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CHANGING PRINT RESOLUTION ON BAAM VIA SELECTABLE NOZZLES

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Abstract

Big Area Additive Manufacturing (BAAM) is an additive manufacturing (AM) technique that rapidly deposits polymer to fabricate large components. However, the increase in deposition rates leads to a decrease in resolution and a consequent decline in part surface finish. A novel technique has been developed where the nozzle diameter can be changed mid-print using a poppet nozzle selector. With this technique, a course resolution can be employed to rapidly fabricate the interior of a part, while a fine resolution can be used on the surface. This allows for improved surface quality and resolution without significantly increasing print time. This work will explain the development of the selectable nozzle and integration with the BAAM system to produce selective high-resolution surfaces on parts.

Introduction

Fused deposition modeling (FDM) is a common method of additive manufacturing (AM) used to fabricate parts layer by layer from thermoplastic materials. In this AM technique, a filament is heated and softened before being extruded on the part surface. This is a well-established AM method and is good for producing parts with complex and intricate geometries.

There are weaknesses with FDM, however. Because filament feedstock is used, the deposition rates are limited. [1] This means that FDM is slow and the build volume is limited. [2] The largest FDM machines, produced by Stratasys, have a build volume of 3ft x 2ft x 3ft. [3] The throughput and size limitations of FDM have been significantly improved through the development of Big Area Additive Manufacturing (BAAM). [4] BAAM uses pellets as feedstock instead of filament. Pellet feedstock enables deposition rates of up to 100lbs per hour and potentially even higher. The build volume of the largest BAAM is 20ft x 8ft x 6ft.

Figure 1 shows a comparison of typical FDM part (left) alongside a BAAM part (right). The FDM part achieves a much higher level of detail and surface finish than the BAAM part. However, the BAAM part was produced in a fraction of the time that the FDM part was produced because of the much higher deposition rates achievable through BAAM.

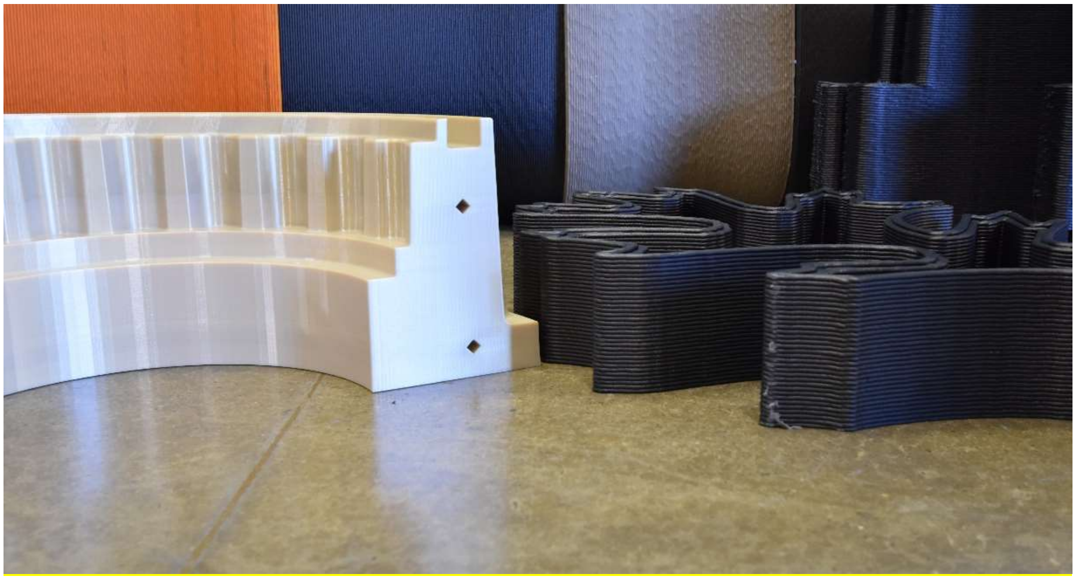

Figure 1: FDM and BAAM comparison

The increase in deposition rates when using BAAM is accompanied by a decrease in print resolution. Typical nozzle diameters for FDM are 0.010in, while typical nozzle diameters for BAAM are 0.3in. This severely limits the level of detail and the surface finish that can be achieved on BAAM parts. In many cases, BAAM parts must be post-possessed to achieve a smooth surface finish. This is commonly done through machining on a 5-axis machining center or router. Machining and post-processing of BAAM parts is typically more time consuming and labor intensive than the initial printing of the part. The cost involved in the post-processing typically represents the bulk of the cost in parts produced on BAAM.

