Discrete Multi-Material Selective Laser Sintering (M^2SLS): Development for an Application in Complex Sand Casting Core Arrays

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Abstract

Conventional sand casting processes often take many weeks or months to produce the tooling required for a casting, in particular the fabrication of sand core arrays for hollow features in a casting. SLS is already being applied to produce complex sand core geometries and reduce production times, but a new development of discretely laying down two different materials and removing one after sintering will allow even more complex geometries and drastically decrease the production times of sand cores. Two of the most significant problems in the current use of SLS for sand cores are the mechanical removal of unsintered powder and damage during part breakout. The second discrete material serves as a support medium through the build and fabrication of the sand core and is removed before casting; the sacrificial second material increases green strength and eliminates time consuming post-processing. The development and plan for implementation of the discrete M^2SLS process is presented.

Introduction

Since the introduction of Selective Laser Sintering (SLS) at the University of Texas at Austin and other solid freeform fabrication, the evolution from a single material to multiple materials was only a matter of time. Currently, many researchers are pursuing multiple material solid freeform fabrication processes [1,2]. Multiple material SLS (M^2SLS) can be divided into two categories: discrete and functionally gradient. Discrete refers to parts built with distinct material regions and interfaces within the part; each material region consists of one material composition. Functionally graded are parts that the material composition within the part changes from one component to another over a finite distance. The grading or blending is functional because the grade allows for the tailoring of physical, electrical, or chemical properties within a single part. Current research at the University of Texas at Austin examine functional graded parts with a WC-Co material system where the percent weight composition of WC is varied to achieve desirable mechanical properties at specific regions [3]. In this paper, the development pertains to a discrete two material system.

Sand casting is an old technology, dating back a thousands years, but still is the most prevalent form of casting, with 15 million tons of metal cast in the United States each year [4]. Simply put, sand casting is the process of imprinting a pattern into sand to form a mold, placing cores into the mold for internal cavities, including a gating system for molten metal, pouring the molten metal, and after cooling, breaking the mold to remove the casting. Sand castings allow for complicated shapes at a relatively low cost. The introduction of rapid prototyping to sand casting is fairly new but has impacted the industry with reduced production times and increased complexity not possible without SFF [5]. There are two RP implementations in sand casting: pattern making and coremaking. Patterns are used to form the imprint in the sand mold.

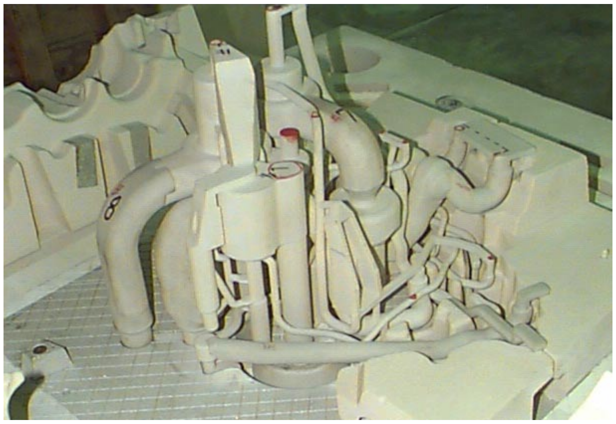

Figure 1: Core array and finished casting

Core arrays form the internal cavities or passageways of casted metal parts, such as internal geometries of engine blocks. Figure 1 shows a complex core array and the resulting finish casting. In conventional coremaking, cores are fabricated in many pieces that would have to be assembled with core paste and placed in the mold and gauged for accuracy of the fit. Cored holes and features are usually limited to ¼" diameter, but there is one special technique that exists to produce small passageways in sand castings; it is called the Dalton® Core. The process uses a copper tubing that is bent to the desired shape and inserted in the mold. A braided refractory sleeve of glass or stainless steel covers the outside of the tube. A chemical solvent, which aluminum is insoluble, removes the copper tube, while the sleeve remains. The sleeve is then removes manually from the hole [6]. This special technique has very limited application, for it cannot be used for varying hole size or complex contoured shapes.

