PERFORMANCE ANALYSIS OF FDM PROCESS MADE ABS MOLDS FOR PLASTIC INJECTION MOLDING: A REVIEW

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Abstract: Conventionally, molds for plastic injection molding process are fabricated using metallic materials using conventional machining processes. Machined metal molds are resilient and therefore could be suitable for mass production of plastic parts. However, with the process of mass production leading to permanent hard tooling, the design is subjected to rigorous testing and iteration before finalization. During design analysis and the iteration process, the demand for plastic parts is at low-volume. Therefore, machined metal molds could be costly and time consuming for low volume and customized end-use products. Fused Deposition Modelling (FDM) printed molds could be a suitable choice for plastic injection molding production for such applications. The present study compares the performance of FDM process made Acrylonitrile Butadiene Styrene (ABS) molds with conventional metal molds for potential use in plastic injection molding process. It was observed that FDM molds could successfully be used for a limited number of plastic injection molding cycles.

***Keywords*: Fused Deposition Modelling, Rapid Tooling, Post-processing Techniques, Injection Molding.**

1. INTRODUCTION

Mold making is one of the influential processes in the overall plastic injection molding process. In general, molds for the plastic injection molding process are made up of metals and fabricated by using various machining processes. The machining process consumes time and cost. Also, it is skill intensive because of its inherent demands for labour effort, material and time. However, machined metal molds are robust in nature and suitable for part demand in high volume. But when there is customization in part design or frequent change in part design and requirement of parts is low, then the mold will be of no use as soon as the demand is met. Even for high-volume demands and mass production of plastic injection molding parts, the design is subjected to rigorous testing, analyses, and prototyping before finalizing and permanent hard tooling, because once the mold is machined, it is quite difficult to make any modification in the design. Therefore, before the permanent hard tooling is done, soft tooling may be a good option for design validation and analysis.

Rapid tooling (RT) can be defined as use of AM process for making molds, patterns, inserts or auxiliary mold components. This might be direct, just like the fabrication of molds or inserts for injection molding or indirect, just like the making of sacrificial patterns for casting [1]. RT can produce customized molds in a quick time with less effort. Most reliable and promising applications of FDM printed molds are related to extremely tailored but low-volume part demand. FDM printed polymer molds could be used for indirect rapid tooling for such demand [2]. Though the demand of parts is low, FDM printed polymer molds could be feasible for direct rapid tools, whereas the machine mold could become of no use due to low demand. FDM printed polymer molds could find their scope with high volume, customized plastic injection molding parts, mainly in two ways: first, as direct rapid tools, to be made rapidly and disposed after completing permissible number of plastic injection molding cycles; and secondly, as predecessor for permanent hard tooling. Metal molds are most suitable as well as promising in the high volume demand of standardized parts. FDM printed polymer molds could be used for product development, performance testing of plastic injection molding parts, and design analysis of molds. Once the finalization of design is done, mold could be machined for a series production of standard parts. The present study is focused on design, fabrication, postprocessing and testing of FDM process made ABS molds for potential use in plastic injection molding.

2. FUSED DEPOSITION MODELLING

After SLA, the FDM is the second most influential layer manufacturing technique (Jain and Kuthe, 2013) [3]. This process is widely used to fabricate final products directly without the use of any die, tooling or molds which are some of the significant constraints of traditional manufacturing process. This technique acquires popularity due to its high-dimensional accuracy, short cycle time, easy to use and easily integrated with different CAD software. FDM is an AM technology commercially used for modelling, prototyping and batch production applications. The applications of FDM comprised of concept modelling, functional prototypes, manufacturing tooling and end-use parts. From the identification of component, prototypes of acrylonitrile butadiene styrene (ABS) plastic material were made for commercial end user applications in injection molding, vacuum molding, vacuum casting, investment casting etc. (Singh, 2013) [5]. The fabricated parts are used for design verification, functional testing, patterns for casting process and medical applications (Nikzad et al., 2011) [4].

2.1 Fused deposition modelling process

Part modelling on CAD software is the initial step where FDM process starts. The CAD file of a part is saved under SLA file format (.STL). The .STL file is then processed by computer software and then part model is converted into number of slices. The transformation from a CAD model to a layered manufacturing depends on a standard surface triangular algorithm. This manufacturing process changed the idea of manufacturing from subtracting material to adding material (Bernard and Fischer, 2002) [6].

There is a facility in software to create part model with low density, high density and solid form. The .STL file then exported to software of FDM machine to generate tool paths. Based on these generated tool paths, the head travels in the x-y plane and deposits material according to the part geometry. The platform holding the part moves vertically downward in the z-plane to begin depositing a new layer on the top of previous one (Figure 1). First layer of base material is deposited on the platform and then feedstock filament starts fabricating part geometry. After the job is completed, removal of base material is done by ultrasonic vibrations and other methods. Various post-processing techniques can be applied to further improve the surface quality of parts produced by FDM.

