WIRE CO-EXTRUSION WITH BIG AREA ADDITIVE MANUFACTURING

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Abstract

Oak Ridge National Laboratory's Manufacturing Demonstration Facility is developing a system that will deposit and embed conductive and resistive elements within a printed bead of material. The system was implemented on a Big Area Additive Manufacturing (BAAM) system using a co-extruding nozzle. It has already been demonstrated that BAAM is useful for the tooling industry, but this could be a great improvement on an established application of BAAM parts. This system will provide the ability to control and monitor the surface of additively manufactured (AM) parts. It will also enable self-heating surfaces of AM parts, which is particularly useful in tooling applications. This system could even be used in the future for embedding other materials not found in pellet form in BAAM parts. This work will cover the development of the co-extrusion system and its integration with the dual-port nozzle and the BAAM system.

Introduction

Traditionally, mold and tool making has not been a fast process. It can take months to handcraft and shape molds into the correct form. In some conventional molds, heat conducting wire is laid in the surface of the mold and a coating is applied over it. This requires many hours of costly manual labor. Mold and tool making can also be quite wasteful because they are often made from a large piece of material that is machined or carved into the proper shape. For these reasons, the tooling industry is one of the primary target applications of large-scale additive manufacturing [1]. Big area additive manufacturing can make large parts quickly because of its high deposition rate of nearly 80lbs/hour. One of the strong suits of AM is the ability to manufacture near net shape parts, which results in much less excess material that needs to be removed and wasted. The plastics used in this process are typically easy to machine, and surface machining is all that is frequently required to make high quality molds. This helps to decrease the material losses in the tooling industry while creating an accurate part.

AM has been utilized in the tooling industry, but there are some problems with its application. Molding processes frequently utilize heated molds to provide proper curing of parts, which is typically done by running wires on the surface of molds. However, the addition of conductive elements to the material used for the surface layers of additively manufactured molds would provide more consistent and efficient heat to the tool and mold areas where heat is needed. The goal of this project was to see if this process could be automated during the AM process. Once this technology is fully developed, it will provide an avenue for the deposit of other filament-like elements within a bead in any area of a BAAM printed part.

Wire Co-Extrusion System

The system was developed on a BAAM system and is comprised of a spool for material, a Midwest Motion Products DC motor and gearbox, a custom wire feed system, a wire feeding tube, a wire-cutter with Bimba air-cylinder, and a dual-port nozzle. Figure 1 shows the initial system mock-up.

