The 3D printing of moulds used in injection moulding processing

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Abstract

The possibility of using additive manufacturing methods such as 3D printing for the fabrication of moulds used in injection moulding processing has been discussed in this report. Two case studies depicting the benefits and draw-backs of such a fabrication approach for moulds are presented. The role of materials in creating engineering advantage for the performance of 3D printed moulds is also presented. The case studies showed that there is significant economic value in using 3D printing to fabricate moulds for small series runs on injection moulding machines rather than using moulds fabricated from milling methods.

Keywords

3D printing, additive manufacturing, injection moulding, carbon fibre, PEEK

Introduction

One of the most high production volume manufacturing methods in industry is injection moulding. This manufacturing method makes it possible for producers to implement a viable economy of scale in their business strategy because the unit cost of products/articles/parts can be reduced to values which make profits attractive. Most consumer goods are manufactured on the basis of this principle. However a key challenge faced in the field of injection moulding is the rather high cost of tooling; mainly moulds and mould-inserts. Design and fabrication of these kinds of tools are expensive because the designs are often complex and need to be fabricated by machining from relatively expensive metallic blocks using expertise that can be costly to maintain.

With the advent of new manufacturing methods such as 3D printing or additive manufacturing (AM) [1] there is now a chance to explore solutions to industry-based challenges which involve design and manufacturing constraints. A key reason for this is the wide latitude of fabrication ease created by 3D printing technologies even for complex part designs like mould-inserts. Also, by using 3D printing technologies, production cost and time can be markedly lowered compared to conventional manufacturing methods [2-4]. The 3D printing workflow is illustrated in Figure 2.

How 3D printing works

Creating a 3D model. Anything you want to fabricate using 3D printing, must first be modelled in 3D using computer aided design (CAD) tools or generated using 3D scanners to capture the shape of the object to the right measurements. Size and shape of the model will correspond to size and shape of the part which is to be 3D printed.

Digitally Slicing the model. This is done with a software that splits the model to very thin slices. Every slice can be thought of as a (2D) piece of paper. The Slicer draws a path that the tool which lays down the material will follow. It does the same for every layer, until it reaches the top of the objects. It also tells the tool (print head) how fast to go, how much to accelerate. This "printing plan" is called G-code.

Printing. The G-code is loaded to the printer then the print job starts. Material is deposited on a free surface or print-bed in a layer by layer fashion until a full 3D object is built.

While the technical advantages of 3D printing makes it an attractive instrument for tool development in injection moulding, at the core of its efficacy is materials as well as the role of the inherent properties of materials. Hence due to cost considerations, polymers have in recent times been exploited as choice material for the 3D printing of mould inserts. The material extrusion (fused filament fabrication (FFF)) 3D printing technology is the most widely adopted AM method for processing of thermoplastic polymers. Such polymers can be applied in various engineering scenarios; in pure form or filled with different materials so as to create properties previously not found in the pure polymer. One of the key challenges in mould material design is the conduction of heat from the liquid material; which is filling the mould insert, to regions distant from the filling cavity. The reason for this being that if the heat in the melt mass remains latent in the cavity then timely solidification process and form-shape formation by the melt material are negatively affected. Ideally the thermal mass of the melt needs to quickly reduce once the mould cavity is filled and this process is aided by the use of mould insert material that exhibit appreciable thermal conductivity.

Most engineering polymers have thermal conductivity in the range 0.03 to 7.0 $Wm^{-1}K^{-1}$[3]. This value is markedly insufficient to quickly transfer heat away from the melt. Even in the absence of cooling-media-assisted processing, the use of mould insert materials which ensure adequate thermal conductivity remains a preferred engineering solution. Therefore mould inserts made from polymeric materials filled with highly thermally conducting materials (such as graphene <1500 to 2500 $Wm^{-1}K^{-1}$>, carbon nano tubes <2000 to 6000 $Wm^{-1}K^{-1}$>, graphite <100 to 600 $Wm^{-1}K^{-1}$> or aluminium <205 $Wm^{-1}K^{-1}$>) can provide a viable solution.

