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Large Format, Large Diameter Filament Additive (FFF) Manufacturing

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OAK RIDGE NATIONAL LABORATORY
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Manufacturing Sciences Division
Advanced Manufacturing Office

Development of Long Fiber Filled Materials for Fused Filament Fabrication (FFF)

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Contents

List of Figures

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Abstract

ORNL worked with 3D Platform to develop new hardware and systems for their largest product, a medium format pellet system known as the WorkCenter 500. 3D Platform provided an Alpha version of the system for ORNL to begin development and systems integration. ORNL focused efforts on integrating a new dryer, safety enclosure, extruder, and build table for improved operation of the system.

1. 3D PLATFORM PHASE 2 REPORT

ORNL and 3D Platform (3DP) worked together on a phase 1 technical collaboration (MDF-TC-2018-148) in 2018 and 2019 wherein a 6mm filament extruder, developed by 3DP, was evaluated. This involved printing calibration and characterization as well 6mm filament supply chain development because existing manufacturers do not commercially offer the larger filament diameter. The project culminated with the successful printing and demonstration of a stamping die.

Phase 2 technical work began in August of 2020 when 3DP delivered the WorkCenter 500 system to ORNL's MDF. The project was completed in July of 2022. The research focused on design, development, and integration of new systems to enable medium format pellet additive manufacturing.

1.1 BACKGROUND

Fused granular fabrication, FGF, is a term often used to refer to polymer extrusion systems that are fed with pellets or other granular materials. FGF is a very similar process to FFF, fused filament fabrication, which has existed for decades and is now available from hundreds of different manufacturers. These systems start at costs in the low hundreds of dollars. Medium and large format polymer FGF additive manufacturing systems are still relatively new to the overall additive manufacturing landscape. To date, only a handful of US manufacturers offer systems of this size, and the prices typically start in the low seven figures. 3DP is breaking into this space with a low-cost, fully featured, medium format system that has an optional upgrade for subtractive manufacturing. The optional CNC router allows the system to do both additive and subtractive processes on the same gantry platform, helping to save valuable shop space. Together, ORNL and 3DP are working to develop and improve the systems needed for FGF systems. This phase 2 research report will outline the work done between ORNL and 3DP to develop and integrate new systems for FGF on a 3DP WorkCenter 500 system.

1.2 TECHNICAL RESULTS

The technical work for this phase 2 project between ORNL and 3DP focused on design, development, and integration of new systems and components for the 3DP Workcenter 500. The first of these was the pellet dryer. 3DP delivered the system with a ConAir drying unit that was to be on loan until ORNL could come up with a more permanent solution that was meant for 3D printing. The ConAir unit was a discontinued product that 3DP could not offer for future machine sales, so they needed a more long-term solution. ORNL selected a H-PDII unit from DriAir. The H-PDII has dual hoppers with separate drying units which allows for two dissimilar materials to be loaded and dried at the same time. The unit was upgraded with closed loop loading and purge boxes. Closed loop loading helps keep the material in the feed line dry by recirculating the same dryer air and not introducing new air that may have moisture. The purge boxes simplify the process of switching material by allowing the material in the line to be quickly purged and recycled back into the dryer. ORNL installed a buzzer connected to the material request signal. This buzzer activates when the extruder continually calls for new material for at least 30 seconds. The alarm activation can signal that the dryer is low on material, or more likely, that material is not properly feeding to the extruder which can be caused by a clog in the line, a hole in the line, or a blockage at the dryer outlet. The new dryer can be seen in Figure 1.

Figure 1: DriAir H-PDII system installed at ORNL MDF.

