



## **Brazing SiC/SiC Composites to Metals**

**Success depends on suitable process conditions and adequate titanium contents in brazing alloys.**

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Experiments have shown that active brazing alloys (ABAs) can be used to join SiC/SiC composite materials to metals, with bond strengths sufficient for some structural applications. The SiC/SiC composite coupons used in the experiments were made from polymer-based SiC fiber preforms that were chemical-vapor-infiltrated with SiC to form SiC matrices. Some of the metal coupons used in the experiments were made from 304 stainless steel; others were made from oxygen-free, high-conductivity copper.

Three ABAs were chosen for the experiments: two were chosen randomly from among a number of ABAs that were on hand at the time; the third ABA was chosen because its titanium content (1.25 percent) is less than those of the other two ABAs (1.75 and 4.5 percent, respectively) and it was desired to evaluate the effect of reducing the titanium content, as described below. The characteristics of ABAs that are considered to be beneficial for the purpose of joining SiC/SiC to metal include wettability, reactivity, and adhesion to SiC-based ceramics. Prior to further development, it was verified that

the three chosen ABAs have these characteristics.

For each ABA, suitable vacuum brazing process conditions were established empirically by producing a series of (SiC/SiC)/ABA wetting samples. These samples were then sectioned and subjected to scanning electron microscopy (SEM) and energy-dispersive x-ray spectrometry (EDS) for analysis of their microstructures and compositions. Specimens for destructive mechanical tests were fabricated by brazing of lap joints between SiC/SiC coupons 1/8-in. ( $\approx 3.2$ -mm) thick and, variously, stainless steel or copper tabs. The results of destructive mechanical tests and the SEM/EDS analysis were used to guide the development of a viable method of brazing the affected materials.

The 1.75-percent-Ti ABA was found to be well suited for joining the SiC/SiC composite with 304 stainless steel. The (SiC/SiC)/Cu joints made by use of the 1.75- and 4.5-percent-Ti ABAs were found to be stronger than were the (SiC/SiC)/Cu joints made by use of the 1.25-percent-Ti. At the time of reporting the information for this article, it was believed that the 1.25-percent titanium

content was insufficient for reacting with the SiC/SiC composite; however, it was uncertain whether an observed difficulty in producing joints of acceptably high quality was caused at least in part by surface contaminants that could consume what little titanium was available for reacting with SiC.

The strengths of the (SiC/SiC)/stainless-steel joints tested ranged up to a maximum of 24.5 MPa for joints made with the 1.75-percent Ti ABA. The strengths of the (SiC/SiC)/Cu joints tested ranged up to a maximum of 23.1 MPa for joints made with the 4.5-percent Ti ABA. The preliminary data on the (SiC/SiC)/1.75-percent-Ti ABA/stainless-steel and (SiC/SiC)/4.5-percent-Ti ABA/Cu joints show that the characteristics of the joints are highly predictable — a quality that is desirable for optimization of design.

*This work was done by Wayne S. Steffier of Hyper-Therm High-Temperature Composites, Inc., for Marshall Space Flight Center. Further information is contained in a TSP (see page 1).  
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## **Composite-Material Tanks With Chemically Resistant Liners**

**Liner materials are chosen for compatibility with reactive and/or unstable fluids.**

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Lightweight composite-material tanks with chemically resistant liners have been developed for storage of chemically reactive and/or unstable fluids — especially hydrogen peroxide. These tanks are similar, in some respects, to the ones described in “Lightweight Composite-Material Tanks for Cryogenic Liquids” (MFS-31379), *NASA Tech Briefs*, Vol. 25, No. 1 (January, 2001), page 58; however, the present tanks are fabricated by a different procedure and they do not incorporate insulation that would be needed to prevent boil-off of cryogenic fluids.

The manufacture of a tank of this type begins with the fabrication of a reusable multisegmented aluminum mandrel in the shape and size of the desired interior volume. One or more segments of the mandrel can be aluminum bosses that will be incorporated into the tank as end fittings.

The mandrel is coated with a mold-release material. The mandrel is then heated to a temperature of about 400 °F ( $\approx 200$  °C) and coated with a thermoplastic liner material to the desired thickness [typically  $\approx 15$  mils ( $\approx 0.38$  mm)] by thermal spraying. In the ther-

mal-spraying process, the liner material in powder form is sprayed and heated to the melting temperature by a propane torch and the molten particles land on the mandrel.

The sprayed liner and mandrel are allowed to cool, then the outer surface of the liner is chemically and/or mechanically etched to enhance bonding of a composite overwrap. The etched liner is wrapped with multiple layers of an epoxy resin reinforced with graphite fibers; the wrapping can be done either by manual application of epoxy-impregnated graphite cloth or by winding of

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](http://www.techbriefs.com/tsp) under the Materials category.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center, (256) 544-0021. Refer to MFS-31401.*

## Thermally Conductive Metal-Tube/Carbon-Composite Joints

Modified solder joints accommodate differential thermal expansion.

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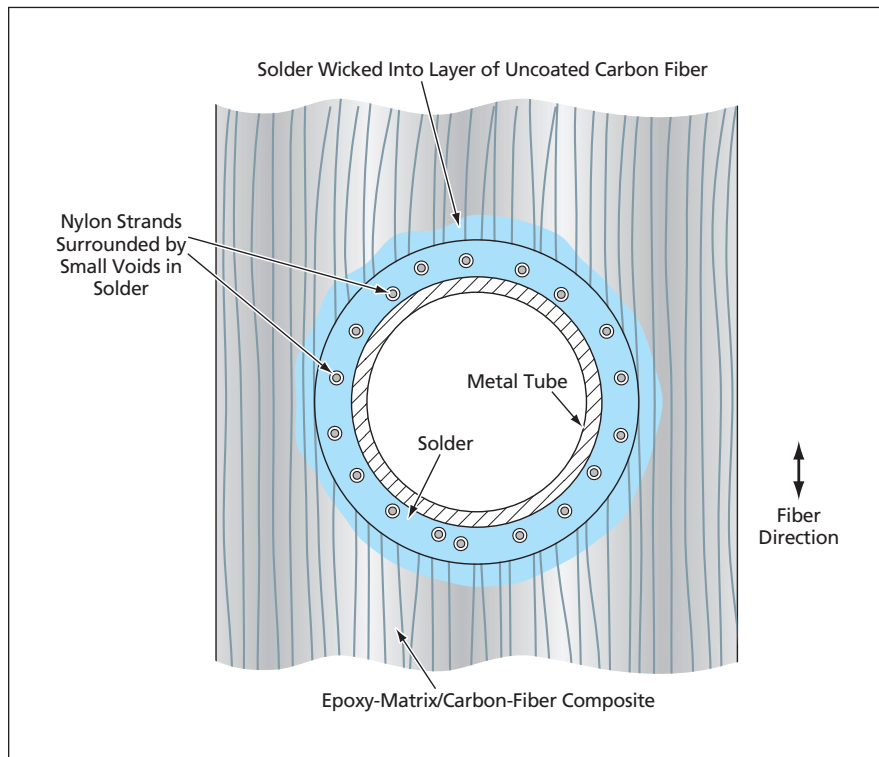
An improved method of fabricating joints between metal and carbon-fiber-based composite materials in lightweight radiators and heat sinks has been devised. Carbon-fiber-based composite materials have been used in such heat-transfer devices because they offer a combination of high thermal conductivity 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.