Analyses Of Micro Moulding Process Of The Microelements From Ceramic Powders

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Abstract:
The article discusses the issues related to moulding of micro-elements from powder materials and it covers the first stage of the process – injecting to the mould cavity and filling the micro-channels. The material, which constituted the composition of a special thermoplastic binder and ceramic powder, was injected. The binder consisted of paraffin, polyethylene, wax and stearic acid. The nanometer powders from Al_2O_3 ceramic material with granularity of 660 nm and 135 nm and irregularly shaped particles were used. Different loading of composition by powder were used. The analyses of the impact of injection parameters, such as the mould's temperature and the temperature of the material, on the quality of filling the micro-mould cavity with the material, were presented. The special moulding insert with micro-channels was made to perform the analyses to that effect with width from 50 to 1000 μm. The presented results of filling the micro-channels indicate considerable influence of the mould's temperature and the cross-section of micro-channels. Slight impact of the material's temperature was observed; however, this factor does not have a considerable influence on filling the channel. The obtained information was used in the experiments of injection the samples for bending tests and tensile tests, and the shapes in the form of toothed wheels.

Keywords: *injection moulding, micro-elements, ceramic powders*

1. Introduction

In the recent decade we have observed intensive development of processes involving production of micro-products and micro-elements related to development of Micro Technologies Systems (MTS). The Micro Technologies Systems combine micro-electronics with many other micro technologies e.g. mechanical, optical, chemical technologies, etc. The objective is to fully concentrate various functions in a single miniaturized product. It should be noted that the dimensions of the produced structures or their components are expressed in micrometres. Previously used methods of production of micro-elements are limited to selected groups of materials. This pertains to the following processes: LIGA, laser processing, erosion, etching, etc [1, 2, 4, 5]. A large problem involves adaptation of well-known technologies from the macro scale to the micro scale. It turns out that this is not always possible or does not give the desired effects because the dimensions of the elements are less than 1 mm. One of the more promising processes is the process of moulding micro-elements through injecting. Such a moulding method allows the production of micro-elements with complex shapes, with high accuracy, in large series, and in a manner that is efficient and competitive compared to other production methods.

The micro injection moulding is based on the currently used method of making products from thermoplastic polymers through injection. It should be emphasized that the first analyses and applications focused on micro-elements manufactured from such materials [3, 5, 6, 7].

The micro-elements injected with metal and ceramic powders are designated for operation in harsher thermal and mechanical conditions than elements made from plastics. In this technology, the problem involves not only making the injection micro-mould but also selecting the parameters for the entire injection process. No tests have been developed which would allow us to unequivocally determine the material's suitability for production of micro-elements by the injection method. Such a test, which is known as the spiral test, exists for macro-elements.

The presented article concerns the analyses of the first stage of micro-element production from ceramic powders. The entire process of micro-element production includes preparation of the mass consisting of powder and special thermoplastic binder, injection, binder removal (debinding) and sintering [8, 9, 10]. The results of filling the channels and the micro-cavity of moulds were presented along with the examples of the obtained shapes. In this part of the article, the impact of temperature of the injected mass and the mould's temperature was discussed.

2. Materials

The injection moulding uses the masses which are the compositions consisting of the thermoplastic binder and the specified micro-powder. In the presented analyses, Al_2O_3 ceramic micro-powders with granularities of 0.66 μm and 135 nm were used.

The description of the individual powders is included in Table 1 and the photographs of the selected powders are presented in Figure 1.

Table 1. Powder description

Powder type	Symbol	Manufacturer	Average granularity	Particle shape
Al_2O_3	M	Martoxide	0.66 μm	Irregular
Al_2O_3	TM	Tamei Chemicals Co, Ltd	135 nm	Irregular

