Hybrid Additive/Substraction Method for Rapid Casting Prototypings with Light-Cured Sand

Dr. Pavel Ikonomov, Western Michigan University

Associate Professor of Engineering, Design, Manufacturing, and Management Systems, has been working on Virtual Reality simulation for more than 25 years. His main focus has been 3-D modeling design and VR simulation in manufacturing and assembly, medical application, large scale dynamic simulation in various research organizations in Japan like Hokkaido University, TMIT and 3D Incorporated and Virtual Reality Center Yokohama (CTO), UCLA (2001-3) and NIST (2002-3). At NIST he was responsible for industrial Virtual Reality Assembly (VADE) and worked with VR simulation for the optical nano-tweezers. Dr. Ikonomov will oversee the development of VR lab simulation part. Dr. Ikonomov has more than 120 journal and refereed conference proceedings publications, three books and book chapter.

Dr. Jorge Rodriguez P.E., Western Michigan University

Faculty member in the Department of Engineering Design, Manufacturing, and Management Systems (EDMMS) at Western Michigan University's (WMU). Co-Director of the Center for Integrated Design (CID), and currently the college representative to the President's University-wide Sustainability Committee at WMU. Received his Ph.D. in Mechanical Engineering-Design from University of Wisconsin-Madison and received an MBA from Rutgers University. His B.S. degree was in Mechanical and Electrical Engineering at Monterrey Tech (ITESM-Monterrey Campus). Teaches courses in CAD/CAE, Mechanical Design, Finite Element Method and Optimization. His interest are in the area of product development, topology optimization, additive manufacturing, sustainable design, and biomechanics.

Hybrid System for Producing Functional Casting Prototypes

Pavel Ikonomov, Sam Ramrattan, and Jorge Rodriguez

Western Michigan University, Kalamazoo, MI, USA

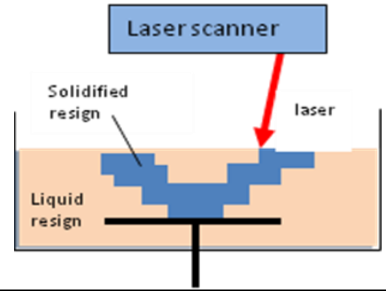
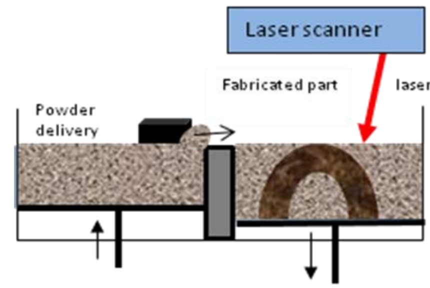
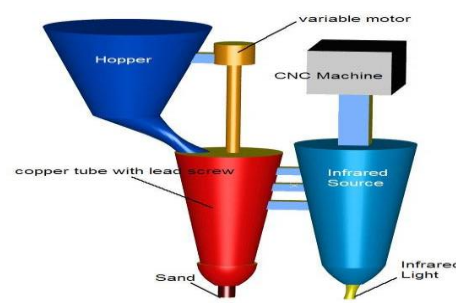
Contact: pavel.ikonomov@wmich.edu

Abstract

Developments in rapid casting technologies have led to a new era of inclusion of 3D printing. Rapid prototyping provides the flexibility and ease of reproducing a sand mold directly from CAD models, eliminating patterning steps, thus reducing the process time for creating prototypes. A novel hybrid technique, utilizing both additive and subtractive manufacturing techniques, has been developed and implemented. This technique finds applications in production of shaped cavities/molds for casted metallic parts for various rapid prototyping and rapid manufacturing application. The proposed concept of simultaneous building and machining of carbon shell sand molds for rapid prototyping (RP) of functional castings utilizes a combination of two RP techniques to eliminate the limitations of both. The proposed new hybrid RP technique based on previous research for developing of novel RP Infrared Light Sintering (IRS) and Machineable Mold Material (MMM) machining technologies. The IRS RP technique is used to build the molds layer by layer from 3D CAD models. The Machineable Mold Material process is utilized in machining of each layer before the next layer is built. The hybrid approach will combine the advantages of both methods to produce RP parts, quickly with high precision and surface finish. The extrusion system for the machineable mold material, machining parameters, and suitable machining tools has be tested and optimized. The outcome of this research will be the ability to produce functional casting prototypes of any size, complexity, and metal that could be mechanically and physically field tested and used as actual parts. To enhance practical research and learning experience of the students applying this hybrid technology, several undergraduate projects, master and Ph.D. allowed student to participate actively in the development of the processes. Numerous research presentation, papers and thesis was produced.

