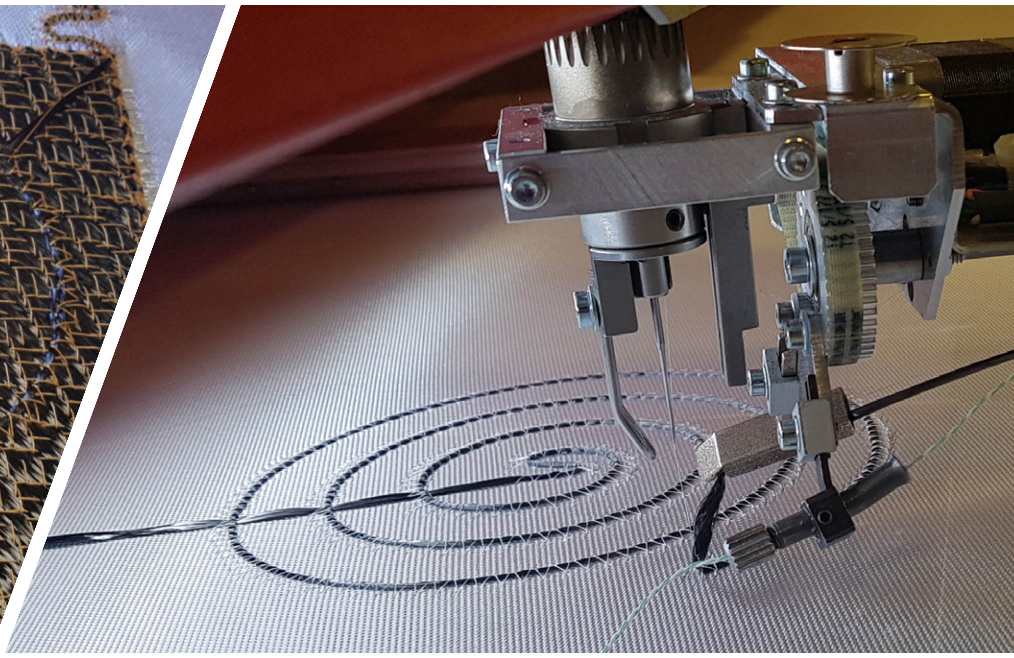
The University Of Sheffield. | AMRC Advanced Manufacturing Research Centre

AMRC Composite Centre
Case Study

Sensing data-driven decisions

Challenge

Develop a process to embed sensors at the earliest stage of a composite components manufacture, so that more data can be collected about the manufacturing process and better insight can be gained into the in-service performance.



Background

Structural health monitoring of composite components typically starts when the part enters service and monitoring equipment is usually bonded onto the surface of a composite. However, a parts life begins long before it enters service and to gain the most value, monitoring needs to begin at manufacture.

Added to this, a greater focus is being placed on traceability during the manufacturing process, with process data becoming essential to the diagnosis of longer-term, in-service failure or performance reduction of components.

In a 12-month, High Value Manufacturing (HVM) Catapult-funded project, engineers at the University of Sheffield Advanced Manufacturing Research Centre (AMRC) Composite Centre investigated different strategies to integrate sensors in the earliest stage of the manufacturing process.

By embedding sensors inside the material, manufacturing processes such as infusion, cure and machining, can be verified through collected data. Without embedded sensors, this monitoring of manufacture and in-service performance would not be possible.