Methods

Two types of materials namely polyetheretherketone (PEEK) and carbon fibre reinforced PEEK (CFR PEEK) were used for the production of the moulds. Designs of the moulds were co-developed with the end-users for manufacture using AM methods. Filament forms of the used materials were separately loaded onto a FFF 3D Printer (P200 machine – Figure 2) manufactured by Apium Additive Technologies GmbH – Germany then used for the fabrication of the moulds. Apium Additive Technologies GmbH have especially developed their 3D printers for high temperature polymeric materials like PEEK and CFR- PEEK. Both materials exhibit relatively high mechanical strength, structural stability up to 250°C. Their thermal conductivities are sufficient for use as mould material in applications requiring the use of low melting temperature materials such as wax, polypropylene, polyethylene and other commodity polymers. The CFR PEEK material is certainly a more technically attractive material to use in a mould system due to its higher thermal conductive property compared to pure PEEK. The heat map indicated below (Figure 3) was obtained from an experiment in which samples of both materials were exposed to a heat source then monitored using a thermal camera.

The 3D printed moulds were then sent to end-users for testing and feedback.

End-user-1 Feedback

The mould insert shown in Figure 4 were fabricated from pure PEEK using 3D printing technologies. This mould is a real part deployable for the manufacture of functional parts and it is capable of withstanding up to 700 bars operating loads prior to failure.

The injection moulded material (polystyrene) was processed at a melting temperatures of 210 °C. One of the key challenges associated with this 3D printing mould solution is the ejection time of the moulded part from the mould. Typically a metallic mould insert allows for about 15 sec from mould filling to ejection while this 3D printed PEEK mould insert took about 90 sec to eject the parts (component of a beauty eye brush) shown in Figure 5. Although this time delay is acceptable for this part, it though raises an opportunity to improve on the in-process-time performance of the 3D printed mould insert.

Key process data

Mould insert material: Pure PEEK (Heat dissipation designed)

Injection temperature: 210°C

Pressure: 600 bars

Cycling time: 3 – 4 min

→ Clamping force on the moulds: 20 tons

Material: Polystyrene

<u>End-user-2 Feedback</u>

Apium P Series 3D Printing technology was used for the fabrication of moulds made out of pure PEEK (Figure 6a) and out of 30% by weight carbon fibre reinforced PEEK (Figure 6b) for the manufacture of technical bellows. The entire production cost of this fabrication was compared with that of an actual existing process cost based on milling and other post treatment procedures for the country Bulgaria (client location) and Central Europe. The findings are illustrated on Table 1 and Table 2.

This 3D printed mould trial demonstrates that 3D Printing can be used to solve real manufacturing based challenges in the field of injection moulding. By using 3D printing technology to fabricate the moulds used for manufacturing the technical bellows, it was possible to reduce the total production cost of the moulds by about 86% and saving fabrication time by up to 66%. This possibility opens an economic relief and huge savings for small to medium scale enterprises using injection moulding in their manufacturing business.

Conclusion

The conclusions derived from this study are as follows:

It is evident that moulds and mould inserts used in injection moulding processing can now be fabricated using 3D printing technologies

There is need to develop new materials for 3D printing which can deliver on the optimal operational thermal requirements of mould

3D printed moulds allow for small series production of plastic parts

It cost less money and time to fabricate moulds using 3D printing methods than for conventional milling methods

Acknowledgement

I acknowledge the following: Julian Scholz, Florian Weber, Sasidhar Gorantla, Simon Flubacher, Pinar Karakas and Udo Lange.

Author contribution

Brando Okolo entirely authored this report with additional data from clients and Apium staff.

Tables

Table 1. List of cost for production of a mould for a technical bellow using milling procedure

Conventional mould making milling + post-treatment	Costs Bulgaria	Costs Central Europe (estimated)	Time Required
Prepare inserts	90 €	200 €	1 Day
Electrode milling	330 €	660 €	1 Day
Contour milling	1,100€	1,600€	2 Days
Create CAM-software	120 €	480 €	1 Day
Eroding deep ribs	120 €	280 €	1 Day
Total costs	**1,760 €**	**3,220 €**	-
Total time required	-	-	**6 Days**

Table 2. List of cost for production of a mould for a technical bellow using Apium P series 3D printer.

