Development of continuously reinforced filament for manufacturing composite materials via open source 3D printing

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Introduction

The approach of developing a continuously reinforced plastic composite via 3D printing is still in its initial stages. Many efforts to increase the mechanical properties of thermoplastic matrices include adding chopped fillers, such as metal-ceramic whiskers, fibers, or compounded powders, into the process of manufacturing of thermoplastic matrices. Unfortunately, current methods have mainly resulted in undesired discontinuous reinforcement materials or in a semi-continuous process. Thus, the lack of continuity in the reinforcement results in weak materials for applications such as impact and fatigue.

The most attractive technology for producing continuously reinforced composite materials via additive manufacturing appears to be through the Fused Deposition Modeling (FDM) 3D printing process of introducing plastic filament into a hot nozzle, followed by its deposition through an extruder head. This system, that is well known, can be modified to incorporate a continuous reinforcement phase during the printing process. The present work will investigate the development of a continuous reinforced filament, as well as the printing parameters and modifications required on a FDM machine to yield a printed structure fully conformed by a continuous reinforced plastic. Such materials that are able to support relative stresses and conditions are sought for high-performance applications in engineering fields of aerospace, military, or automotive.

Applications & Future Research

The research performed may potentially serve as the preliminary stage for a full proposal with the Air Force Office of Scientific Research.

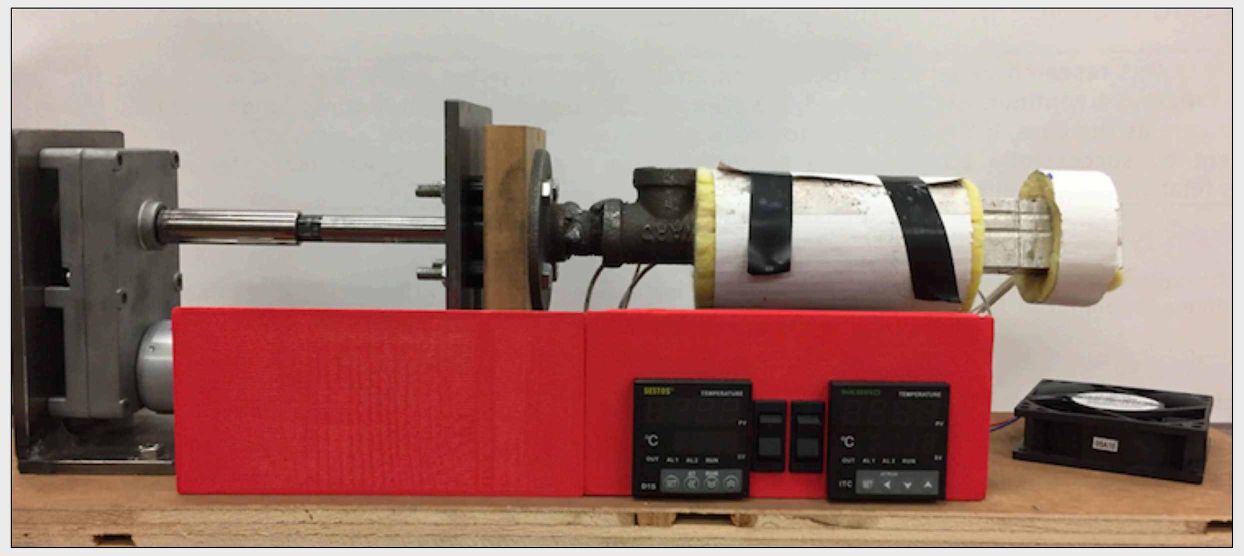
The present project also represents an excellent opportunity to keep building-up a formal research group in the area of additive manufacturing as a pipeline for the current PhD program in Materials Science and Engineering at YSU.

Additionally, future research in the comparative mechanical testing of this continuously reinforced composite to composites assembled via typical lay-up manufacturing process and the claimed continuous process patented by Markforged can serve as groundwork for a patent on the extrusion and printing process.

