Powder Injection Moulding of Micro Parts

Dionizy Biało, Andrzej Skalski

Abstract:

This paper presents and discusses individual phases of forming micro parts using the injection moulding method. Tests involving the preparing of feedstock for the process of injection micro moulding were conducted. The rheological properties for binder-powder compositions were also defined. Tests were conducted for 316L stainless steel and iron metal powders and Al_2O_3 ceramics with granularity ranging from 0.135 μm to 16 μm. Binders consisted of polyethylene, paraffin and wax. Technological parameters of the process of injection micro moulding are presented, including the impact of individual factors on the filling of the mould cavities. Moreover, results of tests with respect to the shrinking of the micro parts as well as of the structure of the material following sintering are presented.

Keywords: *powder, injection moulding, debinding, micro parts, shrinkage.*

1. Introduction

Currently, several methods of micro machining are applied to make of micro parts and microstructures. The most important of these include micro-milling, etching, LIGA technology, erosive and laser micro-machining, plastic micromoulding, etc. [1], [2], [3].

One of the more promising methods is forming of microelements through injection. Such a method of fabrication makes possible the making of micro-elements with complex forms at high replication accuracies in the form of large-scale series at high efficiency that are competitive with respect to other fabrication methods.

The essence of the injection process for forming elements using powders – Powder Injection Moulding (PIM) – involves the preparing of feedstock composed of special thermoplastic binder and powder, preparing the granulate, and forming the parts by way of injection using plastic injection moulding machines [4],[5]. Subsequently, the part is subjected to a debinding process, i.e. the removal of binder, and sintering. The process of micro part injection moulding – μPIM and μMIM (Micro Powder Injection Moulding, Micro Metal Injection Moulding) – is significantly more difficult than any macro injection moulding of products due to the small mass of the micro parts (<0.01 g) and different thermal conditions of the process. It is necessary to use injection moulding machines of special design and operation (different plastifying and feedstock feeding systems).

The filling of micro-channels and micro-cavities with injection feedstock in the case of μPIM is coupled with numerous problems. A small batch of injected feedstock moves along narrow channels and fills mould cavities of very small volume. Feedstock flow is difficult when subject to such conditions, it solidifies quickly and it is more difficult to replicate the details of the design of the micro parts being made.

The present paper looks at the influence of mould temperature and the powder content of the injection feedstock on the course of the filling of the injection mould micro channels and cavities. Metal and ceramic powders of varied granularity (from 0.135 to 16 μm) in quantities of from 45% to 60% of the volume were used in the making of the feedstock.

Results of measurements of shrinkage of the received micro parts following the process of debinding and sintering as well as the structure of the materials in metallographic micro-sections is presented.

2. Tests

A schematic diagram of the process of micro part injection moulding is presented in Figure 1. As in the case of the moulding of macro parts, it consists of the following phases: preparing the injection feedstock, which consists of binder and powder, injecting the feedstock into the mould, debinding (removal of binder), and sintering.

Preparing the injection feedstock includes the making of the binder followed by its mixing with powder. Making binder involves the precise hot mixing of its components, i.e. paraffin, wax, and polyethylene (Table 1). Such a composition guarantees the thermoplastic binder properties that are vital in subsequent phases of the injection moulding process. The ready binder should have the following qualities: it must bond well with powder, facilitate easy injection of the feedstock into the mould, and individual components should be easy to remove during debinding.

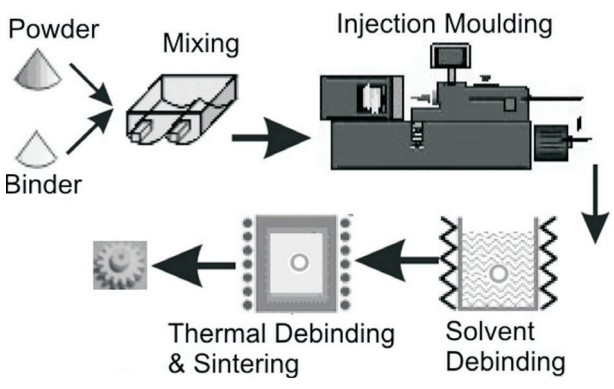

Fig. 1. Schematic diagram of the process of powder injection moulding.

