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Oak Ridge National Laboratory Gate Precast Phase 1

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September 2017

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Advanced Manufacturing Office

MANUFACTURING DEMONSTRATION FACILITY: GATE PRECAST, PHASE 1

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ACRONYMS

AMO	Advanced Manufacturing Office
BAAM	Big Area Additive Manufacturing
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
ORNL	Oak Ridge National Laboratory

ACKNOWLEDGEMENTS

This Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration facility (MDF) project was funded by the US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE) Advanced Manufacturing Office (AMO). This project was managed as CPS Agreement Number: 24764. The lead organization was the Oak Ridge National Laboratory (ORNL). The project duration was from July 28, 2017 through September 1, 2017.

The project partner who led the design and testing of the patters was Gate Precast.

EXECUTIVE SUMMARY

Objective and Tasks. The primary objective of the project was to demonstrate the viability of using carbon fiber reinforced ABS plastic and the Big Area Additive Manufacturing (BAAM) technology to rapidly manufacture molds for the precast concrete industry.

Results and Conclusions. The results of the study demonstrated that the BAAM process could rapidly manufacture molds suitable for precast concrete manufacturing. A second phase of this project will focus on exploring more challenging geometries to aid in identifying limits of the technology.

1. INTRODUCTION

1.1 PROJECT OBJECTIVE

The objective of this project is to demonstrate the feasibility of using Big Area Additive Manufacturing (BAAM) to manufacture tooling for the precast concrete industry. The conventional methodology to manufacture precast concrete is based on manufacturing wooden molds manually (see Figures 3 and 4). The process is slow, expensive and the workforce has shrunk while requiring high skills. The goal of this project is to demonstrate the ability to manufacture a durable precast mold using the big area additive manufacturing process. The first phase of the project will explore the use of different materials to evaluate the durability of the materials for the process. The two primary materials will be glass filled ABS and carbon fiber reinforced ABS. The goal is to identify which material can provide the durability to complete precast concrete test samples while maintaining the required accuracy (less than 0.050" surface defects). Gate Precast will manufacture the part and visually inspect the mold for durability. These tests will serve as the go/no-go decision point.

Figure 1: Precast molds

Figure 2: Precast parts

1.2 PROJECT BACKGROUND

Offsite building construction or prefabrication has been gaining momentum because it offers a better product and faster installation than onsite construction. Architectural precast insulated wall panels are a popular type of offsite commercial building construction. However, the precast industry needs to modernize its manufacturing techniques, which have experienced minimal changes in the past 40 years, in order for it to seize a larger share of the construction market. Advanced manufacturing can transform the architectural precast industry by developing materials and processes that can reduce the assembly time of complex molds. Current mold manufacturing techniques involve assembling mostly plywood sheets and finishing their surfaces with fiberglass reinforced coatings. The availability of skilled craftsmen who can do this task has been continuously declining; therefore, precasters have not been able to keep up with technological advances, such as the ability to design complex geometries through Building Information Modeling (BIM). The precast industry is in need of a new mold manufacturing process that takes advantage of the latest technological advances in order to remain competitive in the construction market.

Figure 3. Left: Molds for precast concrete are typically manually assembled with sheets of plywood that are surfaced with fiberglass-reinforced coatings. Right: Precast concrete piece used as part of a building facade.

ORNL and the Precast/Prestressed Concrete Institute (PCI) have been collaborating on advancing precast construction since 2015. In support of this program, Gate Precast, a PCI member, volunteered an upcoming project that is part of the Site A redevelopment in New York City (see Figure 1) for use as a pilot technology verification and case study of a new mold manufacturing process. The new 42-story building will have a very complex façade in which deep precast panels will serve as solar shading devices. The façade will require about 70 different molds that are ideal to evaluate the proposed manufacturing method versus business as usual. ORNL and Gate Precast will design, manufacture and evaluate 3D printed mold prototypes in June and July 2017; and will start actual production of molds and precast façade components in August 2017. The main goal of this R&D effort is to determine, on behalf of the entire domestic precast industry, whether 3D printed mold manufacturing is, or can become, cost-effective for this industry. To this end, ORNL will gather data on the mold manufacturing process (e.g., 3D printed materials, optimization of mold designs, production time), and mold performance (e.g., durability, quality of concrete surface finish). This information will be compared to data from traditional mold manufacturing techniques. This assessment will de-risk an advanced manufacturing technique that has the potential to be extremely beneficial to the precast industry as it could reduce the manufacturing time of complex molds by about 50%.

