

pellet width, only a thin outer layer is utilized effectively. A TiO<sub>2</sub> loading of 13 weight percent has been found to result in the best removal of Hg, both with and without ultraviolet light. Humidity has been found to impede adsorption, thereby reducing the overall Hg-removal efficiency. An examination of the effects of flow velocity revealed that adsorption

is the rate-limiting step, suggesting a need to improve mass-transfer characteristics to obtain better performance.

*This work was done by David Mazyck, Danielle Londeree, Chang-Yu Wu, Kevin Powers, and Erik Pitoniak of the University of Florida for Johnson Space Center.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this*

*invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## **Lightweight Tanks for Storing Liquefied Natural Gas**

**These tanks are also relatively inexpensive.**

*Marshall Space Flight Center, Alabama*

Single-walled, jacketed aluminum tanks have been conceived for storing liquefied natural gas (LNG) in LNG-fueled motor vehicles. Heretofore, double-wall steel tanks with vacuum between the inner and outer walls have been used for storing LNG. In comparison with the vacuum-insulated steel tanks, the jacketed aluminum tanks weigh less and can be manufactured at lower cost. Costs of using the jacketed aluminum tanks are further reduced in that there is no need for the vacuum pumps heretofore needed to maintain vacuum in the vacuum-insulated tanks.

The single-walled, jacketed aluminum tanks are members of the class of composite overwrapped pressure vessels; that is, they comprise basically, seamless aluminum tank liners overwrapped in composite (matrix/fiber) materials. On each

such tank, the composite overwrap is further encapsulated in a layer of insulating foam, which, in turn, is coated with a flexible sealant that protects the foam against abrasion, ultraviolet light, and other adverse environmental phenomena.

The innovative tank concept admits to a number of variations. For example, the aluminum tank liner can be a common, commercially available aluminum tank liner that is already certified by the United States Department of Transportation for use at pressure up to 3,000 psi ( $\approx 20.7$  MPa). The composite-material overwrap can be made by winding high-strength-carbon-fiber/poly(phenylene benzo-bisoxazole)-fiber hybrid filaments with an epoxy matrix material. The insulating layer can be made by spraying polyurethane foam, waiting for the foam to cure to rigidity, then machining the

foam to final size and shape. The protective outer layer can be formed by brush application of a ductile epoxy or spray application of a truck-bed-liner material.

Of course, if the tank liner is a pressure vessel as in the example above, then the tank can be used to store a high-pressure gaseous fuel. Moreover, in the case of storage of LNG, the high-pressure capability of the tank helps to conserve stored fuel by reducing the need to vent gas to relieve pressure as heat leaks into the tank, causing slow vaporization of the LNG.

*This work was done by Tom DeLay of Marshall Space Flight Center.*

*This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32024-1.*

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## **Hybrid Wound Filaments for Greater Resistance to Impacts**

**PBO fibers are used in addition to high-strength carbon fibers.**

*Marshall Space Flight Center, Alabama*

The immediately preceding article includes an example in which a composite overwrap on a pressure vessel contains wound filaments made of a hybrid of high-strength carbon fibers and poly(phenylene benzobisoxazole) [PBO] fibers. This hybrid material is chosen in an effort to increase the ability of the pressure vessel to resist damage by low-speed impacts (e.g., dropping of tools on the vessel or bumping of the vessel against hard objects during installation and use) without significantly increasing the weight of the vessel. Heretofore, enhancement of the impact resistances of fila-

ment-wound pressure vessels has entailed increases in vessel weight associated, variously, with increases in wall thickness or addition of protective materials.

While the basic concept of hybridizing fibers in filament-wound structures is not new, the use of hybridization to increase resistance to impacts is an innovation, and can be expected to be of interest in the composite-pressure-vessel industry. The precise types and the proportions of the high-strength carbon fibers and the PBO fibers in the hybrid are chosen, along with the filament-winding pattern, to maximize the advan-

tageous effects and minimize the disadvantageous effects of each material. In particular, one seeks to (1) take advantage of the ability of the carbon fibers to resist stress rupture while minimizing their contribution to vulnerability of the vessel to impact damage and (2) take advantage of the toughness of the PBO fibers while minimizing their contribution to vulnerability of the vessel to stress rupture.

