Optimization of Hybrid Metal Printing Process

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Abstract *- This paper presents the optimization of the 3-D Hybrid Metal Printer. This printer, developed at Western Michigan University, offers a hybrid method to create finished functional metal parts using one setup. This 3-D metal printing method integrates an additive and subtractive manufacturing process. It uses a computer numerical controlled machine (CNC) and a method of welding called gas metal arc welding (GMAW). The additive process utilizes GMAW to deposit each layer of metal, then the subtractive process uses the CNC mill to machine the layer. The process is repeated multiple times until the part is complete. This technology has the potential to be brought into areas that do not have the resources readily available to create a part with common manufacturing methods. Optimizing the 3-D Hybrid Metal Printer process includes integrating a real-time scanning system and testing new materials. This scanning system can give instant feedback on the shape and geometry of the part to ensure constant consistency and uniformity throughout the additive and subtractive manufacturing process. With this system, the process and parts can be accurately verified and documented to meet required specifications for structure integrity and tolerances.*

Keywords - *3-D Hybrid Metal Printer, additive manufacturing, subtractive manufacturing, computer numerical controlled machine (CNC), gas metal arc welding (GMAW).*

I. INTRODUCTION

The use and ownership of 3-D plastic printers is becoming increasingly common in the manufacturing and design industry. Almost every company involved in some form of prototyping uses a 3-D plastic printer to allow printing of a newly designed creation. Using plastic 3-D printers is as simple as generating a 3-D model using CAD software, transferring the model to the printer, and selecting print. The auto formation of the CNC (G & M) code is one of the greatest advantages of using 3-D plastic printers since there is no need for the end user to have knowledge in how to program. Also, most plastic materials used in 3-D printers are inexpensive, allowing wide spread usage even to common users.

Disadvantages of using 3-D plastic printers include having to use support material when the geometry of the design is complex, and the strength limitations plastics have as a material. Still, plastic parts have many useful applications but fall short in the strength and durability areas that most metals maintain. This is where the 3-D Hybrid Metal Printer can outperform 3-D plastic printers and have a substantial advantage. The 3-D Hybrid Metal Printer can create a high strength durable metal part that can be applied to real world scenarios. When parts are tested in the field, this will allow instantaneous feedback on the functionality of the part that has been created using the 3-D Hybrid Metal Printer. Current widely used metal printing processes include directed energy deposition and powder bed fusion [1]. As previously stated, metal printing processes have many known advantages, and fewer known disadvantages. The disadvantages include porosity concerns, surface roughness, internal defects, and warping [4].

Although these 3-D metal printing processes have their disadvantages, the advantages still outweigh the disadvantages. The 3-D metal printing industry still has endless possibilities for optimizing the metal printing process to meet quality requirements. Western Michigan University's engineering manufacturing laboratory currently has three operating and fully functional 3-D Hybrid Metal Printers. These 3-D Hybrid Metal Printers were designed and built to create fully functional metal parts without using standard industry techniques such as machining from bulk material or casting. Metal printed parts have been successfully created and tested for several companies to prove what the capabilities and limits of the 3-D Hybrid Metal Printer are.

II. CURRENT METAL PRINTING PROCESSES

Metal printing processes have different techniques to achieve and end result of a finished 3-D printed component. As mentioned earlier, common 3-D printing processes include directed energy deposition and powder bed fusion [1]. Each of these printing processes have their challenges when manufacturing parts.

A. Directed energy deposition

Directed energy deposition, in the simple form, is when material is deposited in a precise location for a heat source to liquefy and harden the material into a

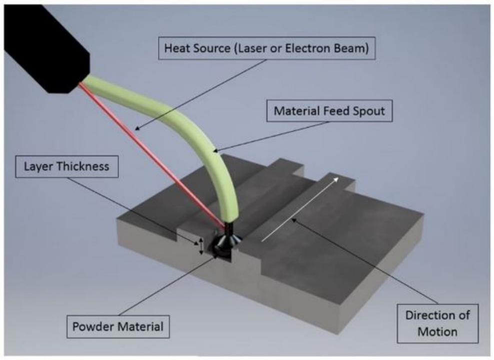

Fig. 1
Direct Energy Deposition

solid layer. This heat source is normally in the form of an electron beam or laser. [5].