The necessity of extensive post-processing on BAAM parts makes BAAM less attractive for many commercial applications. Therefore, it is desirable to find a solution that increases BAAM part quality and surface finish without significantly affecting deposition rates.

One of the most common uses of BAAM is for printing tooling or molds. [5] For example, BAAM has been used to produce molds for composite layups and vacuum assisted resin transfer molding (VARTM). In many of these cases, there are certain surfaces that are critical for the molding operation, while the majority of surfaces are not critical. Figure 2 shows a CAD model of a part produced on BAAM. The model shows a section of the bow for a boat mold. The red represents surfaces critical for molding or for the assembly of the multiple mold components. The total surface area of the part is 24,900 sq in, while the critical surfaces are 3590 sq in. This only represents about 15% of the total surface area of the part. Many of the geometries printed with BAAM have similar ratios of critical surfaces to total surface area. Therefore, it is logical to print the majority of parts at typical BAAM deposition rates, while slowing down deposition rates to print critical areas at a higher resolution.

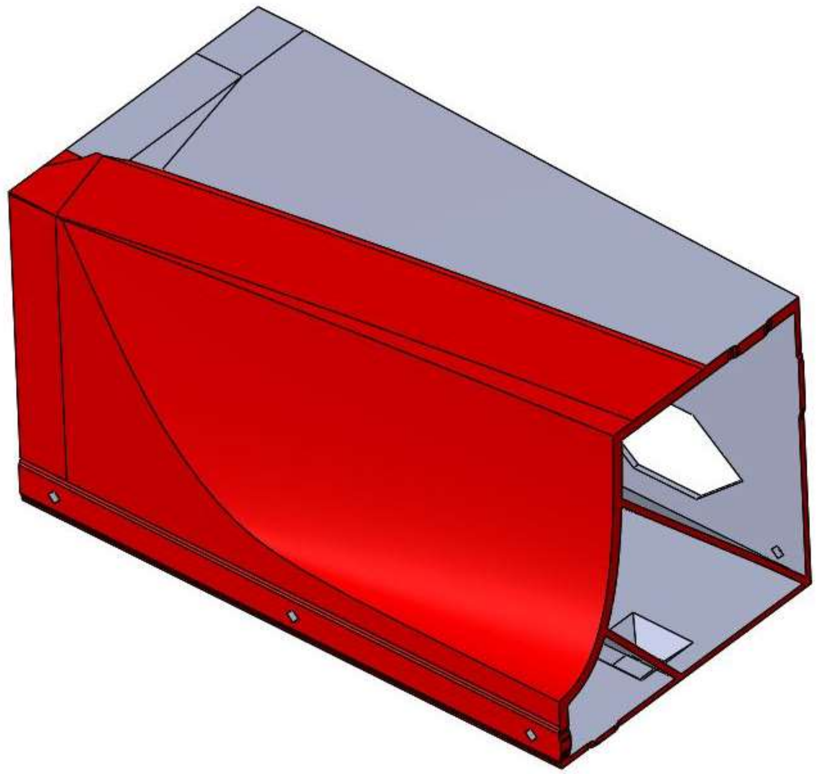

Figure 2: Composite layup tool with critical surfaces shown in red

Multi-Nozzle Diameter Printing

The present research focuses on the ability to selectively choose print resolution on the fly. This enables BAAM technology to print critical surfaces at a fine resolution while printing the rest of the part at a faster, course resolution. Figure 3 shows a diagram of one layer printed with the exterior printed at a fine resolution, and the interior is printed at a course resolution. The orange represents material deposited at a course resolution; the blue represents material deposited at a fine resolution. This enables most the part to be deposited at a course resolution and rapid deposition rates, while the slower, fine resolution deposition is only used on the surfaces of the part where it is needed. In most cases, only some of the part exterior is critical. This results in layers that look more like Figure 4.

