Tooling It Up FOR COMPOSITES


Photo courtesy NGC

F-35 inlet ducts are built in one piece, and are an example of the challenge and achievement of unitization.

Engineers continue to advance new tooling concepts for composite parts

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From Boeing 787s to new Navy destroyers, fiber-reinforced composites are gaining in use. As production scales up, more-efficient manufacturing remains a focus. One key to that efficiency is tooling for composites. These molds and forms give the final shape to a part, and are often integral to their final curing. Manufacturing trends in aerospace, in particular, are prompting a search for new tooling concepts, even while other industries strive for increased efficiency and accuracy. Resin providers are offering newer composites engineered for tooling, even while metallic tooling is seeing its own advances.

"A tool [for composites] must be accurate, rigid, easy to use, and economical," says Bert Erdel, executive technology advisor of the Morris Group (Windsor, CT). In most situations, maintaining tight tolerances means matching the coefficient of thermal expansion (CTE) of the tool to the composite material. This is especially true during a high-temperature cure—up to 180°C or more—a condition often found in aerospace. A mismatch in CTE between tools and large parts at high cure temperatures can induce in-material stresses, and throw off tolerance. Uniform heating is another critical factor, if the temperature of the tool surface varies, this variation also induces material stresses in high temperature cures.

Common tooling materials for composites are aluminum, steel, Invar (an alloy of iron and nickel), epoxy-based composites, bismaleimide (BMI) composites, and graphite or carbon-carbon composite. Aluminum and steel have the advantage of low cost and machinability. Easily modified and repaired, their disadvantage is their high

CTE compared to composites. Invar matches the CTE of composites up to about 200°C or so, but is expensive and heavy. The trade-off for lighter composite tools is typically less durability—metallic tools generally take more punishment and last longer.

"Back in 1982, when I first interviewed at Northrop, I mentioned that one of the biggest challenges in using composites was tooling," remarks Martin McLaughlin, now director of space structures for Northrop Grumman Aerospace Systems (Redondo Beach, CA). While Northrop progressed through all of the usual materials in developing composite tooling, he notes success with two in particular. One is Invar, and the other a combination of working BMI tools made from bulk graphite source tools. "We buy blocks of bulk graphite, glue them up, and then machine them to shape for a source tool. The working tool is made from BMI composite preimpregnated [prepreg] material, the same as we used on the aircraft." This combination worked so well, he reports, that Northrop used it to retool the composite parts for most models of the F-18. Currently, all of the composite tools used in the production of the F-35 employ this combination.

However, he notes that this approach may need improvement as new opportunities emerge. "One of the great advantages of composites is the ability to make unitized, unusual shapes, rather than limit [the geometry of parts] to the formability of metals," notes McLaughlin. "For example, the blended wing-to-fuselage contours on the B2 would have been a nightmare in metal." Added to this ability to create complex shapes is the trend to unitization. It saves mass, cost, and manufacturing time. "We keep looking for the point of diminishing returns on unitizing ever larger parts, and we have not found it yet." This trend is found in fields beyond aerospace. He points out that the new DDG-1000 destroyer will have a composite superstructure and the hulls of minesweepers 150' (45.7-m) long are made from unitized tools. "The bulk graphite is too heavy and not durable enough" for larger parts. A return to Invar tooling yields its own problems such as expense, weight, and long lead times (up to a year in some cases), according to McLaughlin. He believes that in the future it will become increasingly difficult to make these parts from Invar. In addition, he reports satisfaction with their BMI tools but believes they will have scale-up issues with the emerging large unitized applications.

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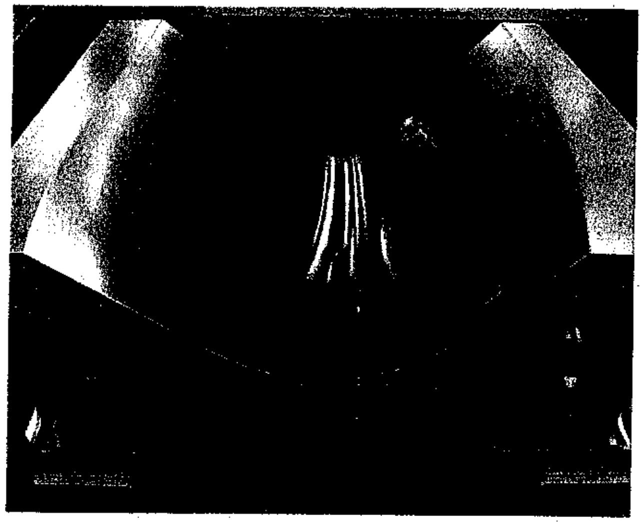
The new generation of composite tooling-material suppliers now offer materials that utilize a two-step cure. The tool is partially cured at low temperature to set its form, then removed and free-form-cured at much higher temperatures—up to 425°F (218°C). "I am optimistic about these new two-step cure systems for tooling materials," he remarks.