B. Powder bed fusion

Powder bed fusion is the 3-D metal printing process that uses a method of light emitting energy source that liquefies a layer of powder to form a solid

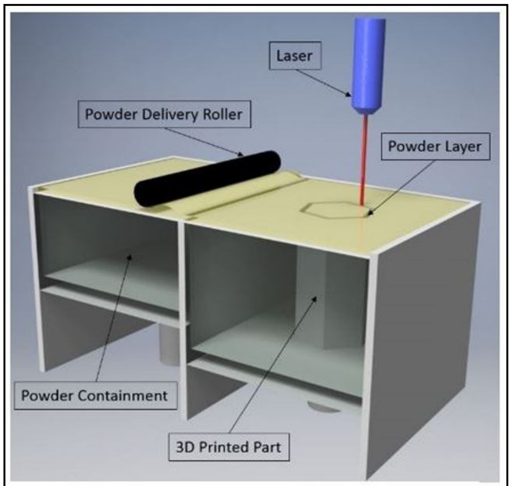

Fig. 2
Powder Bed Fusion

layer of material [2]. Once the powder has solidified, the base plate that the part is adhered too, is lowered to allow another layer of powder to rest upon the previous layer. The light emitting energy source is then activated to liquefy the powder to allow another layer to be formed. This process is repeated until the part is complete. In order to make quality part using powder bed fusion, important factors need to be considered. They include powder characteristics, material contamination, and powder reuse [2].

III. EQUIPMENT AND STEUP FOR 3-D HYRBID METAL PRINTER

Western Michigan University's 3-D Hybrid Metal Printers are comprised of two major components, a computer numerical controlled (CNC) machine and a

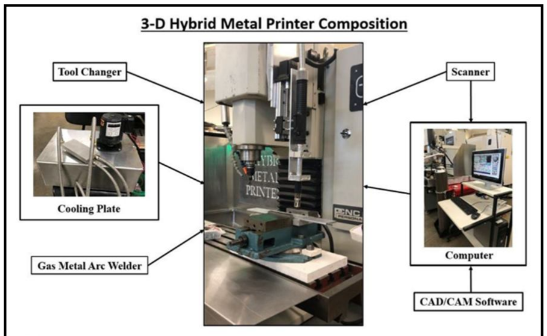

Fig. 3
3-D Hybrid Metal Printer Composition

gas metal arc welder (GMAW). The GMAW arm is attached to the CNC machine as a separate tool device. This device allows for the vertical motion of the GMAW arm which is required for the additive manufacturing process. The 3-D metal printing process is comprised of using a CAD/CAM software to build a 3-D model. When the 3-D model has been designed and formed, a CNC code for both additive and subtractive manufacturing can be created. The subtractive manufacturing process is controlled with the CNC machine while the additive manufacturing process parameters using GMAW is controlled by the welding machine. These parameters for GMAW include wire feed rate and arc length. In addition, the CNC machine is integrated with the GMAW machine which controls the movement, starting and stopping, feed rate, and the height of the additive deposition process.

These parameters set correctly allow for the successful achievement of the additive and subtractive manufacturing. Future optimization

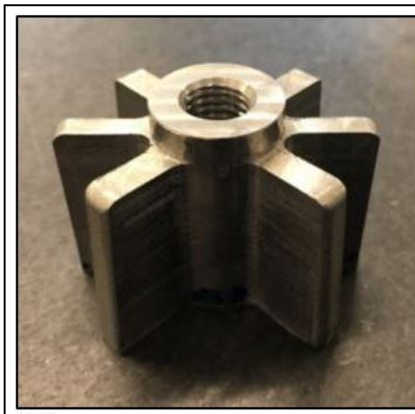

Fig. 4
Successful 3-D Printed Part

includes the development of a unique software to allow the integration between the 3-D Hybrid Metal Printer and the CAD/CAM software.

