Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

CIRCULARITY OF THERMAL REPAIR AND RECYCLING OF 3D-PRINTED THERMOPLASTIC COMPOSITES FOR AEROSPACE APPLICATIONS

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ABSTRACT

Extending the lifespan of composite components through repair and maintenance ensures continued performance during long missions while reducing waste in many aerospace applications. Advancements in additive manufacturing (AM) of thermoplastic composites enable the creation of robust and lightweight structures. Material-extrusion AM, more specifically fused filament fabrication (FFF), consists of the deposition of reinforced composite filaments on a heated platform layer by layer. Manufacturing limitations or defects (e.g., interfilament voids and weak molecular bonding at the interface) can result in interlayer delamination.

Thermal repair in thermoplastic composites involves restoring structural integrity using fusion bonding techniques. This repair approach heats the damaged interface above the material's glass transition temperature, allowing polymer chain interdiffusion across the interface to achieve rebonding at the crack surface. Multi-material AM could directly embed heating elements in composites, eliminating the need for external heating equipment. Conductive fillers can create continuous networks in polymer filaments. 3D printing using these conductive filaments and passing an electric current through them can produce localized resistive heating.

There is limited research on the circularity of multi-material composites, such as those combining fiber-reinforced filaments for strength and conductive filaments for functionality. While multi-material composites can enable multiple cycles of repair, the different components are hard to separate at the end of their life, making recycling complex. On the other hand, without functional materials such as heating elements, it is possible to recycle and reuse 3D-printed fiber-reinforced thermoplastics, although recycling would involve collecting, transporting, and reprocessing. Life Cycle Assessment (LCA) is a framework for assessing the sustainability impacts of a product or process across its life cycle, from raw material extraction to disposal (cradle-to-grave). It can compare repair and recycling scenarios by quantifying environmental, economic, and social burdens.

This study aims to investigate the effect of thermal repair in FFF of thermoplastic composites on the product's overall environmental impact. The material chosen for this study is short carbon fiber-reinforced nylon 12 (PA12-CF), a widely studied material for aerospace applications. The first step involves testing samples with embedded carbon black/polylactic acid (PLA-CB) resistive heaters for three cycles of thermal repair under mode-I fracture conditions. In parallel, samples without embedded heaters are recycled for up to three cycles and tested under the same conditions. LCA methodology is performed on both sets of samples to compare CO_2 equivalent emissions. These comparisons ensure the longevity and sustainability of thermoplastic composites, facilitating their integration in aerospace applications.