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# Industrial Deployment of Computer Aided Manufacturing Software for Hybrid Advanced Manufacturing


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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Manufacturing Science Division
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# *Industrial Deployment of Computer Aided Manufacturing Software for Hybrid Advanced Manufacturing*

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## ACKNOWLEDGEMENTS

This CRADA NFE-20-08287 was conducted as a Technical Collaboration project within the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) sponsored by the US Department of Energy Advanced Manufacturing Office (CPS Agreement Number 24761). Opportunities for MDF technical collaborations are listed in the announcement "Manufacturing Demonstration Facility Technology Collaborations for US Manufacturers in Advanced Manufacturing and Materials Technologies" posted at http://web.ornl.gov/sci/manufacturing/docs/FBO-ORNL-MDF-2013-2.pdf. The goal of technical collaborations is to engage industry partners to participate in short-term, collaborative projects within the Manufacturing Demonstration Facility (MDF) to assess applicability and of new energy efficient manufacturing technologies. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

## ABSTRACT

GibbsCAM, 3D Systems' software product, is a full-featured CAM system that provides powerful CNC programming, capabilities, and solutions, delivering high quality parts without sacrificing ease of use. Oak Ridge National Laboratory (ORNL) collaborated with 3D Systems to evaluate their toolpath generating software being developed for both blown powder and hybrid CNC/additive manufacturing machinery. The current approach in toolpath solutions for additive manufacturing is to utilize subtractive toolpaths created by existing CAM software and reversing it for additive manufacturing applications. GibbsCAM is working to develop a full solution to mitigate the challenges that arise with this approach and deploy a fully customized solution for producing quality, reliable components for a range of different DED systems. When successful, this will be an automated solution deployed through a future release of GibbsCAM software.

# 1. INDUSTRIAL DEPLOYMENT OF COMPUTER AIDED MANUFACTURING SOFTWARE FOR HYBRID ADVANCED MANUFACTURING

This phase 1 technical collaboration project (MDF-TC-2021-08287) began on August 03, 2020 and concluded on June 18, 2021. The collaboration partner 3D Systems, Inc is a large business that owned a full-featured CAM software product called GibbsCAM.

Due to the acquisition of GibbsCAM by Cambrio, the project was terminated during Phase I activities.

## 1.1 BACKGROUND

3D Systems, Inc. is a large company headquartered in Rock Hill, South Carolina and is a leading global provider of 3D printing solutions, offering innovative technologies and materials for 3D printing, rapid prototyping, and direct manufacturing. The company includes a manufacturing service bureau that produces precision and functional prototypes, master patterns for tooling, and production parts for direct digital manufacturing. 3D Systems also includes a software business which develops and sells a wide range of engineering software products, including computer aided design (CAD), CAM, and software for AM.

GibbsCAM, a 3D Systems software product, is a full-featured CAM system that provides powerful CNC programming. The next release of this software product currently under development includes support for Hybrid CNC/metal additive manufacturing technology. GibbsCAM is an expert on efficient and effective algorithms for both machining and additive printing, and ORNL has experience with metal deposition hybrid CNC machines. Working together will allow us to jointly define best practices and techniques to deliver optimal results using hybrid metal manufacturing processes. This collaboration will provide GibbsCAM with access to multiple hybrid machines, inspection tools, and knowledgeable experts in manufacturing. GibbsCAM will provide ORNL with access to software experts with the ability to enable custom tuned software for evaluation and testing at ORNL.

## 1.2 TECHNICAL RESULTS

### 1.2.1 Training

Weekly online meetings were held between a GibbsCAM software engineer and an ORNL technician. GibbsCAM provided ORNL with extensive training on use of their software and ORNL provided feedback from additively manufactured test articles built using the GibbsCAM software. Based on reports from ORNL, GibbCAM continually provided updated software with improved functionality.

### 1.2.2 BeAM Machine

It was intended that GibbsCAM would be evaluated on multiple machines. Since the project was terminated early during phase 1, all test articles were produced only on the BeAM Machine, Modulo 400.

### 1.2.3 Post Processor Development

The post processor is an interface that bridges two different technologies: computer-aided manufacturing (CAM) software and a specific numerical controlled (NC) machine. It translates the toolpath output from CAM software to the input code needed for a specific NC machine.

