

Shape Memory Polymer Bladder Tooling

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PROBLEM STATEMENT

When using lightweight composite materials for the production of military ground and air vehicles, autoclaves have traditionally been used to ensure high-quality composite parts. This dependency on the autoclave has plagued the composite industry with the inability to manufacture high-quality parts at high-volume and low-cost due to labor intensive techniques and large capital equipment costs inherent in the autoclaving process.

The introduction of new out-of-autoclave (OOA) technologies has begun to decrease the dependency on the autoclave. These technologies include the development of new materials and resins and manufacturing techniques. While these materials and processes open up opportunities to produce high-quality composite parts outside of the autoclave, there are still the same tooling drawbacks, particularly for complex geometry and “trapped” components. Complex composite geometries are often needed to provide structurally efficient designs and reduce or eliminate the requirement for fastening. Fabrication of these complex composite parts traditionally requires tooling that is both expensive to fabricate and labor intensive to use.

One of the most labor-intensive types of tooling is associated with complex composite shape where the tooling is trapped or cannot be removed in a single piece. A relatively simple process of laying-up a composite part is complicated when the internal tooling must be removed.

One type of tooling currently in wide use consists of multiple parts that must be disassembled from inside the composite and then reassembled before use. This makes mandrels very expensive to develop, difficult to fabricate, and time consuming to extract from a cured, complex composite part. Each composite part requires the design of a unique mandrel that is sectioned to enable removal from the composite.

A second tooling solution in use is “washout” or loss-type mandrels. The mandrel is made of a material that is rigid during fabrication of the composite part but can later be removed by solvent washout or heat melt-out. These types of mandrels are time consuming to fabricate, fragile to use, and time consuming to remove. Also, the material that is removed must either be collected for reuses or often becomes waste that needs to be disposed.

A third type of tooling that is commonly used is elastomeric bladders. The drawback to elastomeric tooling is that it does not provide a stable lay-up surface for the uncured composite material and can also be easily damaged. The drawbacks present in each of these tooling solutions has a significantly inherent tooling and labor cost, making it difficult to manufacture a cost effective vehicle.

The excess cost and labor associated with tooling can be minimized with the incorporation of advanced tooling technologies. Cornerstone Research Group (CRG) has previously demonstrated Shape Memory Polymer (SMP) bladder tooling that is capable of providing composite consolidation consistent with autoclave cures while providing an 80% savings in manufacturing costs.

WHO CAN BENEFIT?

In addition to the official supporting program, the H-1, CRG has identified multiple markets and platforms that would stand to benefit from a novel manufacturing process. CRG has primarily targeted the aerospace markets to date as a result of their desire for laminate consolidation and low void content.

CRG is currently working with a variety of aerospace customers focused on both fixed wing and rotary aircraft. Working with our industry partners, CRG has identified cost savings opportunities on components ranging from rotorcraft cuffs to engineering stiffening features and composite ductwork.

CRG has identified a market opportunity for Smart Tooling that is comprised of composite components that are complex and/or have trapped features. As a result of the initial design and tooling costs, CRG anticipates the largest market acceptance from manufactures that produce more than 100 units per single design.

BASELINE TECHNOLOGY

Multiple baseline solutions exist on the market today capable of manufacturing complex and trapped geometry composites, however these processes require large up from tooling costs and/or require significant labor to manufacture. These baseline technologies include multi-piece mandrels, washout ceramics and salts, and removable silicone bladders.

Multi-piece Tooling – Multi-piece tooling is assembled and disassembled to allow for fabrication of complex and trapped geometry composites. The tools are designed similar to a 3D jigsaw puzzle that when assembled creates the inner mold line of the composite structure. Once the tools are assembled they are mold released then laid up on with composite material. Once the composite laminate is cured the tool is disassembled for extraction.

Washout Ceramic Tooling – The theory of washout tooling is that once the composite laminate is cured the tooling is either washed out with water or a solvent or the tooling melts out during the composite laminate post cure. The tool form is created by a casting process where a liquid material is injected into a cavity then reacted or cured to make it solid. Once cured the tool requires finishing and sealing prior to use.

