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Topic Insights

An Industry 4.0 Approach to the 3D Printing of Composite Materials

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Carbon fiber composites are lightweight, high-strength engineered materials that can be 10 times stronger than steel and eight times stronger than aluminum at a fraction of the weight of these materials. Composite manufacture has become a growth area for Australia in the past decade, leading to new export markets. However, in order to maintain this lead and momentum, the key challenge to overcome is to increase the rate and lower the cost of production. This can only be achieved by using automation and digitalization to reduce slow and labor-intensive manual processes.

There are currently two existing approaches for the three-dimensional (3D) printing of these materials. The first approach is only applicable for small sample sizes; it involves reinforcing a polymeric 3D printed structure with a small number of fiber tows, resulting in properties that are predominantly the same as those of the base polymer. The second approach is to disperse short (under 5 mm) chopped-strand carbon fibers into a polymer matrix, which can be 3D printed into larger structures. However, the short fibers are below the critical length at which the fiber properties are imparted into the matrix. Here, we report a third approach that utilizes a multiple-head automated fiber/tape placement technology, which enables the manufacture of large structures with mechanical properties equivalent to those of conventionally manufactured composites. This approach facilitates the digitalization of the production process all the way from design to manufacturing process control, and from self-correction to monitoring the in-service performance of a smart composite structure. The facility is one of six Australian Industry 4.0 Testlabs within a national network that was established as outlined in a recent report [1].

In a typical production line, a product change or modification requires significant line modifications and manual interventions. Hence, for such a product change to be profitable, a minimum batch size of the new product is required. In contrast, in the Industry 4.0 vision, smart factories allow individual customer requirements and even one-off items to be manufactured profitably. Such a factory can easily respond to last-minute changes on behalf of the customers and suppliers. Consequently, one of the main objectives of the proposed manufacturing line is to enable it to produce different products with minimal or no manual intervention. This approach will benefit from the development of a robust understanding of process–structure–property–performance (PSPP) relationships—a challenge that the paper in this issue by Qi et al. has made significant strides in addressing via the application of neural network algorithms.

In the Industry 4.0 vision of the manufacturing environment, smart machines, storage systems, and production facilities autonomously exchange information, trigger actions, and coordinate tasks [2]. Hence, significant effort has been extended to enable such networking between machines in different stages of the proposed production line. Swinburne's Testlab will use the Siemens PLM software platform, including MindSphere, to enable equipment from a wide range of manufacturers to communicate with each other. More sensors than are strictly necessary will enable each stage of the production line to collect a large amount of process data. This information will be stored in a secure local cloud, and will also be used immediately to feedforward and feedback production data to other machines in the line, thereby enabling a self-adapting production process.

The proposed line depicted in Fig. 1 is designed to allow product inspection after each stage of the manufacturing process. The inspection data will also be stored in the local cloud. Analysis of the large datasets stored in the cloud may lead to the discovery of new and unexpected correlations between the state of the finished product and the parameters of different stages of the manufacturing process, which in turn may be utilized to optimize the product. This approach was applied in the paper by Gan et al. in this issue; these scholars utilized a self-organizing map to visualize large datasets from additive manufacturing processes. Such information from data analysis will facilitate machine-to-machine communication and lead to the incorporation of a 3D printing approach within carbon fiber part manufacture, in what is known as the Fill's "multilayer" process. This is the world's first high-speed 3D printing process, which will revolutionize composite design and manufacturing by increasing production rates and minimizing cost and waste, while simultaneously increasing design and process flexibility. In this way, it will lead to the mass customization of products made from these materials.

An Industry 4.0 composite manufacturing line cannot be bought as an off-the-shelf solution, as several components or concepts are not commercially available. Therefore, Swinburne has developed a network of suppliers and end users to inform the design and development of the facility. This network includes global original

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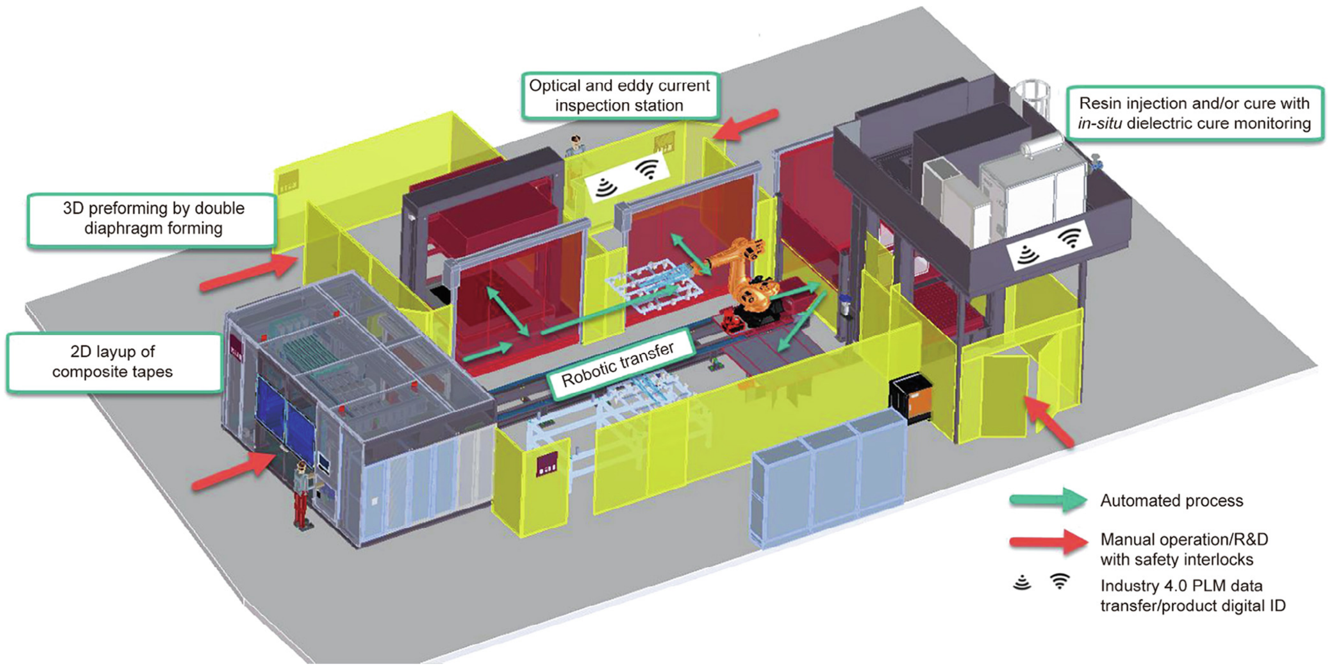

