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PERFORMANCE OF 3D PRINTED POLYMER MOLD FOR METAL INJECTION MOLDING PROCESS

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ABSTRACT

Metal injection molding (MIM) is preferred choice for mass production of intricate and complex parts. However, machining of intricate and complex mold for low volume of part production could be very time consuming, skill intensive and expensive. For low volume requirement of MIM parts, typically for prototyping, design validation and visual inspection, mold experiences small number of MIM cycles and once demand is met, mold is rendered useless. Contrary to traditional machining, polymer molds made through additive manufacturing (AM) process, called Rapid Tooling (RT), could comparatively be a swift and economic approach. For low to medium number of MIM cycles, 3D printed polymer molds could potentially yield performance, comparable with machined metal mold. Present study investigates enhancement of various approaches for 3D printed polymer molds for their potential use in MIM. Consequently, 3D printed polymer molds proved promising for prototype and low volume manufacturing of MIM parts.

Index terms: metal injection molding, additive manufacturing, 3D printing, rapid tooling, surface enhancement, electro-less plating.

1. INTRODUCTION

Metal Injection molding (MIM) is one of the techniques available for series production of near-net shape metal parts [1, 2]. It is defined as the process in which a feedstock, comprising of binder, surfactant and source powder is injected with pressure and heat, in the mold cavity, to attain the geometry of mold cavity[3]. Metal injection molding (MIM) process constitutes injection of metal impregnated feedstock in the mold cavity. The feedstock is allowed to solidify inside the mold cavity and once it is solidified, the mold is opened to eject the part [4]. The design and fabrication of mold for MIM could be a real challenge, typically for low volume demands of intricate parts. Typically difficult topographies like blind holes, overhangs and helical features are common in intricate molds, therefore, machining of such molds could be challenging and once the design changes, the mold is rendered useless [5]. In highly customized low demand applications, especially biomedical implants, each patient requires prosthesis of different dimensions, for which single mold cannot be used repeatedly. Therefore, a tailored manufacturing process is inevitable for such kind of demands.

Fused deposition modeling (FDM) is one of the popular AM technique, after stereo-lithography [6]. It is a process of depositing material layer-by-layer through heated nozzle, whose position is controlled in two axes, on a platform which descends to add third dimension to the part (Figure-1) [7]. FDM could be a promising technique for making of polymer molds for low volume demands of MIM parts[8]. Rapid tooling (RT) is defined as use of AM techniques for mold manufacturing [9]. Though this approach, complex molds can be made quickly and economically, therefore making the overall MIM process swift [9]. For the applications where the part requirement is small and complex features are desired RT could be a promising choice.

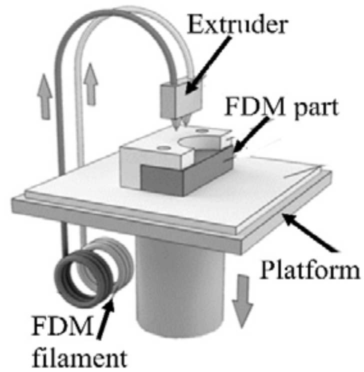

Figure-1. FDM process[10].

Some studies report use of foreign particles in FDM filament, for enhancement of properties [11]. Researchers have successfully used metal-infused polymeric filaments for RT and found the approach suitable for prototype manufacturing of MIM parts. Masood *et al.* [12] studied processing and performance of iron-nylon composite filament for potential use in direct rapid tooling. Thus made molds manifested satisfactory mechanical properties and were observed to be suitable for direct rapid tooling. Nikzad *et al*. [13, 14] and Sa'ude *et al.* [15] studied properties of ABS-iron composites for their potential use in RT. Performance of metal filled polymers was pleasing for their satisfactory use in RT.

Surface enhancement of common FDM polymers through metal coating has been reported in some studies [16-18]. Conventionally, the deposition of metal particles on the polymer substrates was carried out by etching [16, 19, 20]. Concerning the exorbitant and polluting heavy metal alkalis involved in the etching process, chrome and palladium salts have been substituted with physical treatment and ecofriendly chemicals [21, 22]. However,

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some modern studies focus on completely new approach of grafting as a prominent ecofriendly and economical technique for metal plating on difficult substrates, typically polymer s[23, 24]. FDM made molds could be subjected to surface enhancement to allow them to display superior performance [25].

Many researchers have studied performance of FDM made metal infused ABS molds for MIM [12, 13, 15, 26, 27]. Nevertheless, there lies significant gap in investigation of performance of metal filled PLA and pristine ABS molds for MIM. The present study is an attempt to investigate the performance of FDM made polymer molds for low volume production of MIM parts.

2. METHODOLOGY

A) Materials and methods

Mold assembly constituted mold insert and mold block, was manufactured through CubePro DueFDM machine (Figure-1) and assembled according to the CAD model (Figure-2). Mold block was designed in two halves, the upper half was cover plate and the lower half of mold block housed mold insert. Significance of such assembly is that mold insert could be substituted with a new one, and same mold block could be used for subsequent MIM cycles. Mold block was made of acrylonitrile butadiene styrene (ABS), whereas mold inserts were made of ABS and bronze-filled poly lactic acid (PLA).Mold inserts with enhanced design and enhanced material were subjected to MIM to compare performance of each enhancement.