1. Introduction

Early in history of rapid prototyping (RP), now often called 3D printing, development the parts produced were used by design engineers as 3D physical representations of the part model; those RP parts in general were fragile and dimensionally inaccurate with rough surface finish. Today, RP models are used not only for 3D representations but also for producing functional products that may be mechanically and physically examined in testing labs. Then, these product are used to perform its intended function in real application. The RP technology have advanced to the level to produce exceptionally accurate, durable parts, fabricated with a variety of materials using a number of prototyping methods. Though some of the RP technology is used to produce metal casting molds, there are apparent limitations on mold and/or core size and complexity of the structures. Other drawbacks are: relatively higher production cost, relatively slower production time, and lower precision and surface finish of the casting. A novel development in today's advanced RP technologies can lower cost and shorten lead times for high or low volume casting jobs directly from 3-D model.

RP Technique	Advantages	Disadvantages	Schematic
Stereolithography	- Short lead-times - Highly complex parts	- Non-functional prototypes - High cost - Limited part size	
Selective Laser Sintering (SLS)	- Short lead-times - Highly complex parts	- High cost - Limited part size - Functional but not process representative - Surface finish	
Machinable Mold Material Process (MMM)	- Functional\ Representative prototypes - Short lead-times - Low cost No size limitations	- Limited part complexity - Surface finish	
MMM/IRS Hybrid System (Proposed)	- Functional\ Representative prototypes - Short lead-times - No size limitations - Highly complex parts Surface finish	- Reduced sped	

On one side this technology is capable of reduce the cost of lower volume production, while on the other side by providing high quality it can stay competitive with traditional machining for projects running low volumes, down to a single casting [1].

This research and experiments involved many undergraduate students working on several senior design projects for more than 10 years. Further, as the techniques advanced, master and Ph. D students took part of the research, development, and implementation of this technology.

2. Current Technologies in Rapid Prototyping Industry

Today there are numerous RP technologies available to produce 3D prototypes. These technologies may be divided into two major categories based on the functionality of the parts they produce. The first category of parts produced by RP processes are non-functional and are just 3D representations of the 3D model design. Such processes have shorter lead production time but the parts are not functional and can't be mechanically or physically tested. The second category consists of RP processes that produce functional prototypes that are close representatives of the final product and can be tested both mechanically and physically. Customers using prototyping technology find themselves faced with this tough choice of compromising between lead time, quality, and functionality.

In the case of RP for castings the requirements for functional prototypes are even higher especially for highly complex cavity shapes and structures, strength and rigidity of mold material, high level of precision and surface finish of the parts. Some of the prototyping methods available to customers today may be tabulated as shown in the table above.

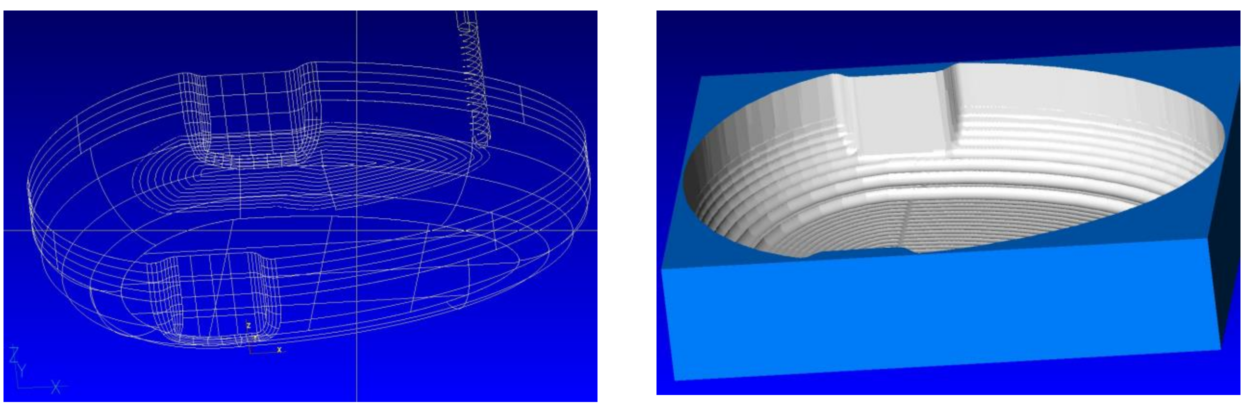


Figure 1. CNC simulation and machining path

3. Hybrid MMM/IRS RP system

3.1 Hybrid MMM/IRS RP system

Although some of the existing RP system can be used to produce complex shapes for casting they still has similar basic shortcoming like, low precision and surface finish quality, and long production cycle. This was the reason behind this research to create a hybrid RP system that combines the advantages of previously developed IRS and MMM technologies.

