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Replication of micro components by different variants of injection molding

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Abstract In microsystems technology, components made by micro injection molding are applied to an increasing extent. The variety of materials, low costs, the high number of sub-variants, and the relatively easy shaping are decisive factors. As further improvement, special variants like micro multi-component injection molding or micro powder injection molding are currently under development at Forschungszentrum Karlsruhe. The goals of these research activities are not only to increase economic efficiency but also to expand the range of materials to metals and ceramics.

1 Introduction

The availibility and performance of micromanufacturing processes is still an important and decisive condition for the economic success of Micro Systems Technology. Injection molding well suitable for medium and large-scale series production represents such a technology.

Currently, new variants of micro injection molding for enhanced mounting processes or an increased range of materials are under development.

2 Micro two-component injection molding

In obvious analogy to the further development of macroscopic injection molding technology, new micro replication techniques promising to result in higher economic efficiency or new products [1, 2], such as micro assembly injection molding or micro insert injection molding, are currently being tested. Both variants facilitate easy assembly and bonding by using insert parts and are expected to lead to a considerable reduction of total production costs [3].

A similar objective is pursued by micro two-component injection molding which additionally allows for the production of multi-component and, hence, multi-functional microcomponents. This two or multi-component injection molding in the micrometer scale would reveal advantages similar to using insert parts. Further perspectives are the manufacturing of micro joints by using polymers with different shrinkage values and the production of microstructured preforms for a subsequent electroplating process (see chapter 3).

The main technical challenges are the process parameters which have to be suitable for both materials and the design of the necessary molding tools which at least have to be equipped with two feeder systems. An important materials question is the adhesion or, in case of micro joints, free-shrinking between the polymeric materials.

First experiments for two-component micro injection molding have been carried out at Karlsruhe Research Center with the aim of producing micro test specimens consisting of two different kinds of polymers (Figs. 1–3) or, as further development, of metals or ceramics.

3 Electroplating on lost two-component preforms

One field of process development for micro manufacturing at Karlsruhe Research Center is presently directed towards large-scale production of metallic parts of high aspect ratio, strength, and surface quality [4].

One concept is focused on a process sequence, combining injection molding of sacrificial preforms with a subsequent electroforming step for replication.

The conductive polymer parts have to serve as substrates for the electroplating step and as preforms. Unfortunately, electroforming on an isotropically conductive substrate (undirected growth) is limited to aspect ratios not higher than 5, because the galvanic deposit will overgrow the apertures of the preforms before they are completely filled with metal, and partially filled cavities are left in the product.

This is caused by the distribution of electric field lines in the electrolyte which is more dense at edges and corners than at plain surfaces. Additionally, metal ion transport velocity can limit the galvanic deposition rate in narrow cavities, as the metal ion concentration there is determined by diffusion only, whereas the concentration near to the electrolyte bulk is usually stabilised by con-

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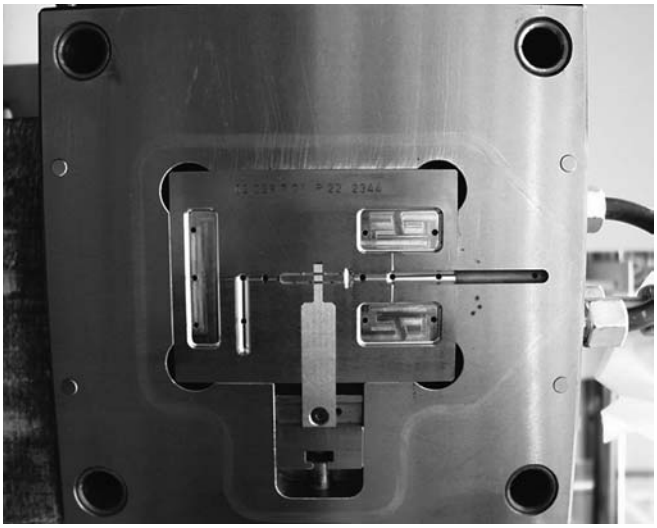