Innovation

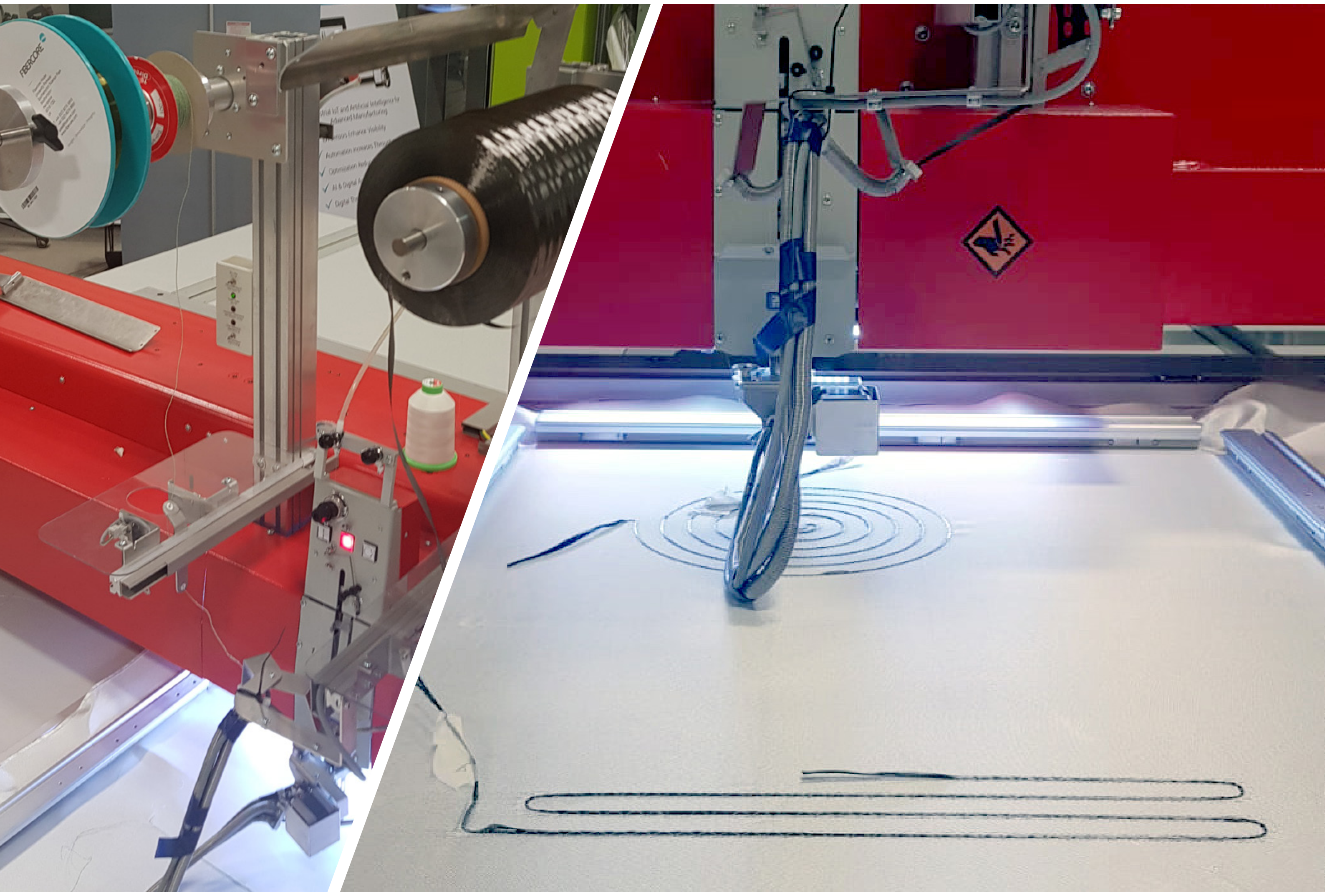
The biggest challenge faced by the AMRC was to find a way to insert the sensors while processing the carbon reinforcement, putting them through very intensive manufacturing processes while keeping the integrity of the sensor until the end of the operations.

The AMRC Composite Centre's state-of-the-art technologies such as 3D weaving and Tailored Fibre Placement (TFP) presented the opportunity to embed sensors right at the start of the process, and a thorough market search identified the most advanced sensors available to deliver the data needed during manufacturing: strain and temperature.

The research identified three embedded sensors:

- Ø 0.2 and 0.08 mm PFA coated K-type thermocouples with National Instruments data acquisition
- Fibre Bragg Grating (FBG) fibre optic cables with SmartScope data acquisition
- Optical Frequency Domain Reflectometry (OFDR) fibre optic cables with Luna ODiSI 6108 data acquisition.

Fibre optics, some measuring just over twice the width of a human hair, were successfully integrated into the weaving and TFP machine despite the challenge of a small misalignment breaking the fibre and negotiation of sharp turns on the spiral shape.