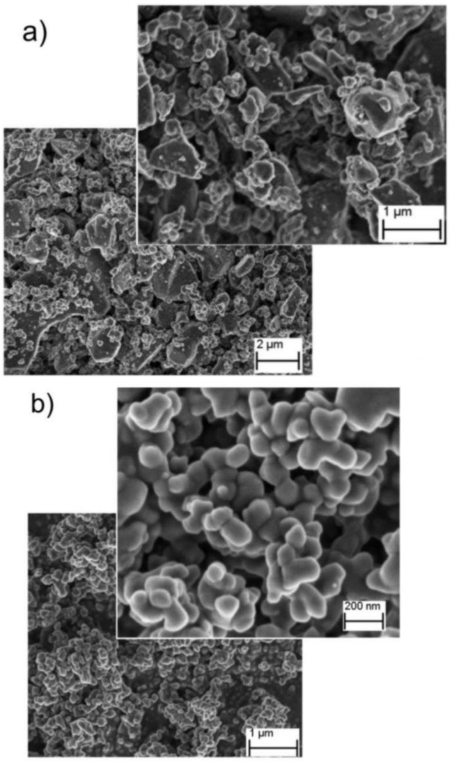

Fig. 1. Al_2O_3 ceramic powders: M, 660 nm (a) and TM, 135 nm (b)

The composition of the binder is as follows:

- LD polyethylene 20%
- paraffin 69%
- Carnauba wax 10%
- stearic acid 1%

Preparation of the injection mass consisting of powder and binder was carried out in a type 2Z mixer with the heating mantle at a temperature of 125°C for a time of 1 hour. Such a period of time was sufficient to prepare a homogeneous mass.

For tests involving injections and filling the micro-channels, the mass with the powder content of V_p = 50 and 55% by vol. was used. Such high V_p values are necessary to produce micro-elements with complicated shapes and very small structural details.

3. Tests

A special injection mould with micro-channels with cross-sections of 0.033; 0.077; 0.13; 0.21; 0.3; 0.54 and 0.84 mm² was designed for the analyses. This was necessary because there are no standardized tests for analyzing the micro-moulding, and the spiral test, which is commonly used in moulding the macro-elements from thermoplastics, cannot be used in the case in question. The mould has a built-in heater with a temperature regulation system as well as a cooling system. The moulding insert is presented in Figure 2. The mould's injection nozzle directed the mass centrally to the moulding insert, from where it continued to flow to micro-channels located along the radii. Dimensions of the channels are presented in Table 2.

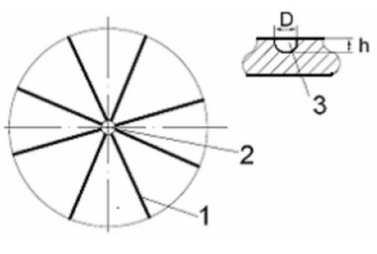

Fig. 2. The moulding insert for evaluating the inflow distance of the mass in the mould. 1 – micro-channel, 2 – injection point, 3 – cross-section view of the channel

Table 2. Micro-channel dimensions

Width	D, mm	0.2	0.3	0.4	0.5	0.8	1
Depth	h, mm	0.17	0.27	0.35	0.44	0.71	0.9
Cross-section	S, mm²	0.033	0.077	0.13	0.21	0.54	0.84

The mould, which was designed in such a way, allows us to simultaneously obtain a series of data from one injection cycle because it gives the information on the process of filling several micro-channels with different cross-sections at the same time.

The following technological parameters of the injection process were used:

Temperature of the mass	T_w – 125, 150 and 170°C
Temperature of the mould	T_f – 25, 40, 50, 60, 70 and 80°C
Pressure	p – 60 MPa
Powder content in the mass	V_p – 50 and 55% by vol.

4. Results

Figure 3 presents the chart describing the dependencies, which are typical of the discussed analyses, between the micro-channel filling process (mass inflow distance, L) and the temperature of the mould T_f. The chart pertains to the mass containing the ceramic powder with granularity of 0.135 µm with powder content in the mass of V_p = 55%.

The obtained results show that as the temperature T_f increases, the flow distance of the material increases.

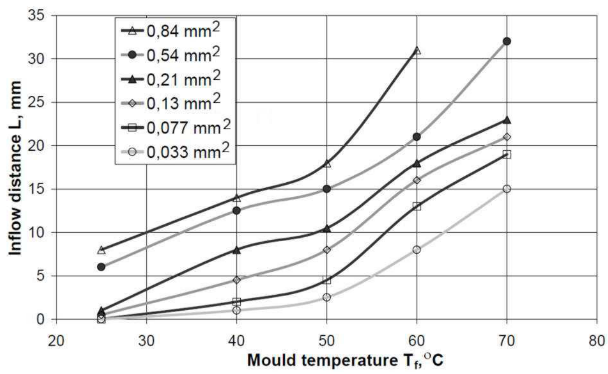

Fig. 3. Dependency among the inflow distance L, the temperature of the mould T_f and the cross-sections of micro-channels for mass with TM powder (135 nm) with V_p = 50% and T_w =125°C

