Micro Precision Parts produced by Powder Injection Molding

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Abstract

Following the worldwide trend of miniaturization micro powder injection molding (MicroPIM) has already reached a remarkable technological level. Smallest structural details of 10µm or even less can be realized and the range of materials spans from ceramics over steels to refractory metals. Part elaborateness and accuracy can be increased by adding an embossing step immediately after injection (compression powder injection molding).

Variants of MicroPIM allow for combination of materials with different, for example magnetical or electrical properties, in a single piece (2C-MicroPIM). A considerable economical advantage is the reduction of assembly costs.

Further on, micro inmold-labelling (IML-MicroPIM) offers additional possibilities for multi-functional devices: A PIM feedstock is injected on the back of green tapes filled with powder particles, too. Both sections are debindered and sintered as one piece to obtain a layered structure. As the tapes can be filled without causing the usual tremendous viscosity increase IML-MicroPIM allows for extended application of nano and/or functional.

Keywords: Micro powder injection molding, compression injection molding, two-component powder injection molding, micro inmold-labelling

1. Introduction

The global trend of miniaturization leads to impressive growth rates of the market volume for micro systems technology (MST) components. Related market researches predict considerable chances for market growth especially for products outside the silicon chip technology, i.e. products made of polymer, metal or ceramic materials. These devices have to integrate many different functions in the smallest possible space. Future application fields cover automobile technology, information technology, biological and medical technology and micro process technology (micro-chemistry).

Manufacturing of such MST components by micro injection molding offers an interesting opportunity especially in case of medium or large-scale fabrication. It is already established for polymer materials. Many MST applications, however, require better materials properties than polymers can provide [1, 2].

Therefore, the adaptation of the well-established powder injection molding (PIM) technology to the micro scale was obviously a promising solution (MicroPIM) as it allows for low-cost series production of components. It will considerably widen the materials spectrum of micro technology as nearly all metals and ceramics available as powders can be processed [3].

2. Micro Powder Injection Molding (MicroPIM)

Just like plastics injection molding, powder injection molding holds an uncontested position among the most efficient methods for manufacturing medium and large quantities of complex precision components. Therefore, adaption to micro fabrication was a logical consequence and since the late 1990´s a lot of attempts had been performed in institutes as well as industry.

As materials special powder fractions of carbonyl iron, steel (316L, 17-4PH), hard metal (WC-Co) as well as Al_2O_3, ZrO_2, and zirconium oxide-reinforced Al_2O_3 ceramics have been applied, just to mention a few. Binders used are quite similar to the ones in macroscopic PIM and consist of polyacetal or polyolefin/wax-based systems usually mixed with certain additives. Injection molding of the green parts is performed on modified small machines or units specially developed for micro replication. The micro components sintered without pressure reach theoretical densities of 97 to 99.5 %. Much more comprehensive descriptions of MicroPIM can be found, for example, in [4, 5] and some key data are given by table 1.

Tab. 1: Current status of micro injection molding technology for different classes of materials, determined by key data.

	Min. lat. dimensions [µm]	Min. details [µm]	AR sunken structures	Tolerances [%]	R_{max} / R_a * [µm]
Metals	30	10	> 10	± 0.5	7 / 0.4
Ceramics	< 10	< 3	15	± 0.1 - 0.4	<3 / 0.2
Polymers	< 5	< 0.1	25	± 0.05	0.05 / 0.05

AR = aspect ratio = ratio of structure height to width, * = depends on type of mold insert used

Just as state of the art in macroscopic PIM the linear shrinkage depending on the feedstock powder loading is in the range of 17 to 22 percent and can be compensated by dimensional oversizing of the micro cavities of the mold inserts. Of course, this procedure succeeds up to certain extent only and failures during shaping of the green bodies cannot be compensated later on. To achieve optimum replication even in the green state the so-called compression injection molding method might be an option. Therefore, comparative trials have been performed at KIT to access the degree of possible improvement for MicroPIM. Examinations were carried out using a typical MicroPIM feedstock filled with 50Vol% zirconia powder. To explore the influence of the compression step explicitly a filigree-patterned mold insert made by X-ray LIGA was applied. Using this arrangement a direct comparison between the test geometries replicated by mere MicroPIM and by MicroPIM plus compression step (Micro-CPIM) could be performed. SEM investigations showed that Micro-CPIM reaches a slightly higher replication quality compared to the conventional MicroPIM process, see Fig. 1. On the other hand, differences are marginal and might be a matter of importance for very small structures with high aspect ratios only. A more detailed description of the comparative trials can be found in [6].

