Paper ID: 70168
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IAF MATERIALS AND STRUCTURES SYMPOSIUM (C2)
Advanced Materials and Structures for High Temperature Applications (4)

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DESIGN OF THERMAL PROTECTION BASED ON CARBON AEROGEL COMPOSITE WITH OPTIMAL STRUCTURE

Abstract

The research of the Sun, planets and small bodies of the solar system using automatic space vehicles is one of the top-priority goals of fundamental space science. During the operation, structures and systems of spacecrafts are subjected to extreme heat loads. The reliable and efficient thermal protection guarantees the successful fulfillment of the mission's scientific goals. Already at the initial stage of spacecraft design it is necessary to solve a set of problems related to the choice of the thermal protection concept and high-temperature heat-resistant construction materials, considering stringent requirements on thermal protection mass. A promising direction in the development of ultralight composites for high-temperature thermal insulation is the infiltration the high-porous open-cell foams with aerogels with extremely low density. This combination of materials makes a composite with overall improved properties than that of either component by itself. The low strength and fragility inherent to aerogels impede production of large monolithic structures. High-porous open cell foams mechanically strengthens aerogel matrix, providing high mechanical characteristics of the composite material. At high temperatures, the thermal conductivity of open-cell foams increases rapidly as radiation through the porous structure becomes the dominant heat transfer mechanism. The infiltration with carbon aerogel allows reducing the radiative conductivity of open-cell foams. Physical properties of foam/aerogel composite are significantly determined by the foam microstructure (cell dimensions, length and cross-sectional dimensions of the struts). This implies possibility to create material with desirable properties, optimal for specific applications. The paper presents a methodology for optimal design of multilayer thermal insulation based on aerogel-filled carbon foam, taking into account the dependence of thermal properties on the foam's morphology. The innovative part of the work lies in determination of the foam cell size together with thickness of layers for multi-layer thermal insulation, ensuring required operational temperature on the boundaries of layers and minimum of total mass of system. The optimization problem is solved using the algorithm based on the projected Lagrangian method with the quadratic subproblem. To illustrate the implementation of the developed algorithm and the corresponding software, the problem of choosing of the optimal layer thickness for the multilayer heat shield of the solar probe along with the structure parameters of carbon foam/aerogel composite, forming one of the layers is considered. The algorithm is applicable for solving a wide range of thermal design problems including the design of advanced thermal protection systems for spacecrafts operating under conditions of extreme thermal loads.