Figure 4: Target Building Design and precast window fascia.

2. RESULTS AND DISCUSSION

The objective of phase 1 is to demonstrate the feasibility of either glass fiber reinforced ABS or carbon fiber reinforced ABS in molds that will be used to cast concrete. The goal is to identify which material has the best durability, lowest cost and what are the required design limitations (wall thicknesses). A prototype mold will be designed, fabricated and tested using two different materials. Gate Precast will manufacture test articles using both materials and visually inspect the molds for durability (wear).

Phase 1 activities:

Task 1.1 – Mold design (ORNL/Gate Precast)
Task 1.2 – Mold manufacturing (ORNL)
Task 1.3 – Part testing (Gate Precast)

Task 1.1 – Mold Design
The molds will be rectangular in shape with differing surface angles. Gate Precast provided ORNL basic geometrical requirements (Figure 5). ONRL would transform the drawing to a 3 dimensional SolidWorks CAD model

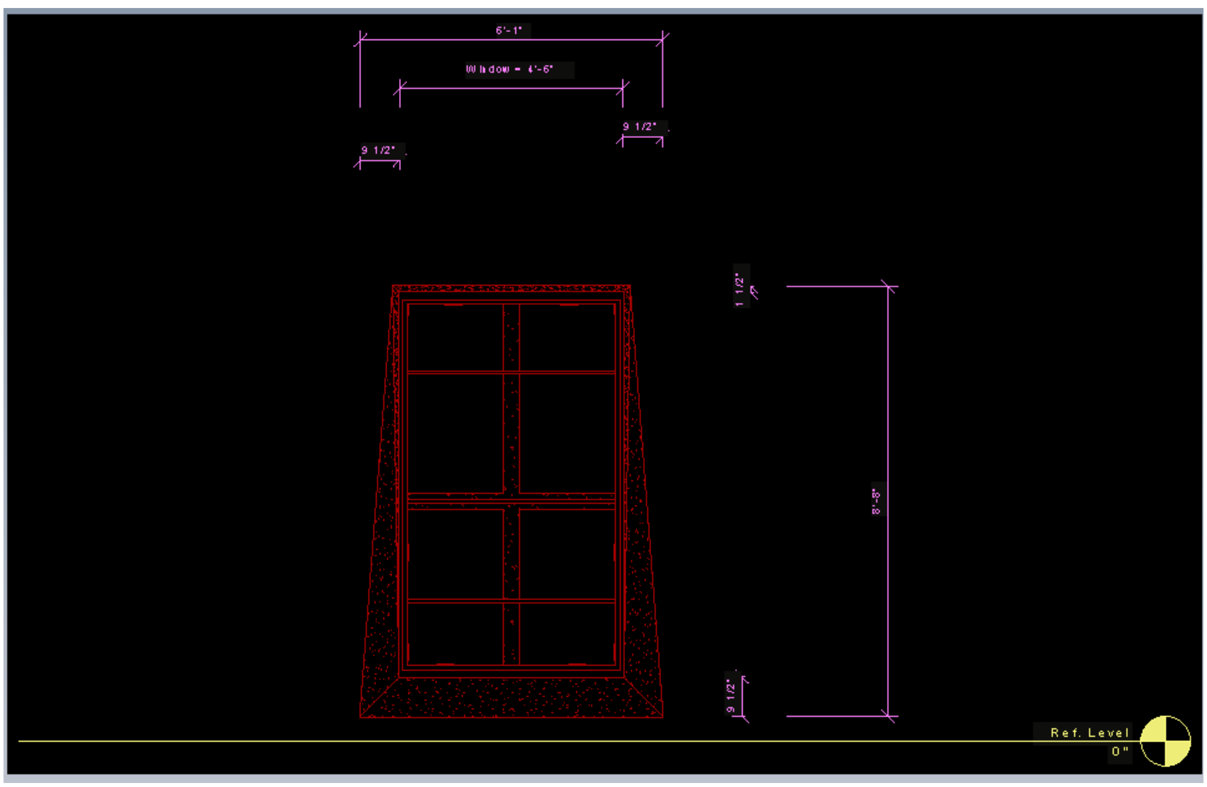

Figure 5: Mold drawing

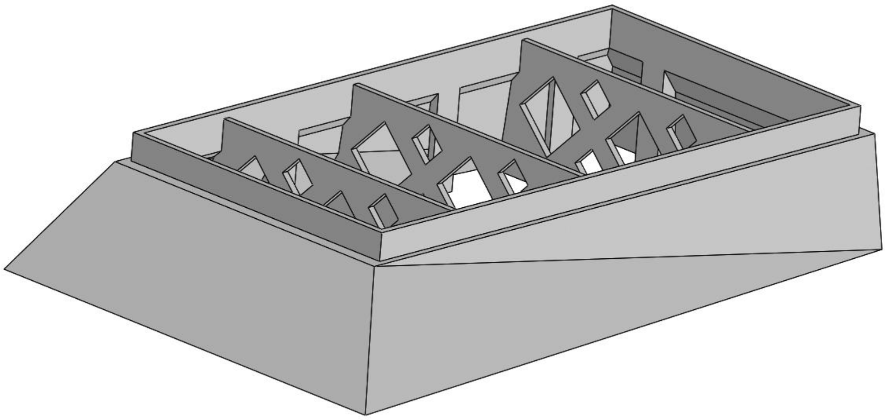

Figure 6: CAD model

The CAD model would be transformed into a stereolithography (STL) file and loaded into the ORNL slicer to create the toolpaths for the mold (see Figure 7). The final toolpaths, or g-code, is displayed in Figure 8.