One of the features that makes the WorkCenter 500 standout is its hybrid manufacturing capabilities. Most systems in the medium to large size class only offer additive capabilities, requiring the end-user to purchase a second system for machining operations. The system, as configured for ORNL, includes a subtractive CNC router for post-machining of printed parts. This allows for one machine to print and machine a part without having to remove the part, use a second machine, or re-orient and relocate the object, saving valuable man hours. The machining operation, regardless of material, often results in a large buildup of chips and dust. There is also the inherent risk for breaking a tool and sending debris outward from the cutter. To mitigate this, typical CNC machines come completely enclosed. This solution is not feasible for the WorkCenter 500 because of its size and complexity. A full enclosure would also prevent building sprinkler systems from functioning effectively in the event of a fire or other thermal event inside the system. To help contain the buildup of offcuts from the machining process and provide a bit of a safety enclosure while not inhibiting the sprinkler system, ORNL designed a moveable enclosure to surround the system up to eight feet. The enclosure is made from moveable panels constructed from plexiglass and aluminum extrusion. This allows the operator to easily see inside but have protection from any debris. Each panel can be disconnected from its neighbor so that large parts can easily be removed from the system. The enclosure can be seen in Figure 2.

Figure 2: 3DP WorkCenter 500 with surrounding enclosure.

The original extruder on the WorkCenter 500 was known to be undersized for the capability of the full system. The maximum output was recorded at 4.75lbs an hour with an experimental blend of PLA (polylactic acid, a common 3D printing thermoplastic). The extruder was water-cooled at the top of the extruder to prevent material from melting too early and bridging. This added complexity to the system by requiring a separate chiller unit and water lines to be run through the gantry to the extruder. The chiller had to be manually turned on each time the extruder was to be heated. The issue with the water-cooler was that it often overcooled the system, preventing the infeed from getting hot enough to help initiate the polymer melting. This increased cooling caused the flowrate to decrease by nearly 75% and torque values to spike well over 100% during normal operation. ORNL resolved this by installing an air-cooled extruder with a larger infeed and longer barrel. The larger infeed allowed more area for passive cooling fins to be installed to help prevent the infeed material from prematurely melting. The longer barrel allowed for more residence time of the material while in contact with the extrusion screw. With this new extruder, throughput has increased to 7lbs an hour and the water-cooling lines can be removed. Over-torque issues still arise at higher speeds, but this will be mitigated by upgrading to a larger motor.

As delivered, the WorkCenter 500 had a build plate made of three individual aluminum plates with a vacuum grid machined into the top. The vacuum grid extended through the end of the plates, which meant it had no natural seal. Rubber or foam O-rings had to be placed within the grids to provide a seal and constrain the vacuum to a certain area. The problem, as ORNL has encountered on several past failed system builds such as the ORNL Blue Gantry research system and the Cincinnati BAAM, is that a pneumatic vacuum and O-ring seal is not sufficient to hold build sheets in place during 3D printing because of the high residual stress buildup. After just a few layers, the part has enough force to warp the sheet away from the vacuum and break the seal. Now the vacuum is doing nothing to hold the print in place. ORNL's solution is to tape the sheet around the edges and create a second seal that can flex with the motion of the build sheet; however, the vacuum grids extending out to the edges on the 3DP build table prevent tape from working properly because there is no area to seal the tape without taping over the grid. Another issue was the strip heaters used for the bed. These metal strip heaters were constrained at both ends, such that when they heated, they would expand and warp away from the bed. When not making contact with the build plate, the bed didn't heat quickly. This combined with the small amount of power dedicated to the bed heaters, 9kW max, meant the bed took over an hour to heat to temperature.

ORNL's design and development of a new build plate system was the primary focus of research during this project. It took several months of iterating on a design with the help of the engineers at 3DP to finally create a new build plate design that would work effectively.

The new build plate design, shown in Figure 3, includes vacuum grids focused on fitting a standard build sheet, 4ftx8ft, as well as a standard half sheet, 4ftx4ft. Alignment markers can be seen at the four outermost corners, used for the full 4x8 sheet, so the operator can quickly position a build sheet. The vacuum grid is separate into two zones. The first zone is for the half sheet and the second zone is for the full sheet, when used in parallel with the first zone. Each zone has multiple vacuum ports to help with equal vacuum distribution, and each zone is surrounded by a groove that can hold an O-ring to help improve the seal. Another key feature is an outer loop for inserting T-nuts for use in manual clamping situations, such as toe clamps. Surrounding the plate are warning messages about proper lifting safety as well as a note about the plate being hot. Figure 4 includes a fully annotated drawing to explain the different features. Figure 5 shows a side perspective of the actual plate with machined T-slot groove.

