

epoxy-impregnated filaments. The entire assembly is heated in an autoclave to cure the epoxy. After the curing process, the multisegmented mandrel is disassembled and removed from inside, leaving the finished tank.

If the tank is to be used for storing hydrogen peroxide, then the liner material should be fluorinated ethylene/propylene (FEP), and one or more FEP O ring(s) should be used in the aluminum end fitting(s). This choice of materials is dictated by experimental observations that pure aluminum and FEP are the only materials suitable for long-term

storage of hydrogen peroxide and that other materials tend to catalyze the decomposition of hydrogen peroxide to oxygen and water.

Other thermoplastic liner materials that are suitable for some applications include nylon 6 and polyethylene. The processing temperatures for nylon 6 are lower than those for FEP. Nylon 6 is compatible with propane, natural gas, and other petroleum-based fuels. Polyethylene is compatible with petroleum-based products and can be used for short-term storage of hydrogen peroxide.

This work was done by Thomas K. DeLay of Marshall Space Flight Center. For further information, access the Technical Support Package (TSP) free on-line at www.techbriefs.com/tsp under the Materials category.

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Thermally Conductive Metal-Tube/Carbon-Composite Joints

Modified solder joints accommodate differential thermal expansion.

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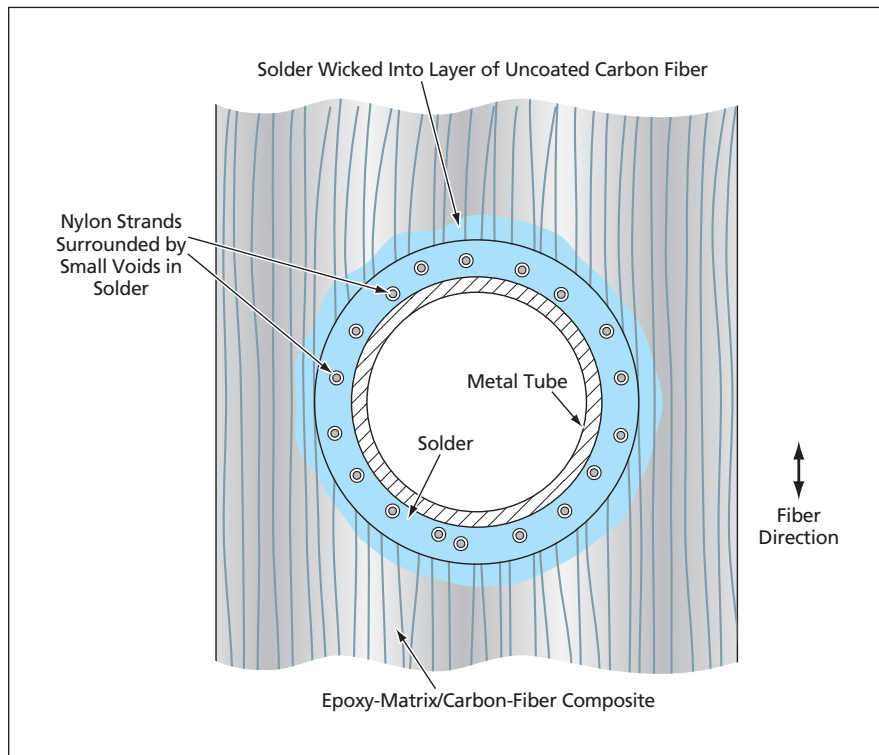
An improved method of fabricating joints between metal and carbon-fiber-based composite materials in lightweight radiators and heat sinks has been devised. Carbon-fiber-based composite materials have been used in such heat-transfer devices because they offer a combination of high thermal conductivity and low mass density. Metal tubes are typically used to carry heat-transfer fluids to and from such heat-transfer de-

vices. The present fabrication method helps to ensure that the joints between the metal tubes and the composite-material parts in such heat-transfer devices have both (1) the relatively high thermal conductances needed for efficient transfer of heat and (2) the flexibility needed to accommodate differences among thermal expansions of dissimilar materials in operation over wide temperature ranges.

Techniques used previously to join metal tubes with carbon-fiber-based composite parts have included press fitting and bonding with epoxy. Both of these prior techniques have been found to yield joints characterized by relatively high thermal resistances.

The present method involves the use of a solder (63 percent Sn, 37 percent Pb) to form a highly thermally conductive joint between a metal tube and a carbon-fiber-based composite structure. Ordinarily, the large differences among the coefficients of thermal expansion of the metal tube, solder, and carbon-fiber-based composite would cause the solder to pull away from the composite upon post-fabrication cooldown from the molten state. In the present method, the structure of the solder is modified (see figure) to enable it to deform readily to accommodate the differential thermal expansion.

In fabricating the composite-material structure, the parts of the carbon fibers adjacent to the hole into which the metal pipe is to be inserted are not coated with the epoxy or other matrix material. The hole is made wide enough to accommodate the tube plus a layer of low-density nylon netting between the tube and the inner surface of the hole. The tube and nylon netting are inserted in the hole, then the solder is melted around the tube. The omission of coating on the fibers adjacent to the hole makes it possible for the solder to wick into the spaces between the fibers and form intimate thermal con-



Small Gaps between the nylon netting and the solder provide flexibility to accommodate differential thermal expansion.

tacts with the fibers. Because the solder does not wet the nylon, a small void forms between each nylon strand and the solder. The thin solder walls that bound the voids are much more flexible than a solid mass of solder would

be; hence, after solidification, the solder can deform to accommodate differential thermal expansion of the various materials present.