Although the hybrid process works well when creating a new process, we are constantly working on process optimization. The melting of the metal, part of the additive manufacturing process, creates very high temperatures. In general, additive manufacturing processes causes an increase in heat. When a considerable amount of material is deposited, heat may create an upward warping of the substructure. Depending on the geometry of the part being printed will determine the amount of warpage that will occur to the substructure. To counteract this issue for our hybrid technology, a cooling plate has been implemented to disperse the heat therefore minimizing the warpage. Without this cooling plate, substructure warpage reaching one quarter of an inch has been observed. In addition to the cooling plate, a measuring device, such as a precise touch probe and a 3-D laser scanner, will be tested to optimize the additive and subtractive manufacturing process.

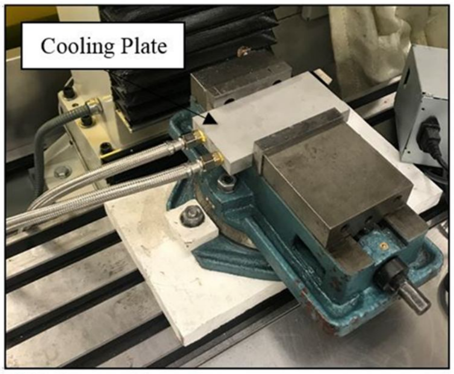

Fig. 5
Cooling Plate

IV. ADDITIVE AND SUBTRACTIVE MANUFACTURING

To begin the 3-D metal printing process, a substructure is securely attached to the CNC machine. This substructure provides a solid platform for adhesion of the part for the printing process to begin.

Fig. 6
Substructure

Once the substructure is secure, the CNC (G&M) code to create the part can begin to run which is comprised of the additive and subtractive manufacturing process. Material is applied to the substructure using the welding technique GMAW. The GMAW arm is attached to and controlled by the CNC machine. The controlling factors the CNC machine has over the GMAW is vertical arc length and machine feed rate. Once a solid layer of material is applied, the CNC machine will retract the GMAW arm to allow the facing of the top and sides of the part. Machining of each layer is required for proper adhesion of the next layer and to be able to achieve complex geometry without support material. This two-step process is repeated multiple times until the desired height and finish of the part is obtained. Each layer produced has a different machining procedure depending on the complexity of the geometry.

An advantage of using the 3-D Hybrid Metal Printer is no support material is required. Numerous parts have been successfully created with this technology and with continued technological advancements, future parts will be tested and created for ongoing improvements. The two materials that have been tested and are currently used are steel and aluminium. Optimization of materials that can be used in the printing process will determine the complete set of applications the 3-D Hybrid Metal Printer has.

V. OPTIMIZATION OF THE PROCESSES

There are currently three areas that need to be improved and developed on for this metal printing manufacturing process. They include reducing material wall thickness, quality control of each material layer, and the integration of the additive and subtractive process into one seamless operation. Of these three improvement areas, research will begin with a white light scanner, a laser scanner, and touch probes that could be adhered to the CNC machine to inspect each layer of material to ensure proper height and adhesion has been achieved. Currently this is being accomplished by the operator.

Although the scanning device has not yet been introduced to the 3-D Hybrid Metal Printer they are in process of being tested and added. The scanner will be imbedded within the system to allow full integration and necessary feedback. The importance of this is to ensure each layer is correct due to the fact that once a layer is finished and the next one is started, there is no way to backtrack and fix the layer below. Cracks and a high amount of porosity could be present, which is a common problem in standard welding practices. These problems could compromise the strength and structure of the part being created. For current layer height, a touch probe is used for measurement of each individual layer of the part. Improvements, such as scanning devices described above are needed to improve efficiency, quality, and reliability.