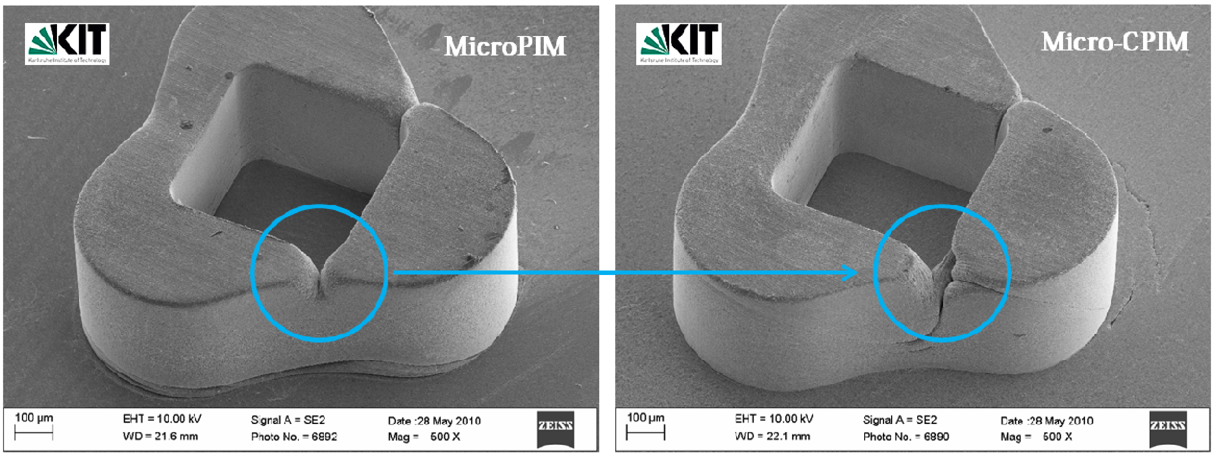


Fig. 1: Comparison of shaping quality with or without additional compression step by a sintered ZrO_2 test structure (housing for a rotary gear wheel pump, mold insert made by UV-LIGA). Results achieved with conventional MicroPIM process (left) and by applying compression MicroPIM process conduct (right).

3. Two-component Micro Powder Injection Molding (2C-MicroPIM)

Due to the high and increasing degree of integration and functionality of MST products, multi-component injection molding can offer decisive benefits for micro fabrication.

Probably the most important objective is the saving of mounting steps, especially if it is taken into consideration that handling of micro-sized components is more complicated than that of conventional-size items so that reduction of assembly efforts is of much higher impact. A further important reason lies in the wide range of micro product applications which is opened by the possibility to combine materials with different or even contradictionary physical or chemical properties. Such combinations might be electrically conductive/insulating, hard/tough, magnetic/non-magnetic etc. In particular even new products can be created by an intelligent arrangement of the materials couples.

As a concequence of these strong arguments multi-component injection molding has already found its way into micro fabrication. This trend is not at least demonstrated by machine manufacturers offering special 2-component micro injection molding units, e.g. the 2K formicaPlast® offered by DESMA TEC [7]. These industrial developments had been accompanied by extensive research in public institutes [8, 9, 10].

If micro multi-component injection molding shall be merged with PIM a few additional hurdles have to be cleared, especially the essential demand that the different materials not only have to be joined during injection but much more this composite has to be preserved during both debinding and sintering. The latter means that sintering temperatures and shrinkage rates have to be adjusted carefully. For this purpose, powder loading, powder particle size and sintering profile are the most important thumbwheels. If all these necessities have been considered, fixed or movable bonds can be generated. An early study on 2C-MIM for fixed joints can be found in [11] whereas movable bonds are described in [12].

Due to the obvious advantages 2C-PIM is already under development for micro applications. Examples can be found in [13] describing e.g. two-component CIM of heating elements or in [14] for micro gear wheels consisting of combinations of alumina and zirconia, both as fixed or movable bonds. Outside of Karlsruhe Institute of Technology, 2C-PIM is, for example, under investigation at Fraunhofer IKTS in Dresden and Fraunhofer IFAM in Bremen. While the former deals with 2C-MIM [15], the latter concentrates on ceramic systems above the micrometer range mainly for the automobive and railroad industries [16]. To obtain permanent connections between ATZ and ZTA ceramics, intermediate layers of ceramic sheets are inserted. Thus, excessive concentration gradients can be avoided [17]. Moreover, interesting findings were obtained on metal-ceramic compounds recently. Among others, co-metal powder injection molding is also being researched into at State Key Laboratory of Powder Metallurgy at the Central South University in Changsha (P.R. China). There, metallic gear wheels with a so-called skin-core structure were manufactured. For better distinction, their core material was enriched with 1 % commercial graphite [18].

