SPECIAL FEATURE

Opportunities for producing dimensionally enhanced powder-injection-molded parts

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During the recent decades, powder injection molding has achieved a significant position as a manufacturing technique for high value-add products. For further progress, the improved dimensional accuracy of the sintered parts is of considerable importance. Investigations into meeting this demand through an enhanced process conduct comprising an additional compression step after cavity filling were performed. To achieve improved cavity filling and investigate influencing parameters, a demonstrator design was developed which enabled the generation of thin membranes by controlled piston movements. The combined injection and embossing process reached replication accuracies of ±0.15 to ±0.4%. An interaction between membrane quality and the compression parameters could be asserted. Moreover, the additional compaction step allowed for reduction of the minimum membrane values to about half of the thicknesses feasible by unmodified PIM processes.

Objectives

In the recent decades, powder injection molding (PIM) has achieved a remarkable status in large-scale fabrication of high-value products. The reasons for this considerable rise mainly lie in the high economic efficiency and the capability for processing a wide range of metal and ceramic materials. For example, latest trials aimed at the processing of high-entropy alloys which offer a remarkable performance of material properties.

A further important benefit of PIM is the capability for near-net-shape manufacturing. However, there are still certain drawbacks which limit the applicability of PIM [1–4]. One of these restrictions concerns the dimensional accuracy of the final sintered parts which is often not suitable for high value-add products and thus requires costly re-working procedures [5–12]. The main reason for this drawback lies in the hardly controllable sintering procedure, i.e. the debindered parts undergo densification and shrinkage without dimensional constraints. Therefore, density gradients, internal stresses, and other inhomogeneities might cause significant dimensional deviations or even distortions.

The usual remedy is to obey certain layout rules while designing the part geometry. One of these guidelines says that variations in the wall thickness should be kept at a minimum [13,14]. Unfortunately, many applications impede adherence to this rule. To make things worse, in many cases, the most filigree sections are the functional ones determining the applicability of the entire product.

Therefore, studies of accuracy-affecting parameters in the case of parts with serious wall thickness differences were carried out. Additionally, a modified tool technology was developed allowing for the implementation of additional compression steps to obtain better dimensional constancies of the final parts.

Layout of the experimental set-up

For the intended examination of the filling behavior and dimensional accuracies of parts with considerable wall thickness variations, a new demonstrator design was created: It is characterized by a relatively voluminous cylindrical ring with a thin membrane as quasi sounding board on the top (see Fig. 1). The task was to fabricate these membranes as thin as possible and to investigate the square sections and reproducibility of the thickness profiles.

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0026-0657/ http://dx.doi.org/10.1016/j.mprp.2017.06.071