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Improved BN Coatings on SiC Fibers in SiC Matrices

Outside debonding would be favored over inside debonding.

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Modifications of BN-based coatings that are used as interfacial layers between the fibers and matrices of SiC-fiber/SiC-matrix composite materials have been investigated to improve the thermomechanical properties of these materials. Such interfacial coating layers, which are also known as interphases (not to be confused with “interphase” in the biological sense), contribute to strength and fracture toughness of a fiber/matrix composite material by providing for limited amounts of fiber/matrix debonding and sliding to absorb some of the energy that would otherwise contribute to the propagation of cracks.

Heretofore, the debonding and sliding have been of a type called “inside debonding” because they have taken place predominantly on the inside surfaces of the BN layers — that is, at the in-

terfaces between the SiC fibers and the interphases. The modifications cause the debonding and sliding to include more of a type, called “outside debonding,” that takes place at the outside surfaces of the BN layers — that is, at the interfaces between the interphases and the matrix (see figure).

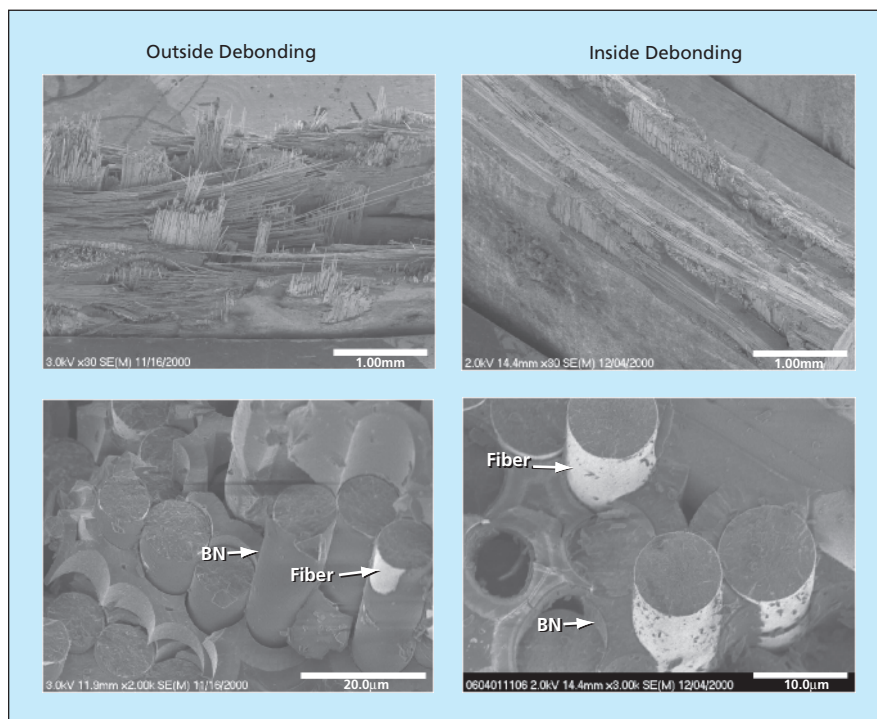
One of the expected advantages of outside debonding is that unlike in inside debonding, the interphases would remain on the crack-bridging fibers. The interphases thus remaining should afford additional protection against oxidation at high temperature and should delay undesired fiber/fiber fusion and embrittlement of the composite material. A secondary benefit of outside debonding is that the interphase/matrix interfaces could be made more compliant than are the fiber/interphase inter-

faces, which necessarily incorporate the roughness of the SiC fibers. By properly engineering BN interphase layers to favor outside debonding, it should be possible, not only to delay embrittlement at intermediate temperatures, but also to reduce the effective interfacial shear strength and increase the failure strain and toughness of the composite material.

Two techniques have been proposed and partially experimentally verified as candidate means to promote outside debonding in state-of-the-art SiC/SiC composites. The first technique is one of application of a weak layer (for example, a layer of C) to the outer surface of the BN interphase. If residual radial tension exists across the interphase (caused, for example, by a thermal-expansion mismatch between the fiber and matrix), then outside debonding could occur during cool down of the composite from its matrix-processing temperature (typically >1,000 °C) to room temperature. If the residual tension is not great enough, outside debonding should nevertheless occur as matrix cracks approach the fibers under some stress conditions.

The second technique for promoting outside debonding is one of heat treatment of the composite at a temperature above that normally used for processing the matrix. During the heat treatment, the BN interphase, which is typically formed in a porous state at temperatures below 1,000 °C, becomes densified by sintering, so that the interphase contracts away from the SiC matrix. This contraction may cause a gap to form between the BN interphase and SiC matrix, or, at the very least, increase the residual radial tension at the BN/matrix interface.

In stress-rupture tests in air at a temperature of 800 °C, the 100-hour failure stress of state-of-the-art SiC/SiC composite modified to promote outside debond-



Specimens of SiC/SiC Composites that have undergone outside and inside debonding are depicted in scanning electron micrographs at various magnifications.