Silicone Bladder Tooling – Silicone Bladder Tooling is used when a controlled outer mold line is required. The composite material is applied to a substructure stiffened silicone bladder then the tooling and composite assembly is placed into a machined cure tool. During the laminate cure the cavity of the silicone bladder is pressurized consolidating the laminate from the inside out. Following cure the pressure is released from the bladder and the substructure is removed, either by disassembly or washout methods, then the bladder is extracted.

TECHNOLOGY DESCRIPTION

First introduced in the United States in 1984, SMPs are polymers whose qualities have been altered to give them dynamic shape “memory” properties. Under thermal stimuli, SMP exhibits a radical change from a rigid thermoset to a highly flexible elastic state and then returns to a rigid state again when cooled. In its elastic state, SMP will recover its “memory” shape if left unrestrained. The “memory,” or recovery, quality comes from the stored mechanical energy attained during the reconfiguration and cooling of the material. SMP’s ability to change stiffness modulus and shape configuration at will makes it ideal for applications requiring lightweight, dynamic, adaptable materials.

Unlike a Shape Memory Alloy (SMA), SMP exhibits a radical change from a rigid polymer to a flexible elastomer and back on command, a change that can be repeated without degradation of the material. The SMP transition process is a thermo molecular relaxation rather than a thermally induced crystalline phase transformation, as with SMA. In addition, SMP demonstrates much broader range and versatility than SMA in shape configuration and manipulation.

SMP is a fully formable thermoset. It exhibits high-performance characteristics of both an elastomer and a thermoset, depending on temperature exposure. While rigid, SMP demonstrates the strength-to-weight ratio of a rigid thermoset polymer; however, normal polymers under thermal stimulus simply flow or melt as thermoplastics, or char as thermosets above their glass transition temperature (T_g) and they have no “memorized” shape to which they return. While heated and pliable, SMP has the flexibility of a high-quality, dynamic elastomer, tolerating up to 800% elongation; however, unlike normal elastomers, SMP can be reshaped or, if unrestrained, returned quickly to its memorized shape and subsequently cooled into a rigid thermoset. Figure 1 shows the elastic modulus of SMP in relation to temperature. Figure 2 shows a chart of storage modulus (stiffness) versus temperature, showing the initial range of a styrene SMP with activation temperatures customizable to between 110°F and 220°F (47 °C to 106 °C).

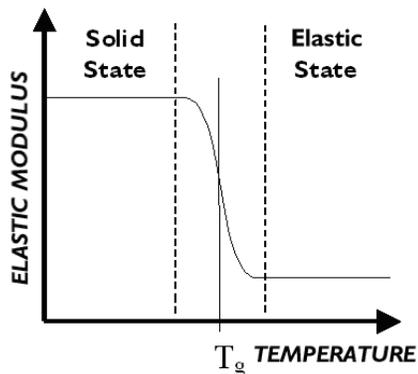


Figure 1: SMP elastic modulus versus temperature

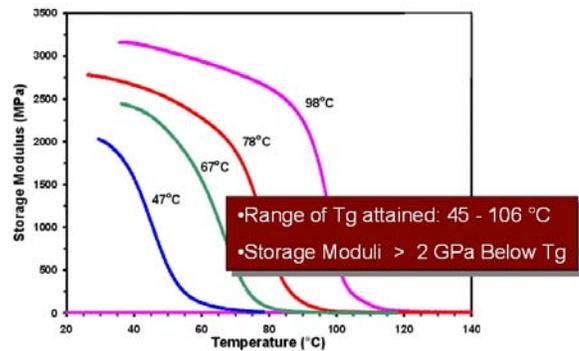


Figure 2: Dynamic Mechanical Analysis (DMA) graph of various styrene SMP storage moduli

SMP Bladders

SMP Bladders are thermoset tooling products that operate first as mandrels and later as inflatable bladder cores. First providing a rigid, durable surface for composite lay-up, SMP bladders then provide flexibility and inflatability when the part is formed against the interior of the final mold. The SMP Bladder process is outlined below:

Step 1- When heated above their activation temperatures, SMP bladders become flexible and can be molded into a near-net bladder shape. When cooled while still under pressure in the near-net mold, they become rigid in the new shape.

Step 2- The resulting rigid bladder is mold released then used as a mandrel for lay-up or filament-winding of a composite part.