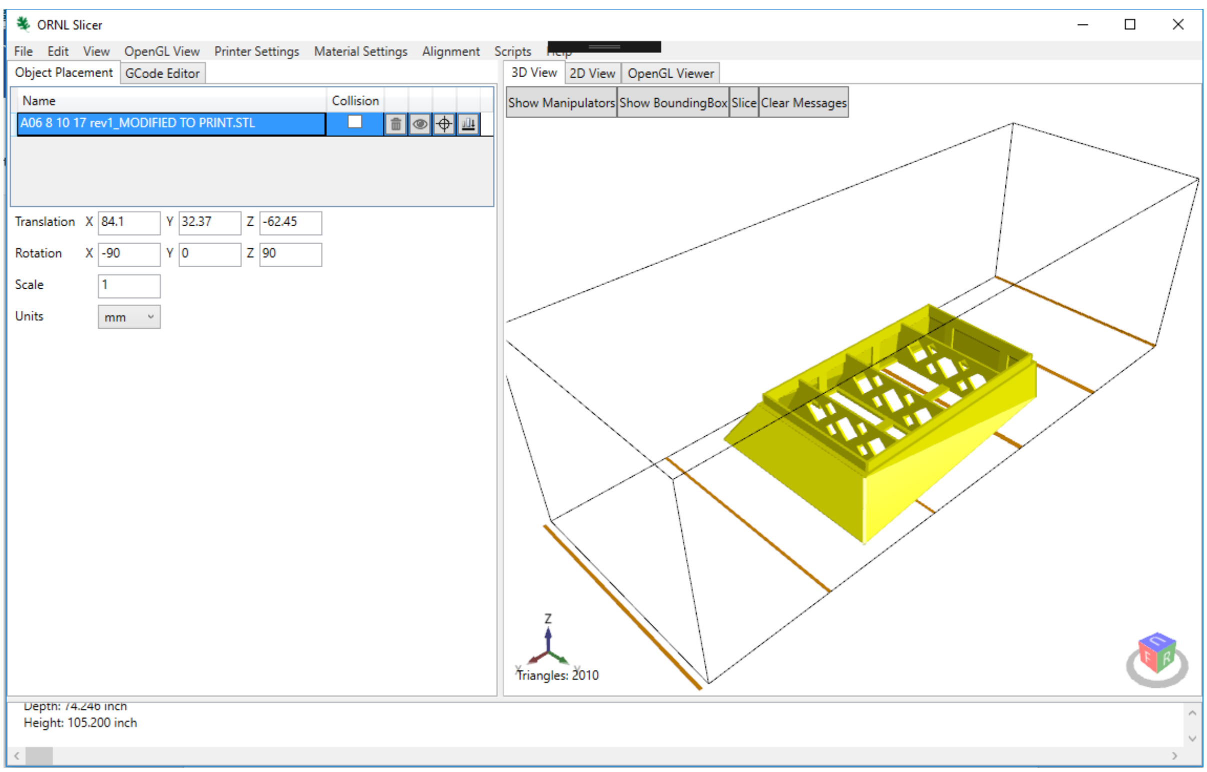

Figure 7: Mold in ORNL Slicer

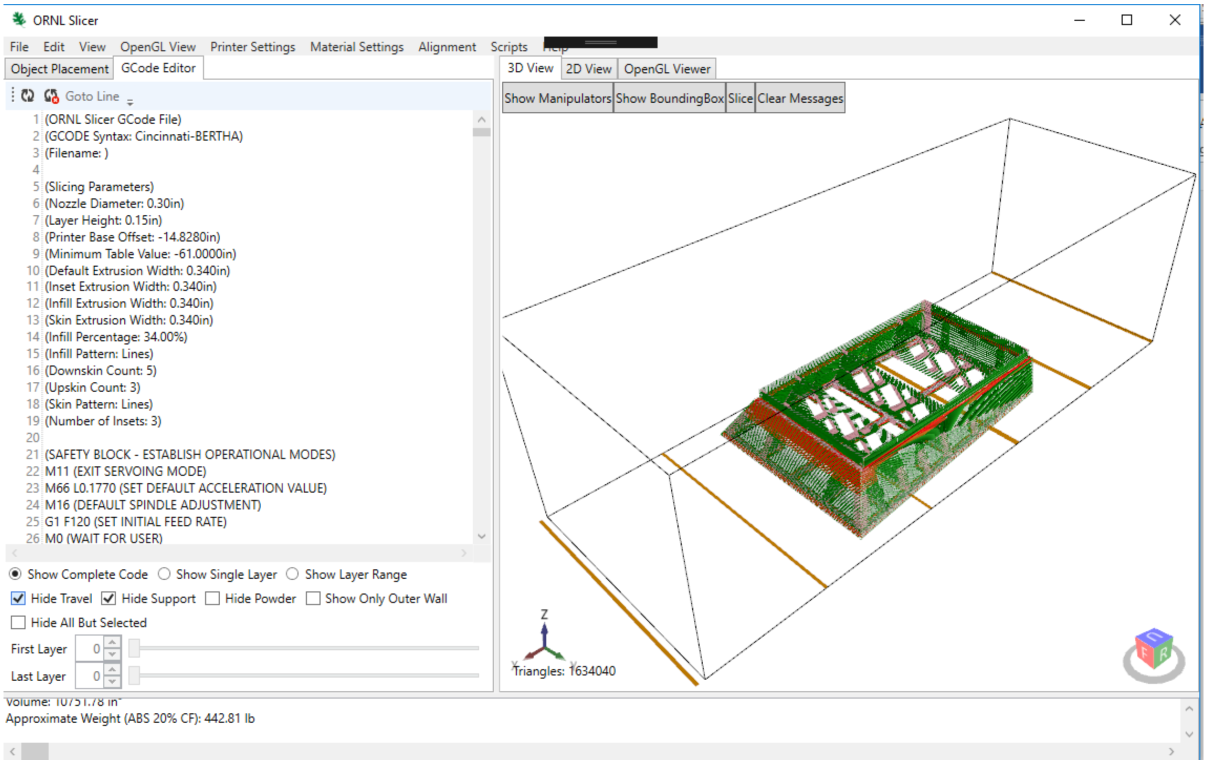

Figure 8: Toolpaths for mold

Task 1.2 – Mold manufacturing

Once the tool paths are generated, the g-code is loaded on the Cincinnati BAAM. The following is a log of the printing settings for the East A06 mold with post processing procedures. The mold weighed approximately 550 lbs and took approximately 8 hours to manufacture. The materials was 20% carbon fiber reinforced ABS plastic from Techmer that costs $5.10/lb. Therefore, the mold used $2805 of material.

East A06 Log

Printed date	8/15/17
Polymer	ABS w/ 20% carbon fiber from Techmer (CF3DP-20)
Nozzle size (in.)	0.4
Bead size (in.)	1/2
Number of beads	2
Printed wall thickness (in.)	1-1/8
Printing time (hours)	8 to 9
Amount of ABS printed (lb.)	550 lb
Bracing	(3) Printed braces

Add-ons	(10) Gussets that reinforce the bottom flange: (2) top, (2) bottom, (3) on each side. Some of these will be used as supporting pads for vibrators.

Machined date	8/16/17 and /17/17
Machining process	
1st pass	0.000 alignment verification
2nd pass	0.150 in. with 1-¼ inch diamond flake carbine insert face mill
3rd pass	0.050 in. with 1-¼ inch diamond flake carbine insert face mill
4th pass	320 grit sandpaper
Wall thickness	3/4”
Machining time	
Setup (hours)	2 (moving from printer to router and calibration)
Machine top (hours)	8 hours
Flip mold (hours)	2
Machine bottom (hours)	3