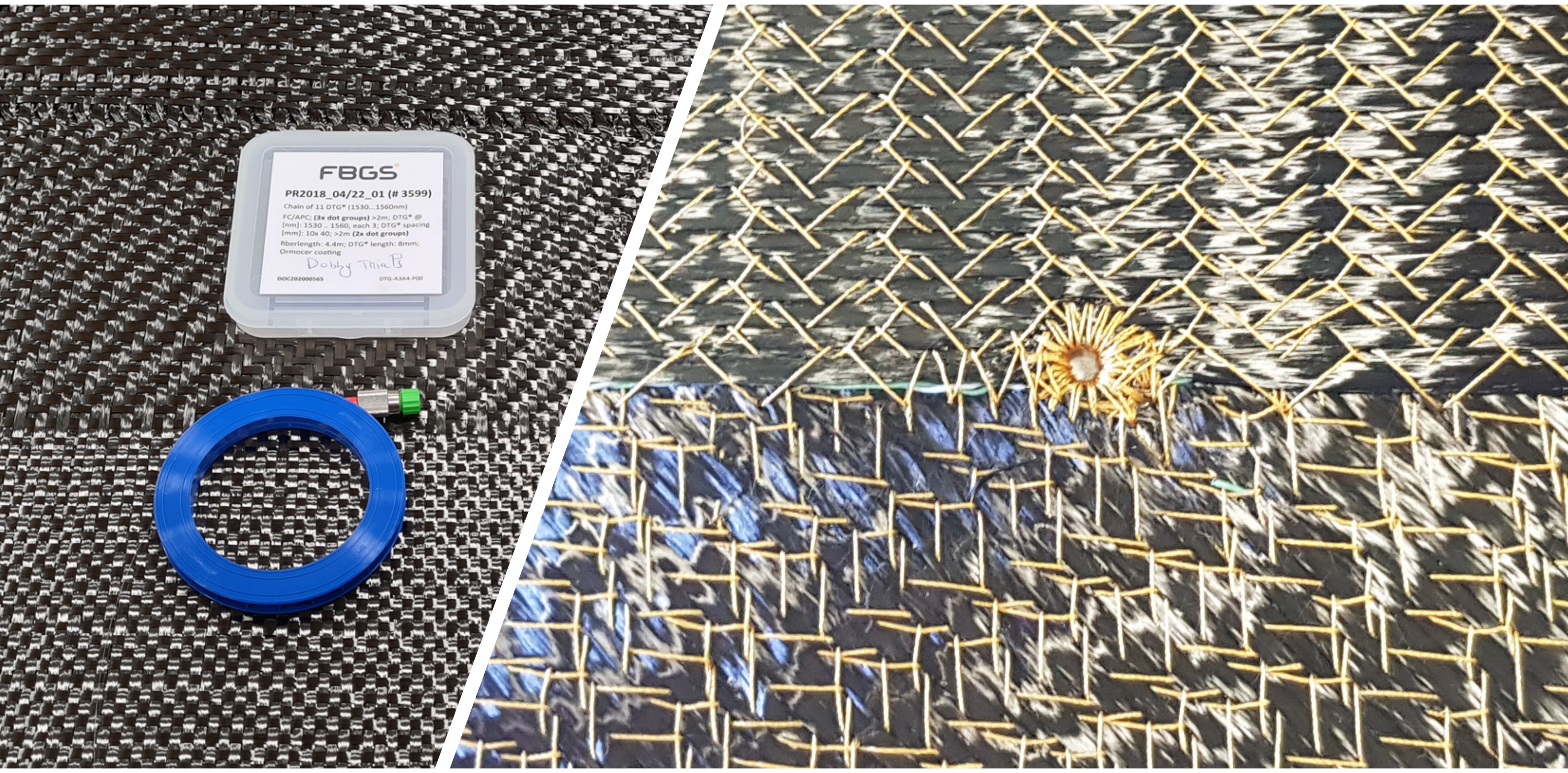
Left: The sensors and carbon fibre are fed automatically through the TFP machine following design instructions.
Right: Initial trials with fibre optics using the TFP machine created spirals and line shapes.

One of the innovative fibres used was a distributed optical fibre, which allowed for strain measurement every 5 mm along the fibre, up to 50 m in length. This technology, as well as the virtual support, were provided by fibre optics developers Luna and Sengenia.

The TFP was able to place a thermocouple 0.1 mm away from a drilling location and by using the AMRC's specialised data acquisition equipment engineers were able to observe a temperature of 148 °C (± 0.35 °C) during drilling, which was beyond the glass transition temperature of 133 °C. Evidence such as this would allow process optimisation to take place to limit the cutting temperature which can be damaging to composites. TFP was also able to position the fibre optics within the preform in specific locations and shapes, which would be required for monitoring more complex components.