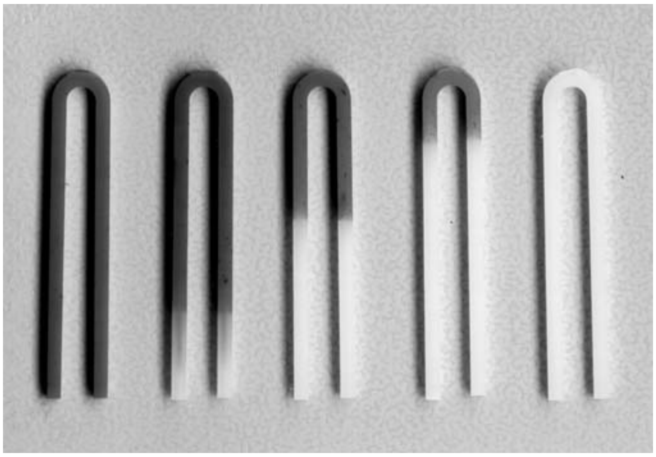

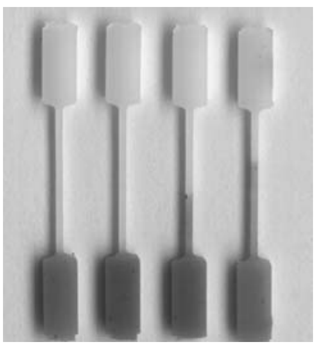

Figs. 1–3. Micro two-component injection molding: View into the molding tool with two feeders and pusher (above); hair needle shaped test parts (middle); tensile test specimen for investigations of weld lines strength (bottom)

vective exchange. Therefore, metal deposition has to start on the substrate/bottom between insulating microstructures only.

At first an electrically conductive plating base is made by injection molding of thermoplastics filled with e.g. carbon black or C-fibers. By a second injection molding step microstructures made of insulating plastics are mounted on these plates. As mold inserts, LIGA-manufactured or micromechanically cut ones have been applied. The quasi-infinite conductivity gradient allows controlled electroplating starting at the plating base only (Fig. 4).

The composed mold acts in the electroplating step as cathode. Aqueous 1.5 M solution of nickel sulphamate $Ni(SO_3NH_2)_2$ is used as the electrolyte and standard current densities are applied to obtain deposition rates of in minimum 12 μm/h nickel at a temperature of 52 °C. Boric acid, H_3BO_3, acts as buffer to prevent local formation of hydroxides, especially in the micro cavities of the structure. The advantage of sulphamate electrolytes is the possibility to achieve low internal stresses in the deposited metal for the formation of a compact bulk material (≈5–10 mm thickness) after the galvanic filling.

Electroforming experiments were carried out on pure conductive polymer substrates to determine the specific characteristics of the material, and on 2-component substrates with microstructures of different types and shapes to study the characteristics and deposition behavior of many different composites like PMMA, POM, PS, PA12, PA6.6 and their conductive versions.

Injection temperature and pressure, melt velocity, conductive filler type and polymer combination have a specific influence on parameters like conductivity, roughness, surface structure and subsequently on the initial nucleation and the applicable maximum current densities.

In each case the conductivity of the filled polymers is lower than that of metallic or metal-coated substrates: The specific surface resistances of conductive polymers of a typical molded substrate range between 10^1 and 10^3 Ω. With rising surface resistance consequences on the initial metal deposition conditions have to be kept in mind. The resistance and with it the deposition characteristics show a strong dependency on the kind of conductive filler. The finer and more homogeneous the conductive filling was distributed in the polymer matrix, the more homogeneous was the nucleation behavior and the following metal growth, and the sooner regular thick layers with electroformed structures were obtained.

The used 2-component injection molded preforms contained some special microstructure devices for the electroforming. Besides pillar-like structures (rosettes) cross-like spinning nozzles were used and designed for a microstructure height of 1 mm. (Figs. 5, 6).

Images of nickel deposits show that also narrow structure cavities were completely filled with nickel (1 mm high). This is confirmed by SEM micrographs showing that also thinnest structures of the microstructure could be accurately replicated. Wall thicknesses of down to 25 μm and aspect ratios up to 40 were obtained for the metal parts. Replication of all structural details took place down to the submicron scale (Fig. 7).

Metallographic texture studies of nickel deposits on isotropically conductive (1-component) polymer microstructures showed tremendous cavities (Fig. 8). Additionally, crossing-overs arise at edges and also at central cavities in case of low aspect ratios (AR ≤ 5).

On the other hand, the metal deposition in 2-component injection molded preforms of the same shape showed massive bodies without failures. A one-dimensional dendritical orientation because of the directed metal growth was determined (Fig. 9).