While unitized composites are growing in size, there is also an increasing demand for higher production rates, notes Michael Gleason, product manager for Hexcel (West Valley City, UT). Higher rates are enabled, in part, by the lower mass of a composite tool (compared to Invar). Lower weight means lower thermal mass, enabling faster heat-up/cool-down cycles. "A composite tool is about 40% as heavy as an Invar tool," notes Gleason. Lower weight also enables automation that is more practical. This is especially true for automated fiber placement (AFP) machines that tend to move the mandrel tooling in combination with the lay-down head. A mandrel tool made of heavy Invar stresses the mechanisms of an AFP more than a lighter composite tool.

Hexcel offers two separate tooling materials: HexTOOL M61, a BMI material, and HexTOOL M81, an epoxy. Unlike the standard prepregs for structural applications that could be used for composite tooling, Gleason notes that these materials are actually quasi-isotropic, using short, randomly oriented fibers that have a 3-D structure to them. "You can lay this up quickly. You do not have to worry



Weber Manufacturing's Nickel Vapor Deposition process deposits nickel atom by atom, making it very well suited for producing metal tooling of complicated shapes, according to the company.

about the symmetry of the orientation as you must with structural prepregs, and lay-down rates are faster." This 3-D, short-fiber structure means these materials are especially suited for post-cure machining. A tool made of Hexcel HexTOOL M61 or M81 can be modified during the life of the tool. Another key benefit of machinability is eliminating the requirement for a precise master mold. "You can lay it up on a near-net-shape master mold, and then machine it to final tolerance." The company advertises a tool of this material capable of withstanding hundreds of autoclave cycles at 180°C. It could be used to a maximum use temperature of 218°C. The Hexcel HexTOOL M61 requires an autoclave cure, and so does the epoxy HexTOOL M81.

Cytec Engineered Materials (Tempe, AZ) also offers both epoxy and BMI preimpregnated resin systems for tooling made of woven carbon or glass-fabric-reinforced composite. Epoxy tooling is generally limited to less than 300 cure cycles at temperatures not exceeding 185°C, making it suitable for low-rate production. It is also well-suited for use as a low-cost solution for prototype and one-off development tool designs, according to the company. For higher-rate production, Cytec offers its Duratool BMI resin systems. These systems require autoclave curing and provide working temperatures of 232°C and very high durability (over 1000 cure cycles at 375°F or 191°C). They are also machinable; the part can be created on a near-net-shape master mold and machined to a specific tolerance.

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At high production rates, composite tooling can provide an economic benefit to an organization, according to David Hulme, field technical service engineer with Cytec. "If you're building a single tool, weight and thermal mass considerations aside, Invar and BMI are similar. For a single tool, BMI may be more expensive, because it requires a master mold. BMI tools become very economical, however, when you need multiple tools to meet production rates. With four sets or six sets of tools, you can divide the master model's cost over the working tools," he explains.

Although composite tooling is sometimes thought to be less durable than metal tooling, Hulme points out an unlikely ally. The push for high production rates means more automated equipment; not only ATLs and AFPs but also CNC ply-cutting machines as well. These are used for kitting the prepreg fabrics used to make parts. "People are not hand-cutting prepregs on the tools as much as they used to. Tools are also not being handled around the shop to the same extent, because robots move them. It helps reduce the damage and abuse tools receive."

While bulk graphite and carbon-carbon composite are longtime staples in composite tooling, a relatively new form of tooling material is carbon foam. Touchstone Research Laboratories Ltd. (Triadelphia, WV) offers its CFOAM for composite tooling. A noncombustible material made from coal, CFOAM carbon foam features a low CTE that matches composite parts, low cost, easy machinability, and high-temperature capability, to 343°C for tooling applications, according to the company. "It's light as well, roughly 1/10 the weight of a comparable Invar tool. We started manufacturing tools [for composites] about five years ago," explains William Welychko, director of advanced composites for Touchstone. "Since then we've manufactured hundreds of carbon-foam tools. The material provides a completely supported tooling surface. Its easy machinability makes for rapid manufacturing, and inexpensively accommodates design changes."