The hybrid MMM/IRS system utilizes a special machineable molding material and a CNC machine, as shown in the last column of the table and Figure 1 above. The machineable mold material is placed and preheated in a hopper. Then, it is extruded in thin beads in layers while an infrared light source cures the resin. As each layer is cured a machining tool makes the necessary cuts before a new layer is placed on top of the previous one thus producing a complex shape and providing high quality. This process is repeated for each layer until the mold is complete. The mold maybe later coated with the appropriate coating to enhance the surface finish and reduce gas associated defects. Finally, the mold is dried and poured.

The next step is producing a cast part. Since the process of casting and mold design is very complicated, analyses and simulations must be performed beforehand to assure quality parts. The College of Engineering at Western Michigan University (WMU) is licensed with the most advanced CAD/CAM, FEM, gating and risers design and solidification software, that will be used to validate the design and process of the part before the actual prototyping. These simulation and processing software are used by both undergraduate and graduate students in their studies and research.

3.2 Functional casting prototypes process phases

The process flowchart, shown in Figure 2, represents the step-by-step procedure followed in order to create the desired sand molds to obtain functional prototypes and replacement parts, following the hybrid rapid manufacturing technique.

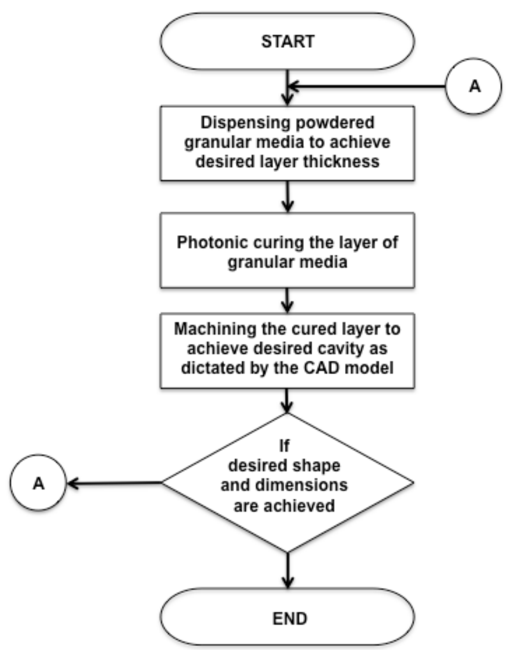


Figure 2. Step-by-step procedure flowchart

4. Methodology

4.1. Methodology description

The sand specimen implemented in this approach was comprised of a thermosetting resin coated carbon shell sand, to enhance the heat transfer between the top and bottom layers. Due to its high heat absorption, the carbon shell sand when exposed to the high intensity light enabled the sintering and curing of up to 8-mm thick layers in a single pass. The ability to cure thicker layers can lead to much higher throughputs for current 3D printing techniques, where the layer-by-layer deposition of sand-binder system is restricted to comparatively much lower layer thicknesses in a single pass. At the same time the hardened carbon shell sand is and easy machinable material that doesn't wear the tool or machine components.

A designed model needs to be modified for the purposes of molding and casting. The required model, if exists, can be acquired from the customer otherwise a new model must be done with a CAD system or reversed engineered and modified from a similar part [5]. A special extruder for extruding the layers of machineable mold material was designed and fabricated. The molding material in conjunction with the part design will require solidification simulation analysis, using solidification software, to machine the mold without the constraints imposed by the cavity size as was the case in MMM RP.