The SLS rapid prototyping process is being used to produce sand casting core arrays. Sandform™, introduced by DTM Corporation, is a polymer-coated sand that can be processed to produce single complex core arrays, as shown in Figure 1. With the implementation of Sandform, the whole core array can be manufactured in a SLS part, with no core assembling and reduced gauging. Figure 2 shows the coremaking procedure using Sandform and SLS.
This new technology was hailed by the casting industry, but the process has many problems and limitations.

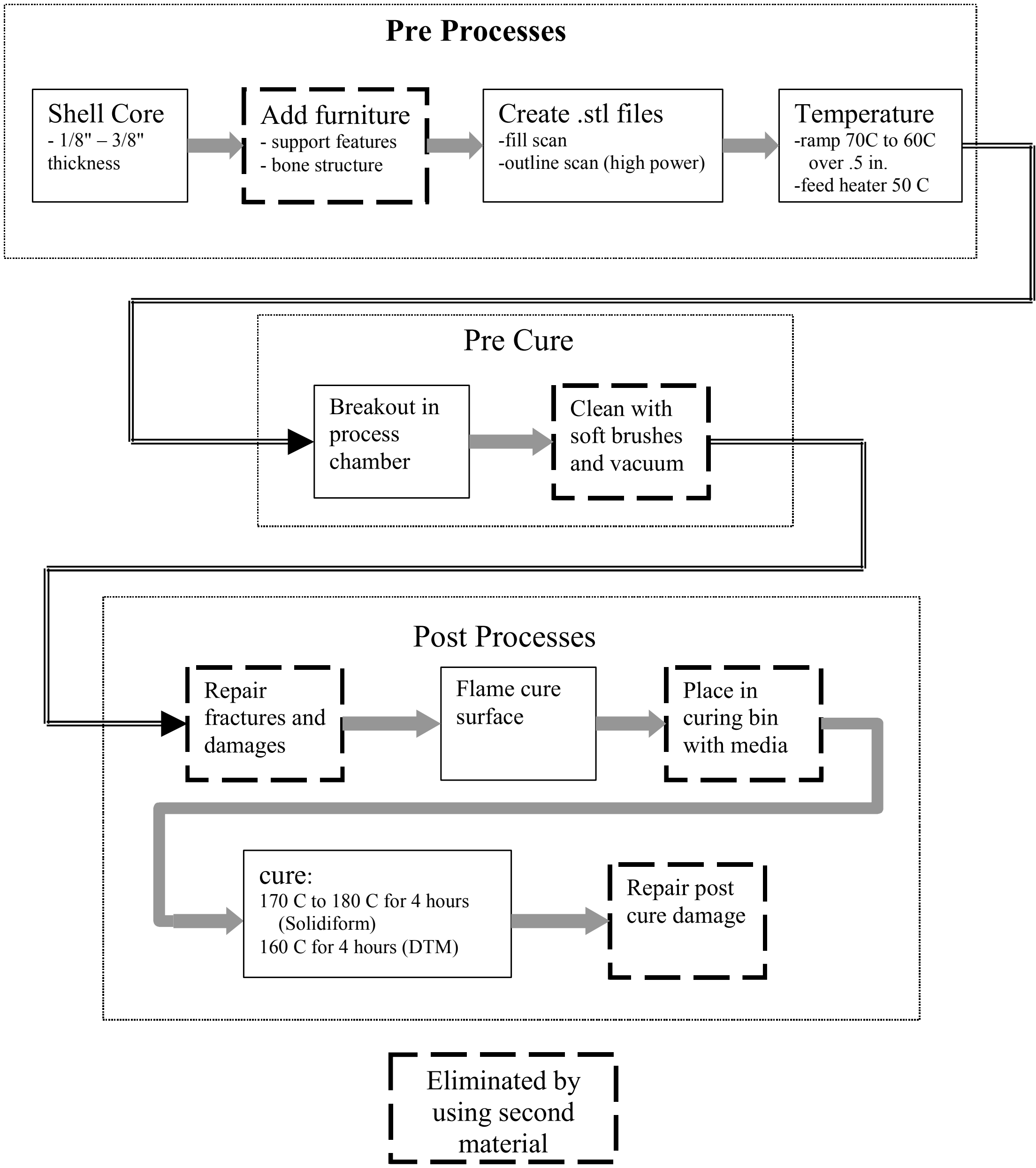

Figure 2: Sandform Process

Current problems with Sandform

Because cores are produced by SLS, extra polymer binder must be added to the sand/binder system to achieve a satisfactory green strength for the SLS build and handling of the part. This added binder causes more outgassing during metal pouring and solidification. With added binder and therefore more outgassing, venting of the core arrays become more important to prevent gases entering the molten metal and forming pockets or cracks.

Venting is achieved by creating passageways inside the core itself. Figure 3 shows a CAD representation of a core with the necessary venting. The vents connect to a core print in the mold to discharge the gas to the atmosphere. For any sand core feature, a vent hole must be present to outgas steam and gas from the polymer degradation during metal pouring; thus for a .125" cylindrical feature, an internal hole must be present in the feature to allow proper venting and still have strength. The vents inside the core can become quite small and intricate, and as mentioned before are limited to ¼" diameter, which restricts the feature sizes that can be realized.