Figure-2. CubePro duo FDM machine.

The MIM feedstock comprised of pure copper powder in poly ethylene (25 wt. %) as binder and steric acid (5 wt. %) as surfactant. MIM was conducted and conclusion regarding mold tooling capabilities were drawn according to mold filling behavior, part quality and ease of ejection.

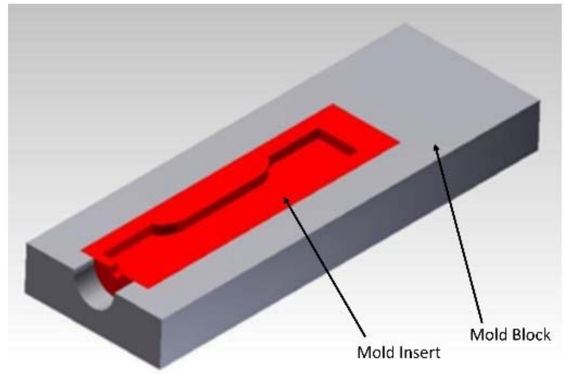

Figure-3. CAD model of lower half of mold assembly.

B) Mold insert with enhanced material

Recently, some composite filaments containing metal particles, to improve stiffness and mechanical properties, have been introduced in FDM. These type of superior materials could potentially yield improved performance when used in mold making for MIM [12, 13, 26, 27]. In the present study, commercially available bronze-filled PLA filament was used to make mold insert [28].The mold insert was assembled in the same ABS mold block to conduct MIM (Figure-4).

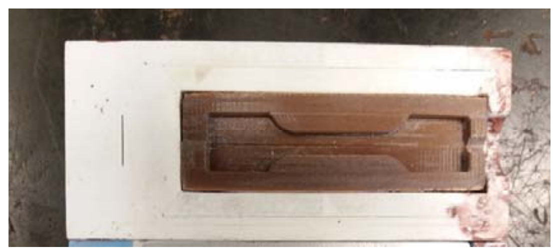

Figure-4. Bronze-filled PLA mold insert (light brown) in mold block (white).

c) Injection molding and part release

Injection molding was conducted using copper based feedstock at 180 ^{o}C temperature and 4.5 bar pressure through vertical injection molding machine (model 100 KSA, Figure-5). Injection time was kept around 12-15 seconds to ensure compete filling of mold insert. After the MIM cycle was completed, the feedstock was allowed to solidify within the mold. Once feedstock was cooled, the mold insert was removed in order to release the MIM part. While ejection from ABS mold insert, MIM part experienced some of breakage, possibly due to adhesion between feedstock and mold wall. Since, polymer is present in both interacting surfaces of solidifying feedstock and mold insert, and injection occurs at elevated pressure and temperature therefore, interfacial adhesion could be responsible for part breakage. Consequently, design of mold insert was modified by splitting it in two halves to smoothen MIM part to eject conveniently from the mold insert.

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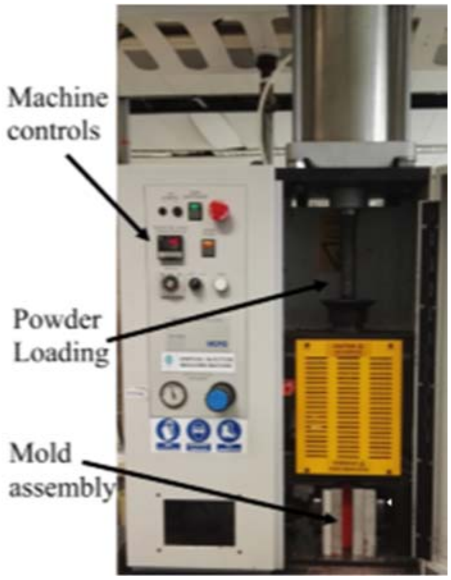

Figure-5. Mold mounted in MIM machine.

d) Mold insert with enhanced design

Since cases of MIM part breakage were noticed in ABS mold insert, therefore, the design of mold insert was modified to facilitate part release. Mold insert was made in two halves and each half was assembled in the mold block (Figure-6). The significance of this design is that mold insert could be opened easily after MIM cycle to release part with quite reduced ejection force, thereby mitigating chances of MIM part breakage. Contrary to the conventional ejection approach where part is forced to eject from the mold insert, through this novel configuration, the mold can be separated from the MIM part gradually. It is hypothesized that the split configuration could assist in better ejection of MIM part thereby preserving the green-part, which could otherwise possibly be prone to damage due to ejection force, typically in polymer RT [29, 30].

Figure-6. Split ABS mold insert.