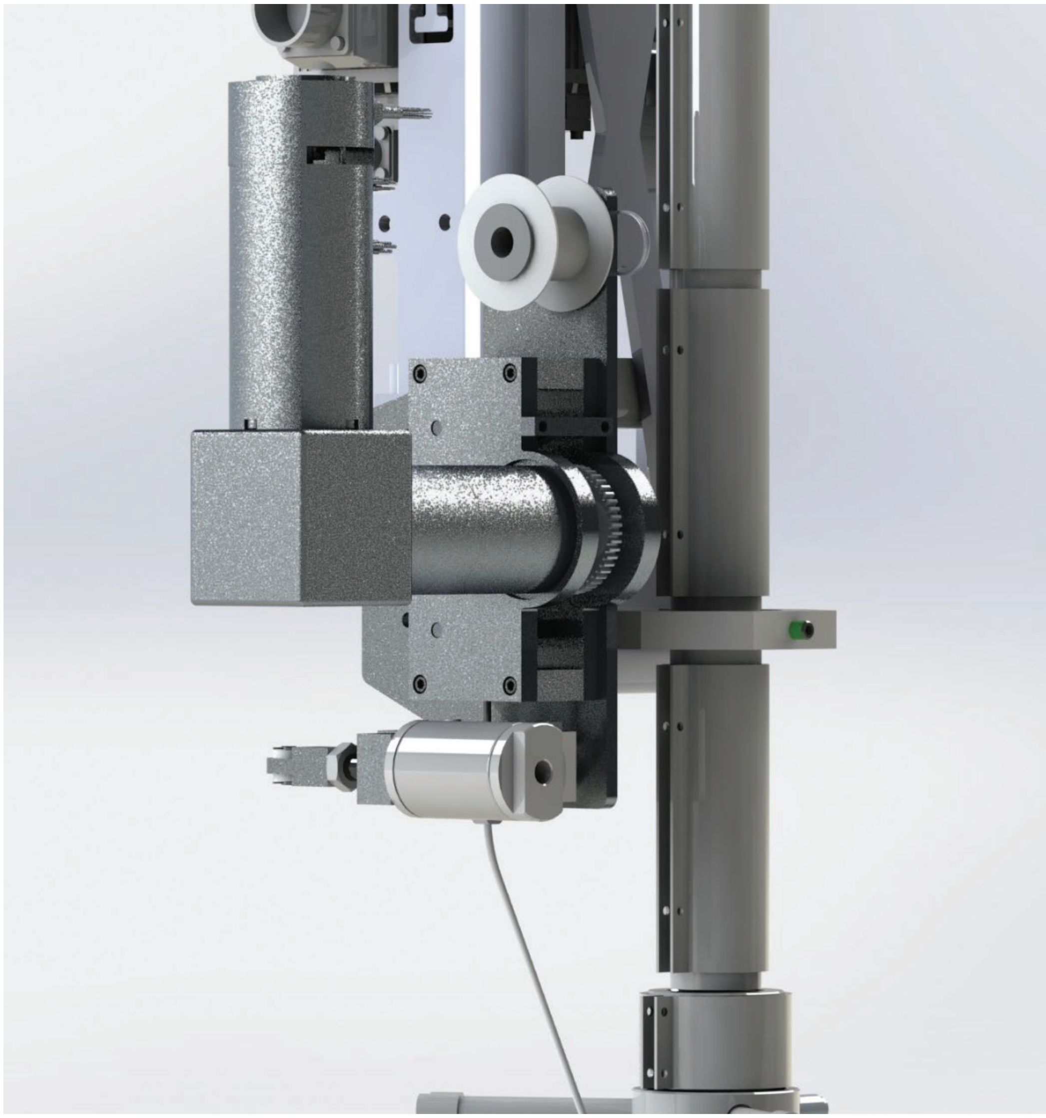

Figure 1: Full Assembly Render (Dual Port Nozzle Not Pictured)

Wire Feeder

The spool, feeder, and wire cutter are all mounted to a plate near the nozzle to eliminate as many mobile elements as possible, and a hard line was run from this assembly to the dual port nozzle. The wire feeder, pictured in Figure 2, is run by a DC motor and gearbox assembly. The wire is pulled from the spool into one side of the wire-feeder where it is fed between two sets of rollers. The gearbox drives a set of gears to rotate the rollers in unison. The rollers are in contact with the wire, and as they spin, they drive the wire forward. The top rollers can be adjusted so more pressure can be applied to the wire as needed. This also helps with initial running of new wire into the system because pressure can be released so the path of the wire has no resistance.