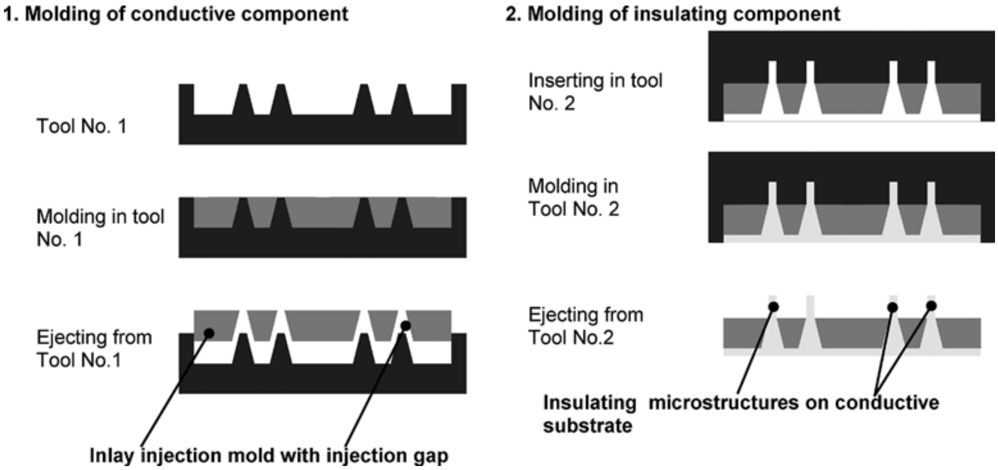

Fig. 4. Scheme: Manufacturing of two-component injection molded preforms

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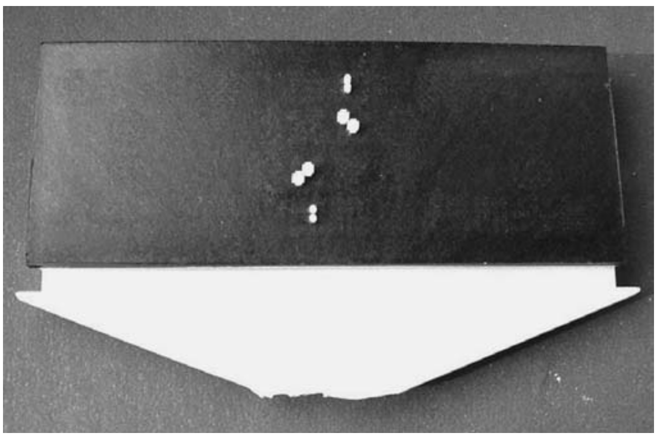
Micro powder injection molding

Presently, micro injection molding can be regarded as well established for polymeric materials, but many applications demand for material properties (mechanical, chemical, thermal) that polymers cannot provide. The adaptation of powder injection molding well known from macroscopic manufacturing of metal and ceramic devices to microtechnology represents a promising approach to solve this dilemma [5, 6].



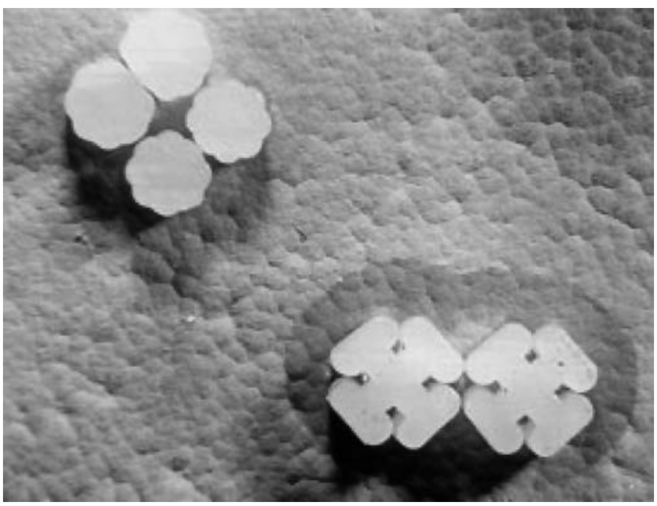
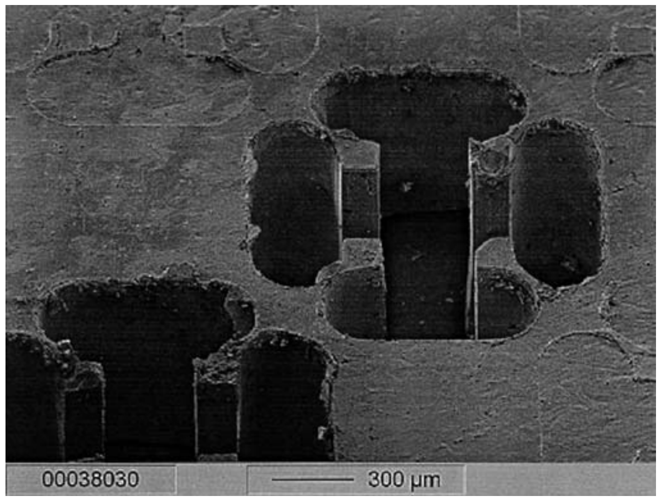