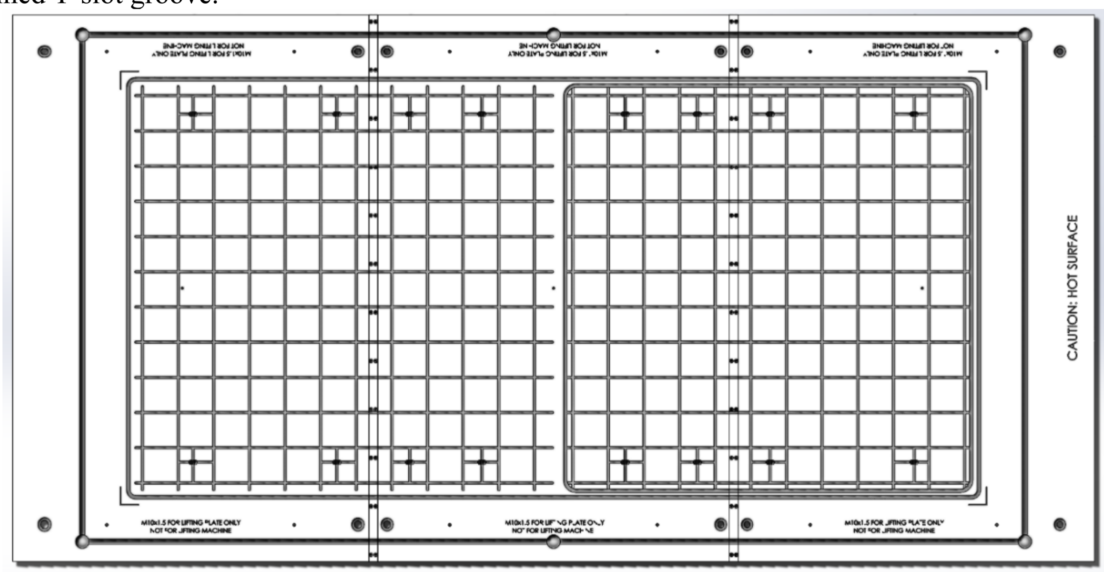

Figure 3: Design of the new build plate system for the WorkCenter 500.