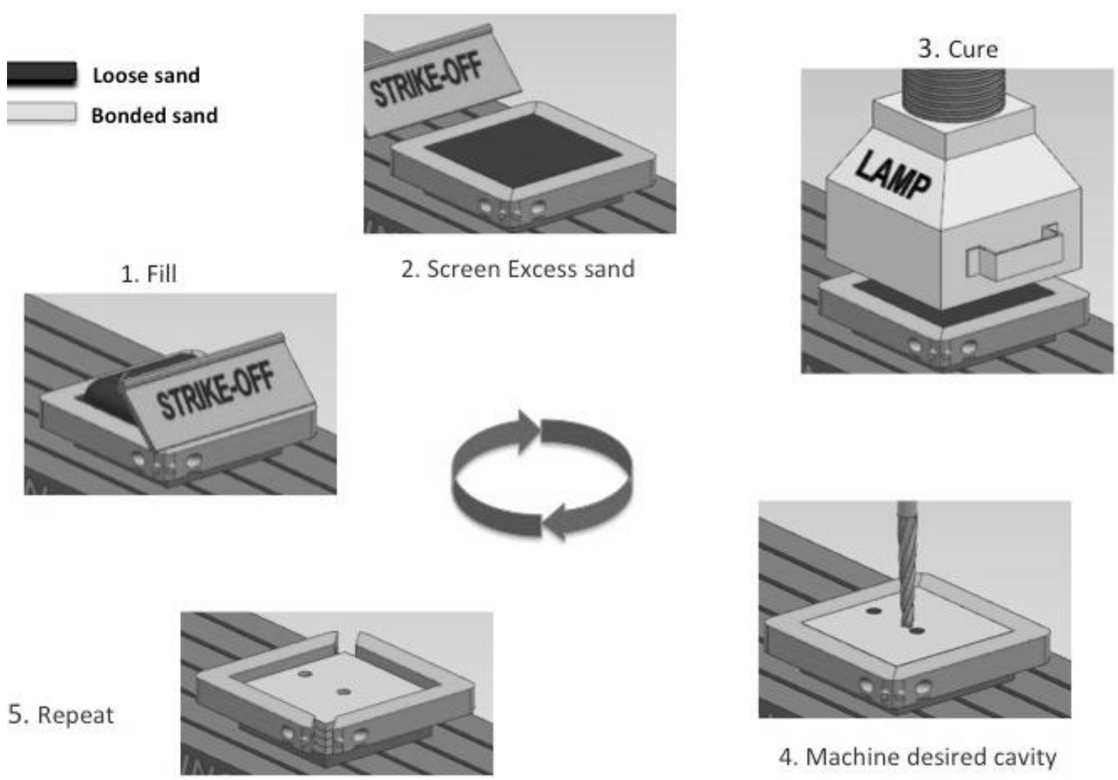


Figure 3 Processes sequence of the hybrid manufacturing technique

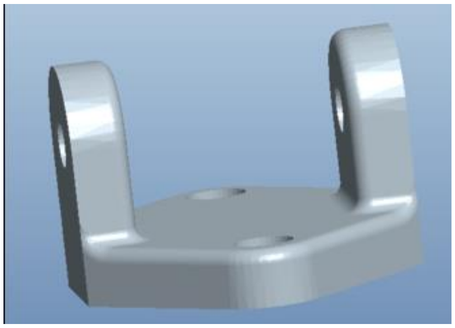


Figure 4. 3D model and finished mold cavity for the proof of concept part

4.2 Results and discussions

Due the capabilities in the area of metal casting and material analysis at WMU we are able to design, produce and test the system in short time. Students at WMU have hands-on experience with simulation and lab equipment and are able to perform all processes required in this research. Labs are equipped with machinery, tooling, and test equipment for a range of materials. After near-net casting, parts undergo material testing to certify metal chemistry, mechanical properties, and metallurgical examination to assure microstructure. The MMM RP system was build and tested piecewise. New method of fast curing of the MMM has been developed and applied successfully creating complex casting parts.

This project has captured the interest and attention of several companies involved in casting supplies and rapid prototyping such as Fairmount Minerals who supply the mold making materials. SPX Corporation provided support in the testing phase. A patent filing was placed for the technology and WMU hold the Intellectual property on it. Several students and faculty were involved in this process. Successful initial design, molds and casting part were produced, see Figure 4. The layered experimental analysis suggests that the proposed media for the light cured system possess the desired physical, mechanical and thermo-mechanical properties. Figure 5. shows a complex mold cavity and a casted part obtained thereof using the hybrid rapid casting approach for castability. These single and double-layered light cured sand specimens are quite stable at elevated temperatures, as revealed from the thermal distorting testing.

Figure 5. Finished mold cavity and casted part of complex part.

5. Conclusion

We developed a technique/process for limited quantity functional prototypes from various casting alloys. A sand mold or shaped cavity with defined level of complexity including curvilinear shapes and surfaces was successfully produced using the hybrid technique, involving additive and subtractive manufacturing with integration of CAD- CAM. The MMM/IRS RP system will provide the industry with the ability to produce representative and functional casting prototypes utilizing equipment available at most machining and casting plants. This system will reduce the lead time, increase the quality, and produce complex shapes that were very challenging and cost prohibitive to produce with conventional rapid prototyping methods. This research and experiments involved many undergraduate students working on several senior design projects for more than 10 years. Further, as the techniques advanced, master and Ph. D students took part of the research, development, and implementation of this technology. All of the students were hired in casting related fields in industry.

6. References

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