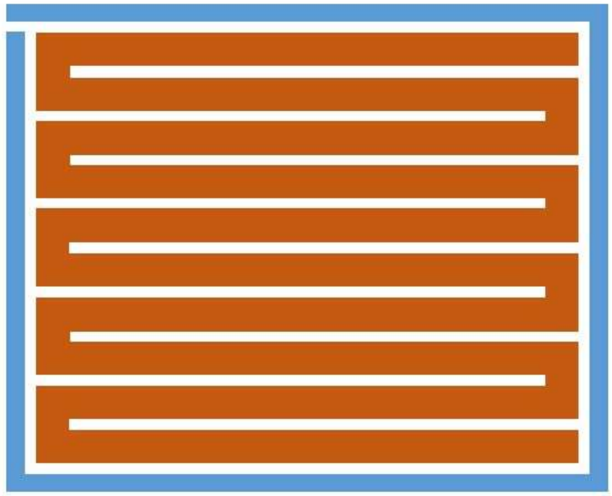

Figure 3: Layer printed at multiple resolutions

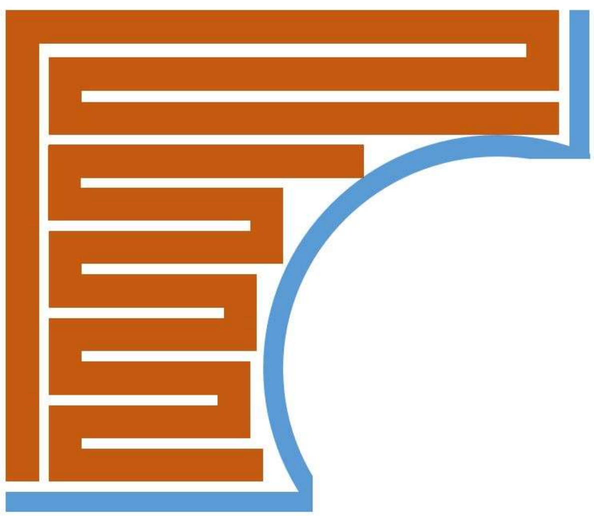

Figure 4: Different scheme for multi resolution layer

As finer resolution nozzles are used, the printed part comes closer and closer to the true geometry of the CAD model. When the CAD part is sliced into layers for printing, surfaces are discretized based on the layer height. This leads to deviation from the specified surface. The larger the discrete layers are, the more error occurs. As the layers are made smaller, the printed part is brought closer to the CAD model geometry. By selectively choosing the nozzle size, the critical surfaces can be printed much closer to the CAD geometry, while non-critical surfaces have larger deviations from the CAD.

Implementation and Testing

To create a nozzle that can change diameters mid-print, a poppet was added coaxially with the deposition nozzle in the polymer flow near the nozzle tip. Figure 5 shows the poppet (grey) inside of the nozzle (green) in the up position (left) and in the down position (right). In the up position, melted polymer flows around the poppet and out of the course hole in the nozzle's tip. When the poppet is in the down position, it blocks flow through the larger hole. Melted polymer is now forced through cross drilled holes in the poppet and out a smaller diameter hole in the center of the poppet, which forms the orifice for fine resolution deposition. With this design, a course or fine nozzle resolution can be selected on the fly.

While there could be two separate nozzles, there are advantages to being able to select the nozzle diameter using only one nozzle. With a single nozzle, the course and fine resolution deposition is co-located. This simplifies motion control, whereas control would be more difficult if there were two separate deposition heads at different locations. Multiple deposition heads could require multiple extruders as well. This leads to an increase in mechanical complexity. These problems are resolved by selecting the nozzle diameter within a single nozzle.

