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OPTIMAL DESIGN OF THERMAL PROTECTION CONSIDERING THE CARBON FOAM MORPHOLOGY

Abstract

High-porous open cell foams can be used as efficient thermal insulation in many high-temperature applications including hypersonic vehicles, re-entry spacecrafts, solar and planetary probes, whose structures and systems are exposed to extreme heat loads. The benefits of such materials include extremely low density, high temperature capability, sufficient strength at the operating temperatures and low thermal conductivity. For example, open-cell carbon foam filled with a carbon aerogel and coated with carbon/carbon or ceramic matrix structural outer shell is considered as an advanced highly insulating and light weight thermal protection system of reusable vehicles. Thermal protection system designed for hypersonic vehicles consists of sandwich panels with silicon carbide outer layers and highly porous silicon carbide core. A promising high-temperature thermal insulation of spacecrafts contains highly porous cellular materials based on glassy carbon with porosity, ranging between 82 and 98 %. Physical properties of cellular materials are determined not only by thermal and optical properties of solid phase but also significantly by their morphology and fabrication technology. This implies the possibility to create open-cell materials with desirable properties, optimal for specific operating conditions. The paper presents a methodology for optimal design of multilayer thermal protection based on high porosity open cell carbon foam, taking into account the carbon foam morphology. The traditional thermal design problem statement implies the determination of layers thickness for multi-layer thermal insulation, ensuring required operational temperature on the boundaries of layers and minimum of total mass of system. In this work the cell diameter, that characterize the material's morphology, is chosen along with thicknesses of layers in order to obtain an additional weight advantage of thermal insulation. The radiation-conductive heat transfer in a layer of carbon foam is described using the available analytical laws to predict the radiative properties of open-cell foams. 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 thicknesses for the multilayer heat shield of the solar probe and the cell diameter of carbon foam, forming one of the layers, is considered.