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Dimensional accuracy and surface texture of additive manufactured plastic inserts for injection moulding.

Frederik Vogeler[1], Ben Van Pee[1], Hilde Jansen[1] & Matthias Faes[2]

[1]*Sustainable Design & Manufacturing, Thomas More University College, Campus De Nayer, Sint-Katelijne-Waver, Belgium*
[2] *KU Leuven, Department of Mechanical Engineering, Technology campus De Nayer, Sint-Katelijne-Waver, Belgium*

frederik.vogeler@thomasmore.be

Abstract
Over the last decade, Additive Manufacturing (AM) has proven to be a reliable method for the production of metal inserts for injection moulding (IM). However, when small-series production is envisaged, these inserts are very expensive. Recent developments in resins allow the use of direct 3D inkjet printing and stereo lithography to manufacture plastic moulds for IM of small series (10 to 100 parts) in a cost effective way. In order to assess the dimensional accuracy and surface texture of these inserts, cases are produced on 3 different systems: Projet, Form 2 and Polyjet. The research reveals that warping due to the AM process is a major issue at the parting and back planes of the inserts. A flatness of 0.52 up to 1.07 mm is observed. Therefore, during the IM process, the inserts are preloaded even before injection due to the closing pressure. However, further research is needed to ensure that this does not lead to premature failure of the mould. At the inside cavity small features seem to show the larges deviation typically about -0.2 to -0.3 mm, except for the Polyjet system which seems to deviate about -0.2 mm over the entire insert, most likely due to an incorrect contour offset in the slicer software. Concerning surface texture *Ra* roughness values range from 0.4 up to 4 µm. For the direct 3D inkjet printing systems the scan direction of the printing process causes the roughness to variate from a 0° to 90° angle. Perpendicular to the scan direction, roughness is higher, this might cause the plastic flow to variate in different directions during injection moulding.

plastic moulds, injection moulding, AM moulds & 3D printed moulds

1. Introduction

Metal based additive manufacturing (AM) techniques such as selective laser melting (SLM) have been used for many years for producing injection moulding (IM) tools [1-3], because they often require complex geometries and conformal cooling. However, metal AM inserts come at a very high cost due to the necessary expensive metal powder bed fusion apparatus and strict powder requirements. These high costs inhibit the economic efficiency when only small series consisting of 10-100 parts are envisioned.

Thanks to recent developments in resins, plastic moulds produced by stereo lithography and direct 3D inkjet printing can also be used as IM tools [4]. The main advantage is that these moulds cost a fraction of their metal counterparts. As a trade-off, these moulds can only withstand about 100 shots for commodity and engineering plastics and 10 shots for high performance and glass filled. The economic series size of these moulds is situated in-between AM for plastic components (<50 parts) and IM(>1000 parts). Plastic AM moulds might close the gap for producing small series of 100 to 500 parts. Moreover, the end-use parts can be produced in the final functional material, which is especially interesting for product testing, verification and validation (e.g.: FDA).

There are some cases reported in literature [4] and white papers provided by machine producers (e.g.: Stratasys, Formlabs), yet little is known on how these moulds perform during IM. Moreover, the quality that can be expected remains unclear. Based on a case study, this article quantifies the dimensional accuracy and surface texture of moulds produced by 3 different technologies: Projet (by 3D Systems), stereo lithography (by Formlabs) and Polyjet (by Stratasys).

2. Inserts design

The considered case study part has an approximate size of (94 × 17.5 × 13.28) mm and is symmetric over the 94 and 17.5 mm distance and some detailed features. Figure 1 shows the parting plane of the mould and final design of the insert at the ejector side. The inserts fit in a steel mould frame which is part of a Master Unit Die Quick-Change System.

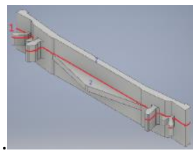
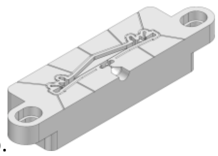
a.  b. 

Figure 1. a. CAD representation of the case study part and indication of the parting plane, b. CAD model of the ejector side insert

The mould is designed for Akulon K222-KGV4 DSM, PA6 material. Autodesk Inventor Mold Design 2018 is used for the mould design and the accompanying Autodesk materials database is used to determine shrinkage compensation. Furthermore a draft angle of 0.5° is applied to the faces perpendicular to the parting plane.

3. Inserts manufacturing and testing

Table 1 gives an overview of the different technologies and corresponding materials used for manufacturing the inserts. The Projet and Polyjet systems are both direct 3D inkjet printing systems, which jet UV-curable resin to build up the 3D part. The Form 2 is an upside down stereo lithography system.