The post processor's translation of basic functions was evaluated and corrected to allow progress in evaluating fundamental toolpaths for deposition. These functions include Laser ON/OFF, Powder ON/OFF, and tool velocity. More complex functions like mixing multiple materials with multiple feeders was not considered a priority in the early stages of this project and therefore, were not fully implemented.

The G-codes used to produce the test articles for this project were a combination of the toolpaths generated from GibbsCAM with some manual edits to the syntax specific to the BeAM Machine.

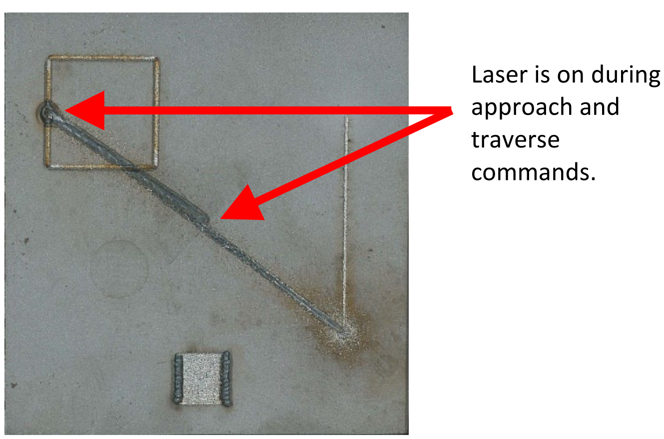


**Figure 1. Errors with Post Processor**

### 1.2.4 Line Extensions

One problem inherent in the DED process involves the control of heat input during the process. CNC machine dynamics are limited when the movement of the tool takes an abrupt change in direction. Maintaining the commanded speed is not always possible while the tool changes direction. For more acute angles or tight radii, the tool must slow down to stay true to the path. If laser power remains constant, this results in increased heat input causing changes in melt pool size, shape and material absorbed. This also occurs at the beginning and end of a path where acceleration or deceleration occurs simultaneously with the laser turning on or off.

The BeAM Machine is designed with a modal option that will regulate the laser power according to changes in tool velocity. It will lower the laser power when the tool slows below the commanded federate. Regulating the power is preferred. However, it can leave gaps in the deposition where the tool velocity is lower including the beginning and ends of every path where acceleration and deceleration occurs. Alternating raster toolpaths of a single layer deposition were observed to have incongruous edges with a variance of approximately 0.4mm (Figure 3). In response , GibbsCAM created a tool within the software to mitigate the lack of deposition at the beginning and ends of each open path called “open toolpath adjustment” (figure 4). This option allows the programmer to add length to open toolpaths by any specified amount. Figure 4 demonstrates how gaps in the deposition can be filled in by using this feature. The open toolpath adjustment made substantial improvements to the 40-layer build by reducing lack of fusion near the perimeter and controlling geometric integrity.

