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<th>Rapid Tooling For Powder Injection Moulding Process</th>
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ABSTRACT: Injection Mould tools for various applications like polymer, wax and powder injection moulding (PIM) processes are usually manufactured with metallic materials like aluminum and tool steel which give durability and efficient functioning of moulds and good service life. Manufacturing of injection moulds is a time consuming process due to the geometric complexity of mould and strength of metallic materials. For a short prototype or pre-series run, the injection mould may be needed in a shorter time and less expenditure. For these applications, 3D printing (3DP) and Rapid Tooling (RT) technologies could be a rapid solution for fast and feasible mould development compared to a machined tool. This current study focuses on the development of powder injection moulds using 3DP with Acrylonitrile Butadiene Styrene (ABS) material. ABS 3D printed moulds can be used for design verification and a short production run for PIM process. The current study indicated that the 3D printed injection moulds development was practically fast and serve the purpose of design verification for PIM parts. Some part defects and breaking was observed due to ejection issues. Secondary RT techniques could be applied for fabricating mould that could produce parts for the production phase.

KEYWORDS: Additive Manufacturing, 3D printing, rapid tooling, powder injection moulding, powder metallurgy.

INTRODUCTION
Manufacturing of plastic parts using the technology of Injection Moulding (IM) is a common polymer processing technique and is used in the industry worldwide (Rosato 2003). In the past decades, the growth in the existing manufacturing industry resulted in fast production rates and less time for products reaching the market. One of the major components for IM industry is the mould or tool used for the production of plastic parts. Conventional mould manufacturing techniques could take substantial amount of time for producing a working mould due to the slow and tedious steps involved. These includes designing the mould, the programming of Computerized Numerical Controlled (CNC) machines, post processing and polishing of the moulds. These days, companies are pushing hard to produce intricate and diverse products in shorter development cycles, targeting improved quality with decreased overall cost. Due to these factors, the mould manufacturers are constantly under pressure to manufacture moulds quickly, accurately with lower cost (Rahmati et. al. 2009). The emergence of Additive Manufacturing (AM) and Rapid Tooling (RT) techniques has offered new degrees of freedom to injection mould manufacturers aiding in reduced mould development time.

With the growing demands of manufacturing industry for Rapid Tooling (RT) techniques, Additive Manufacturing / 3D printing technologies like Stereolithography (SLA) tooling, Direct Metal Laser Sintering (DMLS) and rapid tooling fabricated with polymer materials are showing significant potential in product and tool development fields. Polymeric RT materials especially
epoxy-based photopolymers used in SLA Rapid Prototyping (RP) systems show great promise for injection molding for limited numbers of parts, significantly reducing the time to product. However, they present challenges to designers because of their strength, thermal characteristics, and shorter lifetimes as compared to other mould materials. The study by Colton et al. (2001) presented models of the forces generated during the injection moulding cycle to evaluate the suitability of rapid tools. The models comprise thermal and mechanical loading during injection, cooling shrinkage, and ejection.

Chua et al. (1999) described that Rapid tooling (RT) technology adopts rapid prototyping (RP) techniques and applies them to tool and die manufacturing. RT research is gaining more importance and is starting to challenge the conventional manufacturing techniques. In their study, several RT techniques were discussed and classified. A comparison was made based on tool life, tool development time and tool development cost. The application of Stereolithography (SL) RP technique for the manufacture of moulds for a pre-series injection moulded plastic parts could reduce costs during the product life-time, but it mainly effects the design and manufacturing phases. The study by Beal et al. (2004) describes the Rapid Tooling (RT) technique in powder injection moulding process. It was mentioned that the major difference between conventional and SL tools is the thermal conductivity of the materials used. Steel has much higher thermal conductivity than the SL resins which can drastically effect the cooling rates for the PIM parts. This problem was compensated with adjustments in the injection molding parameters, which made it possible to eject parts from the mould without causing significant defects.