Further continued testing and research will also determine if variations exist within the design that can be manipulated to incorporate a wide range of different materials. These materials include stainless steel, carbon steel, magnesium, copper, and nickel which are alloys that are commonly used in manufacturing industries. Welding and machine parameters will be set based on forthcoming material testing. A design of experiments for weld parameters has been run using only a mild steel material.

Currently, CNC (G&M) codes are being used with the 3-D Hybrid Metal Printer. A unique software will be developed to automatically create a program that the machine can understand and comprehend. This distinctive software will allow the end user to operate the machine without vast knowledge in CNC programming or 3-D printing experience.

VI. RESULTS AND DISCUSSION

Experiments, for optimization of the process, have been conducted consisting of controlling the variables on the 3-D Hybrid Metal Printer. These factors include trim of the arc, machine feed rate on the CNC machine, and wire feed rate on the GMAW welder. The findings in the experiments were that "a wire feed speed of 250 inches/min, machine feed rate of 8 inches/min, and with a trim of 2.8, a bead of height and width 0.2 inches was achieved" [3]. This constant consistency allows for reliable and repeatable additive manufacturing steps in the metal printing process. While setting these variables to the positions mentioned work well while creating certain parts, adjustments may need to be implemented to allow for different dynamic part creation. This design of experiments conducted has only been done with one specified material. Future optimization will include the continuous design of experiments with the introduction of multiple materials that can be used in the GMAW process. The 3-D Hybrid Metal Printer has two key advantages. The first being the combined additive and subtractive manufacturing process. When the additive manufacturing process has concluded with the first layer, the subtractive manufacturing process finishes off the layer. When the subtractive manufacturing step has concluded, the surface finish allows for excellent adhesion of the next layer. The second key advantage is being able to create complex parts that would be near impossible with current standard manufacturing processes.

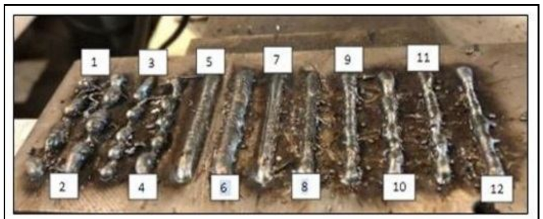

Fig. 7
Weld Bead Trials [3]

Complex parts today have voids and cavities that require extensive knowledge on how to be properly machined and formed. This adds to the complexity and cost when determining how to create a part. With the 3-D Hybrid Metal Printer, parts can be created that have complex geometries and internal cavities that are not possible with standard machining.

VII. CONCULSION

Current testing and printing being performed on the 3-D Hybrid Metal Printer is a part from Forest River. Forest River is one of the largest recreational vehicle manufactures in the United States. The difficulty in manufacturing this part is the height that is required. When a printed part exceeds a certain height, work piece chatter during the subtractive manufacturing process becomes a problem. To fix this properly, mounting locations may need to be adjusted to ensure chatter remains minimal.

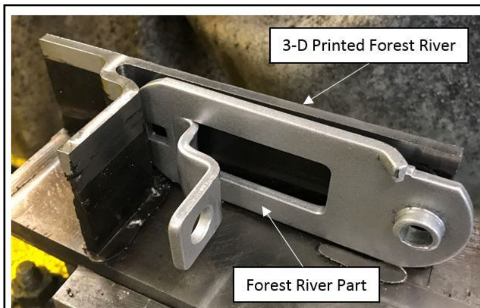

Fig. 8
Current 3-D Printed Part By Forest River

Completion of the part will be when field tests are preformed to ensure proper function at Forest River's manufacturing facility. If the 3-D printed part succeeds, experiments and testing will move forward with future Forest river products along with other companies that want to venture and prototype with this technology.

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