Table 1. Binder composition.

Material	Percentage share
Paraffin	69%
Carnauba wax	10%
PE	20%
Stearic acid	1%

Mixing was performed in a 2Z type mixer with a system for measuring the mixing torque M as well as the temperature of the feedstock T_m.

Table 2. Powders used in the tests.

Powder	Symbol	Granularity	Shape
Stainless steel	316L	16 µm	spherical
Carbonyl iron	OM	4 µm	spherical
	HQ	1 µm	spherical
Al_2O_3	TM	0.135 µm	irregular
Al_2O_3	M	0.66 µm	irregular

Injection feedstock containing binder and powders of varying granularity (Table 2) was prepared. Powder content V_p ranging from 45% to 60% by volume was used. Mixing was conducted until the mass became uniform. A very important parameter during mixing is temperature. Figure 2 presents changes in the mixing torque as a function of mixing time. At the start, the torque M demonstrates significant oscillations in value, which is linked with mechanical breaking up as well as the adding of powder following the dissolving of the binder components. The stabilizing of the torque at a defined value signals the proper state of mixing of the feedstock ingredients. The tests made it possible to establish that the time needed to achieve a uniform feedstock amounted to appropriately 40 minutes.

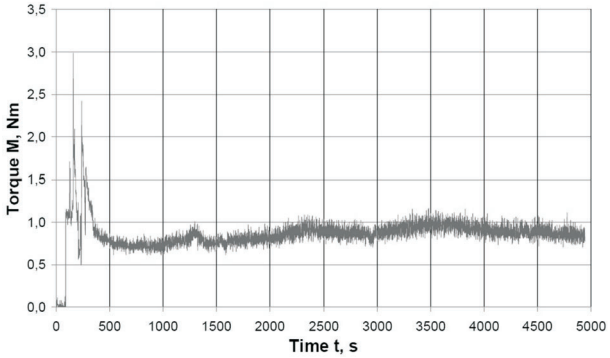

Fig. 2. Graph of mixing torque M as a function of mixing time t for the feedstock with HQ powder at V_p = 55%.

The received feedstock was subjected to the process of injection. A special proprietary injection-moulding machine with thermostatically controlled moulds was used. It makes possible the injection of very small quantities of material in a range from 1 mm^3 to 300 mm^3. Tests were conducted on the influence of temperature of the injected feedstock T_m and mould T_f, injection pressure p, and feedstock powder content V_p on the quality of filling

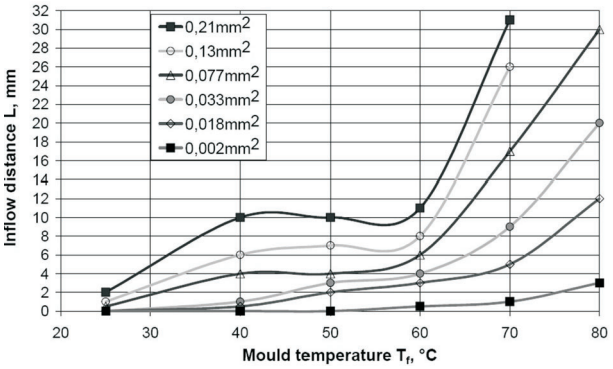

Fig. 3. Impact of the mould temperature on inflow into micro channels of various crosssections for feedstock with OM (4 µm) powder at temperature of T_m = 125°C and a pressure of p = 60 MPa.

of the mould cavities. In preliminary tests a proprietary mould to define the filling of the micro channels was used. It is a replacement for the spiral test used in traditional injection moulding [6], [7]. What was defined was the inflow of the material L [mm] with respect to the cross-section of the channel S [mm^2]. The impact of the temperature of the mould on the inflow is presented in Figure 3. The following results were received during tests: the temperature of the injection feedstock and of the injection pressure p at a mould temperature of $T_f \leq 30$°C have little impact on inflow into the micro channels. Inflow of the micro channels improves significantly upon raising the temperature of the mould $T_f > 50$°C. In this case, the influence of the pressure p and feedstock temperature T_m was also observed.

The received results were applied in preparing specimens for bending test (Figure 4a), tensile test (Figure 4b), and for gearwheel (Figure 4c).