The chart shows the temperature threshold above which it is easier for the material to fill the channels. For larger micro-channels, this temperature is approx. 45°C; for smaller ones it is slightly higher. The cross-section of the channel is an important factor. As it increases, the inflow distance considerably increases. In such case, the stream of material flowing in the channel has a relatively higher volume and therefore a higher weight. Consequently, it cools off at a slower pace when in contact with the mould, which is colder. According to literature [6], under extreme conditions, when the length of the feeding channels is large and the micro-moulds have complicated shapes, in order to facilitate the flow of mass the so-called "Variotherm" process is used during the injection, in which the temperature of the mould reaches up to 100°C.

Figures 4 presents dependencies between the inflow distance L (mm) and the temperature of the mould T_f for various cross-sections of micro-channels and both injected materials.

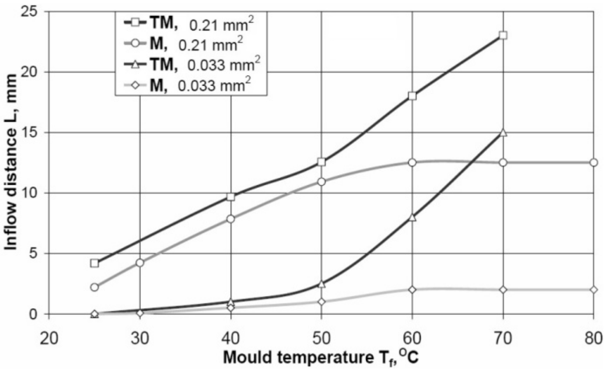

Fig. 4. Dependency between the inflow distance L of mass and the temperature of the mould T_f at V_p = 50% and T_w =125°C a – in the micro-channel with cross-section of S = 0.033 mm², b – in the micro-channel with cross-section of S = 0.21 mm²

If the temperature is lower than 50°C, the inflow distance in the micro-channel with cross-section of 0.033 mm² is similar for the individual materials, and it amounts to 1 and 2.5 mm. After this value is exceeded, the impact of the type of material is observed. The mass with finer powder fills the micro-channels more efficiently, and as the temperature increases, the inflow distance rapidly increases. The mass with powder M with granularity of 0.66 µm fills the micro-channel less efficiently. As the mould temperature grows, the inflow distance increases to the specified level, after which it has approximately the same value despite increase of temperature T_f.

This dependency is similar for the micro-channel with cross-section of 0.21 mm². Increasing the cross-section of the micro-channel resulted in extension of the inflow distance, and the curves for the individual granularities show the same trend. After increasing the cross-section of the channel almost six times, the mass additionally increases the inflow distance and it begins to fill the channel at a lower mould temperature (room temperature).

The next technological parameter, which may result in improvement of parameters of the produced elements, is the temperature of the injected material (T_w). Figure 5 presents the inflow distance figures as a function of micro-channels' cross-sections for the temperature of the injected material of 125, 150 and 170°C. The injected mass contained the ceramic powder with granularity of 135 nm. It may be observed that, as it was predicted, the increase of the material's temperature will improve the efficacy of filling the micro-channel and also filling the mould. In such a situation, it is possible to reduce the temperature of the mould while preserving the satisfactory efficiency of filling it – Figure 6.

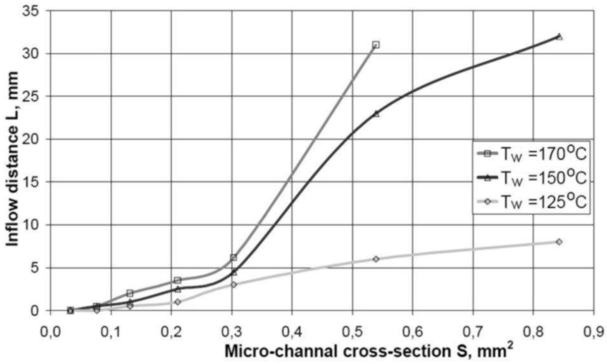

Fig. 5. Dependency of the inflow distance L of the mass on the cross-section of the micro-channel for mass with powder TM with V_p = 50% for mould temperature of T_f = 25°C and mass temperature of T_w =125, 150 and 170°C.