On the weaving side, the team strategically inserted fibre optic cables on the warp direction, between all the 1,000 carbon tows installed on the creel. This secured the sensor while weaving it inside the fabric following a different weaving pattern.

Fibre optic sensors were inserted with a carbon fibre in the warp direction.



Left: FBG sensors were inserted in the warp direction for each pattern.
Right: Thermocouples inserted on the edge of a TFP reinforced hole. This technology gave more accurate data on temperature during hole drilling.

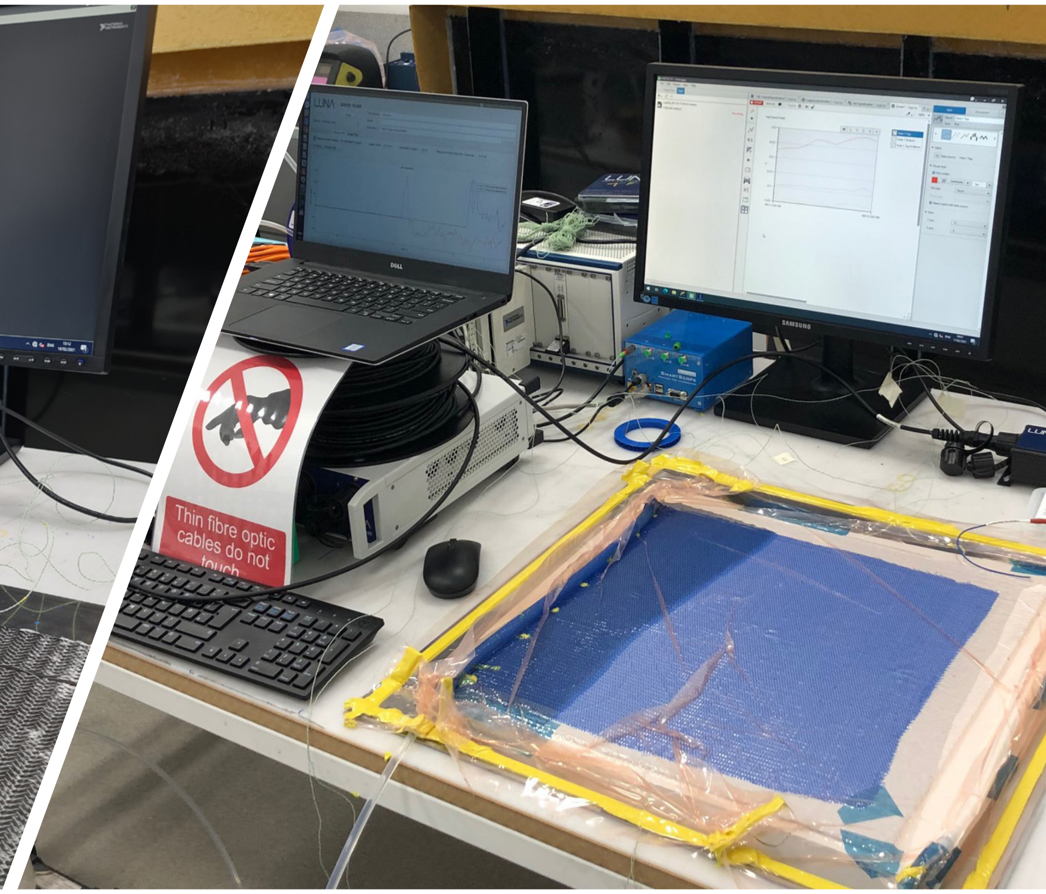
Result

AMRC engineers were able to successfully splice a connector onto an embedded fibre optic sensor, allowing the fibre, FBG and OFDR interrogators to be connected and see a strain response when the dry fibre sheet was touched with the embedded sensors. This meant the sensor had been successfully embedded without damaging the fragile core.