Another problem related to venting is the mechanical removal of the support material or the unsintered powder. The problem actually encompasses all SLS manufactured parts with small holes or cavities. The unsintered powder must be mechanically removed from the cavities. Because of the vents in the sand cores, the sand cores are basically shelled, so they are filled with unsintered sand powder. The low green strength of Sandform adds to the problem of removal because of the increased likelihood of breakage. Common removal methods are gravity, shaking or vibration, and pressure differences (suction or blowing), but with smaller and more complex features, the above methods cannot remove the powder [5]. Figure 3 is an example of a core where the unsintered powder could not be removed.

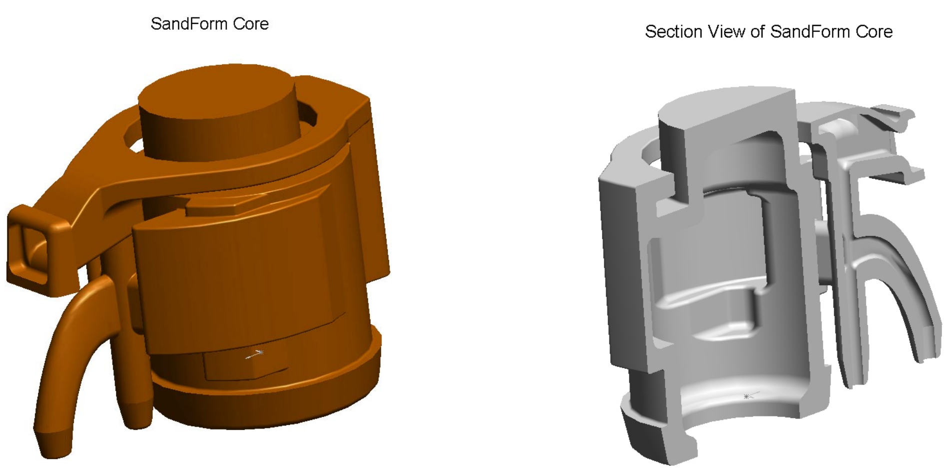

Figure 3: CAD core and section view

In addition, low green strength can cause part damage during breakout of the SLS machine and removing the unsintered powder and part cleanup. Some damage can be repaired with special adhesives, but many cores have to be scrapped. Also, the core can break or crack during the thermal cure cycle. As stated before, binder content cannot be increased to augment the green strength because more binder means more outgassing and more need for venting or larger vents.