4. Inmold-labelling MicroPIM (IML-MicroPIM)

For many technical products it is more common than exceptional that the surface has to have other properties than the core section. There are quite many methods to generate such gradients or even layered structures. In case of polymer replication variants like Sandwich-molding or Inmold-labelling are related to this objective. The latter uses polymer foils or film to be fixed in the tool and subsequent injection resin from the back. Combined with MicroPIM it results in a relatively complex process conduct named micro inmold-labelling (IML-MicroPIM) which combines powder filled tapes with PIM feedstocks. It´s basic principle is that a PIM feedstock is injected around green films placed in a molding tool and filled with powder particles [19]. Both partial sections are debindered and sintered at a time to obtain a layered structure. If the tapes and the feedstocks are filled with different kind of powders, this method offers additional possibilities for multi-functional devices, see Fig. 2. Additionally it allows for extended application of nano and/or functional materials as the tapes can be filled causing less tremendous viscosity increase compared to PIM feedstocks.

Performing IML-MicroPIM, however, is bound to some basic conditions. Probably the most important one is that the shrinkage of the injection molded section during debinding and sintering must be adjusted to the shrinkage behaviour of the tapes. This is usually achieved by using blends of powders with different particle sizes and different solid loadings of the tapes or feedstocks, respectively. In this regard, IML-MicroPIM is quite similar to the 2C-MicroPIM manufacturing of fixed connections. Furthermore, the types of polymers used for the thermoplastic feedstocks must be adapted to the polymers used in the tapes for simultaneous debinding. Special care must be taken for fixing of the tape in the mold - preferably by means of a special handling device - before the injection of the feedstock starts. By subsequent injection molding the same or another type of material will be connected to the tape. The replication parameters will have to be adjusted to the demands of both green tape and high shaping accuracy.

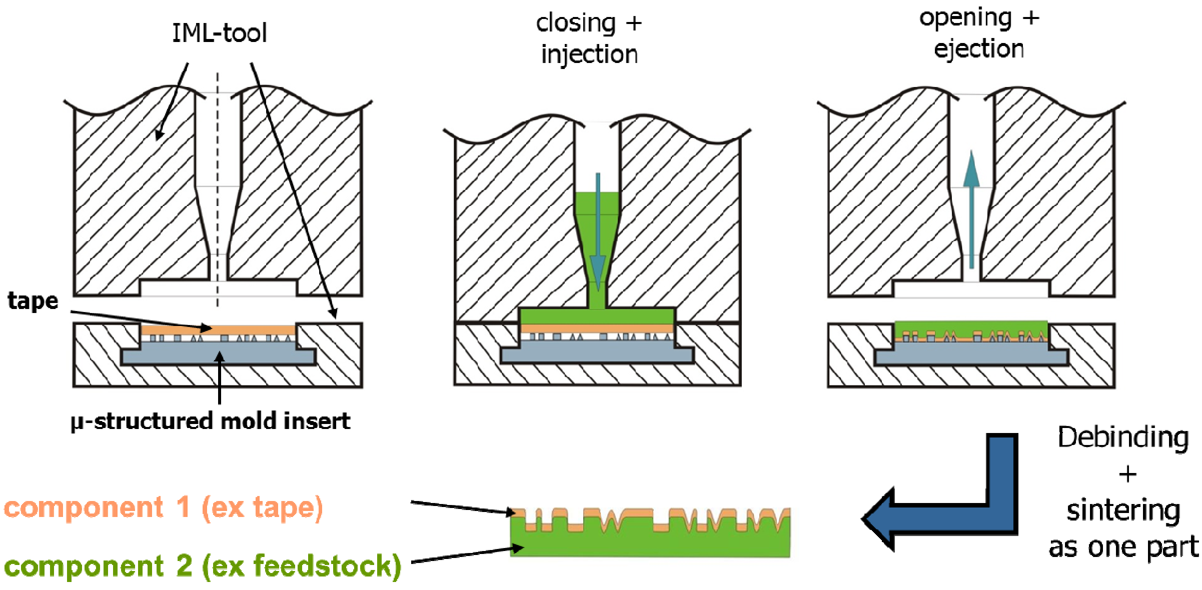
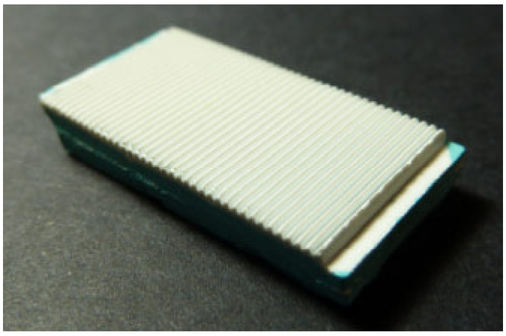
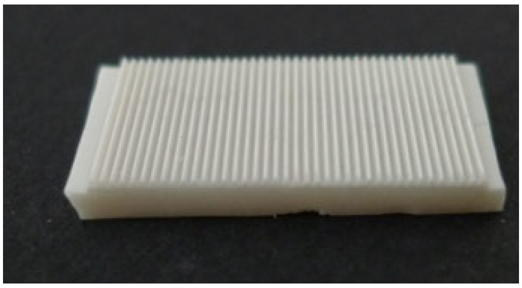