Step 3- The composite lay-up on the SMP bladder is then inserted into a clamshell mold and subjected to air pressure and heat. The heat softens the SMP bladder, so it becomes flexible and inflates, consolidating the composite material against the mold, ensuring even expansion and precise outer surface dimensions on the part. The part is then cured while pressurized. Since the cure temperature of the composite is higher than the rigid-to-flexible transition temperature of the bladder, the bladder remains flexible and provides consistent pressure on the interior of the part.

Step 4- Once the part is cured, the flexible SMP bladder is depressurized and contracts from the inner surface of the part. Because of its flexibility when heated, it can be removed easily and reused. Since the mold was completely closed when forming the part, wrinkling, bridging, and pinching are less likely. The resulting precision part is seamless and requires no taping, sealing, or pleating.

SMP Bladders are capable of supporting composite cure cycles up to 350°F and have the ability to tailor their transition temperatures between 113°F and 250°F.

CURRENT STATE OF DEVELOPMENT

In support of the H1 program, CRG is currently conducting applied development of the SMP Bladder 350 product to the manufacture of the H1 rotor cuff. The SMP Bladder product has previously been flight certified on Raytheon's Miniature Air Launch Decoy (MALD) platform.

The application process for this product requires platform specific design for each composite component as well as tooling designs required for each component. CRG is currently completing the tooling design and anticipating H1 cuff manufacturing mid calendar year 2011.

CRG has also had success introducing this product line into the automotive, marine, architectural, and tire industries.

REFERENCES

All customers under strict Non-disclosure Agreement (NDA) agreements.

WHEN THE TECHNOLOGY WILL BE READY FOR USE

With investment at over \$20 million, CRG has been developing and commercializing Smart Tooling for the last seven years. The Smart Tooling product line is comprised of multiple material systems and tooling philosophies that enable inner mold line (IML) composite cures up to 250°F and outer mold line (OML) composite cure up to temperatures of 350°F. Four basic products comprise the Smart Tooling product line, all with Technology Readiness Levels (TRLs) higher than 6. Some of the Smart Tooling product line, particularly SMP Bladders 350, has been successfully implemented into manufacturing of primary structural flight components for delivery and field deployment resulting in a TRL of 9, "Actual System Proven through Successful

Mission Operations."

The balance of the Smart Tooling product line is commercially available and ready for implementation; however CRG has not yet been able to identify an appropriate production system for implementation and therefore is currently at TRL 6.

In addition to the baseline products offered under the Smart Tooling product line, CRG is developing higher temperature compatible materials that are currently at TRL's 2-6. These novel materials will allow for significantly higher cure temperatures than currently available as well as non-thermal activation mechanisms including electrical and light.

ABOUT THE COMPANY

CRG conducts research and development, from molecule to manufacturing, in an array of markets. Providing technology and product development services, we have established a no-nonsense ability to invent breakthrough technology, bridge the proverbial "valley of death," and deliver a viable product. Our core competencies are systems design, non-metallic advanced materials, and manufacturing process development. Our success stems from the way we couple our technological development with aggressive entrepreneurial business practices. We provide solutions, driving new technologies from early research through final production. We have the proven ability to commercialize products in a number of ways, including spinning off new independent divisions and companies focused on promising technologies mature enough to fulfill a customer's specific needs.

Since its founding, our company has developed an array of unique materials, systems, and manufacturing processes. Many of the results are opportunities waiting to be commercialized through incorporation into future systems or through expansion of their use in new business areas.

A primary purpose of our business is to serve as an incubator of emerging technologies ready to be introduced into the marketplace. Each viable technology stemming from government SBIRs and other research programs has its own potential target market or target system for implementation. Therefore, a specialized business approach is needed to develop and mature each new technology. To address these diverse business needs and opportunities, we create independent divisions or even spin-off companies that focus on commercializing promising technologies. These spin-offs leverage millions of dollars in research and development of a product or system to support application in other business areas.

The formation of a new company focuses on maturing a technology for specific customers. While our Research and Development services business model is to pursue innovative ideas and foster emerging technologies, some of which may not be realized for many years, the spin-off companies customize, refine, standardize, and market technologies that are ripe for implementation. These non-competitive spin-offs are designed to work with our current customers, complementing and supporting their business interests. They also provide involvement possibilities for angel and venture investors and opportunities for employees to pursue new career directions.