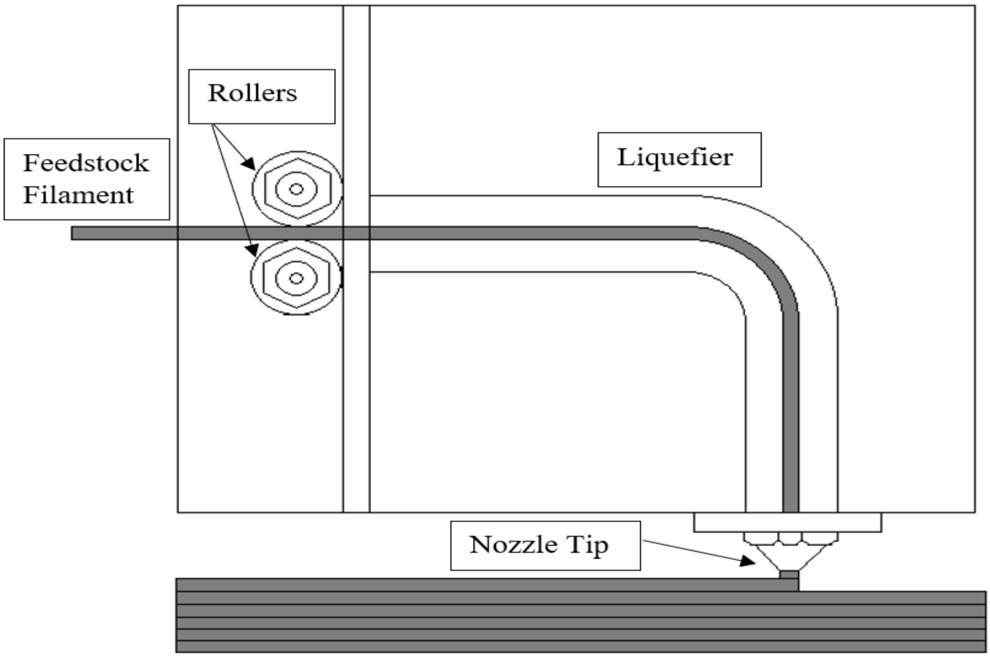

Fig. 1. Schematic of Stratasys FDM process

2.2 Process variables of fused deposition modelling

FDM process includes various process variables such as liquefier head temperature, scaling, density of model, model material and orientation of work part. The head temperature is set as per the type of model material and base material. The latest version of FDM is capable of loading model materials of 12 different types and particular temperature is required to process each material. The liquefier head temperature is automatically adjusted by machine according to the model material selected.

2.3 Materials for FDM

L. N. Marcincinova et al. describes various states of materials used in rapid prototyping such as solid, liquid and powder. The solid state material is available in pellets, wire or laminates form. Nylon, paper, wax, ceramics, metals and resins are currently used materials in rapid prototyping. The basic material used in Fused Deposition Modelling are Acrylonitrile Butadiene Styrene (ABS), polycarbonate, polyamide, polypropylene, polyethylene. But for special FDM applications, materials such as aluminium oxide, PZT, silicon nitrate, stainless steel and hydropatite are used for variety of electroceramic, bioceramic and structural applications [7].

M. Nikzad et al. investigates thermal and mechanical properties of composites of new metal particle filled Acrylonitrile Butadiene Styrene (ABS) for applications in Fused Deposition modelling in rapid prototyping process. This study uses samples for testing prepared from Iron/ABS and Copper/ABS composites in which volume of metal content were kept up to 40% and made by controlled centrifugal mixing, thermally compounded through a single-screw extruder and compression moulding. Due to incorporation of metallic fillers there were significant improvements in mechanical and thermal properties of ABS [8].

3. POST-PROCESSING TECHNIQUES

J. Noble et al. explored three surface finishing processes of the 3D printed parts as they have inadequate surface finish for molding optical components. In their study three finishing techniques were explored as hot pressing with steel shaft, coating with printer resin and mechanical polishing with scraper and buffer. Hot pressing and mechanical polishing required less time than coating process and are easier to control. The coated and polished cavities produced no visible damage from injection molding [2]. L. A. Teixeira et al. states that sulfuric/chromic acid solutions used for surface conditioning (also referred as etching) of plastics before metallization. The presence of Cr (VI) has some dangerous impact on environment even though this bath has good technical performance. Therefore, solutions based on sulfuric acid, with hydrogen peroxide and/or nitric acid used in place of chromic acid as oxidants. After that coating of electroless nickel was applied on selected samples [9].