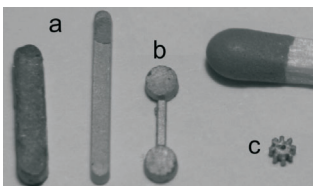

Fig 4. Examples of parts made, prior to sintering.
a – bars for bending tests: 2x2x10, 1x1x12 mm
b – specimens for tension tests: 0.5x0.5x5 mm
c – gearwheels: Dz = 1 mm, m = 0.15, z = 8

Problems with inflow also occur during forming specimens for tensile tests. Figure 5 depicts the impact of mould temperature on the inflow into the mould cavities. Raising the temperature of the mould in the 25°C–75°C range results in decreased viscosity of the feedstock, which significantly improves the filling of the mould cavities.

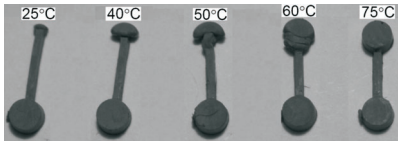

Fig. 5. Appearance of the micro specimens for tensile tests as moulded at various mould temperature and established injection conditions: T_m = 115°C, p = 60 MPa, and V_p = 60%.

Table 3. Injection parameter values for the proper fabrication of micro parts using feedstock with iron powder with a granularity of 1 µm.

Powder contint	T_f	T_m	p
45%	25°C	125°C	60MPa
50%	25°C	125°C	60MPa
55%	50°C	125°C	60MPa
60%	75°C	125°C	60MPa

Table 3 compares the values of optimal injection parameters for the proper making of the specimens out of feedstock with iron powder with a granularity of 1 µm and varied content V_p. As the content of powder increases it is necessary to increase the temperature of the mould. However, too high a mould temperature is not recommended because the efficiency of the process decreases significantly. Too high level of heating influences increasing both the mould heating time and cooling time.

After injection the specimens are subjected to debinding and sintering processes. The debinding process (removal of binder) consists of two phases. The first phase involves the elimination of easily melted components by rinsing them out using solvents. Tetrachloroethylene was used. Following this phase, the specimens become very porous. The time required to conduct this phase is dependent on the size of the specimen as well as its powder content V_p. The conducted tests demonstrate that approximately six hours is needed in order to properly remove paraffin from the specimen. The second phase of the debinding is conducted together with the sintering phase. The value of the debinding and sintering temperature for individual materials is presented in Table 4.

Table 4. Temperature of thermal debinding and sintering.

Powder	316L	OM	HQ	M	TM
Debinding	550°C	650°C	650°C	550°C	550°C
Sintering	1250°C	1110°C	1110°C	1600°C	1450°C

The remaining binder undergoes thermal breakdown at temperatures in excess of 500°C. Evacuation of the products of binder breakdown is made possible by the pores left after rinsing in solvent. Sintering takes place after the total removal of the binder. During sintering the specimens achieve their required mechanical qualities and also undergo shrinkage. Literature often describes the relationship, where the finer the powder, the easier it undergoes sintering because it has greater surface energy. For the same reason, dimensional changes in the specimen following sintering are dependent on the size of the powder used. Figure 6 shows the dependence between shrinkage and powder granularity. The finer the powder used, the greater the shrinkage of the finished product with respect to the mould cavities. Such information is very useful in designing injection mould cavities.

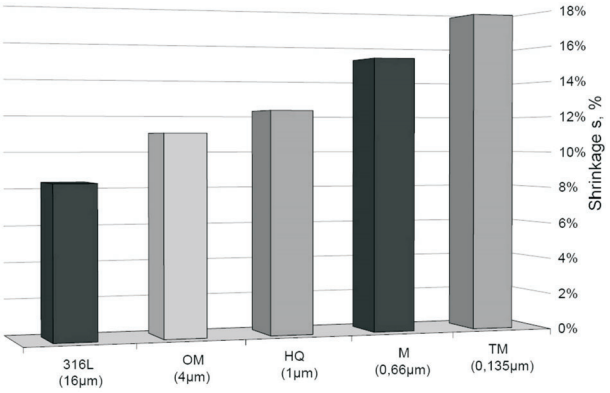

Fig. 6. Influence of the type and granularity of powders on the shrinkage of parts following the process of sintering at a content of V_p = 55%.