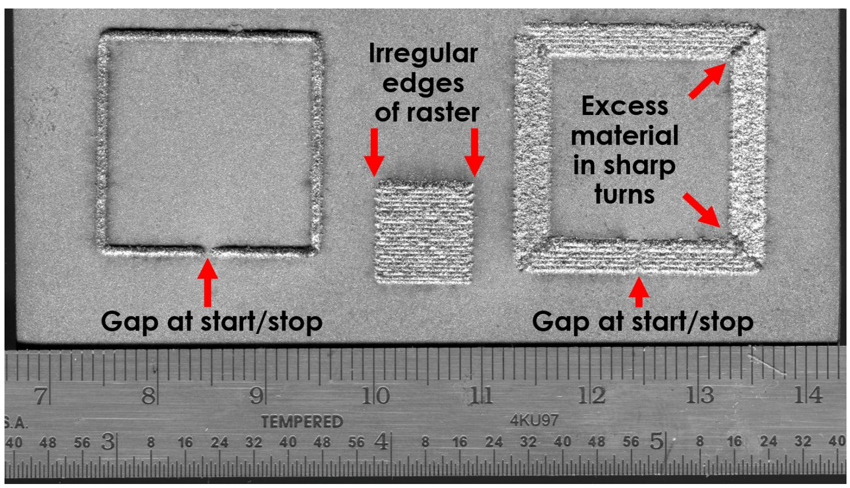


**Figure 2. Lack of material deposition at path ends (single layer).**

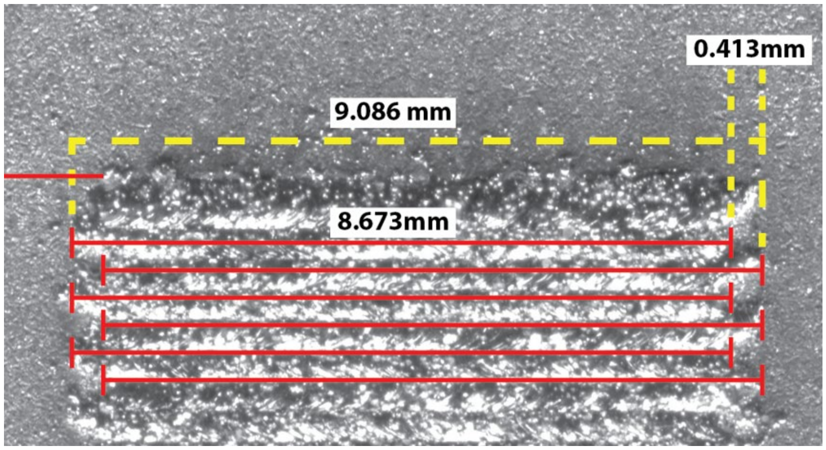


**Figure 3. Lack of material deposition at path ends (single layer).**

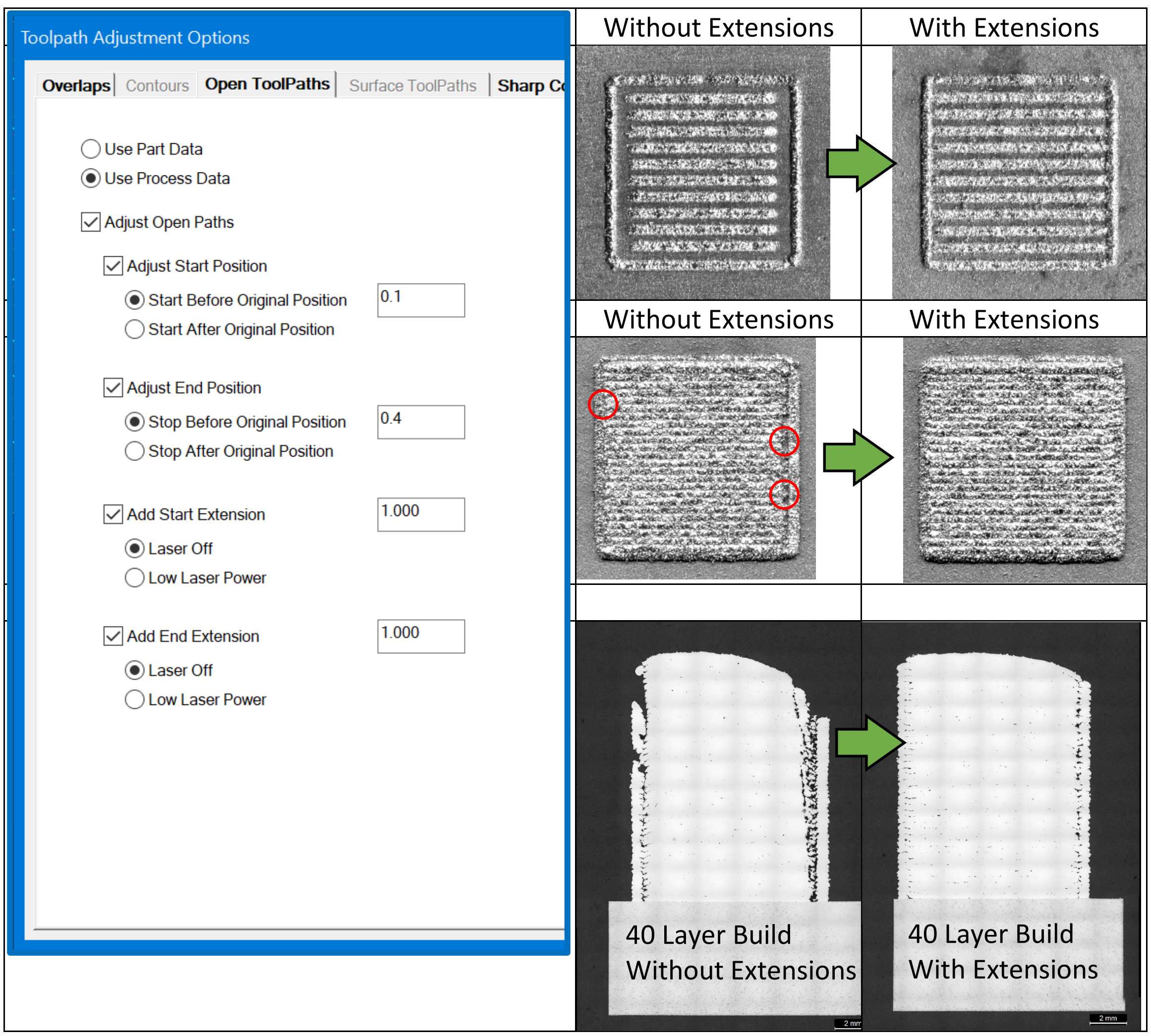


**Figure 4. Open Toolpath Adjustment.**

### 1.2.5 Radiused Raster Endcap

Typical raster infill patterns are problematic due to the acceleration and deceleration at the end of each linear move. If laser power is not adjusted for slower speeds, there will be excessive heat input in those regions and overbuilding will occur. Currently, GibbsCAM will command the laser to turn off as the tool transitions from one raster to the next. For the BeAM machine, the laser OFF command causes a slight delay in the motion of the tool which further complicates the problem. A strategy for using circular arcs to transition from one raster to the next was explored (Figure 5). This strategy allows the laser to remain on while reducing any change in velocity when the tool changes direction.

The 2-Path strategy has a greater arc distance than the 1-path which further mitigates acceleration and deceleration at the raster ends. Both strategies were first used to deposit one layer of material as well as one laser etching without powdered metal (Figure 6). Each strategy was then used to build a 20-layer block (Figure 7). Both blocks held geometric coherence better than expected. In comparison, the quality of the 2-path block exceeded that of the 1-path. Ignoring the surface roughness, geometric integrity and internal density was significantly improved with the 2-path strategy (Figures 8-9). Initial results merit implementation of this method as an option within GibbsCAM. At the time the CRADA was terminated, this technique had not been incorporated into the software.

