

MULTIPHASE PROCESS FORMS COMPLEX SHAPES

Manufacturer adds extrusion and injection molding to thermoplastic pultrusion process to produce corrosion-resistant threaded rod.

One great advantage of the pultrusion process is its ability to efficiently manufacture long, straight composite parts with high strength on the longitudinal axis and a wide variety of complex cross-sectional shapes or profiles. For most of its history, pultrusion's weak point was the difficulty of varying a product's cross-sectional shape or thickness along its length. A case in point is threaded composite rod, in great demand in applications where use of metallic threaded rod is problematic because of mass (composite rod is one-quarter the weight of steel rod), corrosion or thermal and/or electrical conductivity. While pultrusion is ideal for creating the raw rod, the crosslinked thermoset resins used in the process limit secondary reforming options to machining. While threads, today, are routinely cut into thermoset pultruded rod for many applications, a recent development in the pultrusion of *thermoplastic* composites has provided a more practical alternative. A family of patented thermoplastic polyurethanes (TPUs) developed around the turn of the century by Dow Chemical Co. (Midland, Mich.) and spun off in 2004 to Midland-based Fulcrum Composites has made possible the commercialization of a synergistic pultrusion/extrusion process that permits more advantageous and less time-consuming postforming methods.

A PULTRUDABLE THERMOPLASTIC

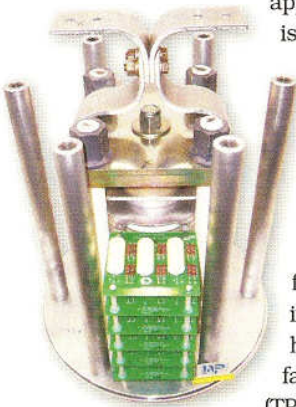
Efforts to pultrude thermoplastics met with limited success for many years, says Fulcrum's president, Chris Edwards, largely due to their higher viscosity. While thermosets are relatively easy to formulate given the very low viscosities required to wet out fibers in a pultrusion die, the viscosity of conventional molten thermoplastic resins typically ranged "100 to

1,000 times higher," according to Edwards, making thorough wetout very difficult. "The problem was solved," he says, "by Dow's development of a range of thermoplastic polyurethanes with a unique characteristic" — the ability to partially depolymerize at their processing temperature and rapidly repolymerize as they cool. In other words, the monomer molecules in the long polymer chains partially unlink as the resin pellets are heated and melted, then quickly link together again when cooled. "Most thermoplastics are produced with a specific molecular weight that stays constant during subsequent processing," he explains. "Normally, any reduction in the molecular weight of these thermoplastics is a one-way event that is considered degradation of the material. The unique aspect of our resin is that we can deliberately decrease molecular weight during processing — and rebuild it afterwards. Low molecular weight allows low viscosity and good wetout. High molecular weight in the final part is necessary for good properties."

Dow's TPU chemistry also exhibits greater toughness and damage tolerance than thermosets. "This, in many instances, eliminates the need to use secondary, off-axis fibers, which, in turn, allows the use of more primary, unidirectional fibers with resulting improved properties," Edwards points out. The TPUs also exhibit a strong affinity for fiberglass, facilitating thorough fiber wetout. Additionally, thermoplastic pultrusion produces no volatile organic compound (VOC) emissions and can be recycled.

