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CHARACTERIZATION OF HIGH-DEPOSITION POLYMER EXTRUSION IN HYBRID MANUFACTURING

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Abstract

Hybrid manufacturing processes that include additive and subtractive operations have unlocked many of the design limitations that were not previously available. Additive processes allow increased design flexibility, customization, and complexity. Subtractive processes enable higher production speeds and improved accuracy and surface finish. This paper describes a hybrid system that combines a computer numerically controlled (CNC) milling machine with a high deposition rate polymer extruder to create artifacts using hybrid additive/subtractive processes. Future research plans are described, including possible applications for this system in multimaterial and multi-process manufacturing.

Introduction

Additive manufacturing processes offer many advantages over conventional subtractive processes. Foremost among these are the expanded design space enabled by layer-by-layer deposition and the low barriers to mass customization and increased complexity. However, additive manufacturing processes also carry well known shortcomings, including longer build times, inferior surface finish, and less control of dimensional accuracy. Subtractive processes offer the opposite—more restrictions on design complexity and customization, but higher output and better control of surface finish and tolerances. Many methods have been explored to combine the best of both additive and subtractive processes, an idea typically called hybrid manufacturing.

One approach that has been recently explored is combining a metal powder directed energy deposition (DED) process with a multi-axis CNC milling process. This can be a custom machine that incorporates both processes, or it can be an add-on module that adds a second process to a commercially available system. Hybrid Manufacturing Technologies offers several such tools, such as the AMBIT (Figure 1). The AMBIT is an interchangeable tool with a CAT 40 head that can be mounted and controlled by a CNC mill.

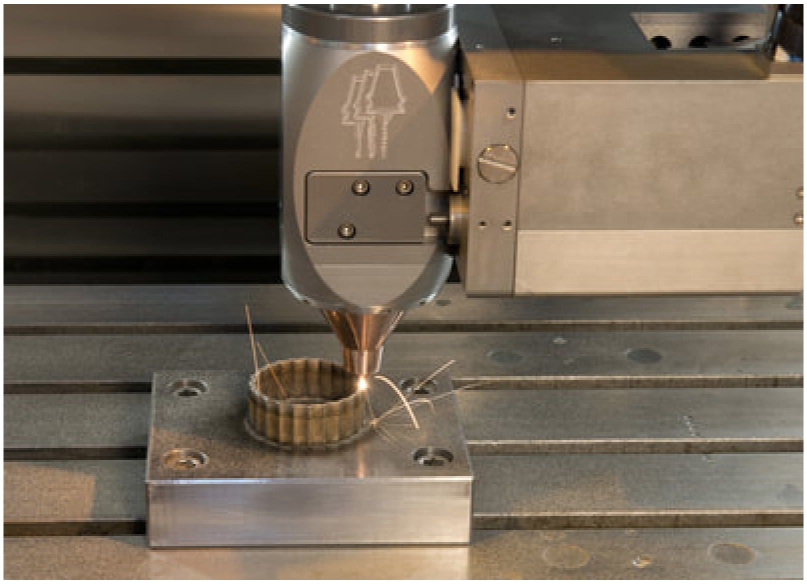

Figure 1. AMBIT metal DED tool

Another technology that is relevant to this paper is that of room-scale polymer extrusion systems, such as big area additive manufacturing (BAAM) (Figure 2). In these systems, large nozzles, efficient heating and shearing subsystems, and the use of polymer pellets instead of filament as feedstock enable high speed fabrication with thick layer heights and large part footprints.

Figure 2. "Strati" 3D-printed car, manufactured in part through BAAM process

<u>Ambit PE-1</u>

These two concepts have been combined in Hybrid Manufacturing Technologies' AMBIT PE-1 polymer extrusion tool (Figure 3). A prototype version of this system has been installed on a Haas toolroom mill at Brigham Young University, where its capabilities and possible applications will be investigated. The AMBIT PE-1 uses the same CAT 40 head as the other AMBIT tools, and includes a miniaturized auger driven by the CNC machine's spindle. This auger helps to shear and blend the polymer pellets as they are melted by a heater in the tool. External connections are needed to the temperature control and the pellet hopper. The tool can print in common polymers like ABS up to 9 kg/hr, and can be switched out for subtractive CNC tools or inspection tools to enable true hybrid manufacturing in a single commercially available set up. Because the same pellets are used as in injection molding machines and other well-established processes, a wide variety of possible materials are readily available for cheaper than the equivalent filaments. Figure 4 shows the prototype head installed on the Haas CNC mill at BYU.

