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Robert M. Lurie[a]; Stephen F. D'urso[a]; Charles K. Mullen[a]
[a] A VCO Space Systems Division, Lowell, Massachusetts

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Structural Ablative Plastics

ROBERT M. LURIE, STEPHEN F. D'URSO, and CHARLES K. MULLEN
AVCO Space Systems Division
Lowell, Massachusetts

INTRODUCTION

Laminated reinforced plastics using carbon or silica fabrics and phenolic resins are widely used for ablative liners of rocket nozzles and for other applications requiring protection of structural elements in a high thermal environment. Under cyclic heating conditions, the phenolic resin chars, thereby providing ablation cooling; on cool-down, cracks and/or delaminations result in the majority of applications. On a reheat cycle, as in a multistart engine or other pulsed environment, a burn-through or other catastrophic failure may occur in the cracked areas.

DISCUSSION

Although the ablator is not designed to be the primary load bearer, structural loading due to imposed environment may cause failure in the weak interlaminar direction typical of two-dimensional laminates. Thus, ablative materials are generally bonded to primary load-bearing structures. The bond must provide sufficient strength and elongation together with a low enough modulus to withstand differential expansion between ablator and structure. The stresses leading to failure are further aggravated due to thermal gradients. In many applications the ablator thickness is sized by the temperature limitations of the adhesive rather than the limitations of ablator or structure. An additional complication arises from the fact that the laminated ablator has a large difference in thermal expansion in its different directions. For silica cloth-reinforced phenolic, the coefficients of expansion are $19 \times 10^{-6}/°F$ and $3 \times 10^{-6}/°F$ in the interlaminar and fiber directions, respectively.

The materials developer and hardware designer are thus faced with a number of problems that must be considered namely, strong thermal gradients, multilayered bonded composites, highly anisotropic ablators, and large shrinkages during charring.

The high strength in a composite is in the direction of filament reinforcement (the weak direction is interlaminar); in addition, the thermal expansion is low in that direction. The development of a three-dimensional reinforced composite in block and cylindrical form at Avco Corporation has been aimed at producing a structural ablator which eliminates the need for the bonded primary structure. This approach appears to present unique opportunities for the design of improved structural ablative applications.

Typical forms of three-dimensional reinforcement may be made from quartz, carbon, graphite, boron, and, as far as is known, all fibers and filaments of interest. Blocks with filaments oriented in three mutually perpendicular directions up to 8 X 8 X 16 in. have been made with filament volume loadings of 50%. These have been impregnated with epoxy, phenolic, polyimide, and Teflon resins as well as resins or pitches which may be pyrolyzed to carbon or graphite. Cylindrical or conical configurations with filaments in the axial, hoop, and radial directions are also readily made and have been constructed in sizes up to 16 in. in diam, 30 in. long, and 2 in. thick, with no apparent limitations in any of these dimensions. The materials may also have varying filament composition. For example, a nozzle could be constructed with hoop and axial filaments of carbon or quartz, overlayed with hoop and axial filaments of boron, glass, or graphite with radial filaments of carbon or quartz. This would provide an integrated ablator and structure with no bond. The potential of this composite for reliable, lightweight, and high-performance systems is evident. On an Avco-sponsored program, a conical shape of quartz hoop and axial filaments over Thornel hoop and axial filaments with radial quartz filaments was constructed as a reinforcement for phenolic resin. The hoop strength was 39,000 psi, the longitudinal strength was 35,000 psi, and the radial thermal conductivity was 0.28 Btu/hr-ft-°F. The ablative performance was equal to or better than that of laminated silica phenolic. The coefficient of expansion of the three-dimensional quartz phenolic both in the filament directions and in the direction of minimum direct reinforcement (the cube diagonal) is 4×10^{-6}/°F. The comparative properties are summarized in Table 1.

The use of three-dimensional composites for applications such as gears, bearings, seals, and other mechanical components is also under investigation. The ability to vary the filament composition and concentration in different

Table 1

Properties	Laminated quartz phenolic	Three-dimensional quartz phenolic
Maximum strength, psi	58,000	60,000
Minimum strength, psi	2,300	17,000
Maximum coefficient of expansion	$19.0 \times 10^{-6}/^{\circ}F$	$4 \times 10^{-6}/^{\circ}F$
Minimum coefficient of expansion	$3.0 \times 10^{-6}/^{\circ}F$	$4 \times 10^{-6}/^{\circ}F$
Thermal conductivity, Btu/hr-ft-°F	0.35 (70° to fabric direction)	0.28 (parallel to one of the filament directions)

directions presents the designer with a wider range of choice. It also places greater emphasis on the stress analyst since the material may be tailored to the loading directions and information on stress distribution can be utilized in material construction. Joint design transition areas between different materials must all be considered.

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