Fig. 2: Schematic outline of the IML-MicroPIM process. The shaping force which presses the material into the micro cavities of the mold insert might be raised by either the injection pressure or by an additional compression step (see chapter 2).

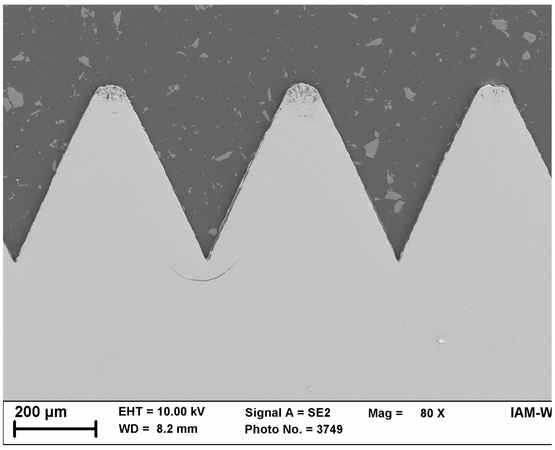
Further demands during process development are the comprehensive investigation and the accuracy of the 3D microstructures of the merging area between the label section and the injected feedstock, see Figs. 3-6. These examinations have to be carried out with both green and sintered samples [20].

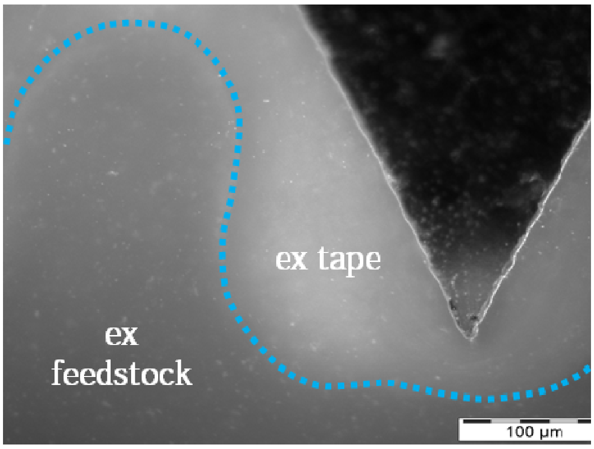
Development of micro inmold labelling combined with PIM is presently carried out within the EU-funded "Multilayer" Large Integrated Project (FP7-NMP4-2007-214122).





Figs. 3, 4: Ceramic green body made by IML-MicroPIM, the tape carries a zig-zag structure of approx. 550µm in height, the PIM feedstock coloured in light green is hardly visible on the back and the corners (left); same part after debinding and sintering, former tape and feedstock showed a tight junction, due to the sintering shrinkage height of the zig-zag structure dropped back to approx. 395µm (right).





Figs. 5, 6: Cut view of the zig-zag structure of a sintered sample, although the junction between tape and feedstock occurs as tight in general slight delamination at the bottom are visible (left), bottom section with the former boundary area between tape and feedstock marked by the dotted line (right).

Outlook

MicroPIM together with its sub-variants clearly represents a constantly advancing manufacturing technology from both the economical and technical point of view. Current R+D trends concern dimensional accuracy and surface quality which are determined significantly by the particle sizes of the primary powders used: Progress of MicroPIM requires finer powders which - in case of ceramic feedstocks - implies the tendency towards ultrafine or even nanoscale particles. To avoid tremendous increases in viscosity bi-modal compositions of conventional- and nano-size particles deemed to be a promising approach.

The various sub-variants of micro powder injection molding with resins and/or tapes merging only in a microscale area represent a promising branch of technology, too. A very important driving force, of course, is to save assembly costs. However, the creation of new product capabilities by combining materials with different - sometimes even contradictionary - properties shall not stand in the background.

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