S. H. Ahn et al. studied the optical transmissivity of the ABSi made parts were increased by applying two postprocessing techniques. In first technique it was achieved by applying elevated temperature while dimensional shrinkage was observed. In second technique it was achieved by provision of resin infiltration and surface sanding which was provided up to 16 % transmissivity without shrinkage [10]. B. Vasudevarao et al. state that to determine the surface quality of the part, layer thickness and part orientation are most important factors. 0.007" of layer thickness and 70^{o} of part orientation resulted in the best surface finish. The surface finish of the part did not much influence by Model Temperature, Air Gap and Road Width. Additional parameters to predict the surface finish accurately including material properties and other process parameters like hatch patterns and envelope temperature [11].

P. M. Pandey et al. studied a simple material removal method named as hot cutter machining (HCM) was used in order to improve the surface finish of layered manufactured part produced by fused deposition modelling. The staircase effect is mainly responsible for surface roughness in rapid prototyping. The HCM method is capable of producing surface finish of 0.3 μm with 87% confidence level. This machining process develops hybrid rapid prototyping system which is capable of both layer-by-layer deposition and machining simultaneously to get functionality and surface finish of improved quality of RP parts [12]. L. M. Galantucci et al. studied the surface finish of ABS prototypes is improved by treating the prototypes with a solution of 90% dimethylketone and 10% water. Although this treatment resulted in reduced roughness and tensile strength, but it has improved ductility, flexural strength. Also, a turbine blade was tested in an industrial case study with the three-point bending test and it has shown that there is no loss of mechanical properties but roughness was reduced [13]. All these techniques of post processing explained in various studies can be categorized into two types: mechanical and chemical (Figure 2).

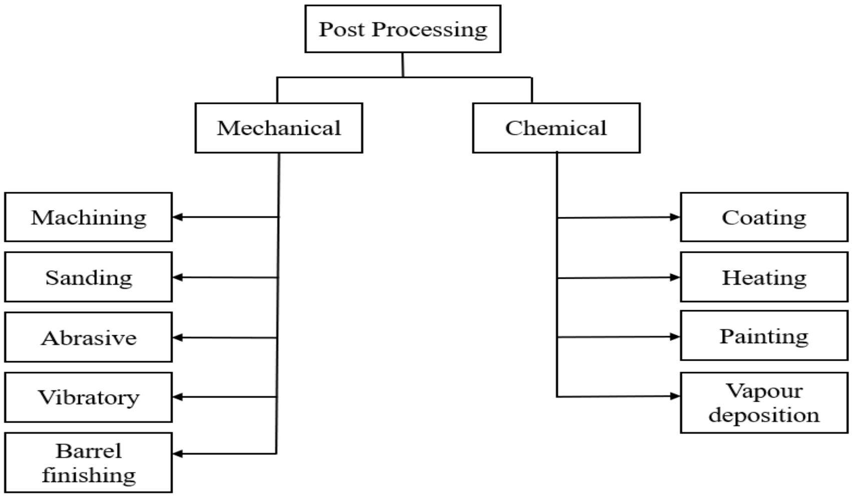

Fig. 2. Post-processing techniques

4. RAPID TOOLING

Rapid tooling (RT) is defined as use of AM process for making molds, inserts, patterns, or auxiliary mold components. This could be direct, like the fabrication of molds or inserts for injection molding, or indirect, like the making of sacrificial patterns for casting [1]. J. Chimento et al. studied performance of 3D printed materials is evaluated for use as rapid tooling (RT) molds in manufacturing custom prosthetic sockets and orthotic interfaces in low volume thermoforming processes. It has been found that Zp140 materials has good performance in wear test and possesses highest strength in the build-up tests. Also, it has been found that pneumatic permeability is much higher than traditional plaster molds and there was no negative impact observed on the thermoforming process [14].

D. S. Ingole et al. studied experiments conducted to develop rapid tooling for sand casting, investment casting and plastic moulding applications. In this study model for time efficient and cost-effective method has developed for manufacturing of tooling. It has been found that there was reduction in overall lead time by 82-93%. In comparison with metal patterns, there was reduction in lead time by 89-93%. Similarly, in comparison with wood patterns, there was reduction in lead time by 73-82%. The patterns produced by RP methods are found to be cheaper than that of patterns fabricated with CNC operations. But cost of patterns produced by RP methods are found to be higher than that of wooden patterns [15]. G. N. Levy et al. described the generic and the major specific process characteristics and materials. Also, future perspectives of various RP processes such as Stereolithography, Solid Ground Curing, Laminated Object Manufacturing, Fused Deposition Modelling, Selective Laser Sintering, 3D Printing for rapid tooling is described in detail [16].

