Fiber-Reinforced Polymer Composites: Pursuing the Promise

High-strength, lightweight advanced composites will deliver a competitive advantage for U.S. industry

Fiber-reinforced polymer (FRP) composites are made by combining a plastic polymer resin together with strong reinforcing fibers. The components retain their original form and contribute their own unique properties that result in a new composite material with enhanced overall performance. Reinforcing polymer material with fibers improves their strength and stiffness.

The polymer resin is typically viscous, and may be easily molded, but is relatively weak. The resin component protects against abrasion or chemical attack to the material surface and acts as a binder for the reinforcing fibers, which mechanically support and transfer loads in the composite.

High-strength, lightweight FRP composites have been widely used in defense and aerospace systems for many years and have been used more recently in luxury automobiles, wind turbines, and compressed gas storage tanks. Lightweight, strong and stiff materials make an attractive combination of properties for manufactured products. Lightweight materials deliver significant energy savings during transportation, and 'lightweighting' is a key strategy in achieving national energy goals. Furthermore, the strength, durability, and structural properties of FRP composites are beginning to expand the service life of industrial equipment, buildings, and other infrastructure.

Advanced carbon and glass FRP composites are particularly promising materials for applications in industry and clean energy. Carbon FRP composites offer a higher structural strength-to-weight ratio over many structural materials, excellent corrosion resistance, and other desirable properties. Glass RFP composites are lower in cost compared to carbon but not as stiff or generally as strong. Biobased materials, currently under development, also show promise for certain end-use applications.

Carbon-fiber composite hood (inner panel) manufactured by Plasan Carbon Composites for the 2013 Chevrolet Corvette ZR1. During manufacturing, a carbon-fabric prepreg (reinforcing fiber and resin) is laidup on a mold and cured with heat and pressure in an autoclave. *Photo courtesy of General Motors*

Manufacturing FRP Composites

FRP composite manufacturing can be an energy-intensive process with high heat and pressure needed to bond the composite material together. In addition, carbon fiber precursors and the raw materials that make up the polymer resin are typically made via conventional energy-intensive petrochemical processes.

Fiber Fabrication

High temperatures are required in the manufacture of both carbon and glass fibers. Carbon fiber can be made from petroleum raw materials that are spun into 'white fiber' precursor processed in a series of high-temperature ovens (to oxidize and carbonize the fiber), and then wound onto spools as 'black fiber.' Glass fiber is made by melting silica in a high-temperature furnace and spinning the resulting thermal-resistant borosilicate onto spools.

The fibers can be woven into a fabric or formed into a tape, depending upon specifications for the component to be manufactured. In some cases, the long fibers are arranged in one direction or the fibers are chopped short and set in multiple directions.

Component Production

There are many different ways to make composite parts. Typically, the strong, stiff, reinforcing fibers are combined with the polymer either before or during part fabrication. These parts are made by layering the composite material over a mold in the final shape of a part (much like the layering of plywood) and then heated under pressure. For some parts with more angles and complex shapes, fiber and resin may be placed together in the cavity of a mold, which is then compressed and heated. For pipes and other long parts, fiber and resin may be extruded through a die and then cured at high temperatures.

Clean Energy Applications

Improved fabrication processes could lower the cost and energy intensity of FRP composites, potentially opening a wide range of applications that promote clean energy and energy efficiency.

Motor Vehicles: Lightweighting is a key strategy to increase transportation energy efficiency and fuel economy while continuing to meet safety standards. A 10% reduction in vehicle weight can improve fuel economy by 6–8% or increase the range of a battery-powered vehicle by up to 10%.[1,2] Compared to conventional steel, glass FRP composite systems can reduce mass by 25−30%, while carbon composite systems can reduce mass by 60–70%.[3]

Wind Turbines: Rigid, high-strength, and lightweight yet fatigue-resistant carbon FRP composites can enable the lighter, longer turbine blades that are needed to increase the generation of wind power.[4]

Wind could be the largest consumer of carbon FRP composites by 2018.[5]

Compressed Gas Storage Tanks: Lightweight, high-strength materials are needed to make the storage tanks for vehicles that run on hydrogen and natural gas. Although carbon FRP composites meet the target performance criteria for on-vehicle, high-pressure hydrogen storage tanks, costs remain too high.[6]

Industrial Equipment: Composites can impart corrosion resistance and other properties that improve the performance of industrial equipment and components. For example, FRP composites could enable more efficient heat exchangers; fans, blowers, and other equipment capable of withstanding corrosive or high-temperature processes; pipes and tanks with extended service life; and better electrical insulation for machinery.

Other industries could benefit by substituting low-cost high performance FRP composites for existing materials. Examples include structural materials for buildings, roads, and bridges; marine vessels; flywheels for electricity storage; and electrical transmission lines.

Challenges

To achieve a more diverse range of applications, research will need to overcome some key challenges associated with advanced FRP composite materials and their manufacturing methods.

Energy Intensity: Carbon fiber demand in industrial and energy applications is expected to grow 310% within the next 10 years.[7] This rapid growth underscores the need to reduce the energy required to produce these carbon FRP composites. They can be three to five times more energy intensive to fabricate than conventional steel.

Production: Fiber and part fabrication are both complex processes. Lowering costs will require more effective and predictable manufacturing processes that reduce cycle times without diminishing performance characteristics.

In addition to lowering manufacturing costs, broader use of FRP materials and structures will require more innovative design concepts, predictive modeling, robust characterization of material properties, performance validation, and process automation.

Recyclability: Enhancing the cost-effective recyclability of FRP composites would save a significant amount of energy—particularly if the process enables repeated recycling without loss of quality and represents a fraction of the original manufacturing energy use and emissions. Advanced recycling capabilities could greatly improve the life-cycle energy footprint of these composites and help meet the rising recycling goals of many industries.

Broad Economic Impacts

FRP composites are a foundational technology that promises to transform multiple industries and markets. Industry analysts expect the global market for carbon FRP composites to grow to $25.2 billion in 2020,[8] and the market for glass fiber composites could reach $16.4 billion by 2016.[9]

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2 Bandivatekar, et al. (2008), MIT On the Road in 2035, p. 45. Accessed 4 February 2014.

3 U.S. Drive (2013), Materials Technical Team Roadmap. p.4. Accessed 4 February 2014.

4 The Minerals, Metals and Materials Society (2012), Materials: Foundation for the Clean Energy Age. p.24. Accessed 4 February 2014.

5 Chris Red and Tony Roberts. (2009), "Carbon fiber: Supply and demand forecast." Industry News, Composites World. Accessed 4 Feb. 2014.

6 Argonne National Laboratory (2010), ANL-10/24. Technical Assessment of Compressed Hydrogen Storage Tank Systems for Automotive Applications, p.17. Accessed 4 February 2014.

7 Sara Black. (2012), "Carbon Fiber Market: Gathering Momentum," Composites World. Accessed 4 Feb. 2014.

8 Industry Experts. Website. Carbon Fibers and Carbon Fiber Reinforced Plastics (CFRP) *– A Global Market Overview*. Accessed 4 Feb. 2014.

9 Industry Experts. Website. Glass Fiber Reinforcements *– A Global Market Overview*. Accessed 4 Feb. 2014.

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