



DEPLOYMENT OF FLEXIBLE MICRO MOULD IN METAL INJECTION MOULDING OF STAINLESS STEEL POWDER

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ABSTRACT

Micro metal injection moulding (μ MIM) can be perceived as one of the key technologies for mass micro manufacturing due to its large scale production capability. In micrometer regime, surface roughness is important in view of the microstructure tolerances and in an application where exposure to friction and wear is necessary. Furthermore, reduction of shrinkage affecting the shape stability in the form of induced warpage is also critical. The use of recyclable-based plastics as binder such as polyethylene, polystyrene, polypropylene and etc. can create a green micro parts manufacturing by recovering waste plastic. Plastic recycling promotes reduction of greenhouse gas emissions and saving the landfill area. For production cost benefits in μ MIM otherwise, the mould design should have the capability to fully or semi operated for each injection cycle and the mould should also be relatively low in cost. This study focuses on fabricating low cost micro moulds with and without ejector system to cope with the aforementioned issues. The binder system used was polyethylene, mixed with stainless steel powder to form the feedstock. Mould inserts were machined from mild steel block by CNC milling machine and cavity was precisely cut out from mild steel plate through electrical discharge wire cutting (EDM-Wire Cut). The EDM-Wire Cut has the capability to cut the conductive materials with close tolerance and relatively cheaper than other method. The part was in dog bone shape with diameter of 2.84mm and the overall specimen length was 9mm. Horizontal plastic injection moulding machine was occupied to inject the feedstock into the mould cavity. Performance of the fabricated low cost moulds were tested and benchmarked by the part shrinkage and surface roughness value (Ra). Results reveal that the obtained shrinkage was within 14 – 19%, produced from both moulds with and without ejector system. The superior surface finish was obtained in average at 0.5 μ m from part that injected through the mould without the ejector system.

Keywords: micro mould, metal injection moulding, stainless steel.

INTRODUCTION

New era witnessed micro systems and related component booming in the area of information and communication technology, medical, biotechnology, micro sensors and micro actuator technology (Z. Liu *et al.*, 2002). It has opened a huge market with potential of driving an economy of a country who owned of the know-how. The rising demand for micro-parts in various applications has prompted the development of various micro-fabrication and micro-moulding techniques in an attempt to mass produce micro-parts. Particularly for micro moulding, special processes have been developed for generating micro-cavities and producing micro-mould inserts (Tang *et al.*, 2007).

The factor to successfully fabricate micro devices is highly relying on a reliability of manufacturing systems that capable of producing the micro component in a mass quantity economically. Microsystem technologies require relatively strict quality requirements. This is because their functionalities are usually dependent on stringent requirements of dimensions, masses or tolerances. When mass-producing microcomponents, e.g. replication of disposable microfluidic diagnostics devices, the consistency of the produced components could be significantly affected by process variability (Zauner, 2006). In addition, moulds design that not equipped with the ejector system can slow down the injection cycle. Figure-1 shows some examples of the mould without the

ejector system equipped. As regards, productivity will be slightly diminished as a result of manual ejection in every injection cycle.

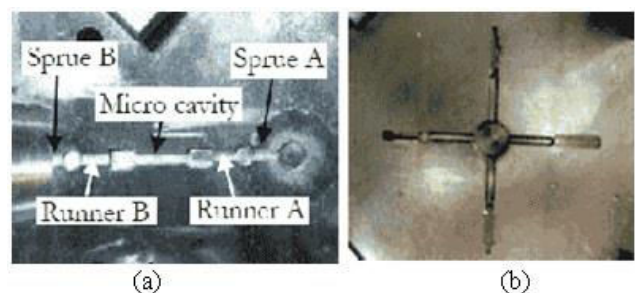


Figure-1. Different micro mould design and concept, (a) die cavity of a two-plate mould with two separate sets of sprue and rectangular runner, (b) die cavity of the micro mould for mono-injection tests, (Barriere & Gelin, 2011).