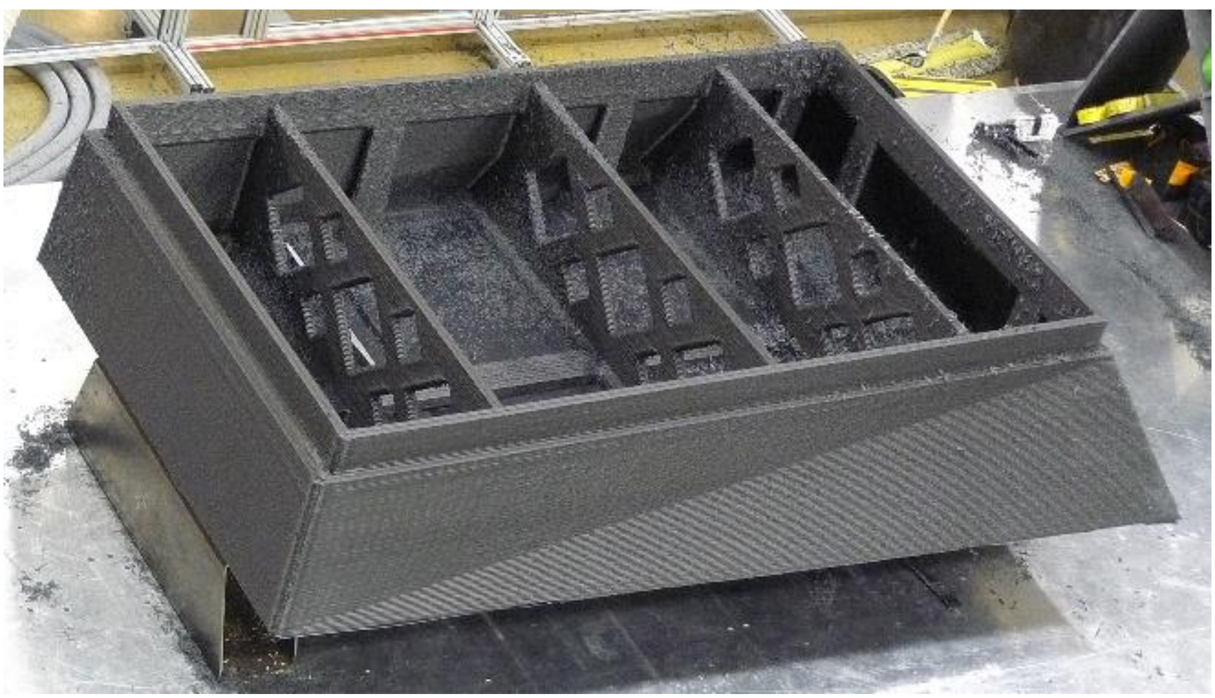

Figure 9: Printed A06

Once the part is printed, it is moved over onto a Thermwood router for finishing (see Figure 9). Using a Faro laser tracker, the printed part is calibrated with respect to the location of the CAD model within the coordinate system of the router. The sides are machined with a flycutter and spiral toolpath pattern (see Figure 10 and Figure 11). The mold is grown over by 0.25". A first pass is run with a 0.000" offset to verify alignment. A second roughing pass is 0.150" deep with a final 0.050" deep finishing pass. It takes approximately 2 hours to set up the mold on the router and 8 hours to machine all of the surfaces. The bottom of the mold must be machined as well which requires flipping the mold. A final finishing sanding is applied over all of the machined surfaces with a 320 grit sandpaper (see Figure 12 and Figure 14).