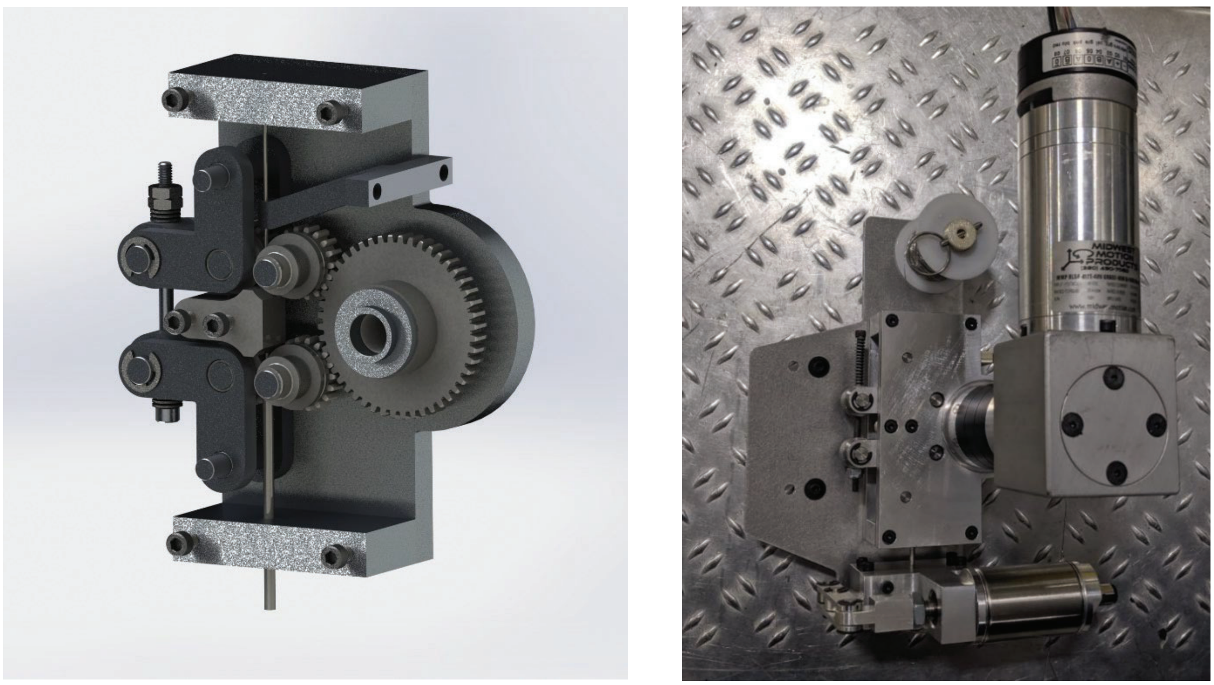

Figure 2, Left: wire feeder assembly with motor plate hidden; Right: spool, feeder, motor, gear box, and cutter

Motor Control

The extruder tip speed was used to control the speed of the motor so that the wire feeds at the appropriate speed. Otherwise, the wire was prone to pushing or pulling out of the bead if fed too quickly or too slowly, respectively. Initially, this was done in a linear manner and adjusted manually. However, there will likely be more work in the future for the path planning of this process because a linear correlation did not always provide the best results. Figure 3 shows a failed part where the motor was not fast enough and the wire pulled out of the part.

Figure 3: Failed part from motor running too slowly

Dual Port Nozzle

The dual-port nozzle was previously developed in order to be able to change nozzle size mid-print [2]. It was modified in such a way that it no longer changes nozzle diameter. The parts that enabled changing nozzle diameter were removed and replaced with the equipment for the wire deposition. The wire enters the nozzle at the top of the last downturn before the plastic exists the nozzle. There is a tube from the wire entry to near the tip of the nozzle where the pressure is lower to decrease oozing of melted plastic from the entry of the wire into the flow. The modified dual port nozzle is shown in Figure 4.

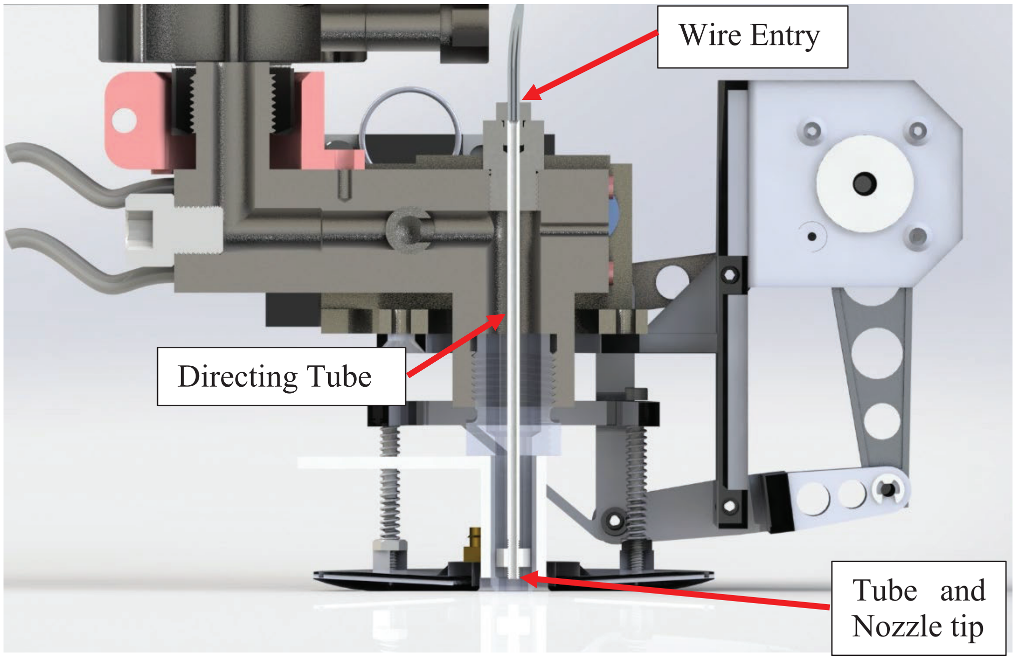

Figure 4: Section View of the Dual Port Nozzle modified for wire feeding

Testing and Results

The first test print was a large, single-bead width circle that was cross sectioned afterward, which is shown in Figure 5. The wire was approximately in the center of the bead width. Figure 6 shows a generic part printed with wire throughout. This part was a segment of a previous mold.