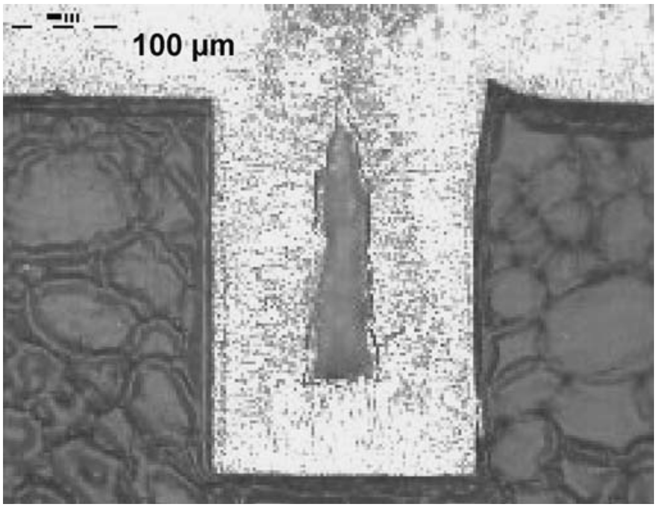
Fig. 5–7. Two-component preform, POM on PA 12-C (above); electroplated Ni surrounding insulating microstructures (middle); SEM imagine of the final metal samples, max. AR of the Ni-body 40 (bottom)

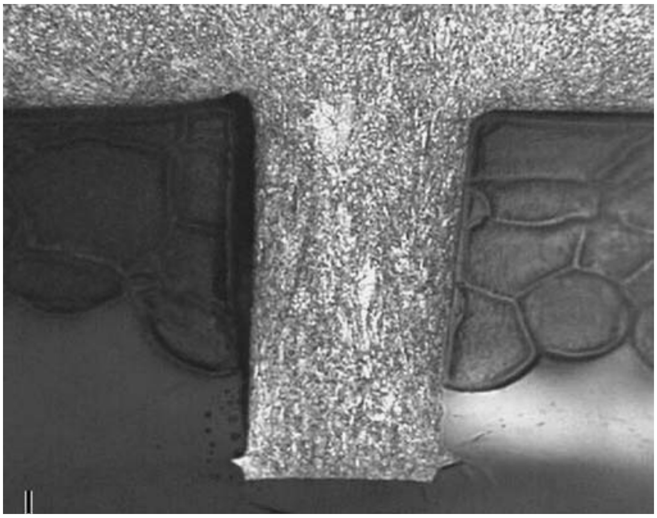


Figs. 5–7. Continued

Micro components can be made of metal (e.g. carbonyl iron, 316L) or ceramic (e.g. aluminium/zirconium oxide) from commercially available feedstocks. Different devices with minimum wall thicknesses of 30 µm and aspect ratios in excess of 10 have been manufactured. The best surface qualities were obtained with ultrafine ceramic powders, depending on the surface roughness of the mold inserts used.

Possible practical applications for micro powder injection molding (MicroPIM) are the manufacturing of components for micro gearwheel pumps made of zirconia for handling very small volumes of hazardous or corrosive fluids (Fig. 10). Further examples would be micro molds made of steel 17–4PH to be applied as high resistive form cavities in future replication processes. Micro samples (tensile and bending specimens) for mechanical tests in the submillimeter range have been produced (Fig. 12). First results for zirconia samples with a cross-section of 200 µm × 200 µm were 2100 MPa three-point bending





Figs. 8 and 9. Cross sections of Ni-deposits in 1-component isotropical conductive perform (above) and metal deposition in a 2-component preform with conductive substrate and insulating microstructures (bottom)