Nagahanumaiah et al. describes development of injection molds through computer aided rapid tooling process selection and manufacturability evaluation. This includes three major steps: first is the process selection of rapid tooling, second is the evaluation of manufacturability and third one is cost estimation of mold. Thus, this study leads to improvement in manufacturability and quality, reduction in cost of molded parts and shorter lead time [17]. D. K. Pal et al. proposed systematic approach by the selection of most suitable route for rapid fabrication of tooling for investment and sand casting processes. In this approach priorities have been given to the tooling attributes, evaluating the compatibility and cost estimation of rapid tooling also conventional tooling by using appropriate cost models. The routes of rapid tooling have shown significant lead time reduction for fabrication of tooling also reduction in fabrication cost of parts of intricate shapes required in small numbers [18].

Y. K. Modi describes use of 3D printed molds as vacuum forming molds to manufacture medical devices. In the results it is shown that calcium sulphate based 3D printing powder possess twice the pneumatic permeability and equal wear ability, flexural strength, hardness, tensile strength and water dissolution than the conventional POP material [20]. P. Dunne et al. described the technical demands of two rapid tooling processes such as enhanced silicone moulding and sand moulding in which casted pattern is compared with a rapid prototype (master pattern) to form a mould which is then used in the manufacture of product prototypes by injection moulding. The demands are discussed by considering several factors into account such as surface finish, surface porosity, dimensional accuracy, thermal resistance and thermal expansion [21].

J. G. Kovacs et al. developed a new method for testing of rapid tool inserts. All type of rapid technology can be tested by using this technique including cooling system. Study of FDM and Polyjet technologies is done and parameters for simulation programs were determined by using this method. The simulation software used to determine the thermal and other parameters of rapid tooled mold inserts. Polyjet insert has shown remarkable advantage over the FDM insert for rapid tooling applications considering surface finish, the density of the models and their heat removal capability [22]. After going through all these studies, a generalized classification of rapid tooling can be done as shown in figure 3.

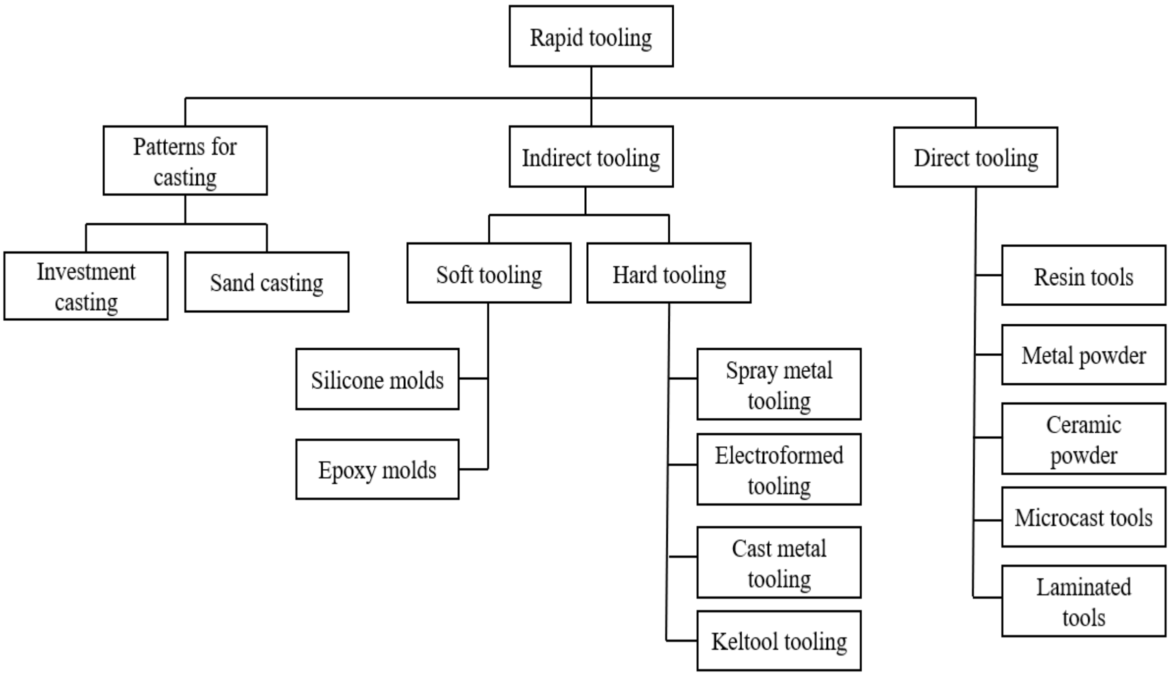

Fig. 3. Classification of Rapid Tooling

5. CONCLUSION

From the literature review it is understood that FDM printed polymer mold has a significant positive impact on plastic injection molding. FDM printed polymer molds can replace conventional metallic molds when there is frequent change in design, low part requirement, design and analysis of prototypes made before permanent hard tooling and customization in design.

The review of the literature indicates that there is limited published work done on the comparison of properties of the injection molded parts produced in FDM printed polymer molds and conventional metallic molds such as strength, density, surface finish, defects, time and cost.

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