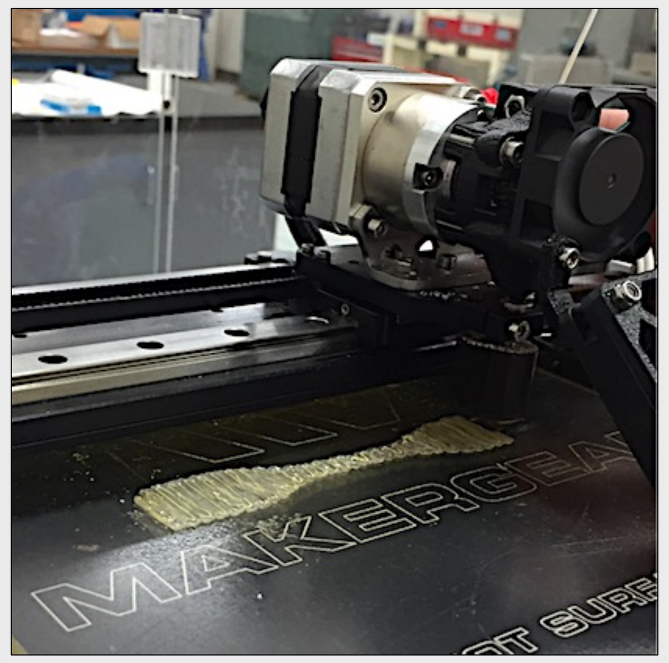
Objectives

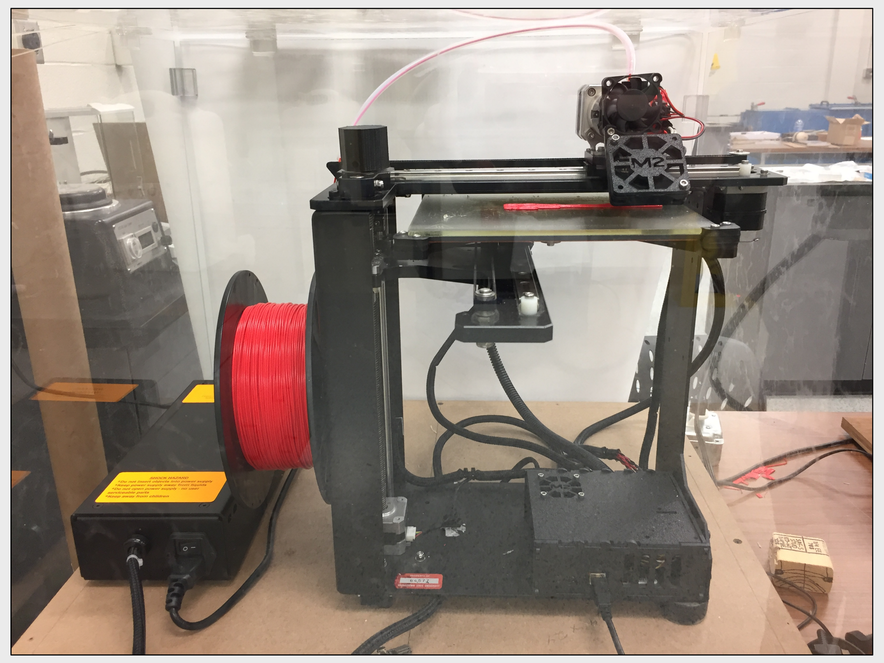
The main objective of this research is to investigate the production of a continuously reinforced filament for the manufacture of composite materials via 3D printing. Additionally, construction of a unique FDM machine with tailored printing profile that can deal with these kinds of novel filaments to build continuously reinforced composite materials.

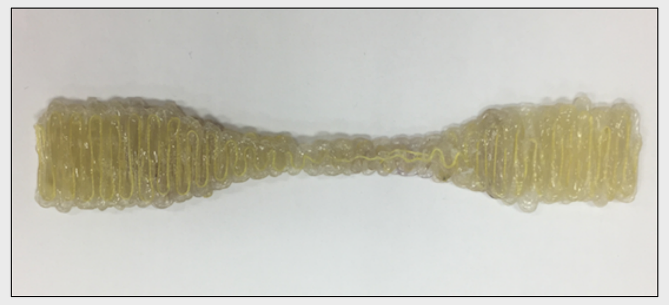
Primary Phase
- Retrofit filament extruder that melts raw plastic pellets into 3D printable filament
- Find optimal reinforcement to use at high-temperature printing requirements
- Coat fiber reinforcement with plastic at appropriate diameter



Secondary Phase
- Upgrade open source FDM machine
- Write printing code to print desired dog bone structure to meet ASTM standards for tensile testing
- Print continuously reinforced composite structure







Methodology

Initially, continuously reinforced filament will be produced. Subsequently, a modified FDM machine will be assembled. The identification of parameters that can print a continuously reinforced composite will follow. In the end, printing of a structure and evaluation of its flexural properties will result.

Stage I. Manufacturing of continuous fiber filament
- Produce through extrusion process
- Investigate ABS and PLA as plastic material, Nylon and Kevlar as reinforcement
- Investigate fiber-polymer wetting interface to ensure strong interfacial adhesion exists within filament

Stage II. Assembly of modified FDM machine
- Modify printing controls – print velocity controlled at every step

Stage III. Printing of continuous fiber composite
- Modify critical controls – direction of printing, velocity

Stage IV. Mechanical characterization
- Perform tensile testing as a basic quantification of efficiency of printed parts

Results

A Kevlar thread has been continuously embedded into a PLA matrix and a continuous filament has been created. The filament has been used in an open source 3D printer and has lead into the manufacture of a successful reinforced printed component.

Further mechanical testing of the continuously reinforced composite material shows that the reinforced PLA matrix had a lower stress, lower modulus of elasticity, and can resist a higher load before failure than unreinforced PLA. Void spaces within the Kevlar reinforced printed material from inconsistent filament diameter are believed to the cause for the values obtained.

	Total Load Before failure (N)	Total Stress (Pa) Before failure (Pa)	Total Strain (mm/mm) Before failure (mm/mm)	Modulus of Elasticity(GPa)
PLA	1059.80286	4561211.046	0.045259366	0.131
PLA Reinforced Kevlar	1013.90417	4385114.158	0.051909618	0.101