Experiments on prototype vessels fabricated according to this concept have shown promising results. At the time of reporting the information for this article, research toward understanding and

optimizing the performances of PBO fibers so as to minimize their contribution to vulnerability of the pressure vessel to stress rupture had yet to be performed.

*This work was done by Thomas K. DeLay of Marshall Space Flight Center and James E. Patterson and Michael A. Olson of HyPer-Comp Engineering, Inc.  
This invention is owned by NASA, and a*

*patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31838-1.*

## Making High-Tensile-Strength Amalgam Components

**Instead of spheroids or flakes, wires are used as the solid constituents.**

*Marshall Space Flight Center, Alabama*

Structural components made of amalgams can be made to have tensile strengths much greater than previously known to be possible. Amalgams, perhaps best known for their use in dental fillings, have several useful attributes, including room-temperature fabrication, corrosion resistance, dimensional stability, and high compressive strength. However, the range of applications of amalgams has been limited by their very small tensile strengths. Now, it has been discovered that the tensile strength of an amalgam depends critically on the sizes and shapes of the particles from which it is made and, consequently, the tensile strength can be greatly increased through suitable choice of the particles.

The term “amalgam” generally denotes an alloy of mercury with one or more other metals (e.g., copper or a copper alloy in the case of dental fillings). Amalgams can also be based on gallium, or gallium alloys, which melt near room temperature. An amalgam is formed by a peritectic reaction in a process called “trituration,” in which the solid metal (e.g., copper) in powder form is ground together with the liquid

metal (e.g., gallium). The grinding serves to break the oxide skin on the solid metal particles, enabling wetting of the clean metal surfaces by the liquid metal. The liquid metal reacts with the solid metal to form a new solid that is a composite of the starting solid metal (e.g., Cu) and an intermetallic compound (e.g., CuGa).

Heretofore, the powder particles used to make amalgams have been, variously, in the form of micron-sized spheroids or flakes. The tensile reinforcement contributed by the spheroids and flakes is minimal because fracture paths simply go around these particles. However, if spheroids or flakes are replaced by strands having greater lengths, then tensile reinforcement can be increased significantly. The feasibility of this concept was shown in an experiment in which electrical copper wires, serving as demonstration substitutes for copper powder particles, were triturated with gallium by use of a mortar and pestle and the resulting amalgam was compressed into a mold. The tensile strength of the amalgam specimen was then measured and found to be greater than  $10^4$  psi (greater than about 69 MPa).

Proceeding forward from this demonstration of feasibility, much remains to be done to optimize the properties of amalgams for various applications through suitable choice of starting constituents and modification of the trituration and molding processes. The choice of wire size and composition is expected to be especially important. Perusal of phase diagrams of metal mixtures could give insight that would enable choices of solid and liquid metal constituents. For example, phase diagrams have revealed that gallium should form amalgams with iron and nickel (as already demonstrated), as well as zirconium, and titanium. Finally, whereas heretofore, only binary alloys have been considered for amalgams, ternary additions to liquid or solid components should be considered as means to impart desired properties to amalgams.

*This work was done by Richard Grugel of Marshall Space Flight Center.*

*This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32254-1.*

## Bonding by Hydroxide-Catalyzed Hydration and Dehydration

**Room-temperature process can be varied to suit optical and non-optical applications.**

*Marshall Space Flight Center, Alabama*

A simple, inexpensive method for bonding solid objects exploits hydroxide-catalyzed hydration and dehydration to form silicatelike networks in thin surface and interfacial layers between the objects. (Silicatelike networks are chemical-bond networks similar to, but looser than, those of bulk silica). The method can be practiced at room temperature or over a wide range of temperatures.

The method was developed especially to enable the formation of precise, reli-

able bonds between precise optical components. The bonds thus formed exhibit the precision and transparency of bonds formed by the conventional optical-contact method and the strength and reliability of high-temperature frit bonds. The method also lends itself to numerous non-optical applications in which there are requirements for precise bonds and/or requirements for bonds, whether precise or imprecise, that can reliably withstand severe environmental condi-

tions. Categories of such non-optical applications include forming composite materials, coating substrates, forming laminate structures, and preparing objects of defined geometry and composition.

The method is applicable to materials that either (1) can form silicatelike networks in the sense that they have silicatelike molecular structures that are extensible into silicatelike networks or (2) can be chemically linked to silicatelike networks by means of hydroxide-