One of the main goals related to the design of a micro mouldable component is the reduction of the shrinkage affecting shape stability in the form of induced warpage. The warpage is unintended phenomenon and caused by the non-uniformity of the shrinkage induced by the complex thermal variation inside the mould. Other critical aspect for microstructured parts fabricated by μ MIM is surface roughness. It is important for two reasons. Firstly, the tolerances of the microstructures are



decreasing toward the range of surface roughness (Ruprecht, Gietzelt, Müller, Piotter, & Haußelt, 2002). Secondly, applications of microcomponents such as micro heat exchangers, micromedical tools or chemical mixers have strict requirements on surface roughness, because surface roughness affects friction and wear at the interface, bioactivity of the material as well as dynamic properties of the confined fluid layers (Bhushan, 1998; Itälä, Nordström, Ylänen, Aro, & Hupa, 2001; Koo & Kleinstreuer, 2004).

Multiple techniques have nowadays emerged to undertake the micro parts fabrication. Priority on economic consideration has demanded technology of micro systems should be a cost effective technique with ability to cope a great diversity of materials processing technologies. Techniques such as X-ray lithography, electro forming, micro moulding and excimer laser ablation are commonly used for the production of micro components out of silicon, polymer and a limited number of pure metals or binary alloys (Z. Liu *et al.*, 2002). However, due to the minituarisation and complexity of the parts, the production cost is relatively very high in most cases and the flexibility between techniques in processing distinct materials are also limited.

To overcome this drawbacks, μ MIM with low cost fabricated moulds have been developed in the present study. The complexity, cost, quality and competition pressure of today's micro part fabrication demand the mould to possess flexibility that make design changes can be done easily. This research focuses on fabrication of micro cavity mould for micro injection moulding with greater flexibility on changing the mould's cavity design. The cavity is machined from a lower cost steel plate that can be easily attached to permanent mould insert. It allows the cavity design to be changed at a very quick time by changing the plate. The use of steel plate-based cavity moulds will reduce the overall cost and setup time.

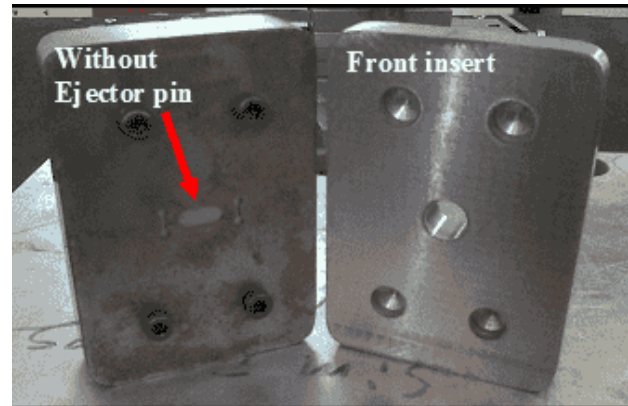
FABRICATION PROCEDURE

Fabrication of front and back insert moulds

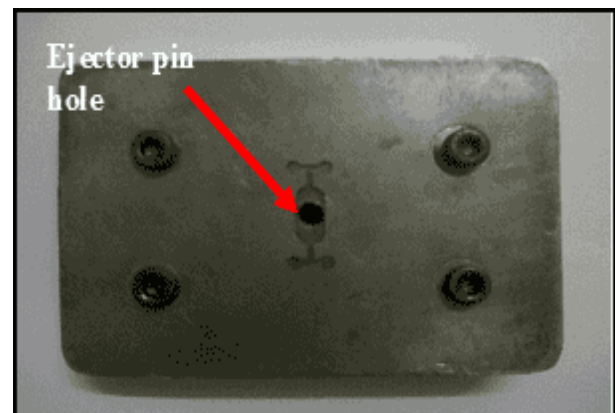
In this study, two mould concepts were used in experimental investigation: (1) Mould without ejector, and (2) Mould with ejector system. The mould without pin ejector system use a manual technique to eject the moulded part out of the mould cavity while mould equipped with the ejector pin capable of ejected the part automatically for every injection cycle completed. The process of front and back insert moulds fabrication was began by designing the mould through Mastercam software. Then, CNC milling was used to machine the moulds according to the design. Surface flattening was completed by the surface grinder machine. To ensure mould meet the specifications, the coordinate measurement machine (CMM) was used to serve this purpose.

The fabricated front insert mould and back insert mould without pin ejector is given in Figure-2(a). Hole for ejector pin on the back insert mould was also drilled by the

CNC milling machine. Figure-2(b) shows a complete assembly of back insert mould with ejector pin hole on a mild steel plate and tighten by the hexagonal screws. The material used for moulds fabrication was mild steel block for low volume application.