The size of powder particles also influences the structure of the received parts. Figure 7 presents metallographic micro-sections for specimens made of the discussed materials (of varying granularity). Parts made of powder with a granularity of over a dozen micrometers (316L) are very porous. Less porous are specimens of OM iron powder (4 µm), and specimens of HQ iron powder (1µm). Ceramic powder TM with lowest granularity (0.135 µm) forms a uniform structure, without pores, following sintering.

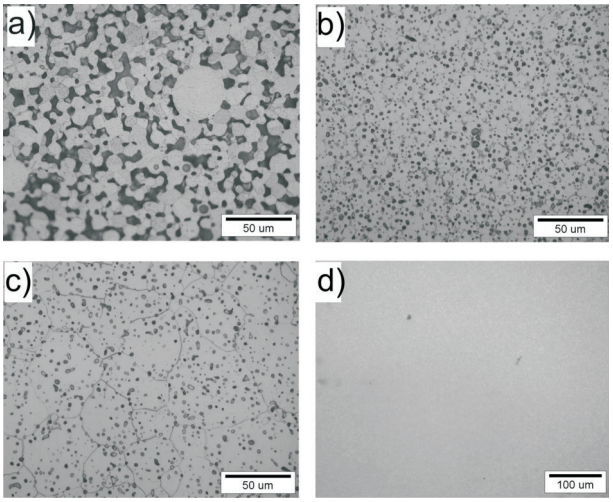

Fig. 7. Metallographic micro-sections of materials following sintering, made of feedstock of at a fixed content V_p = 55% – a) 316L (16 µm), b) OM (4 µm), c) HQ (1 µm), d) TM (0.135 µm).

3. Conclusions

1. The quality of the filling of mould cavities is primarily influenced by the temperature of the mould and the feedstock powder content coefficient.
2. The course of the inflow into the mould is also influenced by the granularity of the powder used. The finer the powder, the greater the viscosity of the feedstock and the more difficult the fillings of the micro-cavities are.
3. Powder granularity also influences the degree of shrinkage. The smaller the granularity the greater the shrinkage of the product and the less its porosity is.

ACKNOWLEDGMENTS
This paper is a fragment of Research Program No. 0309/T02/2006/31 financed by the Polish Ministry of Science and Higher Education.

AUTHORS
Dionizy Biało*, Andrzej Skalski - Institute of Metrology and Biomedical Engineering, Warsaw University of Technology, ul. św. A. Boboli 8, 02525 Warsaw, Poland.
E-mail: dbialo@mchtr.pw.edu.pl
* Corresponding author

References

[1] Oczos K.E., "Micro Parts Forming: Characteristics of Micro Machining Methods," *Mechanik* [Mechanic], 5–6, 1999, pp. 309-327 (in Polish).

[2] Poiter V., *et al.*, "Micro Powder Injection Moulding," EURO PM2000, October 1820, 2000, Munich, Germany, vol. PIM, pp. 259-264.

[3] Hasselbach J., *et al.*, "Investigation on the International State of Art of Micro Production Technology," *Euspen International Topical Conference*, Aachen, Germany, 19th–20th May, 2003, pp. 11-18.

[4] Piotter V., *et al.*, "Micro Powder Injection Moulding: New Developments and Results," *Proceedings of the Euro PM 2008: Powder Injection Moulding*, vol. 2, pp. 331-335.

[5] Imgrund P., Haack J., Rota A., "Current Developments in Micro Moulding of Functional Materials", *Proceedings of the 7th International Conference*, Bremen, May 2007, pp. 115-118.

[6] Stanek M., Manas M., Draga T., Manas D., "Measurement of Polymer Fluidity", *Proc. of the IV International Congress on Precision Machining 2007*, 25th–28th September, 2007, Poland, vol. 1, pp. 285-289.

[7] Biało D., Skalski A., Paszkowski L., "Certain Aspects of the Injection Moulding of Micro Parts from Metal Powders", *Rudy i Metale Niezelazne – Metalurgia Proszkow*, no. 4, 2008, pp. 241-245 (in Polish).