Figure 5: Cross Section of beads with wire

Figure 6: Single Bead Part Printed with Tamper

Some initial test prints were done both with and without the reciprocating plate tamper; a print without the reciprocating plate tamper is shown in Figure 7. The wire appears to be at the top of the bead. The zoomed in segment of Figure 6 shows that, while the wire is not straight in the bead, it is relatively centered and would allow for a small amount of material to be removed by finish machining, which is frequently needed for molds, without damaging the wire. However, it would likely be more effective to have the wire embedded in an internal bead with a perimeter bead printed over it to insure sufficient material for machining as the typical depth of machining is half a bead width and even a straight wire would not be deep enough. More work will need to be done to further integrate this process into the path planning of the machine. If the speed is further optimized, the wire could be put in at a speed to pull the wire straight while not pulling the wire out of the bead. Finer details such as wire lead outs for attachment and stop and start locations for the wire feed will need to be added.

Figure 7: Wire lead out on bead printed without tamper

More work also needs to be done preventing the feeder from jamming. If the there is a pause in motion, any delay in printing, or any latency in the control of the feeder, the feeder continues to feed wire which causes the wire to jam or push wire out of the side of the feeder, as shown in Figure 8. Another cause of jamming is that, if the wire meets too much resistance at the end of the nozzle, the feeding force will buckle the wire causing it to push out of the side of the feeder. If the feed force is decreased, the jam is prevented, but the wire will not exit the nozzle. Further investigation is needed to determine how to address these issues.

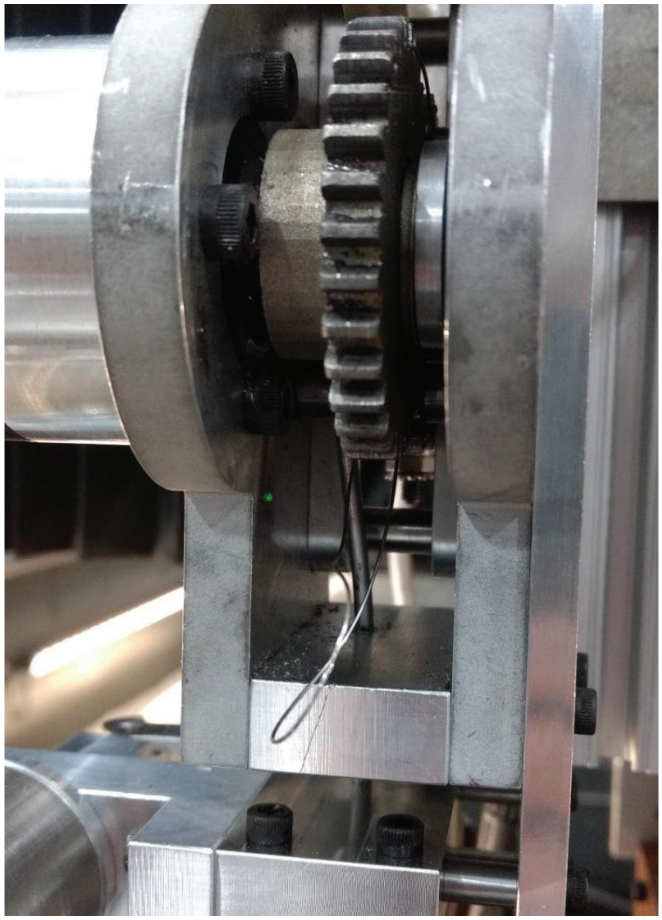

Figure 8: Wire Feeder Jam

Conclusion

This project successfully demonstrated that a wire or filament-like element can be inserted into the bead of large-scale printer. This technology was demonstrated with wire but could be generalized to different applications and machines. Advancements will need to be made on the controls of this system, research is needed on the proper path planning to optimize wire placement, and further investigation is needed to prevent the wire from jamming the feeder while having sufficient feeding force.

References

1. Post, Brian K. et al, "Big Area Additive Manufacturing Applications in Wind Turbine Molds." *Solid Freeform Fabrication Symposium* (2017).
2. Chesser, Phillip et al, "Changing Print Resolution on BAAM Via Selectable Nozzles." *Solid Freeform Fabrication Symposium* (2017).