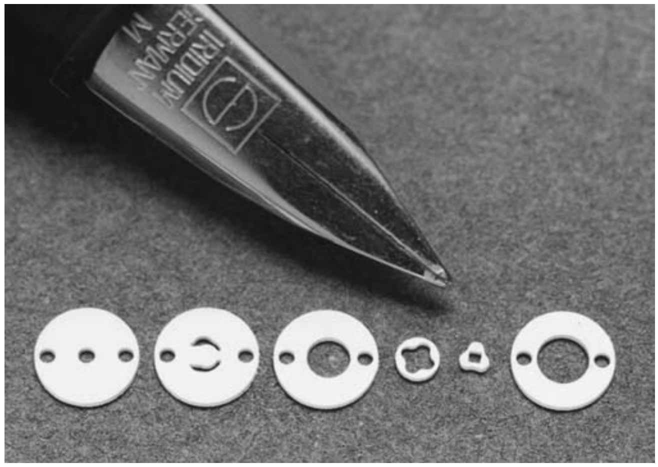
strength which is significantly higher than for macroscopic samples. As a consequence, choices of the right materials have to follow different rules compared to our macroscopic world.

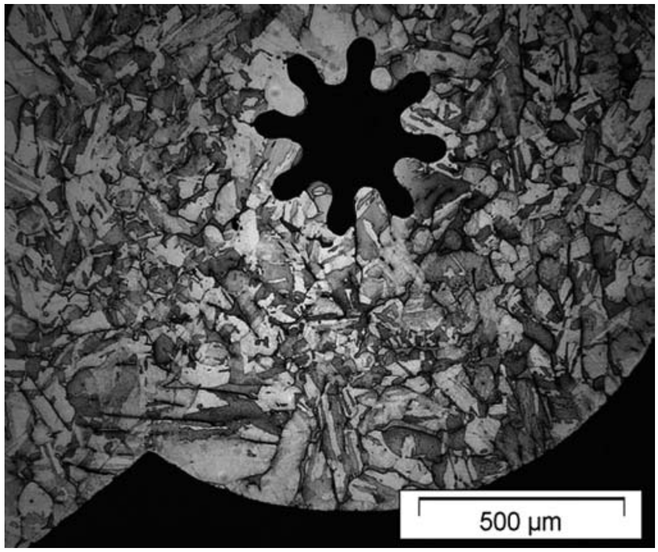
5 Outlook

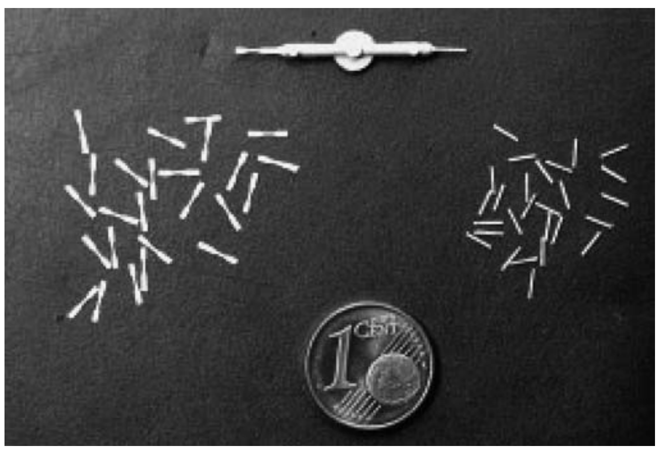
As described above, the technology of micro injection molding exhibits a great potential for large scale production of micro components.

Table 1. Technical data of micro powder injection molding as a function of the powder used

Material	d_{50} (µm)	Max. aspect ratio	Min. structural detail (µm)	Density (% theo.)	R_{max} (µm)
Carbonyl-Fe	1.5	10	50	95	4
316L	4.5	10	50	97	8
Al_2O_3	0.4–0.6	>10	<20	97	3
ZrO_2	0.2–0.4	>10	<3	99	<3







Figs. 10–12. Examples for MicroPIM. Components for annular gearwheel pumps made of zirconia (above), micro steel molds which shall be used in replication tools (middle), tensile and bending test specimen made of zirconia (bottom)

Especially the wide range of materials as well as the possibility of manufacturing multi-component devices have to be mentioned. In order to enhance the performance capability of these techniques, further materials and process development is going on.

It was shown that metallic micro structured components of LIGA-similar high aspect ratios can be obtained by metal deposition in injection-molded 2-component polymer preforms, composed of micro structured polymer patterns positioned on conductive polymer substrates. The type of conductive fillers in the polymer materials determines the characteristics of nucleation, growth and electroforming of metal microstructures.

For micro powder injection molding, these experiments will deal mainly with the utilization of very fine metal powders, as well as near-nano powders in case of ceramic materials. As an interesting combination and further process diversification, micro two-component injection molding using ceramic or metal feedstocks represents an ambitious future task.

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