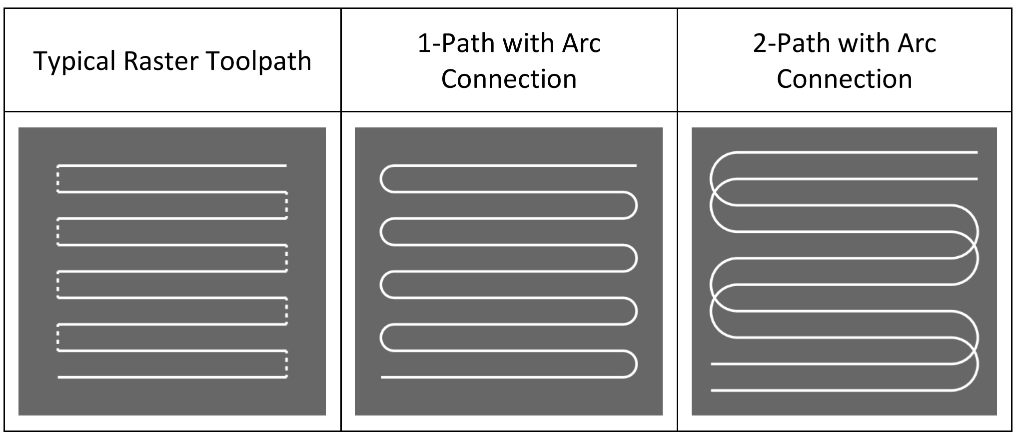


**Figure 5. Radiused Raster Toolpath.**

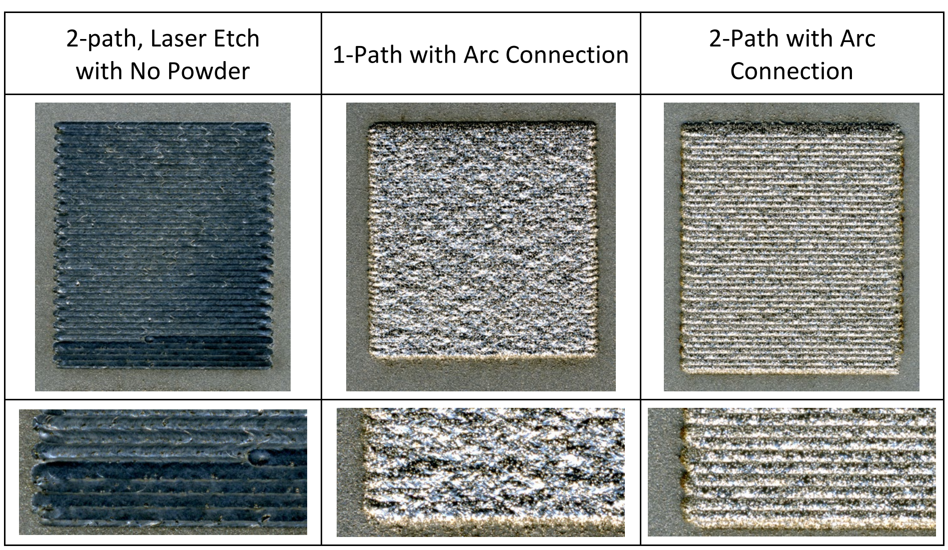


**Figure 6. Radiused Raster Toolpath, Single Layer Deposition.**

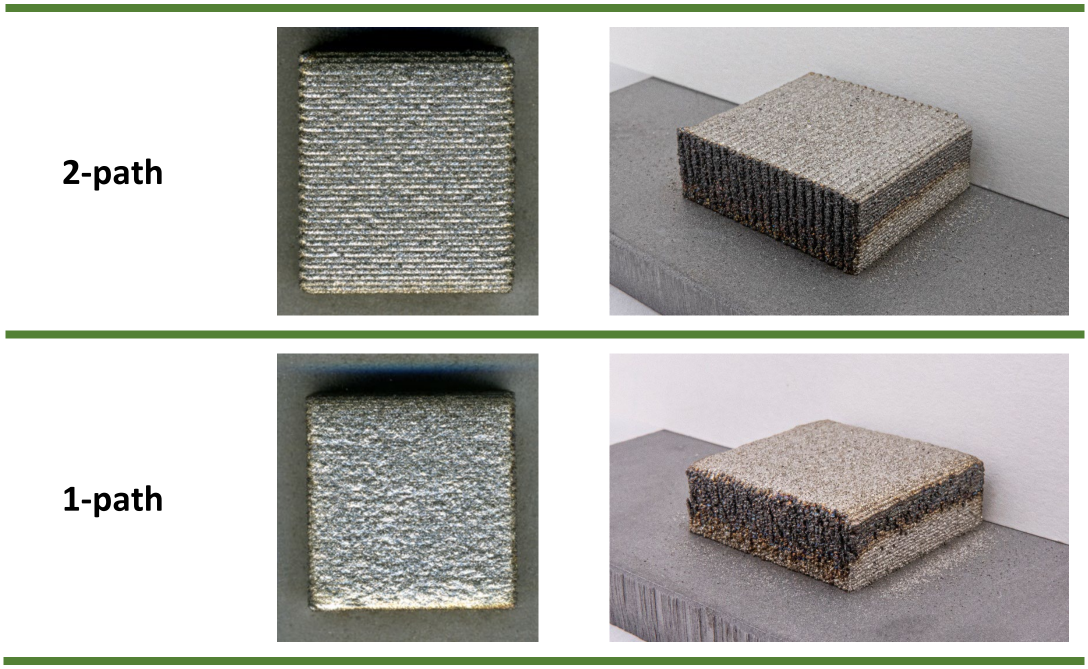


Figure 7. Radiused Raster Toolpath- 20-Layer Deposition.