**Powder Injection Moulding (PIM) Process**

PIM is a combination of powder metallurgy and polymer injection moulding technique. Manufacturing of intricate parts using metal, ceramics & composite materials can be done effectively with PIM process. In PIM process, metal or ceramic in powder form are mixed with a binder usually a polymer or wax that aids the mixture to be melted and injected inside a mould similar to the process of injection moulding of polymers. The process begins with selecting a blend of powder and binder system. The powder is the key element for giving the required mechanical, thermal, electrical and chemical properties to the manufactured part. The binder system will transport the blend to the mould and hold the shape of the part. After mixing and homogenizing, the mixture it is placed in the feed system of the injection moulding machine. After the blended
material is in semi-molten state, it is injected inside the mould. When the part is ready, the mould is opened and part is ejected from the mould in a state known as a "green" part. The green part undergoes chemical process of de-binding to extract the binder system before the final thermal treatment to sinter the part. Sintering is done to achieve the required physical and chemical properties of the part material. The de-binding and sintering treatments cause a 15-25% contraction in the part depending on the powder; binder, proportions and their applications. There is a wide range of applications for PIM technology and it may be used to produce parts for industries such as automotive, aerospace, consumer products, medical implants, computers, armaments etc (Beal et. al. 2004). A basic diagram for the PIM process is presented in Figure 2.

Figure 2: Schematic of the PIM process (German et.al. 1997)

METHODOLOGY

Design and Modeling for Mould
A bio-medical hip implant was selected to be used as test part for metal PIM process using the Rapid Tooling technique. The CAD model for the implant is shown in Figure 3.

Figure 3: CAD model for Implant

3D Printing of the Mould
For the 3D printing, Cube Pro 3D printer was used using ABS material. The 3D printed ABS mould is shown in Figure 4. Some researchers experimented on 3D printed PIM moulds using different materials. Hemrick et.al (2001) did an experimental study on PIM moulds using SLA resins. They measured the adhesion force between the PIM part and SLA mould. Their analysis of the release behavior indicated a link with the thermal properties of the mould material.
**Powder Injection Moulding Process**
The material used for the PIM was copper powder with poly-ethylene as the binder. The feed stock was prepared for the PIM process. Feedstock preparation is an important step in PIM process. The quality of feedstock established the quality of moulding and related de-binding and sintering processes. Feedstock must be homogeneous and has maximum metal powder loading with shape stability and strength after moulding. The feed stock was fed into the vertical injection moulding machine shown below in Figure 5. The injection moulded parts are called Green Parts as they need to go through secondary processes like de-binding and sintering to become the final metal part.

**RESULTS & DISCUSSION**

**Injection Moulding Parameters**
PIM process was tried with different temperatures. Injection temperatures were 160°C, 170°C and 180°C. Among these three temperatures, 160°C was observed to be the optimal temperature for further process. The resulting green part produced by the PIM process can be seen in Figure 6. Some part defects like surface roughness were observed.

Part breaking was also observed in some parts due to ejection issues of PIM parts from ABS mould.
The feed stock of copper powder used in the study was mainly composed of large particles. This could be the cause of surface roughness for the parts due to the poor adhesion between the binder and copper particle.

The reasons behind the breaking of the green PIM part could be the low melting temperature of ABS. Melted PIM feed stock with temperature close to that could create strong adhesion force causing the green part to break. A broken PIM part is shown in Figure 7.

Another probable cause for the green part breaking is due to the interaction between ABS and poly-ethylene binder present in the feed stock. Strong bonding between both polymers made difficult the ejection of the part from the mould and resulting part breaking.

![Figure 6: PIM Injection Moulded Part](image)

![Figure 7: Broken PIM Part](image)

**CONCLUSIONS**
From the experiments following observations were noted for PIM process using 3DP moulds with ABS materials. Optimal temperature for the PIM process in the current study was found to be 160°C. Particle size for the PIM feed stock should be less than 10 microns to produce parts with good quality. To improve the quality of the PIM parts, graphite coating for the ABS mould is recommended. Nylon filament for the 3DP is recommended because of its high melting temperature as compared to ABS filament.
Another recommendation is the nickel plating for the ABS mould used for PIM. This could increase the functionality and durability of the polymeric ABS mould and widen the applications of AM/3DP technologies (Janaka Rajaguru et. al.)

For a quick prototype fabrication of polymer or wax injection mould parts, ABS moulds could be a faster and feasible choice. ABS mould can be fabricated with 3D printing technique much faster than conventional tooling.

REFERENCES


