Manufacturing & Prototyping

Manufacturing Large Membrane Mirrors at Low Cost

Shapes are determined by edge retention fixtures rather than by precise molds.

Marshall Space Flight Center, Alabama

Relatively inexpensive processes have been developed for manufacturing lightweight, wide-aperture mirrors that consist mainly of reflectively coated, edge-supported polyimide membranes. The polyimide and other materials in these mirrors can withstand the environment of outer space, and the mirrors have other characteristics that make them attractive for use on Earth as well as in outer space:

- With respect to the smoothness of their surfaces and the accuracy with which they retain their shapes, these mirrors approach the optical quality of heavier, more expensive conventional mirrors.
- Unlike conventional mirrors, these mirrors can be stowed compactly and later deployed to their full sizes. In typical cases, deployment would be effected by inflation.

Potential terrestrial and outer-space applications for these mirrors include large astronomical telescopes, solar concentrators for generating electric power and thermal power, and microwave reflectors for communication, radar, and short-distance transmission of electric power.

The relatively low cost of manufacturing these mirrors stems, in part, from the use of inexpensive tooling. Unlike in the manufacture of conventional mirrors, there is no need for mandrels or molds that have highly precise surface figures and highly polished surfaces. The surface smoothness is an inherent property of a polyimide film. The shaped area of the film is never placed in contact with a mold or mandrel surface: Instead the shape of a mirror is determined by a combination of (1) the shape of a fixture that holds the film around its edge and (2) control of manufacturing-process parameters.

In a demonstration of this manufacturing concept, spherical mirrors having aperture diameters of 0.5 and 1.0 m were fabricated from polyimide films having thicknesses ranging from <20 μm to 150 μm. These mirrors have been found to maintain their preformed shapes following deployment.

This work was done by Larry J. Bradford of United Applied Technologies for **Marshall Space Flight Center**. *Further information is contained in a TSP* *(see page 1).*

MFS-32176-1

Double-Vacuum-Bag Process for Making Resin-Matrix Composites

To prevent formation of voids, volatiles are removed before applying consolidation pressure.

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A double-vacuum-bag process has been devised as a superior alternative to a single-vacuum-bag process used heretofore in making laminated fiber-reinforced resin-matrix composite-material structural components. This process is applicable to broad classes of high-performance matrix resins — including polyimides and phenolics — that emit volatile compounds (solvents and volatile by-products of resin-curing chemical reactions) during processing. The superiority of the double-vacuum-bag process lies in enhanced management of the volatile compounds. Proper management of volatiles is necessary for making composite-material components of high quality: if not removed and otherwise properly managed, volatiles can accumulate in interior pockets as resins cure, thereby forming undesired voids in the finished products.

The curing cycle for manufacturing a composite laminate containing a reactive resin matrix usually consists of a two-step ramp-and-hold temperature profile and an associated single-step pressure profile as shown in Figure 1. The lower-temperature ramp-and-hold step is known in the art as the B stage. During the B stage, prepregs are heated and volatiles are generated. Because pressure is not applied at this stage, volatiles are free to escape. Pressure is applied during the higher-temperature ramp-and-hold step to consolidate the laminate and impart desired physical properties to the resin matrix. The residual volatile content and fluidity of the resin at the beginning of application of consolidation pressure are determined by the temperature and time parameters of the B stage. Once the consolidation pressure is applied, residual volatiles are locked in. In order to produce a void-free, high-quality laminate, it is necessary to design the curing cycle to obtain the required residual fluidity and the required temperature at the time of application of the consolidation pressure.

Single-vacuum-bag processing in an oven is one of the most cost-effective techniques for making fiber-reinforced resin matrix composites in cases in which resins undergoing curing do not emit volatiles. However, this technique is often ineffective in cases in which volatiles are emitted. In order to produce a void-free composite laminate, it is imperative to remove the volatiles before commencing forced consolidation. A single-vacuum-bag assembly inherently hinders the removal of volatiles because the vacuum-induced compaction interferes with the vacuum-induced outgassing. The present double-vacuum-bag process eliminates this interference while still providing for vacuum-induced compaction.