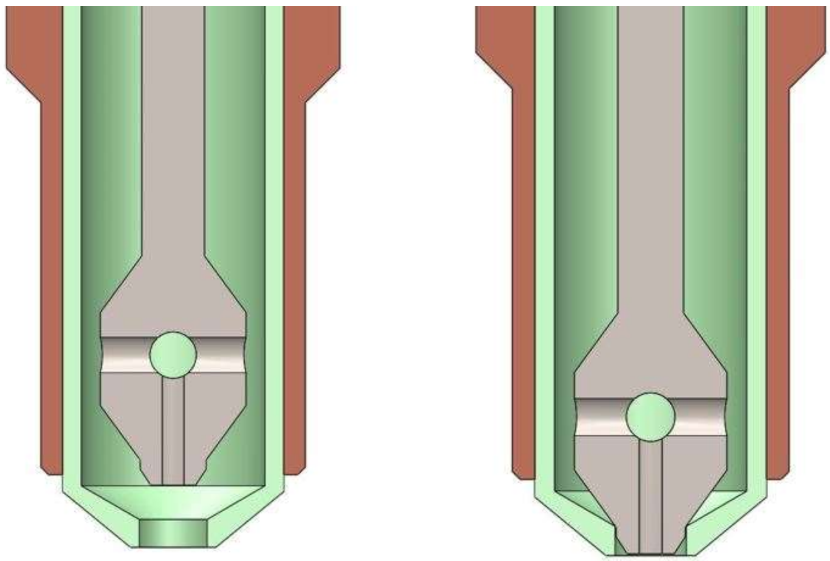

Figure 5: Nozzle diameter selection poppet

An initial design of a system to implement this is shown in Figure 6. Melted polymer flows from the extruder through a heated block to the nozzle where the selection valve is. Actuation of the poppet was achieved via air cylinders.

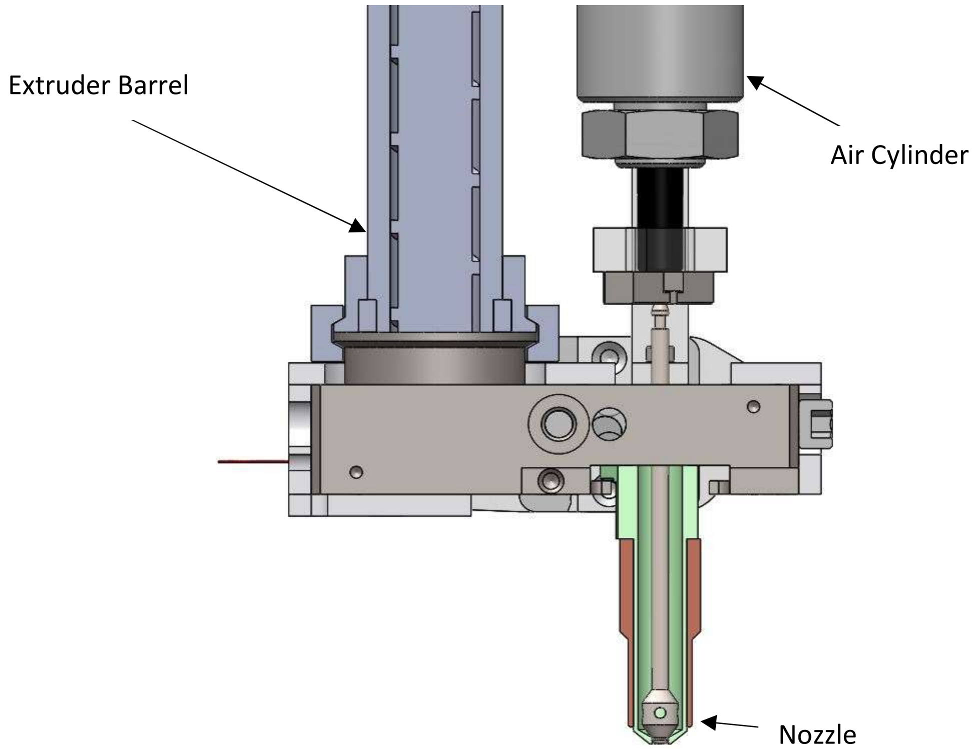

Figure 6: Nozzle offset from the axis of the extruder barrel

To implement the multi-diameter nozzle, printing with a 0.2 inch nozzle was chosen for the course resolution while a 0.1 inch nozzle was chosen for the fine resolution nozzle. It is helpful that the ratio of course-to-fine nozzle diameters be a whole number. This allows for an even number of fine beads to stack up to the height of a course bead. Other ratios of course-to-fine nozzle diameters could be tested allowing for a larger discrepancy between the course and fine nozzles.

An initial prototype was tested on an existing BAAM platform. Figure 7 shows the prototype setup on the extruder. With this setup, a test part was printed with a 0.2 inch diameter nozzle for the interior and a 0.1 inch diameter nozzle for the exterior. A control part was also printed with the same geometry and a 0.2 inch nozzle diameter for the entire part. Bead heights were half of the bead widths leading to 0.05 inch layer heights with the fine nozzle and 0.1 inch layer heights with the course nozzle.

