Building Fiber Optic Strain Sensors into Metal Components

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Why Built-in Sensors?

Various sensors and sensing technologies are used throughout industry to detect and respond to external stimuli for control and monitoring purposes. These sensors are conventionally attached to the component or system externally since gained information is adequate for the application. In some cases, external mounting can confuse the data collection, limit the gained information, and create challenges for sensor mounting due to the use limits of adhesives, like high temperature or humid environments. Therefore, it is desirable to build-in these sensors into the metal matrix directly to provide in-situ information and robustness. 3D metal printing offers the opportunity to build these fiber materials directly into the metal matrix.

Ultrasonic Additive Manufacturing and Fiber Optic Sensors

Ultrasonic Additive Manufacturing (UAM) is a 3D metal printing technology that uses high frequency ultrasonic vibrations to scrub metal foils together layer by layer as opposed to using a directed energy heat source (e.g., laser, e-beam, etc.). UAM systems are integrated into computer numerical control (CNC) frameworks to enable subtractive operations interchangeably with the additive ultrasonic process—a form of hybrid additive manufacturing. Ultrasonic joining is a solid-state (no melting) process, which enables direct integration of temperature sensitive components into the 3D metal part. Fiber optic strain sensors are particularly vulnerable due to their temperature sensitive inscriptions, commercially common plastic coatings, and large thermal expansion mismatch with many metal alloys (i.e., cracking susceptibility). Melt-based 3D metal printing has been used to build some fiber types into metal, yet voids around the fiber, atmosphere requirements, dimensional accuracy, and cracking remain challenges [1].

There are many different types of fiber optic strain sensors. Common traits are their small size, electromagnetic immunity (light powered), remote interrogation, multiplexing, low noise, high temperature operation, and long length capability. These attributes are attractive for certain industries and applications such as aerospace, nuclear, and oil & gas. These sensors work by measuring internal stress in the fiber via light reflections.

How it Works

To embed small fiber materials into a metal part, a channel path is cut during the CNC stage of the UAM process. The fiber is then placed into the channel and consolidated with the additive stage. Metal flow in the UAM process (which is similar to metal flow in friction stir) creates a strong mechanical joint between the matrix and sensor material, which in turn enables excellent strain transfer to the metal matrix for stress and temperature measurements. An instrumented bracket is shown in Figure 1 along with a micrograph of a consolidated fiber. The fiber is fully integrated with the metal matrix.

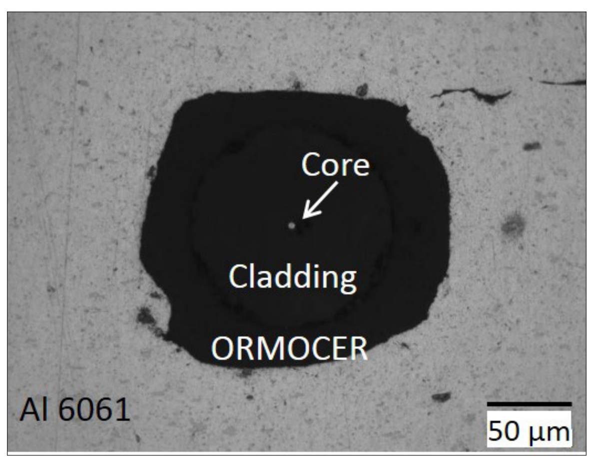

Figure 1. Building fiber optic strain sensors into aluminum components. A bracket is shown with the sensors embedded near the stress riser in the bracket, a measurement impossible to make with externally mounted strain gauges. The metal flow induced in the UAM process creates a strong mechanical joint between the fiber and matrix.

Fundamental work has shown that the joint strength between the fiber and metal matrix is stronger than the yield stress of the metal and that the joint does not degrade with fatigue loading [2]. Fabrisonic collaborated with EWI's mechanical test lab to perform this testing. This joint robustness enables technology scale-up and application evaluation. The team is also collaborating with NASA Langley Research Center for advanced mechanical testing and analysis. Fatigue data from the bracket in Figure 1 is shown in Figure 2."