3. RESULTS AND DISCUSSIONS

A. Mold insert with enhanced material

Bronze-filled PLA mold insert was subjected to MIM with copper based feedstock. Since it carried bronze metal particles, the heat dissipation of the said mold insert was superior to pristine PLA mold insert. Due to better heat dissipation, less mold swelling and rapid cooling of MIM part were observed. Metal infused polymer molds possess comparatively superior surface finish and mechanical strength. Bronze infused PLA mold tools was successfully used for about scores of MIM cycles. Compared with ABS mold insert, MIM part breakage in said mold insert was relatively less frequent and ejection could also be carried out through ejector pins. Still split design could further ease the part release. A downside of PLA, compared to ABS is that the heat deflection temperature of PLA is less compared to ABS since PLA has less straight chain smaller monomer structure [31]. Localized deformation of mold insert was observed at places where MIM machine nozzle touches the mold and mold packing line. Mold packing line could appear in MIM part, which is convenient to remove in prototype parts. Other defects like feedstock inclusion, mechanical failure, part breakage during ejection, short shot and under runs were however insignificant.

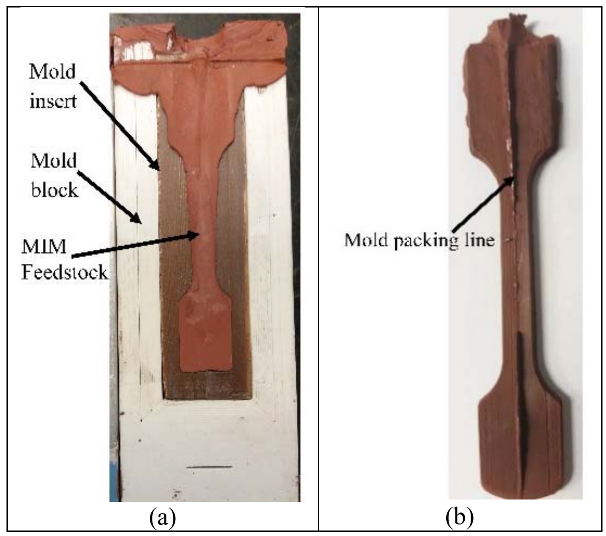

Figure-7. (a) MIM using bronze-PLA mold insert; (b) MIM part.

B. Design enhancement

Design enhancement is attributed to facilitate ejection of MIM part. The split mold insert could be opened to eject MIM part with virtually zero force, thereby preventing it from breakage. After scores of MIM cycles, mold packing line at joining site of split mold insert could become prominent in MIM parts because some feedstock could penetrate in the gap due to high pressure and temperature. This could be prevented by ensuring that both halves meet face-to-face before initiating MIM cycle, so that no room is left for feedstock to penetrate and solidify inside. Nevertheless, if the line still appears, it can be removed easily with simple post-processing in as molded and sintered MIM parts.

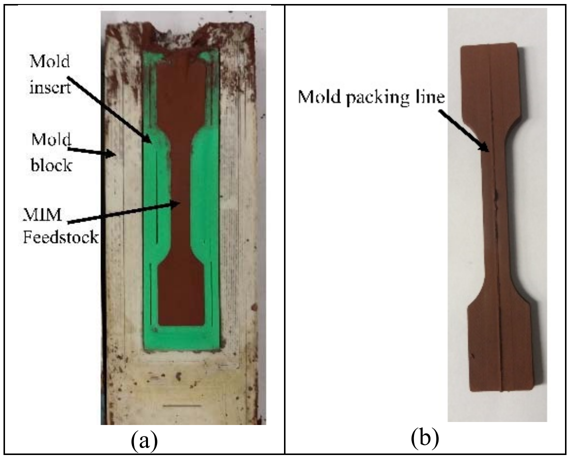

Figure-8. (a) MIM using split ABS mold insert (b) MIM part.

Mold insert was observed to undergo slight swelling due to pressurized and heated injection of feedstock. However, it shrinks upon cooling, therefore firmly grips the MIM part. Since split mold is opened laterally, therefore breakage due to gripping effects of mold insert could also be avoided.

4. CONCLUSIONS

FDM produced polymer molds turned out to be suitable for MIM. ABS and PLA filaments could be processed in almost every FDM platform. Due to lower heat deflection temperature of pure PLA, it was not used for mold making except when infused with metal. Pristine ABS sustained scores of MIM cycles before substantial deformation. Bronze filled PLA however, displayed best overall performance in terms of mold cavity filling, MIM part release and reproducibility. Nevertheless, after equal number of MIM cycles, deformation of bronze-PLA mold insert was more compared to ABS insert. Mold packing line appeared in Bz-PLA made MIM parts after scores of cycles. Split configuration was observed to be very convenient to eject MIM part with virtually negligible force and therefore possess negligible chances of part breakage. Need for ejector pins or any ejector tool was ruled out in split configuration. The packing of split insert did not hamper the feedstock flow inside the mold cavity and the mold filling behavior was observed to be defect free. Downside of split configuration is that it should be ensured prior to MIM that the split line may not be obvious enough to let feedstock penetrate and solidify inside. Finally, it was concluded from the above study that FDM made polymer molds are promising tools for prototyping and low-volume production of MIM parts. Depending on the number of MIM cycles and nature of feedstock, appropriate selection and improvement of polymer mold could be made.

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