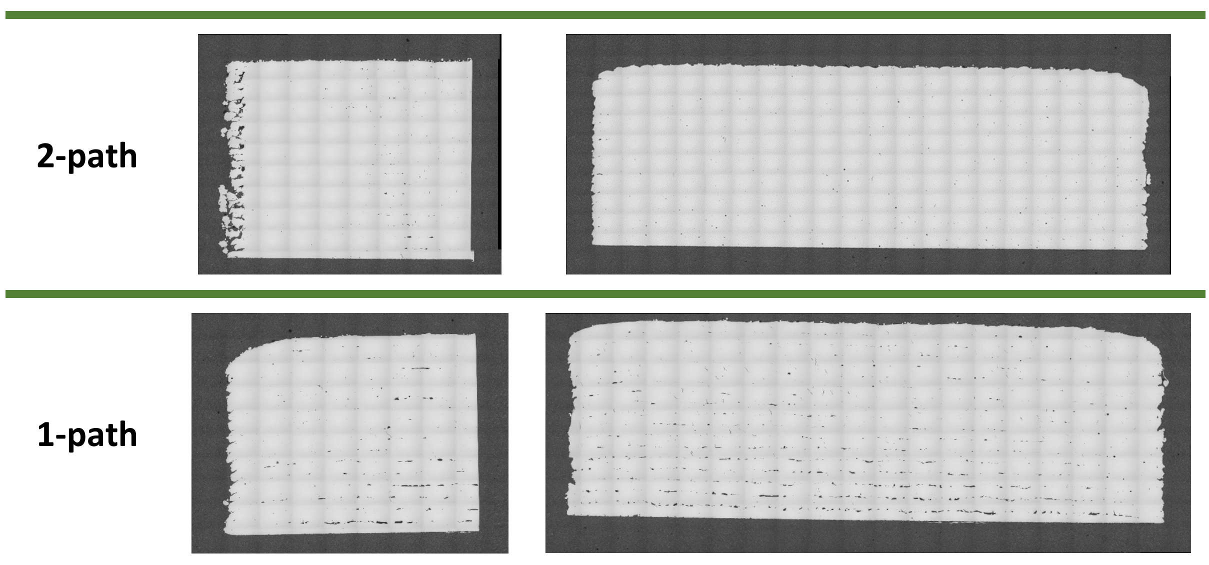


Figure 8. Radiused Raster Toolpath- Density.