The Dow TPUs are processed using custom-designed resin-injection dies and modified pultrusion equipment built by Fulcrum and its licensee and European partner, Top Glass SpA (Osnago, Lecco, Italy). While the Fulcrum process is similar to conventional thermoset pultrusion,

Source: Fulcrum Composites/Top Glass SpA



Threaded thermoplastic composite rod (in the photo, the vertical, white rod secured with purple thermoplastic bolts), can be made with Fulcrum Composite's hybrid manufacturing process, yielding a strong, nonconductive connection for electrical equipment assemblies.

it differs in several respects. Fiber wetout, for example, is assisted by a proprietary pressure system built into Fulcrum's dies. "The pressure in the pultrusion die varies throughout the die, and how this is done is one of our trade secrets," Edwards says. The variable-pressure dies are shorter than those used for thermoset pultrusion, ranging in length from 6 inches to 24 inches (152 mm to 610 mm), depending on the profile size. The dies are heated to 250°F to 300°F (121°C to 149°C), with individually controlled heating elements. The pulling system features belt-type or cleated pullers that continuously draw the part through the die, rather than the more common hydraulically driven, reciprocating pullers. Control software developed in-house maintains a balance between puller speed, resin feed rate and process temperature. Moreover, Fulcrum uses a manually operated angle grinder, instead of the conventional automated cut-off saw, to cut through the part at its designated length (typically 20 ft/6m). This method works well without stopping the line, Edwards says.

With a system in place for pultruding thermoplastic composites profiles, the stage was set for Fulcrum to add, as the following illustrates, two postforming capabilities that make possible efficient production of threaded rod and other surface-modified products, without resorting to machining.

A POSTFORMABLE PULTRUSION

Fulcrum's threaded rod consists of three layers, a core pultruded rod, a coextruded interlayer and an injection molded outer layer that forms the threads, all made using a rigid form of Dow's TPU.

The core rod, a 70 percent glass-reinforced uniaxial pultrusion, provides the tensile strength required in service. Fulcrum typically uses Owens Corning (Toledo, Ohio) standard E-glass pultrusion roving in 2400 g/km tex lineal density; a higher density roving might be used for large profiles, and lower tex might be used for small profiles. Glass content in the parts ranges between 66 and 76 percent by weight.

When the basic rod is pultruded, an unfilled version of the same TPU forms a thin, continuous exterior skin (cap) in a coextrusion die just downstream from the pultrusion die. For the threaded rod application, this functions as an adhesive layer that bonds extremely well to the pultrusion and to the final layer, the overmolded threads. In other applications, however, the coextruded polymer permits Fulcrum to add color, modify the texture, add ultraviolet (UV) protection and/or increase abrasion resistance. As the part exits the pultrusion die, it enters the coextrusion die. The heat of the TPU being fed into the coextrusion die slightly melts the matrix resin on the surface of the part, and the combination of heat and the extrusion die pressure bonds the resins together. The typical thickness of the cap layer is

0.020 inch/0.5 mm, although Edwards says both thicker and thinner skins are possible. "Cap layers of abrasion-resistant TPU to 0.5 inch/12.7 mm have been produced," he says.

Edwards notes that TPU is introduced to the process as a diced hexagonal pellet. The pellets are thoroughly dried in a dehumidifier/drier and conveyed, using dried air, directly to the feed throats of two standard screw extrusion machines. The extruders mix and melt the pellets, respectively, for the matrix resin and the surface skin at 250°F to 300°F (121°C to 149°C), and then direct the mixes through feed manifolds into ports in the injection die and the coextrusion die. Because of the nature of the TPU, no mold release is needed in the die or in the resin.

The part cools and hardens as it exits the coextrusion die. Cooling methods depend on the profile. While a very small part might cool efficiently in ambient air, Edwards explains that for larger profiles, cooling options include spraying the profile with water or immersing it in a water bath. Edwards prefers the spray method. "Evaporation converts the water to steam and is a more efficient means of heat removal than sending a part through a water cooling chamber, which just heats up the water."

Production rates during this phase can vary between 4 ft/min to 20 ft/min (1.22 m/min to 6 m/min), depending on the part size. Typical runs are 10 ft/min (3 m/min), but a very small rod might run at 20 ft/min (6 m/min). Finished pultrusions for threaded rods are cut to 8-ft/2.4m lengths.