(a)



(b)

Figure-2. Fabricated mould inserts, (a) Without ejector pin, (b) With ejector pin.

Fabrication of mould cavity on steel plate

The cavity on a mild steel plate was cut out by Sodick AQ55L series EDM Wire Cut machine. The cavity was in 2D geometry with controlled depth and at every injection cycle, two parts in dog bone shapes will be produced. Details gating system on the cavity plate is shown in Figure-3. Gate is functioned to control flow of feedstock into cavity and also provides a practical and easy means of separating the parts from the runner. Tool Maker microscope was used to measure the dimensions of cavity. Figure-4 shows the fabricated mould cavity on a steel plate and Table-1 gives the final dimensions of the gating system.

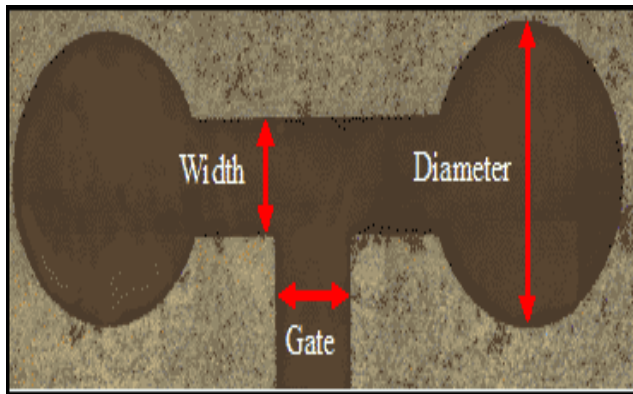


Figure-3. Cavity and gate system on steel plate.

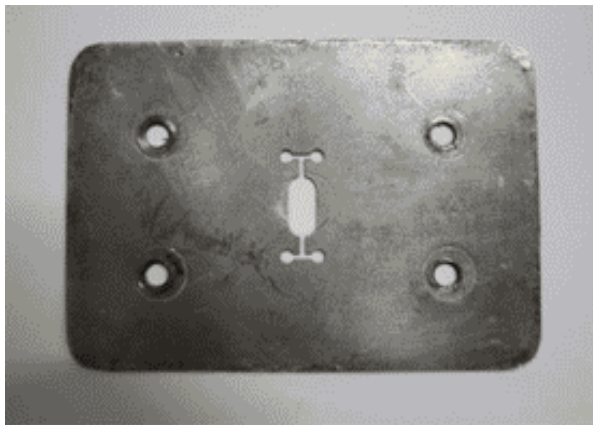


Figure-4. Wire EDMed steel plate with gating system.

Table-1. Dimensions of mould cavity.

Cavity system	Size (μm)
Gate	1105
Width	1119
Diameter	2822
Depth	766.5

EXPERIMENTAL PROCEDURE

Micro metal injection moulding process

After moulds fabrication was completed, next step is to inject the feedstock into cavity. To perform this, an in-line screw type horizontal plastic injection moulding machine with clamping force of 69 kN was occupied as depicted in Figure-5. The machine offers a stable injection for precision part at a lowest possible cost. The injection machine equipped with clamping mechanism to repetitively open and close the mould, permits smooth injection of the feedstocks. The feedstock material comprises of stainless steel with polyethylene used as a binder. Basically, the metal injection moulding procedure includes:

- Plasticizing - the conversion of the polymer material from its normal hard granular form at a certain temperature, to the liquid consistency necessary mixed with the stainless steel powder for injection at the suitable melt temperature.
- Injection - is the stage which the feedstock is introduced into the mould to completely fill the cavities.
- Chilling - is the action of removing heat from the feedstock to convert it from a liquid consistency back to its original solid state.

Table-2. Horizontal injection machine setup.

Types	Machine Setting
Injection Temperature ($^{\circ}\text{C}$)	170
Pressure, p (MPa)	1.5
Injection Velocity (%)	15
Injection Time (s)	2

Table-2 shows parameters setting for the μMIM process. In order to yield a satisfied micro part quality, (M. H. Ibrahim *et al.*, 2011) recommended the injection time $\leq 5\text{s}$, injection temperature $\geq 160^{\circ}\text{C}$ and injection pressure $\geq 11\text{ bar}$. The experiments were carried out at Polymer and Ceramics Laboratory in UTHM.