Figure 3. Hybrid Manufacturing Technologies AMBIT PE-1 polymer extruder for CNCs

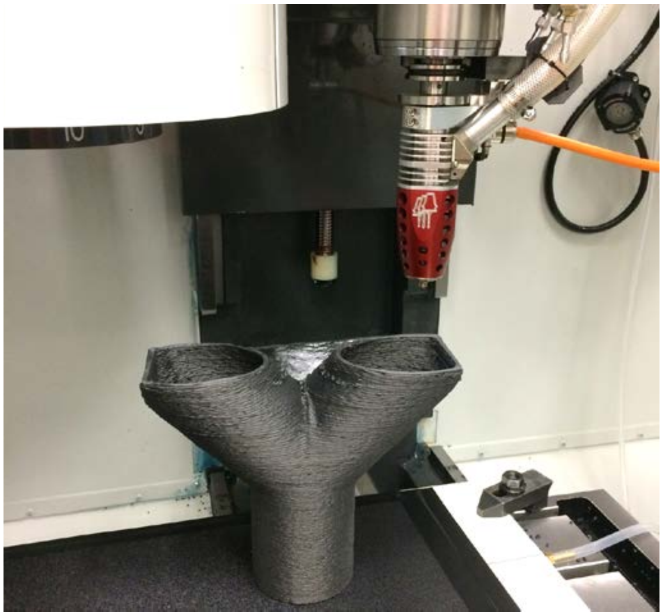

Figure 4. AMBIT PE-1 prototype installed on a HAAS CNC mill at BYU

Proposed Research Road Map

Research regarding this hybrid manufacturing process will occur in four general stages. During the first year, to occur in fall 2018, our students will complete the set up and characterization of the AMBIT PE-1 tool. In particular, we will determine optimum settings for the default material—ABS with chopped carbon fiber—and consider which parameters are tuned similar to calibration of FFF machines, which behave more like BAAM, and which may behave in unique ways in this application. We will also print test specimens in CF-ABS to compare material properties to similar materials printed on FFF or injection molded.

During the second stage, after the system is performing reliably, we will investigate the viability of using this system for both additive and subtractive processes. In metal DED hybrid systems, the additively produced material is welded securely to the build plate, allowing subsequent milling and other subtractive processes without refixturing the part. However, polymer systems typically secure the printed material to the bed by using similar materials (e.g., printing ABS onto an ABS sheet), softening the bottom layers on a heated bed, using adhesives like glue or tape, or allowing the material to seep into small perforations on the build plate. These methods are sufficient to prevent the part from coming loose during fabrication, but may not be secure enough to secure the part against the torques and horizontal pressures experienced during milling operations. We will investigate and test variations of these existing solutions, as well as possible novel solutions like print-in-place clamps and mechanical interlocks (like tongue-in-groove) with the bed.

The third stage, which can be run in parallel with the second, is to characterize the system and adapt it for use with high performance and high temperature polymers. These polymers, such as PEEK, PEK, PTFE, PPS, PEI, and PC, are in high demand for engineering applications where high strength and high temperature survivability is needed. However, these materials are difficult and expensive to find in filament form, and most FFF machines are not set up for such extreme temperatures. With the AMBIT PE-1's use of pellets, these materials can more easily be used in additive designs.

The fourth planned stage of research is to consider possible applications for this technology, especially opportunities for using the process in multimaterial and multi-process designs. Possible hybrid combinations where this tool could be advantageous include cladding high performance materials over less expensive bulk materials for tools and molds, printing polymer on metal substrates, printing metal on high-temperature polymer, continuous polymer functional gradient materials (FGMs), and even embedded electromechanical sensors and motors. The eventual goal would be the incorporation of additive manufacturing into true CNC automated manufacturing, with single-program multimaterial hybrid process planning and automatic ejection of the finished part.