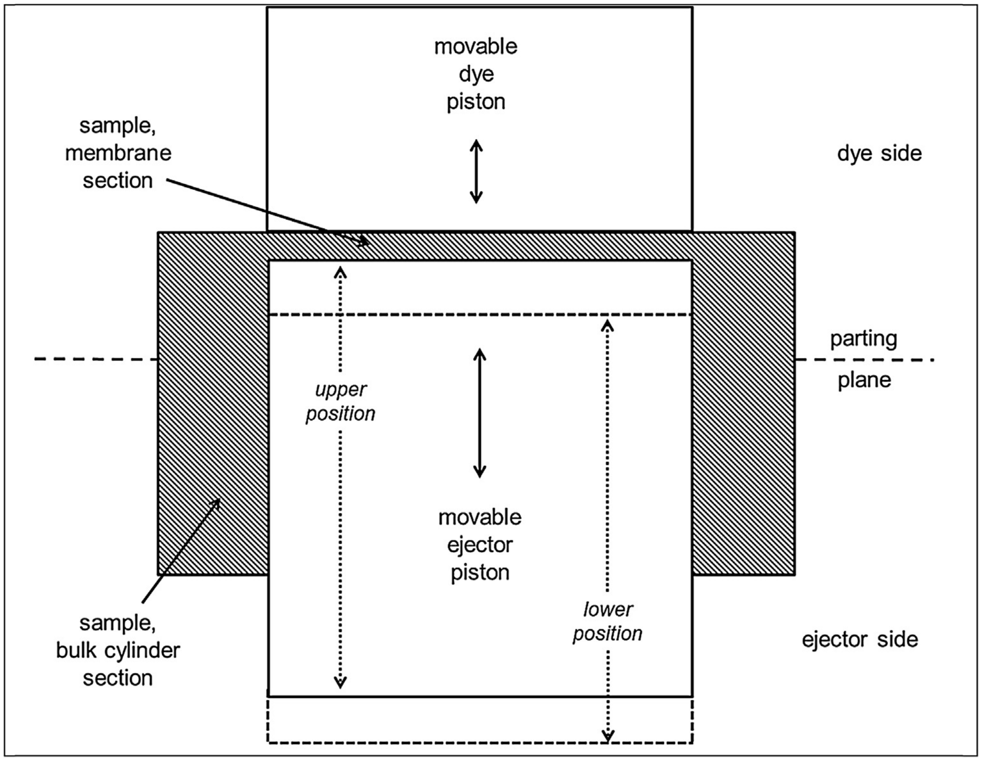

FIGURE 1

Scheme of the new demonstrator design consisting of both bulky cylinder and thin membrane sections. Whereas the outer diameter in the green state was 4.8 mm, the membrane thickness can be varied in a range of 600 μm to less than 200 μm. Additionally, the lower position of the ejector piston is indicated by a dashed line. The pistons themselves allow for moving up and down, thus varying the volume of the cavity. After the injection step, the feedstock can be compacted further.

The twin-piston tool applied here had been already used for previous experiments [15,16]. During these experiments, the pistons enabled a subsequent compression of the feedstock in the membrane cavity, thus enabling a defined adjustment of the membrane thickness. Further information about the tool design and functionality can be found in [8].

Whereas the volume of the demonstrator itself was 0.065 cm^3, the entire molded part had a volume of ca. 1.6 cm^3. Additionally, an extension factor of 1.167 had to be taken into account to compensate the sintering shrinkage. The annular cylinder was equipped with auxiliary features to facilitate mounting in test modules at a later stage. Following the experience of previous R&D projects, melt temperature was set to 165 °C and tool temperature to 60 °C.

The next task was to determine the best suitable design of the runner system and to identify critical flow conditions likely to occur. For both purposes, simulations were carried out using the software program MOLDFLOW Autodesk. In order to fill the cavity as symmetrically as possible, two different layouts of the runner system had to be considered [8]. The square-cut areas in sum were the same for both variants. For the four-point runner system, this means that surface and wall effects played a disproportionately larger role compared to the two-point design. Usually, such a constellation leads to higher shear stresses but the simulation results showed that shear rates would be in an acceptable range. Therefore, due to the less pronounced welding lines, the four-point design was finally chosen for the tool.

Experiments and results

For the experiments described here, a typical 17-4PH micro powder injection molding feedstock was applied. Solid content was 63 vol% of the stainless steel powder with a mean particle diameter of ca. 4.5 μm. As binder, the so-called GoMikro system developed at KIT was applied. It contains 50% paraffin wax, 45% polyethylene, and 5% stearic acids plus certain additives mainly for improved powder dispersion.

The injection molding machine was an Arburg Allrounder 420 C equipped with a 15 mm PIM injection unit.

It was not surprising that complete filling of the membrane by a simple, i.e. unaltered, injection of the feedstock was clearly limited. Several trials including parameter variation showed that thicknesses down to approximately 400 μm were feasible. In the case of smaller gaps, however, filling became incomplete. The injection molding process itself could be performed quite accurately. For example, the outer diameter of the sintered cylinders varied in a range of only ±0.15%.

For further reduction of the membrane thickness, the pistons were used so as to achieve a modified process conduct:

- pull back the pistons to open a relatively wide membrane cavity;
- inject the feedstock into this cavity;
- push the pistons forward until the final membrane thickness is reached.

The green bodies produced by this novel method were debindered and sintered using typical microPIM parameter sets, i.e. no

Please cite this article in press as: V. Piotter, et al., Met. Powder Rep. (2017), http://dx.doi.org/10.1016/j.mprp.2017.06.071