DESIGN OF MULTIFUNCTIONAL COMPOSITES AND THEIR ADVANCED ADDITIVE MANUFACTURING

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1. Context and overall view

Additive manufacturing (AM) or 3D printing is a recent approach that enables the quick fabrication of structures featuring complex geometries without extra tooling and labor. This technology refers to a family of processes of joining materials in order to fabricate objects layer by layer from a 3D computer-aided-design (CAD) model. Recent progresses in advanced manufacturing techniques and in the development of compatible materials push the boundaries for manufacturing of many industrial parts such as high-performance composite structures, functionally graded materials, and smart composites. Despite the recent advancements, the development of new materials and processes is still required to accelerate the utilization of AM in composite manufacturing.

Our research work at LM^2 research group at Polytechnique Montreal targets the development of various composite materials and advanced AM processes. On the material side, we develop new types of composite materials consisting of thermosets, thermoplastics or UV-curable resins reinforced with different fillers such as short carbon fiber, fumed silica, silver nanoparticle, etc. On the manufacturing side, our current efforts focus on the development of advanced customized 3D printing platforms for non-planar fast production of large composite structures and also for the multi-material printing of multifunctional composites featuring various properties (e.g., mechanical resistance, piezoelectricity). This short abstract covers select recent scientific achievements from Prof. Therriault's team.

2. Our recent select achievements in materials formulation and AM processes

2.1. Short carbon fiber-reinforced thermoplastic composites

In collaboration with a few colleagues and some key players of the aerospace industries in Canada (Bell Textron Canada) and France (Safran Group and ArianeGroup), LM^2 research group is developing high temperature-resistant thermoplastic (HTRT) composite materials for the fused filament fabrication (FFF) AM process. Following the initial research work on FFF printing of short carbon fiber-reinforced Nylon-12, our team evolved to the 3D printing of aerospace-grade HTRT (e.g., PEEK, PEI and their blends) and their short fiber composites (see x-ray imaging of highly reinforced thermoplastic filament in Fig. 1a). These materials have successfully been tested for their processability, printability, and their mechanical performance (e.g., composites with ~7 times improvement in stiffness compared to pure polymer). The developed materials are planned to be used for printing of multifunctional (e.g., mechanical and acoustic) components in aircraft engine fan case and some parts (e.g., chassis) of a composite lunar rover.

2.2. Filled thermosetting materials

We have recently achieved printable thermosetting composite materials by modifying a commercial aerospace-grade product, originally used as a hand-applied sacrificial coating on aircraft engine fan cases. The new formulations developed by our team enabled the AM of lightweight sound absorbing structures to provide multifunctionality (i.e., acoustic and abradable) to the coating with the relatively

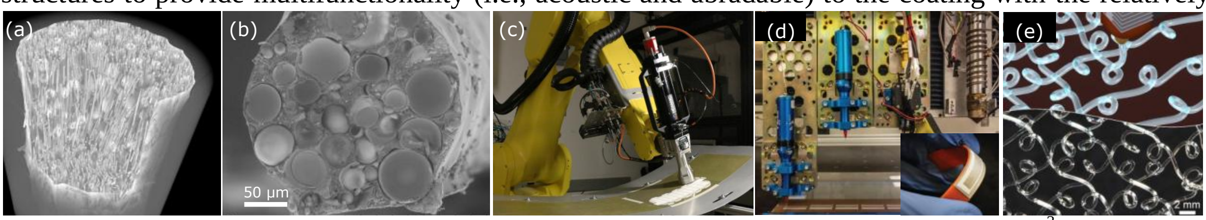

Fig. 1 – Select recent activities in additive manufacturing of multifunctional composites at LM^2, Montreal.

high printing speed of 250 mm/s. The printing speeds and shape fidelity (see uniform circular cross section shown Fig. 1b) achieved using the materials we developed demonstrate their potential for large-area fabrication.

2.3. Six-axis non-planar AM

Most current commercial printers still rely on a 3-axis motion system that is limited to small planar printing envelope and low printing speed. We have recently developed a six-degree-of-freedom robotic infrastructure for the high-speed AM of relatively large-scale composite parts. For example, we designed and fabricated a multinozzle printhead (which contains an extrusion array of 26 fine nozzles of 250 μm inner diameter) that allowed us to rapidly manufacture microscaffold networks of thermosetting composites (see a photo during the robotic deposition of a non-planar microscaffold in Fig. 1c).

2.4. Multi-material multi-process AM

One of our recent research efforts was on the development of a printing platform for multi-material multi-process printing. This platform consists of a high-speed and high-resolution positioning stage combined with multiple custom-made and commercially available printing systems (see an example of printing head configuration in Fig. 1d). These printing systems are designed to be compatible with different types of printable materials (e.g., thermosetting [1] and thermoplastic composites [2], piezoelectric inks [3]). The ability to print different materials of various functionalities enables the creation of the next generation of smart composite structures featuring embedded sensors, acoustic and energy harvesting materials, to name a few. So far, our team has recently developed novel highly conductive and piezoelectric materials that could be used as inks for multi-material 3D printing of the electrodes and the piezoelectric core, respectively, of our energy harvesting devices.

2.5. Instability-assisted printing of high toughness composites

Our team pioneered the design and the instability-assisted printing of high-toughness microstructured fibers inspired by the spider silk. We created a transparent impact-absorbing composite based on the toughening mechanism that involves sacrificial bonds and hidden lengths also found in spider silk [4] (see images of microstructured fibers in Fig. 1e). Our developed composite consisted of an elastomer matrix and an instability-assisted 3D-printed fibers with sacrificial bonds and alternating loops. Unfolding the hidden loops after bond breaking and matrix cracking can resist impactor penetration.

3. Conclusion

At the LM^2 research group at Polytechnique Montreal, our research focuses on composite materials design and their advanced additive manufacturing for transportation, aerospace, microelectronics and biomedical fields. We are not only developing new multifunctional composite materials, but we are also developing innovative additive manufacturing concepts for next generation of polymer composites.

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