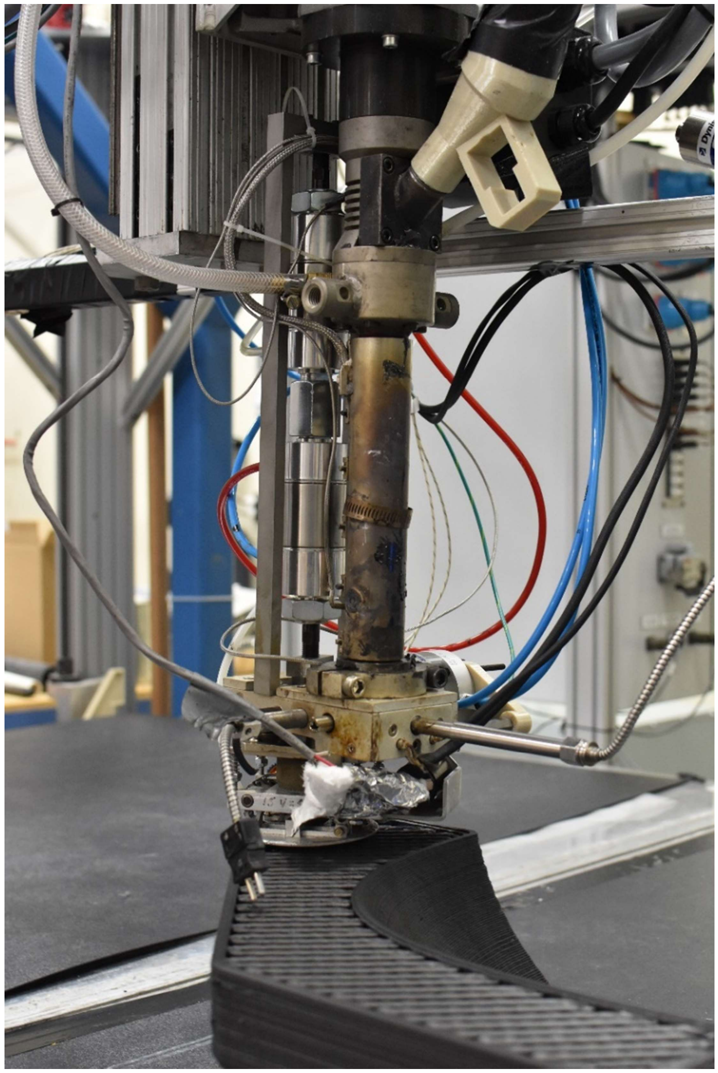

Figure 7. First iteration of multi-diameter nozzle

The multi-nozzle part took 3 hours and 48 minutes to print, while the control part took 2 hours and 25 minutes to print. This represents a 57% increase in print time for twice the resolution on the part surface. Printing the entire part at the fine resolution would have taken an estimated 9 hours and 5 minutes. Therefore, the multi-resolution print took 58% less time than it would have taken to print the entire part with the high-resolution nozzle. Printing the entire part at a high resolution would not have increased part surface quality at all, over multi-resolution printing. Figure 8 graphically shows the differences in print times and the corresponding resolution of the exterior of the part.