By filling the pores of the foam and using a high-temperature epoxy paint system, a surface can be created that's suitable for pulling a limited number of parts in a prototype environment. A hardened epoxy or BMI surface is best for production tools. "We can convert the tool to a production tool with a durable surface after development, and after all geometry changes [are finalized], for a fraction of the cost of brand-new tools from Invar," states Welychko. A partner in this development is Hexcel, which offers either of its tooling materials as a surface finisher to the CFOAM tool. CFOAM's light weight and machinability means it could be used—with a BMI finish coat—directly as a working tool, eliminating the expense of creating a source tool. "This saves both time and money, and is the direction of the future."

Metal tools in general

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A CFOAM tool may be a choice for out-of-autoclave because, surprisingly, the foam is a good conductor of electricity. "Because the foam is a conductor, we are able to pass a current through the foam, which then acts like a heating element. With the aid of a thermal imaging camera, we can dial in the heating uniformity of the complete tool. Once we put a surface on the tool such as HexTOOL, it further normalizes the heating pattern, ensuring that there are not any hot spots," explains Welychko. While CFOAM seems to be an exotic material, he states that most shops currently familiar with composites already possess the basic capital equipment and expertise required to use it.

Metal tooling still has a place in composites work. "Metal tools in general produce a better surface, like Class A automotive hoods and decklids. They last longer, they're vacuum tight and can be self-heated, and are widely used in compression molds with a fast mold release. They are very well suited for making 1000–100,000 parts or more," remarks Tom Schmitz of Weber Manufacturing (Midland, ON, Canada.)

To overcome some of the geometry limitations of conventional metallic tooling, Weber uses chemical vapor deposition of nickel (NVD) to produce pure nickel molds with complicated shapes. NVD is a two-stage chemical process that converts bulk nickel powder into solid nickel shells. The process deposits nickel, atom by atom, onto a machined positive mandrel which has the same shape as the tool. An exact replica of the surface is reproduced with virtually no limitation in the resolution of the surface texture, according to Schmitz. The resulting shell is 99.98% pure nickel with no residual stresses, according to the company. "The thermal conductivity is 3x better than steel and 8x better than Invar, and provides an even heating surface and faster heat-up and cool-down rates. Uniform, thin nickel in complex shapes is capable of changing temperature at a rate of 150°F (66°C) per minute. NVD typically varies no more than ±2°C across the whole face of the tool. We have developed tools for engine components [that are curing] at such high temperatures [700°F or 371°C] that you cannot even use Invar. The material will pull the carbon out of the tool face."

Because operators machine the master only once, this is a technique that is, again, especially suited for high-volume applications. They produce nickel leading edges as thin as 0.008" (0.2 mm), and tools up to 1.5" (38-mm) thick, although typically they are 0.250" (6.4 mm). Aerospace applications take advantage of this tooling approach, as Schmitz notes that complicated geometries like ductwork and fairings have been made with NVD shells, where it is easier to machine a master model. "The uglier the shape, the easier it is to justify with NVD nickel shell." To date they have produced tools as large as 14 × 14 × 4' (4.27 × 4.27 × 1.22 m), though he believes there is no limitation, because they produce tools welded from segments created in their 10' (3-m) long deposition chamber.

RocTool (Atlanta, GA) offers another innovation in metal tooling with its 3iTech inductive heating system. While heating metal tooling with hot water, hot oil, or cartridge heaters or electrical cartridges has advantages, the inductive-heating system offers even more value in high-volume, high-throughput applications. This system heats the mold using electromagnetic induction. RocTool integrates inductors inside the mold to match the shape of the part. Placed several millimeters from the surface of the mold, the inductors heat a reduced area of the tool near the surface by conduction.

"It heats the tool uniformly and very quickly," adds Jose Feigenblum, research and development manager for RocTool. Coupled with cold water pumped through cooling lines, cycle times are drastically reduced, according to the company. "We have some examples where resin introduced into the tool took 1 hr to cure at 80°C. We [evenly] heated the tool to 130°C, and reduced curing time to 2 min—a 30× improvement in curing time."■

Want More Information

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