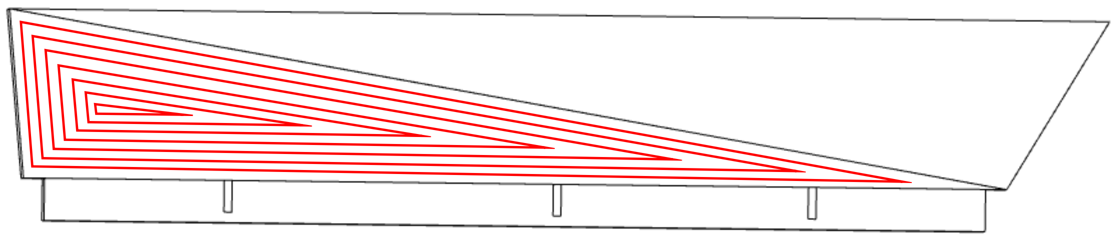

Figure 10: Cutting pattern

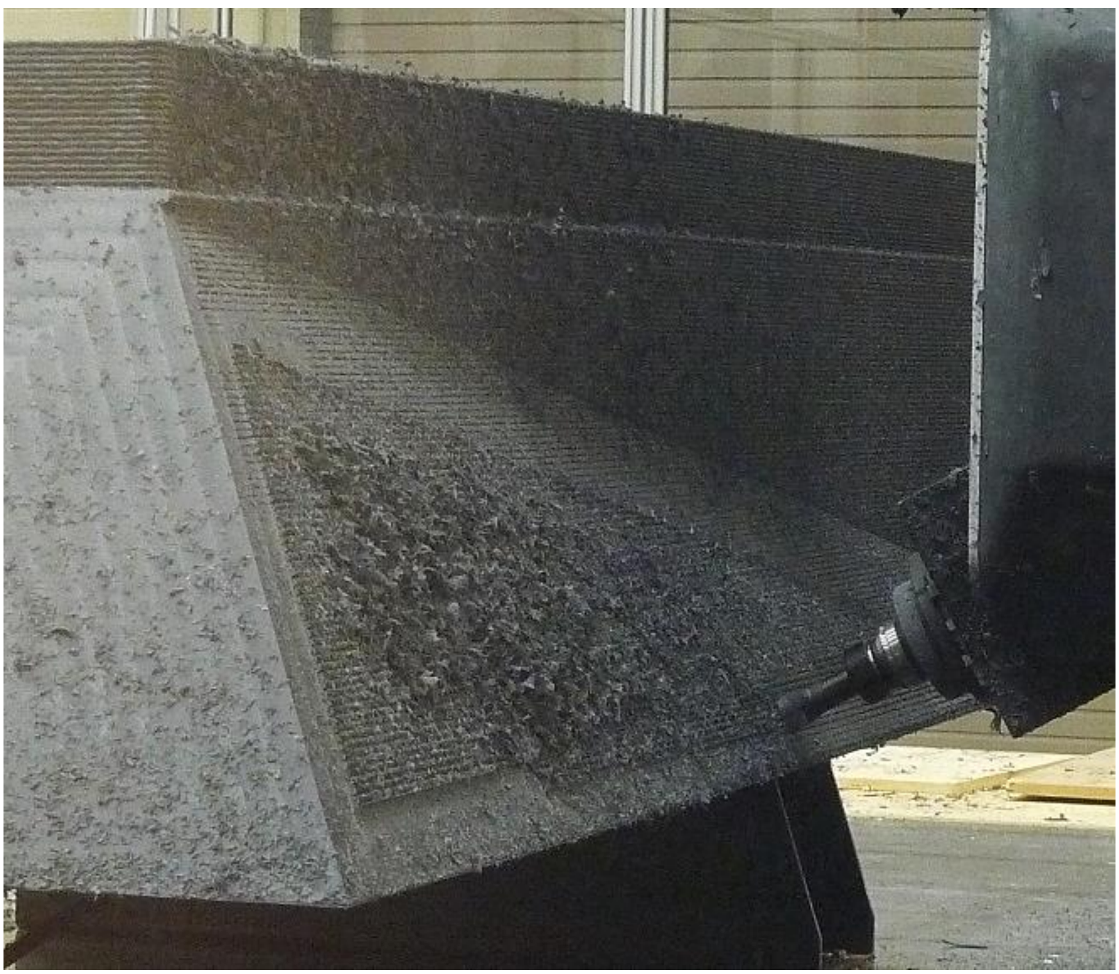

Figure 11: Cutting pattern

Figure 12: Final mold overview

To achieve sharp corners, all corners had a slight protrusion to add extra material to eliminate the risk of too short of a radius produced through the printing process (see Figure 13 and Figure 14).

