

## Innovation Drives Composites Production

### Faster machines and advanced programming software are key to the more widespread application of composite structures

*Bruce Morey, Contributing Editor*



The Mongoose V1 recently completed qualification tests, laying thermoset composite at 60 lb/hr (27 kg/hr) over a test fuselage section. An articulated head allows it to operate inside molds as well as outside mandrels.

Never satisfied, the composites community is continuing to find ways to make automated tape layers (ATLs) and automatic fiber placement (AFP) machines more productive and efficient.

"For automated fiber placement machines, we are only seeing the tip of the iceberg [for future demand]," says Tino Oldani, president of Ingersoll Machine Tools (Rockford, IL). "As both manufacturers and customers gain experience, we develop ways to produce more parts on AFP machines. There are parts made today that one or two years ago were not considered feasible with AFP."

Ingersoll recently completed a series of tests with its new Mongoose V1, a vertical AFP machine. The Mongoose boasts a newly designed head and creel module with automatic exchange. Automatic quality control uses a proprietary mix of scanners and cameras to inspect the surface as the machine lays material, comparing the workpiece to stored CAD data. This system alerts the operator if there is a problem, such as broken fiber. "Half the problems can be corrected by the machine without operator involvement," says Oldani.

This first Generation 3 machine produces layup speeds advertised at from 50 to 60 m/min, a cut speed as high as 50 m/min, and an add speed of 50 m/min. During a 10-hr test,

using 16 individual ¼" (6.4-mm) tows, the machine deposited carbon fiber at a rate of 60 lb/hr (27 kg/hr) over a test area measuring 2 x 6 m and having a 3-m curvature. It laid down composite material at a surface rate exceeding 8000 ft<sup>2</sup>/hr (743 m<sup>2</sup>/hr) with no roping or twisting of material, according to the company.

The machine places fiber inside molds as well as on the outside of mandrels. "A rotating mandrel for convex placement is 7–10x more expensive than a female mold," says Oldani, "with additional money spent for the rotating units. The Mongoose was designed with a special articulated head and fiber path to reach into molds and lay down fiber. This increases the possibility of making more different types of parts." For example, one of his customers decided to build an engine nacelle inside a mold using AFP. This process—originally designed for hand layup—is cheaper with an AFP process, and produced a lighter part that met specifications./p>

While there has been an understandable focus on large composite parts to meet the needs of aerospace—such as Boeing's composite 787 fuselages—some companies are thinking smaller. Coriolis (Lorient, France) is a company that believes in the use of robots to achieve affordable automation—perhaps because they had no choice but to do so. "We are a young company, the average age of our employees is only 32," says Clementine Gallet, managing director. "We developed a new economical and simple solution because we did not have enough money to buy heavy systems. Our patented solution comes from our engineering work in composites, robotics, and software development."

**The company's solution** is a fiber placement system built on an existing six-axis articulated arm robot that draws material from a separate cabinet. Additional external axes of motion can be provided by using a linear track motion and a rotary unit in the end-effector. With a claimed maximum speed of 60 m/min, a repeatable path accuracy of ±0.5 mm, cut and restart accuracy of ±2 mm, and a cut speed of 48 m/min, the system uses ¼" (6.4-mm) tows in configurations that include from eight to 32 tows. The company advertises a production rate of 60 m<sup>2</sup>/hr with two robots. One robot lays down tape while the second robot is off-line being prepared to do so. If both robots are used to lay tape, they provide a lay-down rate of approximately 40 lb/hr (18 kg/hr). The compact head is capable of operating inside concave surfaces with a radius of one meter or greater. Coriolis has delivered seven systems to aerospace customers, according to Gallet. The systems lay dry fiber, thermoset, or thermoplastic material.



Automated Dynamics is looking to robots for affordable automation. The company recently announced its AFP/ATL-0510 robot system for tape laying or fiber placement.

Others with a longer history in the field are thinking about robots as well. "We focus on affordable automation," says Jim Mondo, president of Automated Dynamics (Schenectady, NY). The company's experience base includes delivering 50 AFP or ATL machines in 17 countries, and producing more than 11,000 composite structures. "We typically build smaller parts where economics matter," he remarks. This focus on smaller components requires building AFP and ATL machines that are "right-sized" for the application and budget, Mondo explains. "While we supply a wide variety of AFPs and ATLs on filament winding and gantry platforms, lately we have been moving into robots. They have a decent work envelope, and you get a lot of [independent] axes, so you can make smaller, complex parts economically." Automated Dynamics' most recent entry into this field is its AFP/ATL-0510 fiber placement/tape layer, which is built on a Kawasaki robot platform. It builds parts within a 3.0 x 1.5 x 1.2-m work envelope. "Our laydown rates are comparable to those achieved by larger machines, but the lower investment in our equipment enables a payback in two to three years," says Mondo. The company has three robotic systems in place, and expects the number to grow.