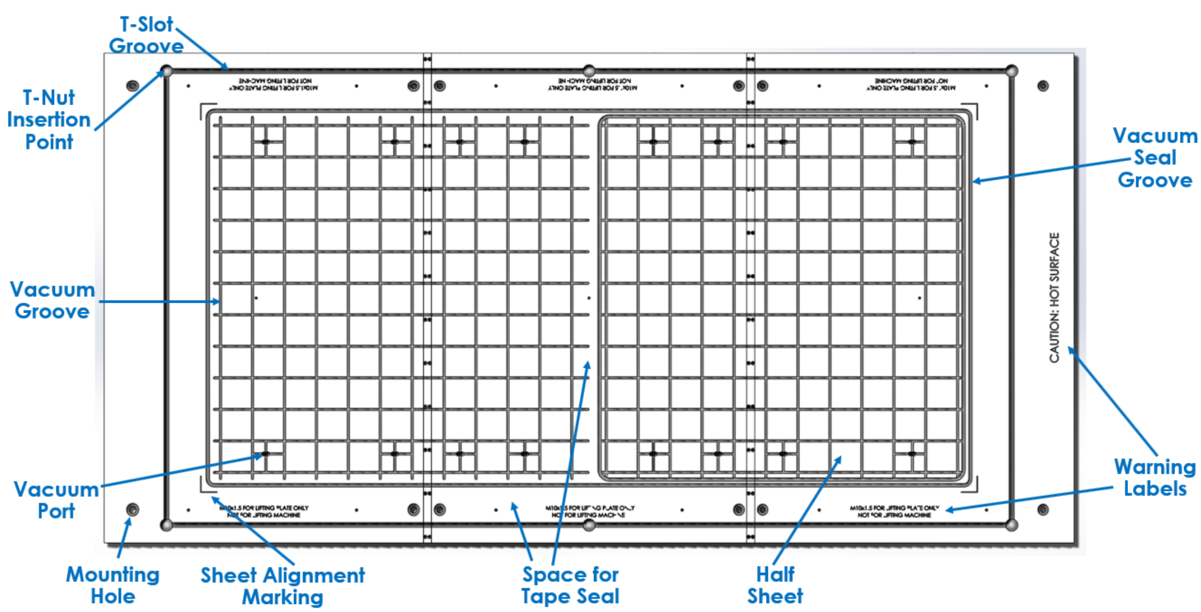

Figure 4: Build plate design with labels for all design features.

Figure 5: Side angle of the T-slot groove.

Heaters for the bed build plate system are resistive silicone adhesive heaters from Watlow. These heaters, an off-the-shelf product for easy integration, are 12”x24” and include an embedded thermocouple. Fourteen total heaters are installed to the bottom of the three main build plates. Figure 6 shows the underside of one build plate with heaters attached.

Figure 6: Center build plate with six silicone heaters installed.

To control the 14 bed heaters, ORNL integrated a new stand-alone heater controller for the build table. This system has triple the power output of the original design and allows for independent control of up to sixteen heater zones, each with a separate thermocouple. While the build plate design is custom, the heaters and control units are off the shelf products that can easily be purchased and integrated to a system. ORNL developed the housing to hold the controllers seen in Figure 7.

Figure 7: Heated bed controller panel.

1.3 IMPACTS

The 3DP WorkCenter 500 is a brand-new system that offers a lot of capabilities for an attractive price point. As the field of medium and large format additive manufacturing of polymers continues to develop, there will be an increased need for robust machines that have hybrid capabilities. Together, ORNL and 3DP have increased the capability of this low-cost American made system. The developments in this project can be applied to more systems than just the WorkCenter 500. Through this project, ORNL has worked with DriAir to develop new capabilities to ease the integration of pellet dryers to additive manufacturing. This project also created a lot of documentation, including a conference paper pending publication at Solid Freeform Fabrication 2022 titled "Build Plate Design for Extrusion-Based Additive Manufacturing", outlining the process of designing and developing an effective build plate system as well as a reviews of existing systems.

1.3.1 Subject Inventions

There are no new subject inventions as a result of this project.

1.4 CONCLUSIONS

Phase 2 of this project resulted in several new systems designs, improvements, and integration to increase the capability of medium and large format additive manufacturing. Work with a new DriAir system allowed for dual material drying with closed loop loading and reduced material waste with purge boxes. A new extruder integration allowed for increased material throughput. An improved build table allows for manufacturing of larger objects while maintaining dimensional accuracy and with the ability to mechanically fixture objects for the machining process. This new build plate design also resulted in a conference paper that has been accepted for publication in 2022.

Future work will involve upgrading the extruder motor size to allow for increased throughput on the extruder. The current motor is often maxed out and cannot support the torque requirements needed for extruding at higher throughputs. This upgrade will require a new motor drive, higher power cabling for the motor, and an appropriately sized gearbox.

2. PARTNER BACKGROUND

3D Platform is the trusted global leader in industrial-strength, large-format 3D printers. Based in Roscoe, Illinois, USA, the entire 3D Platform team is focused on driving advancements in technology to innovate, design, and build next-generation equipment for additive manufacturing. Their global distribution network supported by Certified Service Providers has helped them deploy more large-format, open-market 3D printers than anyone else. To learn more about 3D Platform, visit www.3dplatform.com.