Student: **Wout De Backer**
Date & Time: **Friday, Aug 18, 2017 at 2:00 pm**
Location: Faculty Lounge, Swearingen (first floor toward Main St. 1A03)
Committee: Dr. Ramy Harik – Advisor
Dr. Michel van Tooren – Advisor
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Dissertation Title:

Multi-Axis Multi-Material Fused Filament Fabrication with Continuous Fiber Reinforcement

Abstract

Fused Filament Fabricated, or common 3D Printed parts, have reduced mechanical properties in the build direction of the print, and are thus generally weaker than their equivalent injection-molded parts. Furthermore, Computer Aided Design and Manufacturing (CAD/CAM) tools have evolved together with the evolution of processes for subtractive and deformative based manufacturing methods. For Additive Manufacturing to gain traction in industrial environments, the process specific algorithms need to be developed and implemented in CAD/CAM software. There is a need for reinforcement of both the material and the structures and for proving the industrial capabilities of AM, in particular fused filament fabrication, through a new set of processes that complement the existing design paradigm. A promising solution to the above mentioned problems of strength is investigating the characteristics of engineering thermoplastics and through the addition of continuous carbon fibers in the print. Unfortunately, engineering-thermoplastic impregnated carbon fiber tows do not exist, or come at a high price due to the low demand and pure filament is currently only available for proprietary printers at steep prices. Additional strength in the inter-layer bonding may come through the addition of local reinforcement deposited on an existing structure in the build direction, which implies stepping away from layer-by-layer manufacturing using true 3D deposition and toolpathing. This is only possible by exploiting the full benefits of a 6+ degree of freedom FFF system.

A KUKA robotic platform with 6 degrees of freedom forms the base of an in-house developed industrial-scale 3d printer, capable of printing with engineering polymers with continuous fiber reinforcement. Polyetherimide (PEI) pellets were acquired and extruded within tolerances into a usable 3D printing filament. PEI-CF filament was developed through wet impregnation in a PEI solution. A specialized nozzle design and printing bed were researched, designed, integrated and tested on the KUKA platform, for which dedicated toolpathing software was written with path optimization capabilities. The path optimization software significantly reduces the file size and increases the accuracy of the tool pathing. Complex, compound objects can now be sliced without the restrictions of common slicers and 6-axis directional reinforcement can be added to various types of base geometries. Three configurations of the printing technology were assessed: one where the end effector si mounted to a conventional 3D printer, one where the bed is the KUKA end effector and the nozzle is stationary, and one where the nozzle is the KUKA end effector and the bed is stationary. The developed printers were used to print coupons for a multitude of tests to evaluate and quantify the mechanical performance, fiber-volume ratios, void-volume ratios and surface quality of the pellets, filaments and printed parts.

Several demonstration components were printed as a proof of concept, demonstrating the technology readiness of this process for aerospace applications. The methods, processes and results discussed show great promise for the implementation of functional additive manufacturing on 6 degree of freedom platforms in high-performance demanding industries.