

Smart Vehicle Concepts (SVC)

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3D Printing of Smart Structures with Embedded Optical Fiber Sensors

An optical fiber, which consists of a thin glass fiber coated with a plastic layer, allows light to be guided from one end of a fiber to the other with minimal loss light. Fiber Bragg Grating (FBG) sensors are a special type of optical fiber that measure local deformations, or strains, through deviations in a reflected wavelength of light. These extremely precise strain measurements can be used to monitor the internal condition of structures. To that end, FBG sensors are embedded in carbon fiber reinforced composites such as those used in aircraft frames, windmill blades, and high performance vehicles. The ability to embed these flexible and brittle sensors into metals has been limited until now.

This breakthrough investigates embedding FBG sensors into metallic structures through ultrasonic additive manufacturing, a recent 3D printing technology that uses ultrasonic metal welding to additively weld metallic foils. Since the process takes place at low temperature, there is no melting of the protective plastic coating on the FBG sensors.



Aircraft actuation systems require embedded condition monitoring and load sensing devices. Courtesy of Moog Inc. and airline photo from iStock.

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When an array of FBG sensors is embedded into a metallic structure, or into a hybrid metallic/non metallic structure, a seamlessly integrated sensing network becomes possible. Such networks are immune to electromagnetic interference, and are mechanically robust, non-invasive, and operate at high frequencies. The SVC research team has demonstrated the successful manufacture of test parts that have embedded FBG sensors. These were tested in static and dynamic conditions over a range of strains, frequencies of operation, and temperatures.

In this study, FBG sensors were embedded in aluminum 6061 using a high-power ultrasonic additive manufacturing system developed and manufactured in the U.S. by Fabrisonic, Inc. of Columbus, Ohio. The system is based on a computer numerically controlled milling machine that includes end mills for subtractive operations, a 9 kilo-Watt of power ultrasonic welder tool, a laser etching system, and a fully automated tape feed system for feeding metallic foils to the process. The ultrasonic vibrations generated by the welder head were used to scrub impurities and oxides away from the faying surfaces bringing metal to metal into intimate contact under high mechanical force to metallurgically weld the metals. A unique feature of the ultrasonic additive manufacturing process is that it takes place without melting of the metallic foils. The low process temperatures enable the embedding of glass, plastics, organic fibers and other materials without compromising their integrity.

Aircraft components are life-critical. As a result, methods are needed to monitor their structural integrity and functionality in real time. Traditional methods based on foil gages require redundancy to address failures created by electrical contacts, and cannot perform health condition monitoring inside of metals. This breakthrough changes this paradigm by making it possible to directly address these limitations. The applicability of FBG sensors is not limited to aircraft applications; other areas of use include rotating machinery, vehicle structures, and civil infrastructure.

Economic impact: In 2015, commercial airlines spent about \$50B on maintenance, repair and overhauls of aircraft fleets worldwide. An estimated \$65B will be spent in 2020. As aircraft systems become more complex and higher performing, along with the continuing need to make aircraft lighter and more fuel efficient, methods to improve the quality, reliability, and predictive ability of structural health conditioning systems are becoming ever more critical. Methods such as those of this breakthrough will bring significant savings to aircraft manufacturers, while also improving safety.

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