All of these problems point to the overlying problem of the post-processing time of the Sandform sand core arrays. Between cleaning and repairing, a person can spend over four hours per part, which is a considerable amount of time even in low volume runs of less than a 100 pieces [5]. Granted, the SLS sand cores do cut the production times of cores, but there is still an incredible potential to improve the process.

A two material discrete system solves the problems and improves process

Seeing the current problems with Sandform and realizing the possibilities, one would think this a perfect opportunity to employ a multiple material system. A two material SLS system would greatly improve the functionality of Sandform. First, the unsintered powder removal step would be eliminated from the process, cutting the post-processing time; at the same time, handling would be minimized because there is no need to handle the core to remove loose powder, which would also cut down on the probability of breakage and therefore repairing a damaged core. Next, the second material would add green strength to the core, acting as a skeleton to give the part strength and support, which means less breakage.

Besides solving the current problems, a two material system would enhance Sandform. The hassle of removing unsintered powder would be eliminated to allow smaller and more complicated features to be implemented in core designs. Small features require small venting, so previous designs that were impossible to make because of the difficulty of removing unsintered powder can be made possible. Also, the added strength and support of the second material would give the necessary integrity for smaller and more complex features. Another added benefit is in the mold assembly. Since the core can be made in a single piece, there would be less time needed to fit the core to the core print, and better accuracy could be achieved because there would be less chance for error in the placement of the core.

Concept development

In order to develop a discrete multiple material system in a timely and effective manner, some limitations were imposed on the project from the outset. The system is to work within the Sandform coremaking process parameters. The research is driven by the application to sand cores; therefore, the overall goal is to produce complex sand core arrays with Sandform, not necessarily to produce a whole new system. This is not to say that the discrete M^2SLS system could not be applied to other applications or is not designed with other applications in mind, but the focus is Sandform.

Having defined the goal, the development work was decomposed into three main functions: powder delivery, material selection, and powder removal. For each function, brainstorming and other concept generation techniques were engaged to find possible solutions. Then, the possible solutions or ideas were weighed against a criteria, including feasibility, complexity, and cost. From the criteria, concepts were combined for each function. Although material choice and powder removal are independent functions, the two are actually coupled to each other in the synthesis of a concept because the removal of powder is process dependent which would affect the material selection.

Because of intellectual property issues at this time, details cannot be discussed in this paper concerning the concept development or prototyping of the discrete multiple material system; however, the criteria for development is given below:

Material Selection and Removal

- Does not interfere with sand/phenolic system
- Minimize residue
- SLS "friendly" material
- Fast removal
- Inexpensive
- Safety and minimize health risks

Powder Delivery

- Minimize mixing between layers
- Use SLS technology
- SLS "friendly" powders
- Minimize complexity and control of system (K.I.S.S. principle)
- Adaptable to current SLS machines

Many materials were tested for use as the secondary discrete material. Tests included thermogravimetric analysis (TGA), as well as performance in the SLS process. The tests yielded two to three possible materials for further experiments with the entire prototyped system. A proof-of-concept prototype was built and tested the feasibility of the powder delivery system. It exhibited favorable results with many insightful solutions to problems that were unforeseen.

Future work and conclusions

The next step is to create a beta prototype that incorporates the enhanced powder delivery system and the use of possible materials. This system will produce simple shapes and parts that can be further tested in the Sandform coremaking process, along with more extensive material testing with the Sandform and second material. Once the material system and powder delivery system have been proven satisfactory, foundry tests will be performed with simple shapes to verify the workability of the system with foundry standards.

This paper has presented the advantages, problems, and potential of Sandform in the sand casting industry. Sandform is successful but has its problems and limitations that could be solved and enhanced with the development of a discrete multiple material SLS system. Since a solid design approach was followed, the prototypes have produced promising results, and the material system has encouraging possibilities.

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