Fig. 1. The concept for Swinburne's Industry 4.0 Testlab, which will demonstrate a pilot-scale cyber–physical production system.

equipment manufacturers (OEMs) and Tier 1 suppliers, as well as Australian small and medium-sized enterprises (SMEs) that are integrated into their supply chains. The Testlab will digitally integrate three key components: ① the Fill's multilayer process, ② preforming of the deposited fiber, and ③ resin infusion and curing. The centerpiece will be the Fill's multilayer process (Fig. 2), which is a unique approach to the 3D printing of fiber that is completely digitally controlled and capable of depositing a layer (on a 1.6 m by 1.6 m tool) every 15 s. This process enables unprecedented production rates, design flexibility, and control of fiber orientation. To maximize the potential of the design flexibility of this process, a partnership with ARENA2036 at the University of Stuttgart will explore the use of new digital design technologies for the optimization of fiber orientation and part geometry, with an emphasis on design for manufacture.

Founded in 1966 and currently employing around 800 people, Fill is a global leader in the design and supply of automated solutions, machinery, and equipment for various industrial sectors, and is located in Gurten, Austria. The newly premiered multilayer system is capable of producing near-net shape fiber stacks in the very short cycle times demanded by the automotive industry. The concept offers high flexibility in part design and maximum material savings. The process accepts material input as a feed from a spool and has the potential to utilize carbon-fiber-reinforced thermoplastic tapes, low-tack prepreg systems, and carbon fiber tows. It is capable of depositing a layer of fiber onto the rotatable stacking table every 15 s in a highly controlled manner, meaning that parts can be tailor-made and formed into a 3D part in a controlled and efficient manner. The world's first multilayer machine will be supplied by Fill; its prototype was launched at the JEC World in Paris, in March 2019.

The Testlab incorporating the Fill's multilayer process is designed to be multifunctional and expandable in order to enable users to test and implement new concepts as they are developed.

A national network of Industry 4.0 Testlabs is being established in Australia, supported by the federal government. Each Testlab will focus on a different product involving a unique cyber–physical system. Swinburne's Industry 4.0 Testlab for 3D printing of composites will incorporate a world-first additive manufacturing approach in the manufacture of these lightweight engineered materials. The outcome will be a showcase for the digital transformation of a pilot manufacturing process, while facilitating R&D. It will display Australia's Industry 4.0 vision and enable collaboration with the international pioneers of Plattform Industrie 4.0 in Germany and the US Industrial Internet Consortium. Swinburne has established partnerships with global economies in Germany (ARENA2036 at the University of Stuttgart and the University of Applied Sciences Ravensburg-Weingarten), Austria

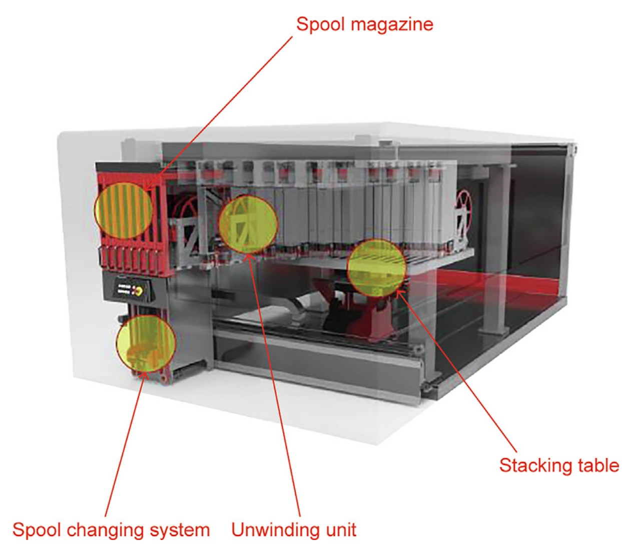

Fig. 2. Schematic of the direct fiber deposition process developed by Fill (Austria) showing key features such as the automatic spool changing system, unwinding unit, and stacking table.

(Fill), and Israel (Plataine), and with Australian companies (Quickstep Technologies, SensaData), to undertake Industry 4.0 platform capability development. This includes both fundamental research and rapid prototyping leading to the commercialization of new technologies.

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