Total 10 samples were injected. Samples that injected through the mould without ejector system are labelled as A, B, C, D and E while with ejector system are F, G, H, I and J. The dimensions of all the injected parts were measured by tool maker measuring microscope and subdivided into diameter, thickness and width as illustrated in Figure-3. Surface roughness was also measured to analyse the surface quality of the products. In normal circumstances, the surface of the injected part is critically determined by the fabricated mould. Next, the samples will undergo solvent and thermal debinding process to remove the unnecessary binder.

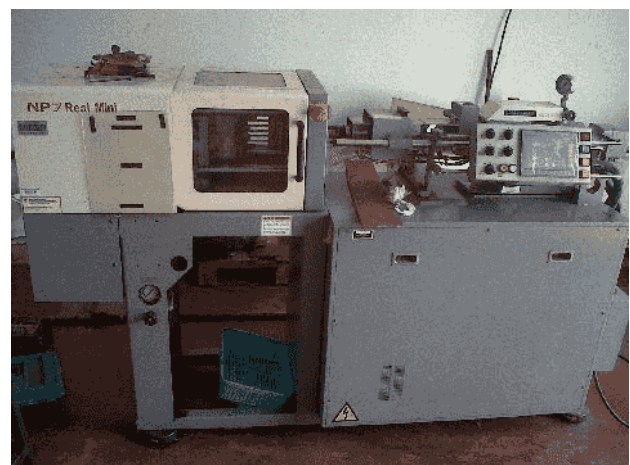


Figure-5. Low cost horizontal plastic injection moulding machine.



Solvent and thermal debinding

After injection moulding, the part produced was subjected to solvent debinding process. Chemical of heptane was used during the solvent process. In this study, thermal debinding process has also been applied for the sake of simplicity, safety and environment respect. Prior to the debinding, the weight of part was measured and later it was debinding in oven at temperature 70°C. During the injection stage, the binder is used to transport out the powder particle to fill out the mould cavities, so it has to be eliminated in the debinding stage (Barriere & Gelin, 2011). The part was heated in the oven at 70 °C for 4 hour. After that, the weight of part was again measured to calculate the weight losses.

FINDINGS

Results of shrinkage

The shrinkage factor was studied by comparing the size of the produced part from injection moulding after debinding with the size of cavity in the mould plate. The dimensional characteristics considered in the shrinkage analysis were thickness, diameter and width. Measurements were accomplished by the tool maker microscope.

From the results shown in Figure-6, the lowest total shrinkage occurred at sample J (13.34%), and the highest was at sample H (24.09%), both from mould with the ejector pin system. The average shrinkage of five samples from mould without ejector pin system was 14.42% while from mould with the ejector pin was 19.14%. It can be clearly seen that the average shrinkage from mould without ejector pin is superior than its counterpart by 4.72%. The results also indicate the shrinkage is badly affected on the thickness section for all samples. The shrinkage was found lowest in overall at the circumference of sample's diameter.

Results of surface roughness

Figure-7 shows values of surface roughness, (Ra) for all ten samples. The lowest surface roughness value for mould without ejector pin system is at sample E, 0.36µm and for mould with the ejector pin system at sample I, 0.63 µm. The average surface roughness values of five samples for mould with and without ejector system are 0.75µm and 0.5µm respectively. It shows that mould without ejector system can produce part with better surface finish. The strong reason was anticipated from the mould design itself that absence from the ejector hole. The results proved that difference mould system will affect the surface roughness of the part produced.

The appearance of the injected samples are shown in Figure-8. Both samples are taken from the lowest shrinkage value of two different moulds system. Sample H exhibits smooth surface with little incomplete filling on the circumference diameter occurred. Nevertheless, sample C from mould without ejector system shows formation of flash and incomplete filling occurred slightly severe at the walls of round shape.