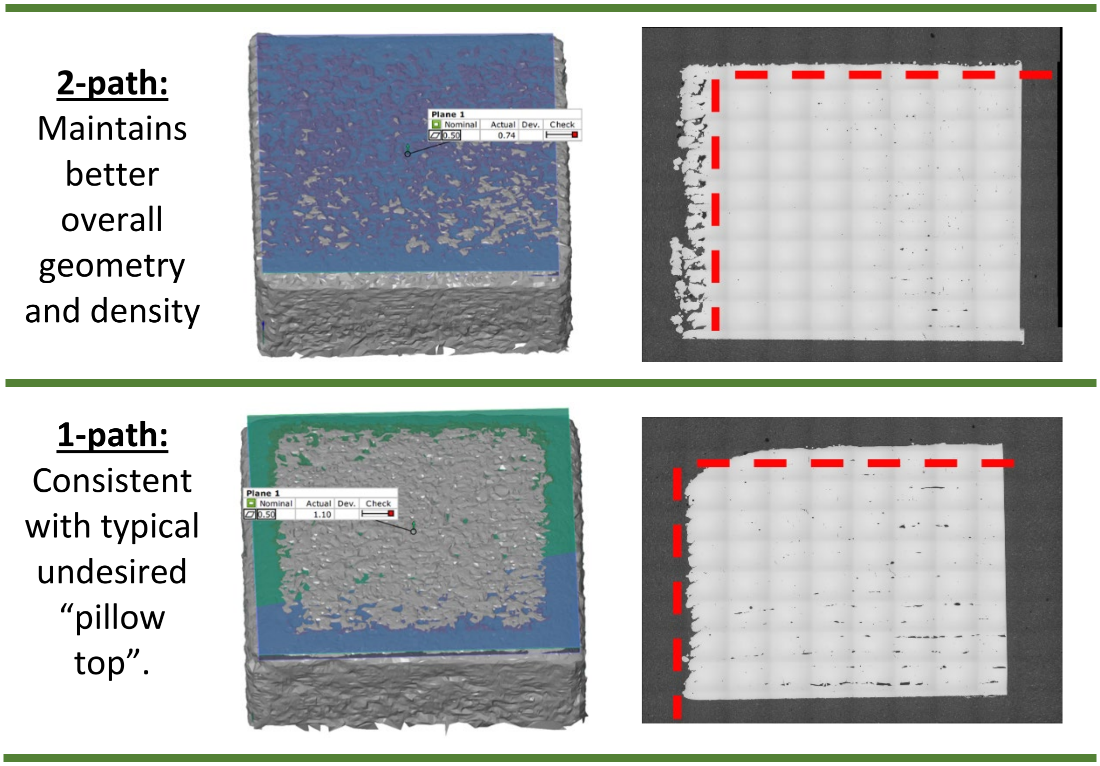


**Figure 9. Radiused Raster Toolpath- Flatness.**

### 1.2.6 Weave Data: Corrugated Wall

GibbsCAM features a selection of additive toolpath patterns that resemble techniques used by professional welders (Figure 10). These patterns were not fully evaluated prior to the postponement of the CRADA. However, one pattern was used to conduct an experiment to demonstrate that strength and rigidity can be added to the interior of walls without filling them completely. One weave option was expanded to mimic a sine wave that was then used to function as corrugated support between two thin walls (Figure 10). Depending on the application, such reinforced structures could be used in place of fully dense interiors which reduces part weight, build time, material cost, and material waste. The resulting parts were successfully manufactured as designed (Figure 11).