INJECTION MOLDING THE THREADS

The third, performance-critical thread layer is then injection molded using long-glass-filled, rigid TPU, which, Edwards says, provides strength to handle torque stress applied when nuts are tightened on lengths of rod used to connect joints. "Ideally, we would want $\pm 45^\circ$ architecture to resist shear," he admits, "but that's not an option for our process. Random 0.5-inch/12.7-mm length fiber is the closest we could get — and it works."

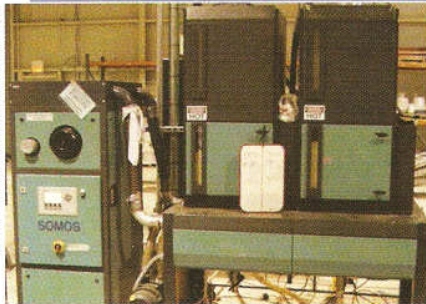
Fiber volume here varies between 28 and 45 percent, depending on the size of the threaded rod. "Smaller diameters are harder to overmold because there is so little space between the uniaxial core and the base of the thread," Edwards explains. "The material must flow into the injection die through a very thin passage and still carry sufficient random fibers into the threads to provide the necessary shear strength." But Edwards points out that strength tends to be less critical in smaller diameters because they are typically used to assemble nonstructural items, while the larger diameters are generally used for structural connections that call for higher fiber content for greater strength.



Applications for Fulcrum Composites' pultrusion/extrusion/injection molding process include threaded rod for flange joints in chemical pipe (threaded studs hold the pipe flanges together, above) and other threaded or otherwise overmolded connectors (top photo).

Source: Fulcrum Composites/Top Glass SpA

Step 1



Thermoplastic pellets are dried in a dehumidifier and blown by dried air to the feed throats of two separate extruders, which supply TPU for the rod matrix and the coextruded surface skin.

Step 2



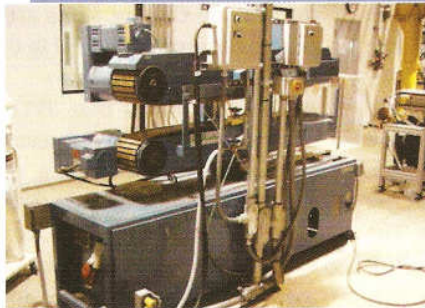
Glass roving is loaded onto racks, threaded through tensioners, and then drawn through the forming tooling, dies and pullers.

Step 3



Resin and pultrusion/coextrusion dies are preheated to melt temperature, set and then monitored by Fulcrum's computerized control system (above). After resin feed is started, pultrusion process parameters are adjusted to achieve through wetout.

Step 4



In Fulcrum's pultrusion/co-extrusion process the pultruded stream is pulled through the dies by standard extrusion belt-type pullers.

Step 5



When the process stabilizes (after about five minutes) coextrusion of surface skin begins. Photo shows pultruded rod exiting the pultrusion die (left) and passing through co-extrusion system (center), where a yellow surface/cap layer is applied (right).

Step 6



Pultruded rod with surface skin (cap layer) is pulled out of the coextrusion die. The blue, segmented hose sprays cool water on the rod as it exits the die to reduce cooldown time.

Step 7



An 8-ft/2.4m section core rod is placed in the injection die. Long-fiber TPU is ram-injected into the die, forming threads on that section. After cooling, the rod is indexed downstream and threads are formed on the next and successive sections.

"We use the same resin for both the matrix and surface wherever possible because it makes everything so much simpler," Edwards notes. Typically, both the matrix and surface resin are rigid TPU, but nylon, polycarbonate and a softer elastomeric TPU (favored for its grip characteristics) also have been coextruded over the hard TPU pultrusion matrix for other specialized applications. Edwards points out that the Dow TPUs can be formulated to achieve hardness ranging anywhere between the soft elastomer (65 to 70 Shore D) and the rigid version used for the matrix, which he says is "off the scale for Shore D measurement, with mechanical properties more like polycarbonate."