DISCUSSIONS

From the observation, it was found that the shrinkage has affected the injected part quality of all samples. A homogeneous distribution of the powder particles and binder in feedstock is important as it helps to minimize segregation in the injection stage and then to obtain an isotropic shrinkage after sintering (M. Ibrahim, Muhamad, & Sulong, 2009). Therefore, the gating system and cavity on the fabricated moulds should be machined and polished properly to promote uniformity of the feedstock flow. On top of that, powder loading should also be increased to minimize the effect of shrinkage. According to (German & Bose, 1997), higher powder loading is in favour of the compact retention as it will enhance sintering and minimize shrinkage. The percentage of shrinkage obtained in the present study such as in sample J was 13.34% and average 14.42% was obtained for five samples from mould without ejector system, indicate that the results can be accepted. The results obtained by (Quinard, Barriere, & Gelin, 2009) in his study on the properties and behavior using 16µm SS316L with LDPE and PP as a binder, the shrinkage was in range 12 to 15%. The unwanted higher shrinkage can usually results to greater distortion and less sintering densification (German & Hens, 1992).

Surface roughness also amongst important factors in the process of micro part fabrication. Low surface roughness of the micro component can improve its service life and perform better by reducing wear and tear. The best surface finish obtained was at the part that produced through mould without the ejector system, in average of 0.5µm. By using mould without ejector system, feedstock filling can be very smooth. The microstructure obtained are flat indicating good filling during injection molding according to (L. Liu *et al.*, 2005). Furthermore, surface finish can also be further improved by deploying small particle sizes during the injection process (Rota, Duong, & Hartwig, 2002; Ruprecht *et al.*, 2002).

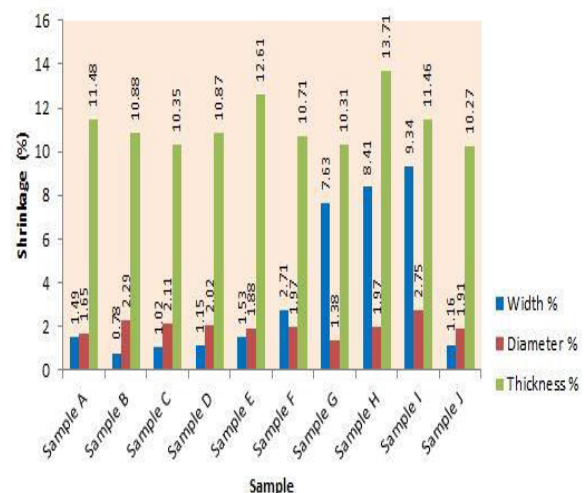


Figure-6. Shrinkage on injected parts from different mould concepts.



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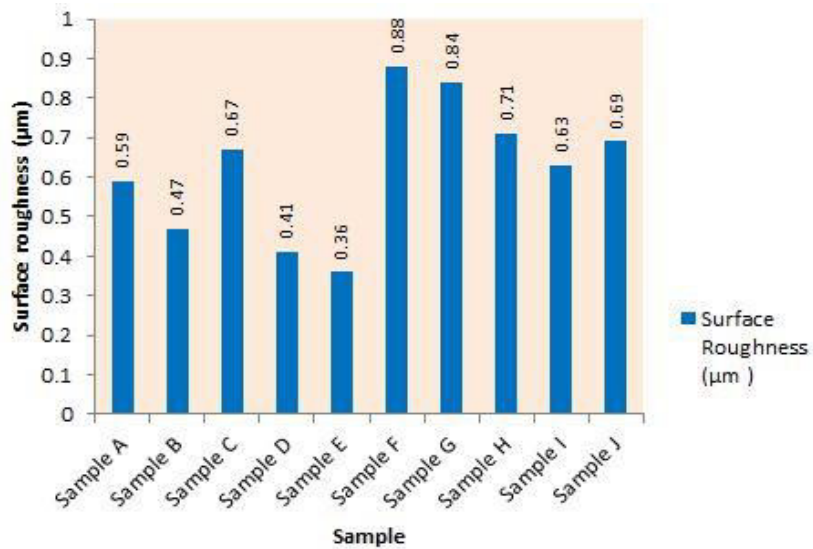


Figure-7. Surface roughness (Ra) value of injected samples.