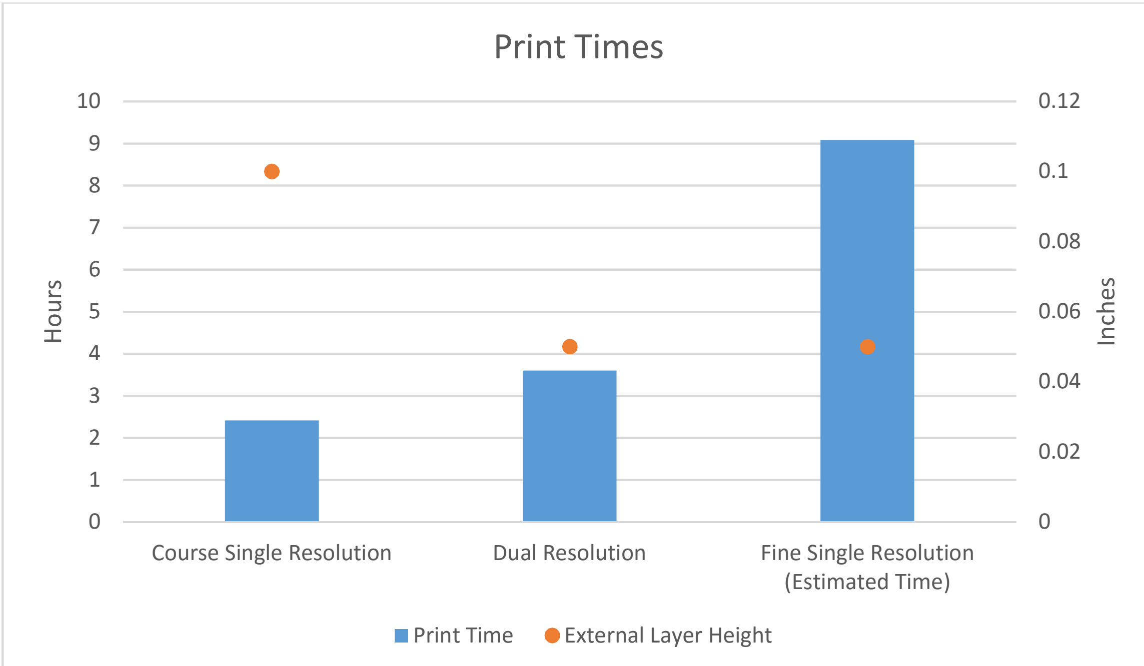

Figure 8. Comparison of Print Times

On the multi-nozzle part, the entire exterior was printed with a fine resolution. As discussed above, on most parts printed on the BAAM, only a fraction of the surfaces will require the fine resolution. However, the slicing software that prepares the parts for printing does not currently have the capability to selectively print only some surfaces at a fine resolution. Once this ability has been implemented in the software, multi-resolution parts can be printed much faster by only applying the fine resolution to critical surfaces.

Photographs comparing the parts are seen in Figures 9 and 10. The fine resolution print visually shows a significant increase in part quality. The layer striation size has been halved due to the doubling of resolution. This leads to a much higher surface quality, as is qualitatively seen in these figures. As research continues, the use of smaller diameter nozzles on the fine resolution setting will be investigated. This would lead to a further reduction of layer size and consequent further increase in surface quality.

Ultimately, it would be ideal to eliminate post-machining for most applications. Instead of machining, critical surfaces could be printed at very fine resolutions, and the minor deviations left in the part could be filled with surface coating techniques. Continued research will work toward achieving this goal, especially through the use of even finer nozzles

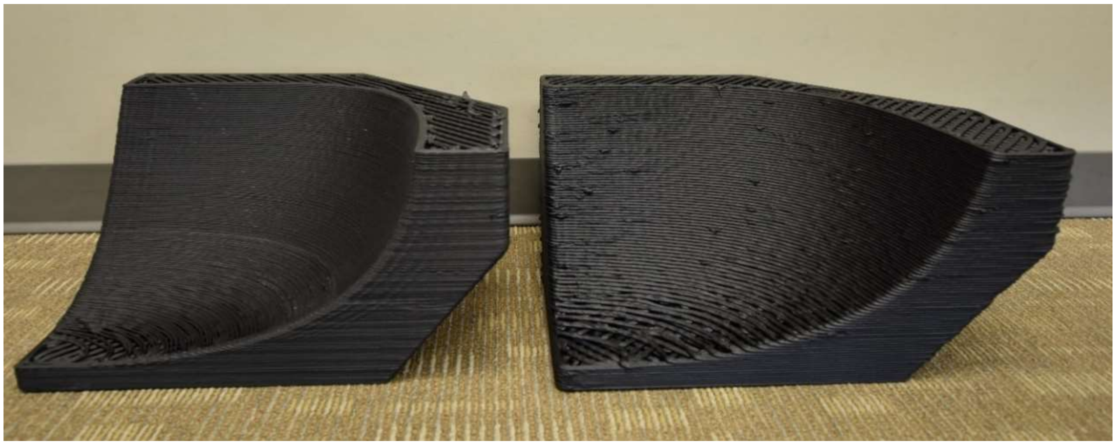

Figure 9: Comparison of multi-nozzle (left) vs. single nozzle (right)

