                | 257                 | –                               |
| +125                     | 64951                 | –                     | –               | –                         | –                   | –                   | 16.58                           |

Figure 4. The loading diagram of the bending test.
Acknowledgements
This work was done during the complex project and was financially supported by the Russian Federation Government (Ministry of Education and Science of the Russian Federation). Contract No. 02.G25.31.0147.

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