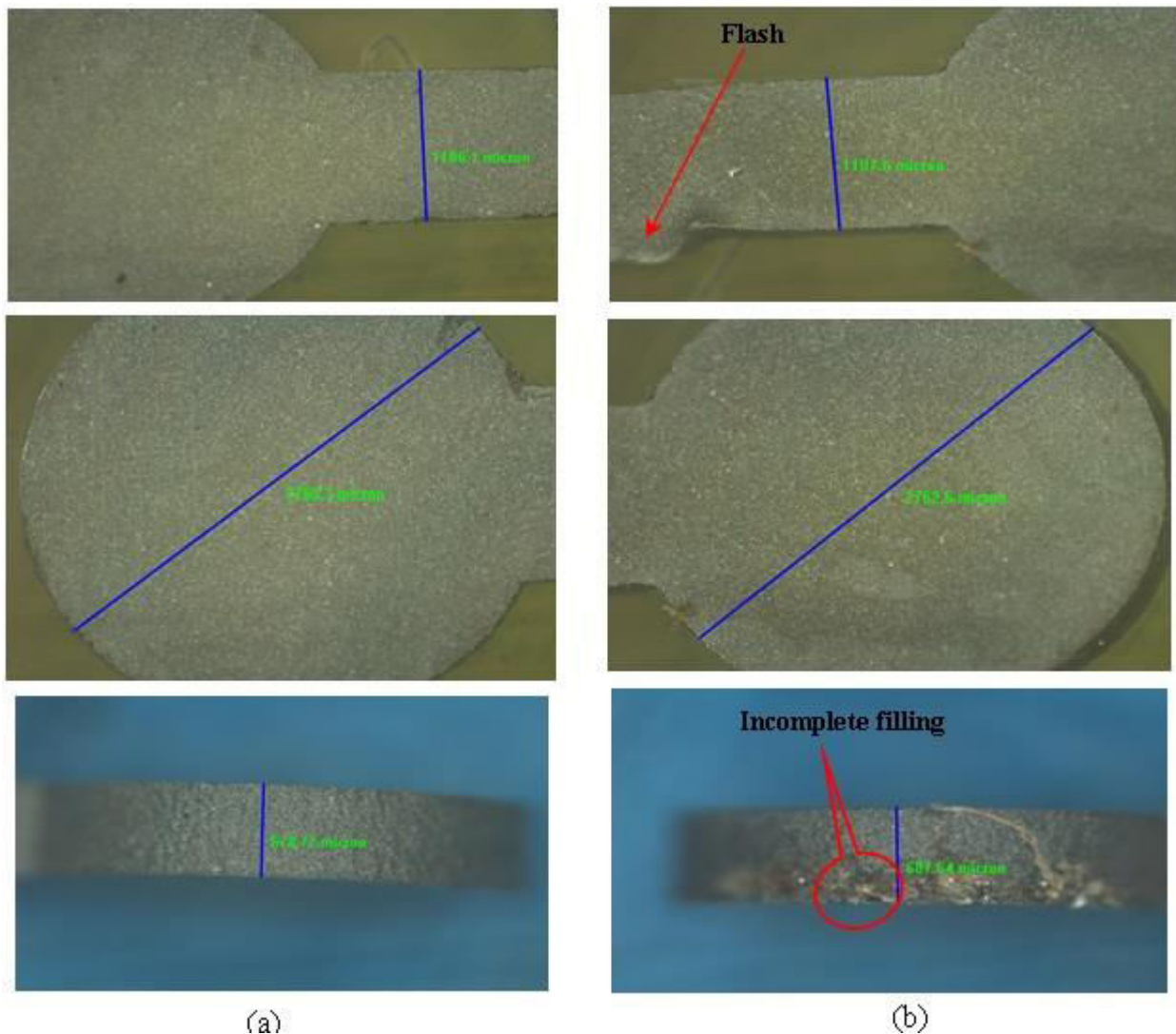


Figure-8. Appearance of specimens from lowest shrinkage values produced at different mould design, (a) Sample H, and (b) Sample C.



CONCLUSIONS

This research demonstrates deployment of the flexible self-fabricated low cost micro moulds to produce product of intricate shapes via metal injection moulding. Positive results have been obtained to prove that the μ MIM with the designed inserts makes micro part of complex shapes with close tolerance is possible to be achieved. The use of mould with the ejector system can expedite the production of micro parts with acceptable quality comparable with those without the ejector system. This methodology has the characteristic to cope with fast and sustainable growing request for miniaturized component such as in biomedical, optical and IT technology application in the near future.

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