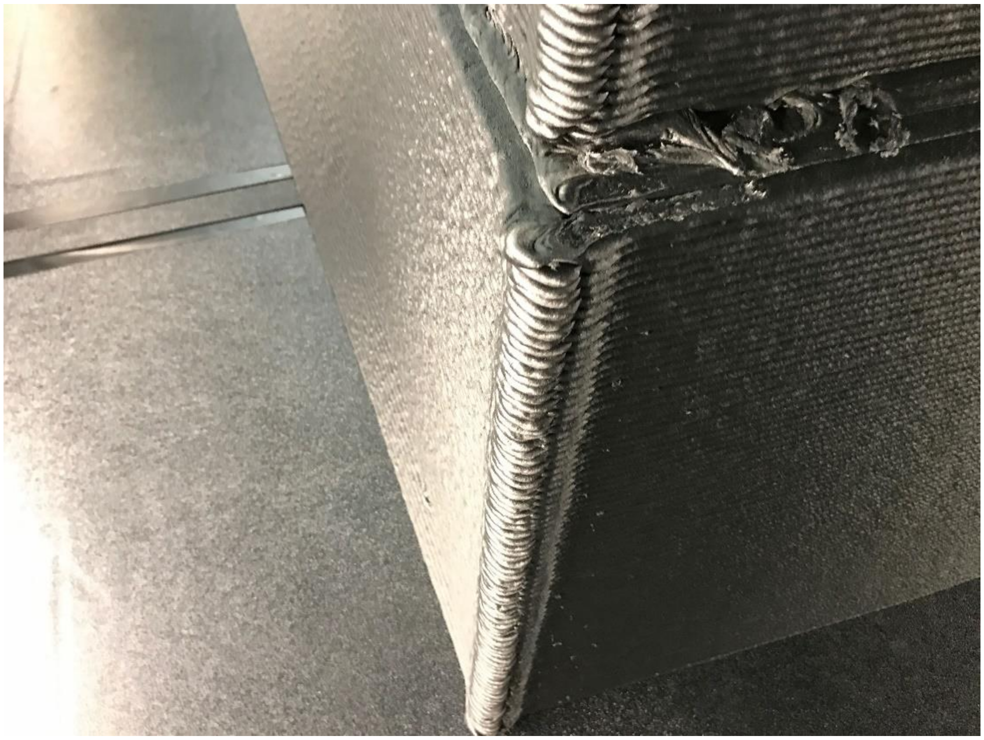

Figure 13: Over grown corners

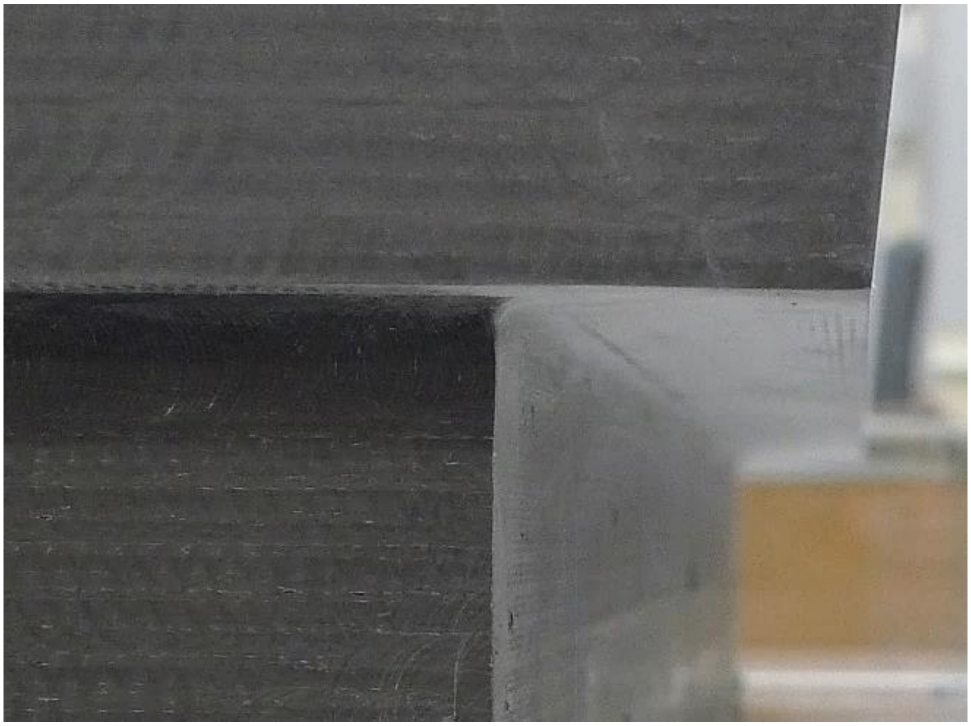

Figure 14: Final mold closeup

There was a printing defect in one corner. To repair, an epoxy was applied to the mold on the damaged area prior to machining and permitted to fully cure.

Figure 15: Repair section

Task 1.3 – Part testing

The mold was delivered to Gate Precast for testing and evaluation. The surface finish was sufficient for evaluation of durability. The mold is placed within a box (see Figure 16) with reinforcing rebar (Figure 17). Concrete is poured within the mold and vibrated to remove any air. Once cured, the precast concrete is removed (see Figure 18 and Figure 19).

Figure 16: Pattern within form

Figure 17: Installation of reinforcements

Figure 18: Final part

Figure 19: Side view of final part

The results of the phase 1 activities are sufficient to move forward to a second phase focusing on exploring more complex geometries.

3.1 PATENTS

No patents were the result of this effort.

3.2 PUBLICATIONS AND PRESENTATIONS

There are currently no other publications on this effort.

3.3 COMMERCIALIZATION

The project has demonstrated feasibility of the process. The goal of the second phase is to manufacture a variety of different geometries and test for viability and durability.

3.4 RECOMMENDATIONS

The project has demonstrated feasibility of the process. It is recommended that the project now transitions to the second phase to manufacture a variety of different geometries and test for viability and durability.