Microwave-Assisted Plasma Manufacturing of Carbon Fibers

Background

Significant weight reduction and corresponding increases in fuel economy can be achieved in automobiles by replacing dense metals with strong, lightweight materials. Carbon-fiber-reinforced composites are an excellent candidate for this lightweight material and offer significant weight-saving potential because of their remarkably high strength, high elastic modulus, and low density. Composites are structures containing two or more components, in this case the reinforcing fiber and a resin.

Other valued properties of carbon fiber composites are good fatigue resistance, dimensional stability, corrosion resistance, lower tooling costs, and greater design flexibility. By designing composites into an entire vehicle subsystem, the total number of parts to be formed and later joined can be reduced. Such a systems approach leads to significant reductions in vehicle weight and simplified manufacturing.

For example, replacement of steel and aluminum body panels and chassis components with structurally equivalent carbon fiber composites offers up to 68% weight reduction, resulting in savings of up to 40% in fuel consumption. Carbon fibers have been used in high-performance applications for several decades, but their relatively high cost has constrained their use in the automotive industry. Carbon fibers with the properties needed for automotive applications currently sell for $6 to $16 per pound. A cost of $3 per pound is believed to be the threshold for widespread automotive use.

Researchers examine carbon fiber produced rapidly by the microwave/plasma processing device.

Carbon fibers are derived from one of two precursor materials, either pitch or poly-acrylonitrile (PAN) fibers. Pitch-based carbon fibers have much greater stiffness and are used in high-performance applications, such as military aircraft, spacecraft, and missiles. They are less suitable for automotive applications because of their cost and relative brittleness. PAN-based carbon fibers are lower in cost and are used primarily in sporting goods and construction. They are under intense development to further reduce costs and tailor their properties for a myriad of applications.

The Technology

The conversion of PAN to carbon fibers is normally accomplished in four continuous stages:

- Oxidation followed by stabilization of the polymer
- Carbonization to convert the fibers to nearly 100% carbon
- Surface treatment to provide better adhesion to the resin
- Sizing to protect the fibers during further processing and to provide a resin-compatible interface

The carbonization step involves heating the fibers to 1000–1500° C in an inert atmosphere. Researchers at Oak Ridge National Laboratory (ORNL) are developing microwave-assisted plasma (MAP) technologies to carbonize and graphitize PAN precursor. Using continuous MAP processing creates a carbon fiber with very uniform properties, suitable for use by the automobile industry at a significantly reduced cost over conventionally produced fibers.

ORNL has also developed a novel method for producing an axially undulated surface on the carbon fibers using plasma technology and microwave radiation. The undulated surface allows the fibers to interlock mechanically with the resin matrix, thereby resisting fiber pullout. Mechanical properties that are compromised by fiber pullout, notably interlaminar shear strength and in certain cases axial compression strength, should be enhanced by producing fibers with axially undulated surfaces.

ORNL's initial continuous pilot unit was designed to achieve a line speed of 6 inches per minute to demonstrate technical feasibility. Recently, line speeds in excess of 200 inches per minute have been achieved. This exceeds most conventional processing line speeds.

ORNL's MAP carbon fibers have achieved a tensile modulus of between 29 and 32 million pounds per square inch (Msi) and ultimate tensile strength of 342–424 thousand pounds per square inch (Ksi), exceeding the target values of the FreedomCAR and Fuel Partnership. Comparable conventionally manufactured carbon fibers attain 31 Msi modulus and 485 Ksi ultimate strength.

Commercialization

Three patents have been awarded and others are pending on this technology, which has the support of the U.S. carbon fiber manufacturers. Considerable interest has been generated in industry, and there have been many inquiries concerning technical and economic data from fiber and processing equipment manufacturers.

Benefits

- Savings of 40% in direct production costs and a reduction in the cost of finished carbon fiber of about 18%
- Faster processing speed over conventional production methods
- Reduced space requirements and capital outlay for plant and equipment
- More uniform product quality and reduced waste

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