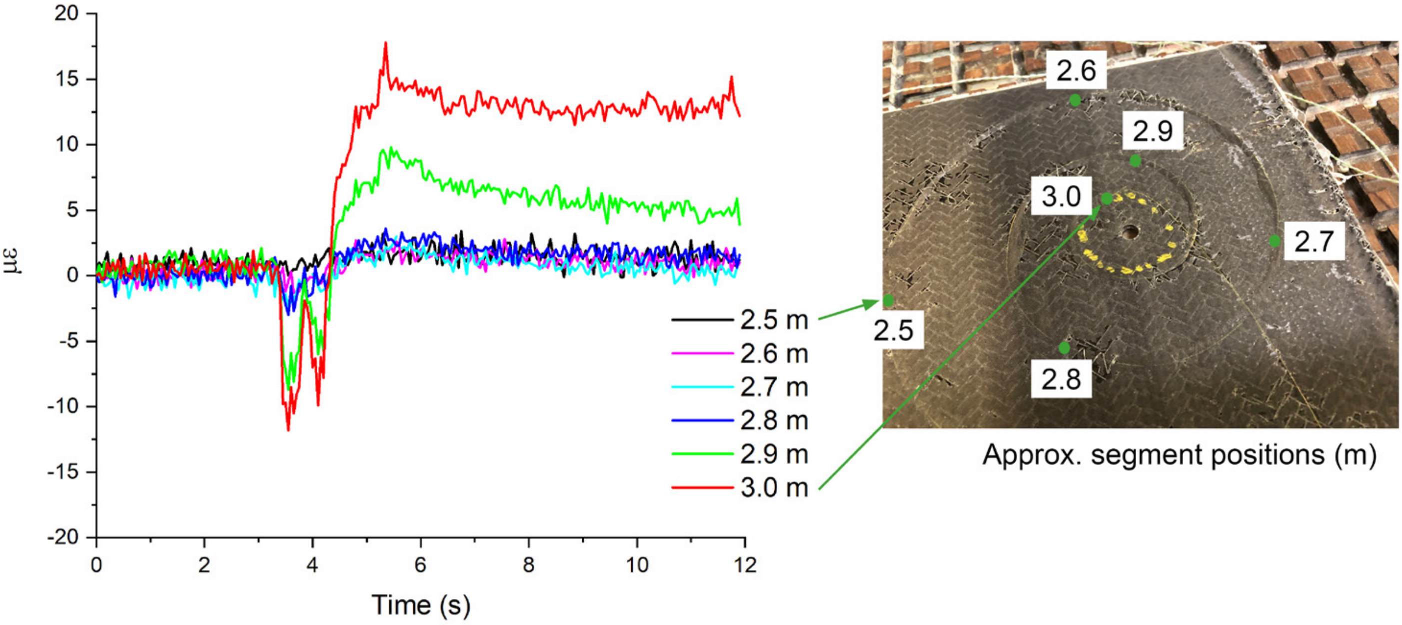
Real-time strain was recorded during each stage of composite manufacture: resin infusion, thermoset curing, drilling and edge trimming operations.

The project is the first step towards providing data-driven manufacturing health of parts prior to entry into service. In the future, a database of manufacturing strain data for a given component could be obtained, and machine learning could be used to determine if the strain collected during infusion, cure and machining will adversely affect the parts performance. This database could be used to form individual part properties for the bespoke design of products in the aerospace or automotive composite industry.

The AMRC has developed a true cradle to grave solution. Parts can be embedded with sensors at the start of their life and then allow temperature or strain to be measured to the end of its use.



Left: An AMRC engineer touches the sensor to show the variation of the strain on the screen. Right: The infusion is monitored with FBG, OFDR and thermocouples embedded in the TFP and weaving demonstrators. Top: Drilling of the TFP demonstrator with thermocouple sensor.



A graph showing the strain results from drilling trials for each of the sensor locations on the embedded TFP fibre optic spiral.

Impact

AMRC engineers have developed a future ability to make data-driven choices about manufactured parts, be they strain or temperature related.

The data collected from the sensors embedded in the composite will be used in downstream manufacturing processes, establishing a more accurate traceability during composite manufacturing and feeding advanced simulation work and machine learning. The outcomes will benefit the wider UK composite industry by using data-driven decisions to increase a component's performance, real-time quality control and establish a through-life health monitoring system.

By embedding sensors, scrapped part rates can be reduced by either controlling the manufacturing process more thoroughly or by showing that any defects are within manufacturing tolerances. Indeed, it may be possible to extend the lifespan of parts, rather than replacing them after a set amount of time.

Industry-wide use of intelligent workpieces with embedded sensors could enable an increase in productivity and could result in significant time and cost savings over a component's life cycle, reducing cost while increasing value and reducing the number of out of specification parts through the use of data-driven decisions.

The team has now started to explore how manufacturing health data can be recorded which can then be used as a baseline for through-life fatigue of a part, thus increasing the overall safety.

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