To injection mold the threads over the rod, the end of an 8-ft/2.4m length of capped core rod is placed in a thread-shaped injection die in an automated injection molding machine. As in standard injection molding, the long fiber-reinforced TPU pellets are fed through a hopper into the barrel of the machine, where they are electrically heated to melt temperature (250°F to 300°F or 121°C to 149°C). The die closes and a shot of the molten material is ram-injected into the die. The shot weight is typically slightly more than the actual weight of the part to avoid having the ram bottom out in the die. Just before it bottoms out, the ram is held under hydraulic pressure while the material fills and packs out the cavity. After a cooling cycle of about 40 to 50 seconds, the die opens, the threaded section is indexed downstream, the die automatically closes again over the next section of smooth rod and the process is repeated. The production rate for injection molding the threads ranges between 2 ft/min and 3 ft/min (0.6 m/min and 0.9 m/min).

The long fibers in the overmolded material help optimize the thread strength. "In our molded threads, we find the 0.5-inch/12.7-mm-long fibers spread in random directions over two or three of the molded threads, making the threads themselves much stronger." The other advantage is that the threads are molded over, rather than cut into, the uniaxial rod. A thread-cutting process severs the continuous fibers in a conventional thermoset pultrusion, and fiber ends are not protected by the resin from direct exposure to corrosive environments. In strongly alkaline environments, for

example, compounds such as sodium hydroxide (NaOH) can wick into the fibers and dissolve them. Fulcrum's overmolding process ensures that fibers are fully encapsulated by the resin, an important safeguard even if corrosion-resistant (CR) fibers are used, such as Advantex, developed by Owens Corning and alkali resistant (AR) Glass developed by Saint-Gobain Vetrotex (Chambéry Cédex, France and Valley Forge, Pa.). Although these fibers are specifically designed to resist alkali attack, they can degrade if exposed directly to a highly alkaline environment. (Owens Corning on Nov. 1 finalized the acquisition of the reinforcements and composites activities of Vetrotex for \$650 million (USD). Excluded from the transaction was Saint-Gobain's reinforcement facility in Wichita Falls, Texas. Owens Corning also sold facilities in Belgium, Norway and Pennsylvania as part of the deal.


Part samples are tested for wetout, dimension and thickness of the surface skin at the beginning of a pultrusion run. But Edwards notes that when the process is in operation, it's very stable, and parts are of consistent dimension and quality. Moreover, no secondary

fabrication procedures are required; the threaded rods come off the production line finished and ready to ship. The customer usually cuts the delivered rod to appropriate shorter lengths that are suitable to the application.

LOOKING AT THE POTENTIAL

The largest market for Fulcrum threaded rods is in highly corrosive environments where metal versions are impractical — for example, in flue gas scrubbers, salt-producing or salt storage plants, and seafront applications, such as piping joints for fish-spawning structures built in North Carolina by LaPaz Group LLC (Lenoir, N.C.). Rods are sold as an OEM product in English and SI sizes, with matching injection molded nuts. Edwards estimates that Fulcrum's threaded rods are a \$2 million to \$3 million (USD) market, but he adds that the "performance of our threaded rod is helping to open other applications [that have] much greater potential than threaded rod." According to Edwards, Fulcrum's secondary injection molding process can be used to form other complex surface features over the pultruded part, creating parts such as ladder rungs and

end connectors for rigging systems — both sailboat rigging and nonconductive rigging to anchor electrical poles. Additionally, the company's profiles can be modified cost-effectively using a thermoforming process, provided that compatible thermoplastic resins are used. The pultruded shape is heated and then it is either thermostamped in a mold or bent around pins to form angled lengths. (Thermoforming, however, is limited by the glass modulus. Glass fibers usually break when stretched or compressed more than one or two percent.)

Edwards says such capabilities could open up whole new markets for thermoplastic composites. 

— Donna K. Dawson, Senior Editor



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