**Thermoplastic composites** are another key point in the cost equation, according to Mondo. Unlike thermosets, they do not require autoclave curing, and are easier to recycle. "We heat it, squeeze it, and freeze it on the fly using proprietary and patented technology," explains Mondo, speaking of the company's automated fabrication of thermoplastic parts. The advanced thermoplastics Automated Dynamics works with include continuous fiber-reinforced polyetheretherketone (PEEK), polyetherketoneketone (PEKK), and polyphenylene sulfide (PPS). The economics of part manufacture with thermoplastics help make the use of these materials attractive. Joining thermoset parts like stiffeners to a panel requires co-curing, adhesively bonding, or mechanical fastening. "However, with thermoplastics, separate stiffeners placed in a tool and melt-bonded on the fly with fiber-reinforced thermoplastic reduces weight, assembly labor, fasteners, and manufacturing complexity," says Mondo.

"The future of advanced thermoplastic composites is here. They compete not only with thermoset composites, but also with aluminum on cost and titanium on performance," agrees Jon Fox-Rubin, president and CEO of Fiberforge (Glenwood Springs, CO.)

To produce volumes on the order of 50,000 parts per year or more, Fiberforge uses an ATL technique that is a variation on Sheet Molding Compound (SMC). SMC is formed as sheets, then press-molded or stamped. Fiberforge combines that idea with ATL to precisely place and orient fibers in a flat 'blank' that is then press-molded or stamped. For layup, their patented Relay Station ultrasonically tack-welds individual courses unidirectional thermoplastic/fiber tape together. These 'tailored blanks' are then pressed under heat to remove voids and consolidate the thermoplastic. The blanks are heated to process temperature, fed into a matched-mold press to form the final shape, and trimmed as needed. Common advanced thermoplastic composites used include PEEK, PPS, and PEKK. "If it comes in a pre-preg format, we can use it," says Fox-Rubin. Unlike the random, chopped fibers of SMC, the fibers in these thermoplastic composites are long and precisely oriented, resulting in higher strength and lighter parts. Third parties supply presses and trimmers, and existing presses used in metalworking operations are often employed, according to the company.

Aimed at smaller parts, three machine designs from Fiberforge build blank sizes from 0.5 x 0.5 m to 2 x 2 m. Flat blanks are laid at high volume, up to 418 lb/hr (1890 kg/hr), depending on machine configuration. This performance, combined with the postprocess consolidation and stamping operation, provides high throughput. The company reports using matched molds made of aluminum or steel, with lead times for mold acquisition of about two to six weeks. There are three systems in use: two external to the company and one used by Fiberforge for production contracts. As an example of high volume, the firm recently won a contract to produce 20,000 backpack frames for an Army subcontractor. Fiberforge is also working with DRS and Sikorsky developing next-generation CH-53K helicopter internal cargo system components for the US Marines.

**Software also improves productivity.** While MAG Cincinnati (Hebron, KY) retains its place as a major supplier of FPS, it views its software as an important tool for productivity. MAG recently performed a demonstration layup in which its Viper 6000 consistently laid material at rates in excess of 50 m/min. The test section was about 2 x 6 m, with a curvature of approximately 6 m in diam. The company says this lay-down speed includes the rate for the first ply on the tool, which is the most difficult ply, because of the challenge of getting the prepreg material to adhere to the tool surface.



The Coriolis robotic system lays thermoset, thermoplastic, or dry fiber, and is capable of concave as well as convex deposition.

Acknowledging that productivity is all-important to its customers, Randy Kappesser, VP and general manager for MAG Cincinnati, also points to the company's Advanced Composites Environment Suite (ACES) as a key enabler driving productivity. By combining part design, material properties, and machine characteristics, ACES calculates cycle time and material usage. "ACES is a CAM package for automated composite manufacturing," explains Kappesser. Like other CAM packages, a simulation module illustrates in video how a part program works. ACES reads geometry from Dassault Systèmes (Vélizy-Villacoublay, France) CATIA V4, and laminate design information from CATIA V5's composite workbench or FiberSIM from Vistagy (Waltham, MA). Characteristics modeled include speeds, path angle, fiber orientation, roller conformance to the surface, number of plies, tow tension, and tow width. The engineer selects the optimum program for productivity through trade-off analyses, Kappesser explains. After optimization and post-processing, the program produces machine control language (G-Code/MCode) to make the part on the machine.

"Producibility is just as important as productivity," emphasizes Kappesser. "Just as in the metalcutting world, the engineer needs to know if the part can be created as designed. Each machine has its limitations. Factors flagged by ACES include fiber steering limit, orientation errors, gap and fiber band conformance, collision avoidance, and machine travel. For example, many AFPs have minimum-course lengths.

Other problems pop up at the end of courses, when the machine encounters corners, cavities, or recesses—all common in AFP applications. "There is a whole host of producibility parameters engineers need to assess before laying plies," says Kappesser. "As a leader in this field, we have probably made more parts than anyone else. A lot of that knowledge is captured in ACES in default settings and on-line help." ACES has five main interface screens with roughly 100 menu selections, and provides access to more than 1000 parameters. The package was developed over 20 years after programming many challenging composite laminate parts. This experience helped the company develop wizard interfaces and default parameter templates that make the interfaces easier to use.

