The use of 3D Printed Foundry Patterns for Aluminum Casting with Oil Bonded Sand Molds

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Abstract

This paper presentation outlines early-stage results from research into the use of low-cost 3D printing to create foundry patterns for Aluminum metal casting with oil bonded sand molds. The paper outlines findings and observations in relation to the practical challenges in using Fused Deposition Modeling (FDM) 3D printing for this application. The paper provides observations from first-hand practical investigations of the complete workflow including pattern design, fabrication via 3D printing, mold making, casting and fettling/finishing of the parts. Observations will be delivered as researcher reflections of the process and include strategies and approaches in relation to the use of patterns with the particular surface texture that is characteristic of FDM produced parts. Numerical data will be provided to assess final aluminum part accuracy in relation to the printed pattern.

Background and Motivation for Research

Metal foundry applications have long been one of the target applications for companies developing 3D Printing/Additive Layer Manufacturing (ALM) technologies, due to some significant attractions of using ALM for this application. Foundry pattern making is traditionally a very skilled task, which can be both costly and time-consuming. ALM technologies provides the potential for reducing both time and cost in this process and also present advantages in terms of accuracy as well as new opportunities I regards to the range of geometries that that can be produced via casting. In particular the potential of producing foundry molds directly from CAD files without the need for a physical mold pattern is one of the attractive propositions presented by ALM. An early example of this approach was ZCorporation gypsum powder-based 3D printing system which included the option for a printing medium (Zcast), which was specifically formulated for the direct printing of foundry molds from CAD files. While the ZCoperation technology is no longer available, other companies supply ALM machines that can produce foundry molds with a similar approach, such as: Voxeljet, EnvisionTEC/ Viridis3D and Exone [1].

The direct fabrication of molds without the need of mold patten is an aspect that is unique to ALM technologies, however 3D printing is also used in conjunction with more traditional foundry workflows were physical mold patterns *are* employed such as the *investment* and *sand-casting* approaches.

With the investment casting approach, the mold a pattern is typically produced in vax and then covered in refractory molding medium such as plaster or ceramic shell. Once the mold covering process is completed the vax pattern is melted out leaving a void for the molten metal to be poured into – a process also known as *lost wax* casting. The investment casting approach can also be successfully carried out through the use of common 3D polymer filaments, such as PolyLactic Acid (PLA) – although the melting process for such polymers require higher temperatures to ensure the pattern material is completely removed through combustion rather than melting. Some filament [2] are available that are specifically formulated to for this purpose where no ash residue is being generated to enable high quality casting.

With the sand-casting approach, the mold is made of sand but mixed with a binder that ensure the sand remain in the desired mold shape during the casting process. The binder can be in the form of a resin which facilitate the sand to set into rigid shapes. In this approach both organic and inorganic binders (such as sodium silicate) are used. However, sandcasting can also be done with non-setting binders such as clays and/or oils which makes less rigid molds. This approach relies on the mold maker manually compacting the sand around the pattern, with the mold's structural integrity and surface fidelity achieved by the oil and clay biding the sand together when compressed. This process has a number of potential advantages compared with other foundry approaches – in particular the majority of the sand can be readily be reused for new molds after a cast. Furthermore, red sand does not require mechanical mixing equipment and the process can therefore be carried out in smaller set-ups with limited foundry facilities. However, the process do also present challenges in terms of the workflow, particular when using patterns fabricated via FDM 3D printing – at medium to large scale. Foundry molds made with oil bonded sand are somewhat delicate and the removal of the mold pattern has to be done with great care to avid corners and edges breaking off, the surface texture of FDM fabricated patterns is particular challenging in this regard. This is an area where relatively little research has been carried out and this paper reports on early-stage investigations to address this research challenge.

The vision with this research is to provide knowledge for independent practitioners and small business to integrate in-house 3D printing capability with small scale foundry set-up for a complete manufacturing workflow.

Research Methodology

The research is carried out as pratical investigations of the complete workflow of the design, pattern development, molding and finally metal casting of the test parts. Data from the research has been recorded as images and notes from researcher observations. Numerical data has also been recorded in terms of measuring the size of the mold pattern and the finished parts. Researcher reflections are used to evaluate the overall result of this practice-based investigation.

Research Aim and Objectives

The purpose of the research is to explore the practical challenges and potential advantages of using low-cost 3D printing technology for pattern making in traditional foundry workflows with oil bonded sand mold. Objectives in this main aim include:

- To explore the 3D printing settings to achieve an optimal balance of surface quality, structural integrity and print/fabrication speed.
- To investigate draft angles strategies and orientation of the 3D printed layers in relation to the molding process.