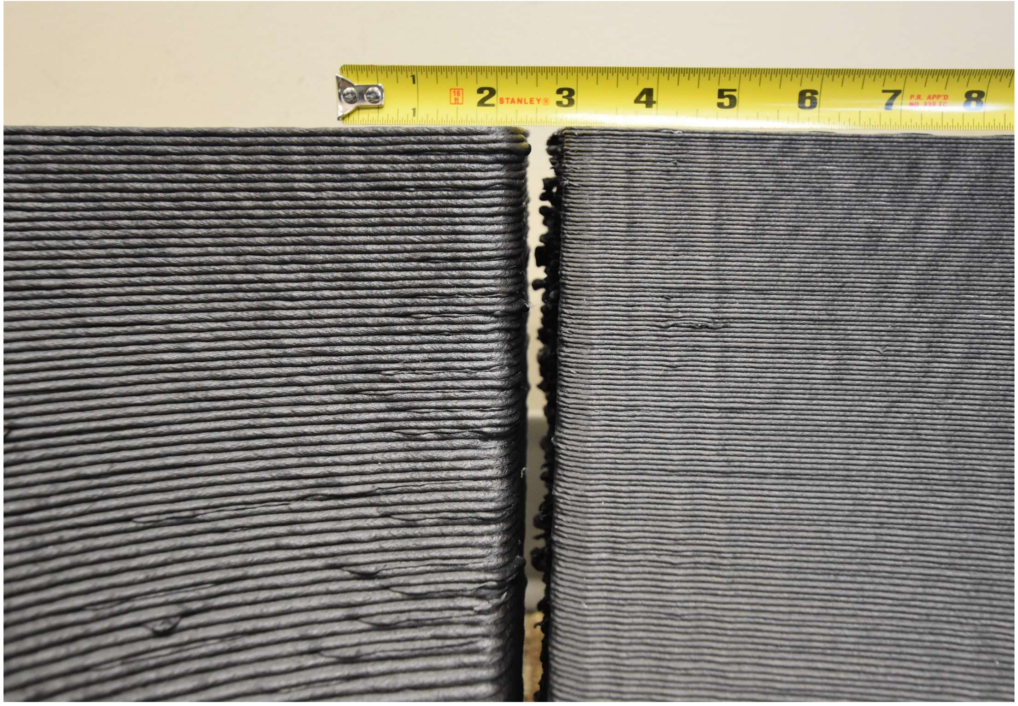

Figure 10: Close-up comparison of surface finishes

Initial tests reveal some issues that will need to be resolved in future research. First, the starts and stops of extrusions were not clean when printing with the 0.1 inch nozzle because the flow latency of the extruder is amplified on a finer diameter nozzle during starts and stops. This led to significant globing on the seam as shown in Figure 11. Methods of dealing with this issue on the seams have been examined and will be explored in future research.

Figure 11: Globing on starts and stops

There are also issues on shallow curves where gaps show the infill underneath the external contours. This is shown in Figure 12. Conventionally, this would be solved by using skins on the top of these sections. The algorithms for adding skins in a part with multiple resolutions is significantly more complex than with single resolution parts. While this problem has been explored, these algorithms have not been fully developed and implemented yet.

Figure 12: Lack of skins

Conclusion

The feasibility of selecting print resolution on the fly with a poppet nozzle selector was demonstrated for the BAAM process. It was demonstrated that this method allows an increase in resolution on critical surfaces. A test part was printed with the exterior at twice the resolution of the interior. This allowed for a doubling of exterior resolution without a significant increase in print time over a conventional BAAM part.

Future work aims to continue exploring high resolution fabrication while using the lessons learned thus far. Work needs to be done to improve the starts and stops of extrusions. The use of even finer nozzles for the critical sections will also be explored. Software algorithms that allow selection of critical faces to be printed at a fine resolution also need to be developed. Algorithms for improved skins must be developed as well.

The potential significance of this work is great. The commercial viability of BAAM for use in producing commercial tooling and molds has been limited because of the expense of post-processing BAAM parts. The ultimate goal of this research is to reduce, or nearly eliminate, the amount of post-processing required.

If the resolution of critical surfaces were to come off the printer with a very fine finish, only minor post-processing would be required. This could potentially include minimal manual finishing and light surface coatings. Thus, additively manufactured tooling would be nearly ready to use as it came off the printer. This would represent a revolutionary savings of time and money in the tooling industry. The work presented here demonstrates that selection of resolution on the fly is feasible, and it paves the way for moving toward the goal of minimal post-processing of BAAM parts.

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