Table 1 Technologies and materials for manufacturing the inserts

Technology	System	Machine	Material
Direct 3D inkjet printing	Projet, by 3D Systems	ProJet MJP 3600	VisiJet M3-X
	Polyjet, by Stratasys	Object500 Connex	Digital ABS
Stereo Lithography	Form 2, by Formlabs	Form 2	High Temp

For determining the dimensional accuracy a GOM ATOS COMPAC M2 fringe projection 3D scanner is used with a (250 × 190 × 190) mm measuring volume. Surface roughness is measured by a Taylor-Hobson Surtronic 3+ 2D tactile profilometer, according to the ISO 4288 (DIN 4768) standard, with a 12.5 mm sampling length, using a Gaussian filter with a 2.5 mm cut-off length (λ_c) and no short wavelength filter (λ_s).

4. Results

4.1. Dimensional accuracy

Concerning the external features of the inserts, the flatness (defined as 2 parallel planes with the smallest distance enveloping all measured points) of the three most important planes are checked: the parting plane, the sprue side and back of the insert. The parting plane is most essential as a high flatness value could cause flashes during IM. Colour maps of the parting and backplane deviation show warpage effects due to the 3D printing process. Plastic moulds are more flexible than metal moulds and this effect will be overcome during IM by the mould closure pressure.

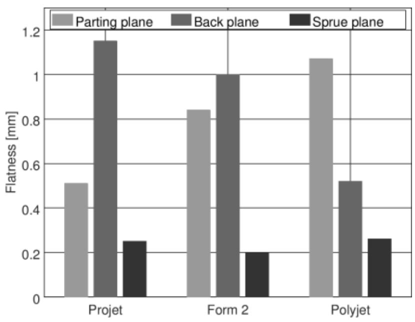


Figure 2. Flatness of the external insert planes.

The flatness values are compared in Figure 2. Worst case is the Polyjet insert with a flatness of 1.07 mm, during closure of the mould a gap of 2.14 mm will need to be overcome by the IM clamping force. Figure 3 reveals that smaller cavity features are produced too small (up to 0.3 mm). This will also lead to the final IM part features being produced too small. Except for the Polyjet insert which is about 0.2 mm smaller over the entire cavity.

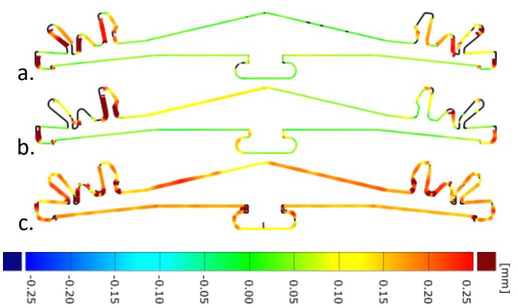


Figure 3. Deviation of the inserts cavity manufactured by: a. Projet, b. Form 2 and c. Polyjet

4.1. Surface texture

Roughness was measured at the parting plane and side planes (Figure 4), for Projet and Polyjet the parting plane is perpendicular to the building direction and the scan direction of the inkjet print heads is along the long side of the insert.

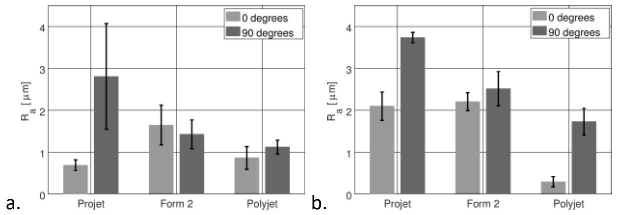


Figure 4. *Ra* insert roughness at the parting (a.) and side (b.) planes, measured at 0° and 90° to the inkjet scan direction. Error whiskers represent 1 σ variation, over 5 measurements.

As concerns the Projet inserts, a clear directional effect caused by the scan direction is present in both planes, where *Ra* for the 90° orientation is comparably larger than the 0° orientation. This effect is only noted in the side plane for the Polyjet parts, whereas it is not noted in the Form 2 parts. In terms of absolute *Ra* values, the Polyjet performs the best on average, followed by the Form 2 and the Projet.

5. Conclusions & future work

The plastic AM inserts manufactured by Projet, Form 2 and Polyjet all suffer from warpage, which causes the parting and back plane to deform. While the Projet insert has less warpage at the parting plane (0.51 mm) and more at the back (1.15 mm), Polyjet shows the opposite (1.07 mm and 0.52 mm). Small cavity features suffer from large deviations (up to -0.3 mm), except for the Polyjet insert which has an overall deviation of -0.2 mm. The latter is probably due to an incorrect contour offset in the slicer.

Concerning the surface roughness, *Ra* is highest for the Projet inserts (*Ra* < 4 µm) and lowest for the Polyjet inserts (*Ra* < 2 µm). For the Projet system the print direction has the largest influence on the roughness in different directions. For the Polyjet system print direction can only be distinguished at the side planes.

As future work, the effect of the warping on the loading of the inserts during the IM process has to be studied in order to ensure that no premature failure will occur. Hereto, a numerical model will be constructed that is able to predict the occurring stresses and strains during the IM process. This model will furthermore be validated using Digital Image Correlation in order to ensure its credibility.

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