- To investigate other practical challenges of oil bonded sand molds created from FDM printed patterns.
- To establish accurate figures for the size differential from FDM mold pattern to final aluminum part.
- To provide an overall evaluation of the advantages and disadvantages of using FDM printed foundry patterns with Petrobond based foundry molds.

Technologies and Processes Employed in the Investigation

A Creality CR10 S4 was employed as the 3D printer for this research – this machine is a consumer level FDM system, which at base configuration cost around $500. The machine for this research has had a number of upgrades and modifications including: upgraded heated bed, Bondtech direct drive filament feed, volcano extruder nozzle, BL calibration touch probe and enclosed printing chamber. The filament used was standard white rPLA 1.75mm diameter from the company *Filamentive*. The oil bonded sand use to in the research was the widely available product *Petrobond* [3], which also known as *red sand.* Aluminum was sourced as surplus industrial cast stock, and while the exact alloy composition was difficult to determine, the metal is believed to be of a standard 300-series (Al-Si-Cu or Al-Si-Mg) composition.

The test pattern use in this investigation is a design for a nozzle for a hydraulic clay extruder. The design is a two-part construction, with two identical parts forming the complete nozzle design. The dual part construction required the whole process of molding and casting has to be carried out twice, which facilitated an investigation with repeated cycles of investigations. The scale of the pattern could be considered quite large, both in relation to 3D printing and the foundry process with the longest dimension of the part being 395mm. The pattern was designed with particular considerations to ensure that draft angles were incorporated which would aid the removal of the pattern from the delicate sand molds. In this approach the 'body' part of the nozzle was designed with faceted sides, filleted internal corners and tapered edges with a minimum of 1º draft angle. However, given the geometries and function of the part it was not possible to design tapers to all surfaces of the pattern. The design of the part was also considered in relation to the layered texture characteristic of FDM 3D printing. Given the large size of the part a relatively large 3D printing nozzle diameter (0.8) was used in conjunction with 0.3 mm build layers to achieve an appropriate balance between print time and surface resolution. The pattern was printed in two parts to avoid the need for scaffolding support for the overhangs of the flanges. Two endcaps were also printed separately to aid the mold making process. The evidence of the FDM process on the surface of the pattern have the potential of creating small undercuts which the Petrobond sand can adhere to – thus making the removal of the pattern from the mold difficult with the risk of breaking off fragile sections. The orientation of the pattern design on the printing platform is therefore a critical aspect of the process. The 3D printed layers ideally have to align with the direction the pattern is intended to be removed from the mold. With the particular geometries of the pattern tested in this research achieving this was not entirely possible. The flanges of the nozzle design had to be at a 90º angle in relation to the main body and the texture resulting from the FDM process had the potential to course difficulties with the pattern removal. To overcome this issue a strategy was devised where thin (1mm) 'steps' were 3D printed separately and attached to the inner corners of the flanges. These steps were used in conjunction with the outer edges of the flanges as guides between which car body filler was applied. This approach ensured that 'non-aligned' texture on the flanges was not only smoothed by the filler but also slightly tapered to aid the pattern removal.

The final aluminum parts underwent cleaning, fettling, examination and measuring to determine the shrinkage in relation to the 3D printed pattern. Data were taken from 17 points of the cast parts and used to calculate the shrinkage from pattern to final aluminum part, which was calculated to be 0.91%.

Figure 1: Images from the workflow of the investigation, foundry pattern being printed via FDM, two-part 3D printed pattern with separate end-caps, molten aluminum being poured (Photos by T Jorgensen 2020).

Interim Results and Findings

The pattern was used in two complete cycles of mold making and aluminum casting workflows. These cycles resulted in the successful production of the two-sided nozzle design. The investigation indicates good potential of using FDM pattens in a complete foundry workflow with oil bonded sand. The research has produced knowledge on how particular strategies in terms of part design and 3D printing orientation can be effectively utilized in strategies to ease the molding process. Documentation of the complete production workflow will be delivered in the presentation as well as details of planned further investigations.

References

[1] I. Kauppila, 'Casting Metal Parts with 3D Printed Patterns – Best Practices', *All3DP Pro*, Jan. 06, 2021. https://all3dp.com/1/casting-metal-parts-with-3d-printed-patterns-best-practices/ (accessed Sep. 04, 2021).

[2] Polymaker, 'PolyCast™', *Polymaker EU*, 2021. http://eu.polymaker.com/product/polycast/ (accessed Sep. 11, 2021).

[3] J. Winter, 'Sand binders', *John Winter*, 2021. https://www.johnwinter.co.uk/product/sand-binders/ (accessed Sep. 05, 2021).

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Jorgensen has a background as a professional designer for the ceramics industry before developing a career in academia. Jorgensen research interests includes: digital fabrication, glass & ceramics design and interdisciplinary innovation.

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