Most suppliers of AFPs and ATLS supply CAM software. For instance, Ingersoll Machine Tool provides its iCPS package, which includes interfaces to FiberSIM as well as important design features, such as composite tailoring and critical-points verification. Automated Dynamics offers their FPM (Fiber Placement Manager) with an integrated front end to SolidWorks from Dassault Systèmes, or imports surface geometry via IGES or STEP. In addition to handling typical fiber-program details, FPM also allows multiple AFP and ATL robot configurations. Coriolis supplies a package for programming its robots, including multiple robot configurations. Fiberforge offers a package for designing the layout of its 2-D tailored blanks.

**Manufacturing composites requires** tight linkage with design. Composite parts must be modeled in CAD before producing CAM instructions, just as is the case with metal parts. Unlike metal parts, however, modeling composites calls for additional information such as ply thicknesses, fiber orientation, and sequence. Enter FiberSIM, a composite-engineering environment fully integrated in commercial 3-D CAD systems, according to Olivier Guillermin, director of product and market strategy for Vistagy. "FiberSIM lets the designer develop a complete and detailed model of the composite part. It then creates and seamlessly transfers the manufacturing data from design to the shop floor," says Guillermin. "FiberSIM can be used on very large and complex applications, such as entire composite fuselage sections." He says that FiberSIM runs in CATIA V5 from Dassault Systèmes, Pro/Engineer and Wildfire from PTC (Needham, MA), and NX from Siemens PLM (Plano, TX).

Engineers need to optimize the composite manufacturing process during the development process, where it's easier to recognize and address manufacturing issues. For example, FiberSIM's Automated Deposition Design module for AFPs and ATLS automates creating composite design elements, such as ramped edges and "bird beak" corners, as well as accounting for minimum course length and minimum deposition angles. FiberSIM enables users to efficiently manage thousands of engineering and manufacturing changes of all kinds that inevitably arise during the composite part and assembly development process, according to Vistagy.

Some see the need for machine-independent software. CGTech Corp. (Irvine, CA) recently announced a strategic partnership with Vistagy to integrate their two software suites. CGTech believes there are similarities between the state of today's AFPs and ATLS and the state of the CNC metalcutting industry of the 1950s and '60s. "The technology is difficult to adopt for all but the largest manufacturers because of the high infrastructure costs. The process technology is complex, and understood by few. Finally, software provided primarily by machine manufacturers results in limited software advances. When a machine tool builder is also developing the software to program their machines, the software tends to be restricted to the technology of the machine," explains Bill Hasenjaeger of CGTech.

CGTech's Vericut Composite Programming (VCP) and Simulation (VCS) software solves these problems, according to Hasenjaeger, because it is designed independent of any specific CNC fiber-placement machine. He compares it to modern CAD/CAM

applications that support a variety of CNC machines. The software suite reads CAD surfaces and ply boundary information to create layup paths. "Then our simulation [VCS] reads G-code posted from VCP and simulates the machine motion, emulates the CNC logic, and applies fiber material as commanded by the NC program," explains Hasenjaeger. "The user can then closely evaluate his process before sending it on to the physical machine."

Dassault Systèmes (Paris, France) has taken an all-encompassing view towards software. Combining the strengths of digital design with its CATIA brand, digital simulation with its Simulia brand, and digital manufacturing with its Delmia brand, Dassault Systèmes provides a PLM solution for composites that covers the entire manufacturing process. At the center of this solution lies the CATIA design application called Composite Part Design. "With Composite Part Design, the product engineer designs in the context of the manufacturing process, providing insight into producibility and productivity requirements early in the design process," says Laurent Delsart, CATIA R&D composites partnership and strategy.

On the manufacturing side, Dassault Systèmes' technology partners provide dedicated modules in the Dassault Systèmes PLM environment to yield seamless integration. "Delmia provides a dedicated infrastructure for process planning, resource programming, and simulation, on top of which specialized partners can develop specific applications for composites," explains Delsart. "So as to provide the best solution, we work with partners with particular expertise in fiber placement and tape-laying machines." Such partners include Ingersoll Machine Tools with its iCPS software, Coriolis for robotic-based fiber-placement with their CATFiber solution, MTorres (Pamplona, Spain), and Forest Line (Granby, QC, Canada). There is also an interface to MAG Cincinnati's ACES V2 software.

To predict the complex structural behavior of such parts, the entire Composites dataset can be analyzed with Simulia's Abaqus FEA product suite and other major solvers. Abaqus FEA simulates composites behavior, including delamination and damage, through cohesion elements and virtual crack closure technique (VCCT). It also seamlessly integrates with CATIA Composite Part Design through the Composites Link product developed by Simulayt (Brookwood, UK). In parallel, CATIA Structural Analysis for Designers provides associative design analysis iterations."