Production with Apium P Series 3D Printer	Costs Bulgaria	Costs Central Europe (estimated)	Time Required
Preparing 3D model	120 €	250 €	0,5 Days
Printing (material, personnel and depreciation costs)	77 €	77 €	1 Day
Post-treatment	40 €	120 €	0,3 Days
Total costs	**237 €**	**447 €**	-
Total time required	-	-	**2 Days**

Figure 1. Apium P220 3D printer for industrial application

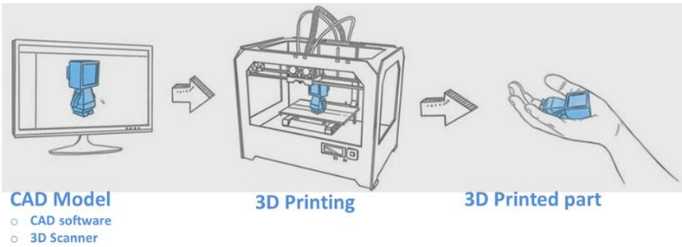


Figure 2. Schematic workflow of 3D printing process [5]

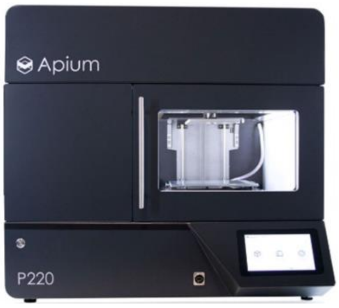


Figure 3. Heat map of pure PEEK and CF-PEEK indicating faster thermal conduction in CF-PEEK.

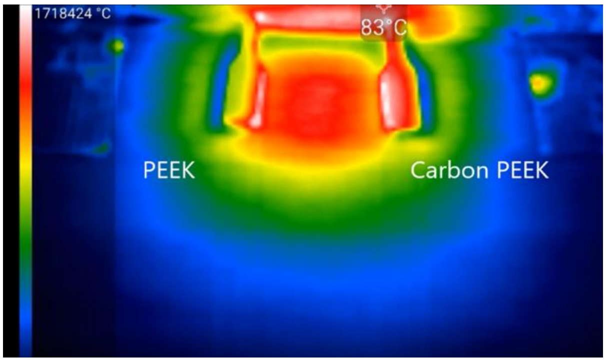


Figure 4. (a) 3D printed PEEK mould insert with moulded parts still in the mould.

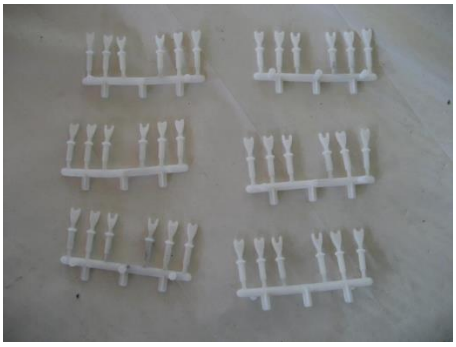
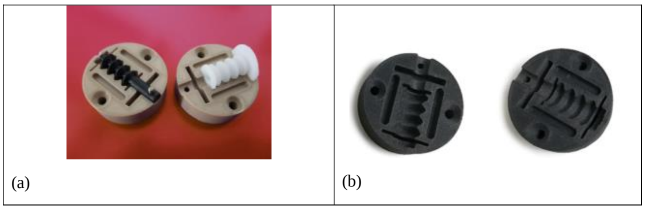


Figure 5. Moulded parts of a beauty eye-brush handle manufactured from a 3D printed PEEK mould.

Figure 6. 3D printed moulds for manufacture of technical bellows (a) carbon fibre reinforced PEEK moulds (b) Pure PEEK moulds with moulded parts in position. (Images courtesy LIM Technics)



References

[1] A. Gebhardt, Rapid Prototyping, Carl Hanser Verlag, Munich (2003).

[2] 3D Printed Mold versus Aluminium Tooling, Posted by Kip Hanson, In the Digital Thread (a Proto Labs Blog), 30 March 2016.

[3] 3D-Printed Prototype Molds Versus Aluminum Tooling, Brent Donaldson (Editor) Additive Manufacturing Blog, 3 May 2018

[4] Precision prototyping: The role of 3D printed molds in the Injection Molding Industry, Lior Zonder and Nadav Sella, White Paper Stratasys, 2014.

[5] https://blogs.library.mcgill.ca/hsslibrary/the-history-of-3d-printing-3d-printing-is-probably-older-than-you/