Figure 2 depicts the double-vacuum-bag assembly used in this process. Fiber-reinforced, reactive-resin-matrix prepregs are laid up between a steel caul plate and a steel tool plate. This sub-

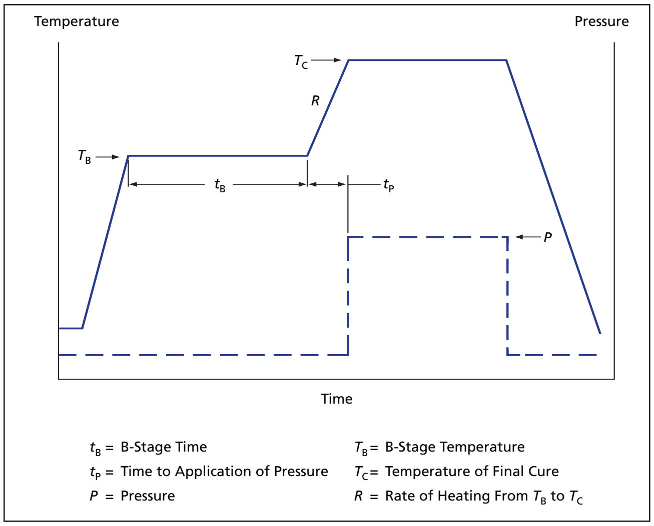

Figure 1. These **Temperature and Pressure Profiles** are typical of the curing cycle of a composite laminate containing a reactive resin matrix.

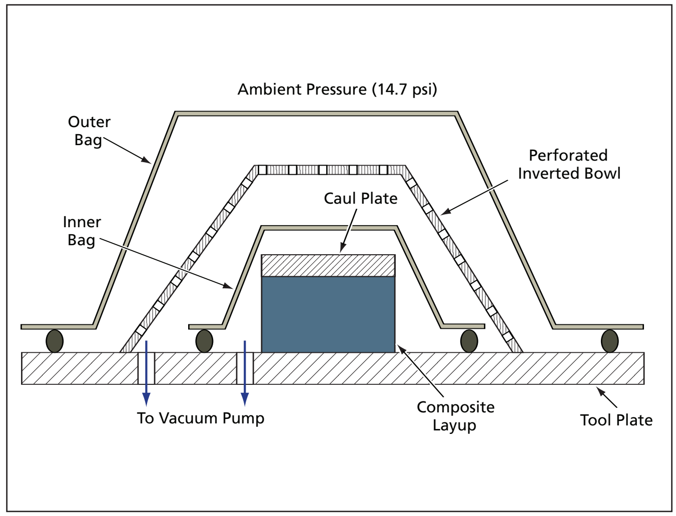

Figure 2. This **Double-Vacuum-Bag Assembly** makes it possible to maintain vacuum (for removal of volatiles) during the B stage, and then to apply consolidation pressure during the high-temperature curing stage.

assembly is then enclosed by a vacuum bag, designated the inner bag, which is sealed around its edges onto the tool plate. Through a port built into the tool plate, the interior of the inner bag is connected to a vacuum pump. A tool that amounts to a perforated inverted bowl is placed on the tool plate outside the perimeter of the inner bag. Another vacuum bag, denoted the outer bag, is installed over the perforated inverted bowl, sealed to the tool plate, and connected to a vacuum pump in the same manner as that of the inner bag. The perforated inverted bowl must be rigid enough to withstand atmospheric pressure when the outer bag is evacuated.

This double-vacuum-bag assembly is placed in a forced-air-circulation oven and subjected to prescribed curing cycle. During the B stage, full vacuum is applied in the outer bag, causing the outer bag to collapse onto the perforated inverted bowl. At the same time, a slightly lower vacuum [typically, a pressure of 2 in. Hg (≈7 kPa)] is applied in the inner bag. Because of the greater pressure in the inner bag, the inner bag expands against the perforated inverted bowl, leaving no compaction force on the composite layup. Hence, volatiles are free to escape and are removed by the inner-bag vacuum pump.

At the end of the B stage, the atmosphere is admitted to the interior of the outer bag, and full vacuum is applied in the inner bag. Therefore, the outer bag becomes loose from the perforated inverted bowl and the inner bag collapses onto the caul plate at atmospheric pressure, which now serves as the compaction pressure. The vacuum in the inner bag, and thus the compaction pressure, is maintained during the high-temperature ramp-and-hold period of the curing cycle.

This work was done by Tan-Hung Hou and Brian J. Jensen of **Langley Research Center**. *Further information is contained in a TSP (see page 1).*

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, Langley Research Center, at (757) 864-3521. Refer to LAR-16877.