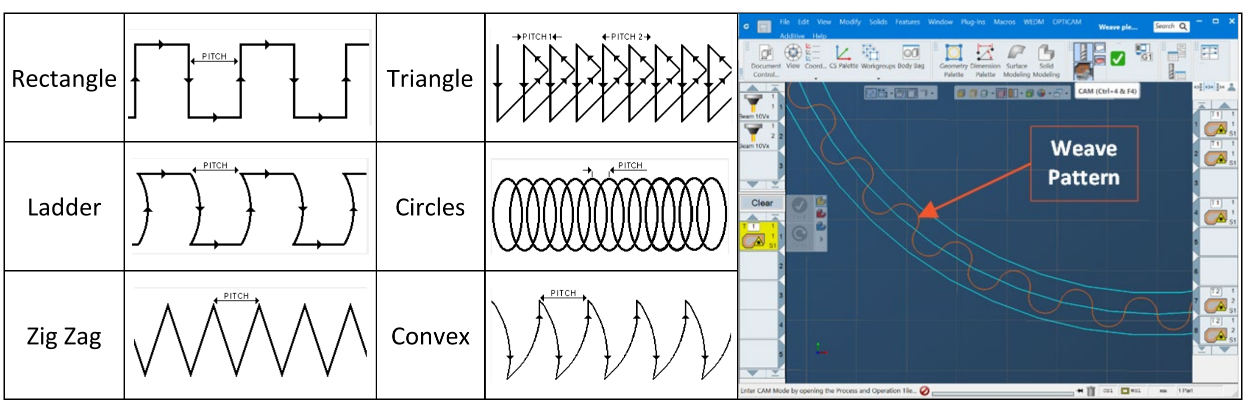


**Figure 10. Weave Patterns.**

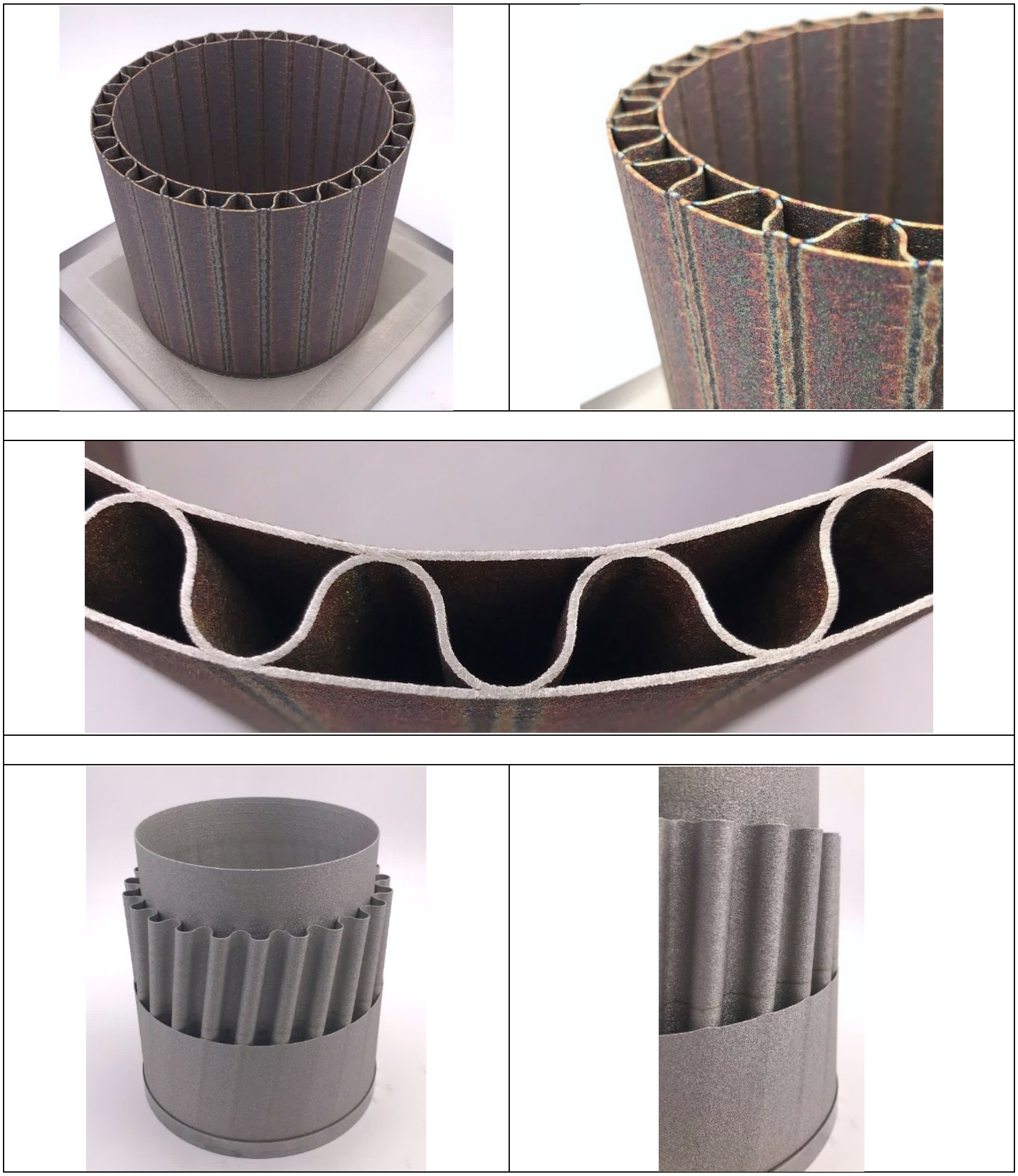

**Figure 11. Corrugated Wall Builds.**

## 1.3 IMPACTS

The latest version of GibbsCAM does not feature the additive module. After the acquisition of GibbsCAM by Cambrio, the parent company suspended development of the additive module within GibbsCAM. If development of this technology resumes and a version of GibbsCAM containing the additive module is released, the impact to advanced additive hybrid manufacturing could be substantial since viable complete solutions to DED toolpath programming still do not exist.

### 1.3.1 SUBJECT INVENTIONS

NA

## 1.4 CONCLUSIONS

GibbsCAM's additive solution has great potential for being a valuable tool for advanced Hybrid Manufacturing. The full capacity of GibbsCAM's additive module was only partly evaluated during our partnership and has yet to be released to the public. The beta version continues to be a valued tool for additively manufacturing test articles used for ongoing research at the Manufacturing Demonstration Facility. It will be of great benefit to our research in advanced manufacturing and to the private sector manufacturing industry when this technology becomes fully developed.

# 2. PARTNER BACKGROUND

3D Systems launched the 3D printing industry in 1986 and has been leading additive manufacturing innovation ever since. Their broad portfolio of hardware, software, and material solutions spans from plastics to metals, and is backed by industry-specific engineering expertise housed in their Applications Innovation Group. They take a consultative, application-focused approach to solving the most difficult design and production challenges. The combination of their solutions, expertise, and innovation helps their users defy conventional manufacturing limitations and maximize the value of additive manufacturing. Headquartered in Rock Hill, South Carolina, with offices, manufacturing facilities, and Customer Innovation Centers around the globe, 3D Systems has the expertise and resources to advance industries.

GibbsCAM® is cutting-edge CAM software for programming CNC machine tools with the power and flexibility to make parts the way you want. With its single, shop-friendly interface that is customizable and easy to navigate, enabling users to maximize productivity. A CNC programmer, machinist, or manufacturing engineer will find familiar terminology, icons that make sense, and logical processes. With GibbsCAM, CNC programming is flexible, fast, reliable, and efficient.