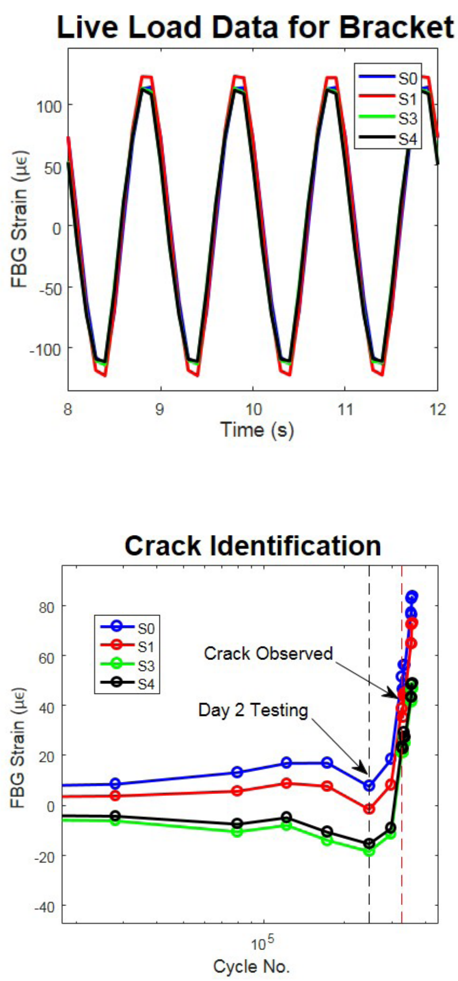

Figure 2. FBG strain information from fatigue test at NASA LaRC. Live load data can be used for monitoring and control while high outputs can be used to identify and track damage evolution.

Technology Outlook

Building fiber optic strain sensors into metal using UAM is still in its infancy, yet shows strong promise. To help with technology transition and adoption, the team is working to explore other key areas. For example, sensor use is made friendlier by building fiber terminations/ connectors into the part directly. Metal coated fibers are also of interest due to their high operating temperatures, see Figure 3. Lastly, other metal matrix alloys and applications are being evaluated in conjunction with EWI additive manufacturing group.

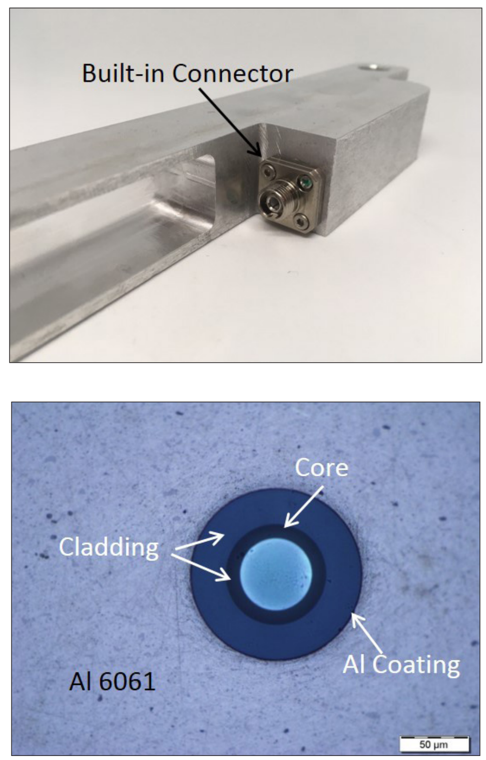

Figure 3. The future of embedded fiber optic materials. Built-in connectors are used for usability and robustness. Metal coated fibers are used for higher temperature applications.

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2. A. Hehr, M. Norfolk, J. Wenning, J. Sheridan, P. Leser, L. Patrick, and J. A. Newman, "Integrating Fiber Optic Strain Sensors into Metal Using Ultrasonic Additive Manufacturing", *JOM*, 2017.

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