Simultaneous impact of temperature of the mass and temperature of the mould on the inflow distance in channels with various cross-sections is presented in Figure 6. The obtained curves confirm that the conclusion is right. An increase in mass temperature T_w results in the inflow distance increasing, especially for larger cross-sections of micro-channels. In addition, increasing the mould temperature facilitates the flow of mass, which is very important for small cross-sections of micro-channels when the increase of T_w itself does not have a sufficient impact on filling the micro-channels or micro-moulds.

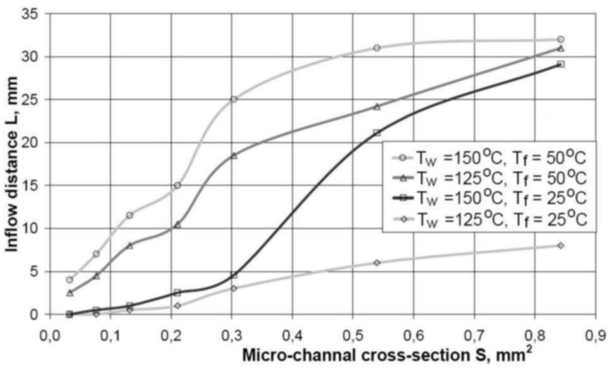

Fig. 6. Dependency of the inflow distance L of the mass on the cross-section of the micro-channel for mass with powder TM with V_p = 50% for mould temperature of T_f = 25 and 50°C and mass temperature of T_w = 125 and 150°C

It should be remembered that the temperature of the material and the mould should not be excessively increased due to the possibility of degradation of the mass before its injection into the mould cavity.

The presented results of the analyses were verified through production of micro-elements in the form of bars for bending tests and samples for tensile tests, as well as miniature toothed wheels. The examples of such elements are presented in Figures 7 and 8.

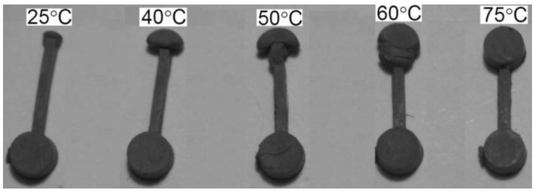

Fig. 7. Micro-samples for tensile tests moulded at various temperatures of the mould and with the following injection conditions: T_w =115 °C, p = 60 MPa and V_p = 60%

It is visible that filling of the micro-mould in not complete as the mould temperature is too low.

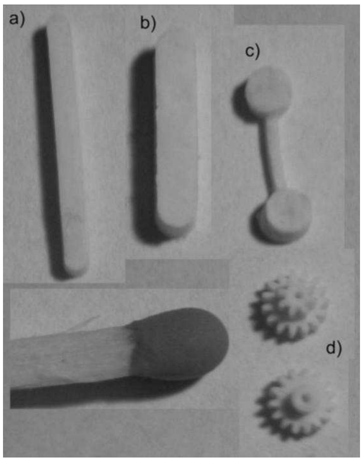

Fig. 8. Examples of moulded micro-elements before sintering
a – bars for bending tests: 1x1x10,
b – bar for bending tests: 2x2x12 mm
c – sample for tensile tests 0.5x0.5x5 mm
d – toothed wheel

5. Conclusions

The following conclusions may be drawn on the basis of conducted analyses of filling the micro-channels through the process of injection moulding of micro-elements from ceramic powders:

- The proposed analysis method, which uses a special moulding insert with many channels with different cross-sections, has turned out to be very useful in evaluating the behaviour of the masses consisting of ceramic powder and binder during the process of micro-injecting.
- The greater the cross-section of the micro-channel, the longer the inflow distance of the mass with the set T_w, T_f and p.
- The most important parameter, which determines the course of filling the micro-channels, is the mould temperature. It has to be considerably higher than in the case of moulding of macro-elements with ceramic macro-powders.
- The finer the powder particles, the easier it is for the mass to flow to micro-channels.

An increase in temperature of the injected mass results in improvement of filling the micro-channels and micro-mould cavity.

AUTHORS

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