The Effect of Powder Loading on Dimensional Variability in PIM

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Abstract

Dimensional variation in powder injection molding (PIM) is one of the key issues for broadening the use of this process to a greater number of applications. Process capability has only been addressed by a few studies in the technical literature and manufacturing details still remain proprietary. In this study, the dimensional variability of a metal injection molding (MIM) process for 316 L stainless steel is reported. The main variable investigated in this part of a series of experiments on variability is the powder loading of the feedstock. A design of experiments (DOE) approach is used to statistically analyze the effect of the powder loading on the variability of multiple dimensions of a typical MIM component after molding and debinding.

Introduction

As a net-shape process, powder injection molding (PIM) has very high demands on dimensional precision and variability. In this respect, the powder loading of a feedstock plays a key role in the powder injection molding process. On the one hand, it has to be as high as possible in order to minimize shrinkage during debinding and sintering; on the other, if it is higher than the critical powder loading, this may result in increased wear and process instability. Too high or too low a powder loading can therefore have a detrimental effect on the dimensional precision and variability of an injection molded component.

The importance of the powder loading for obtaining a feedstock with advantageous properties has been widely discussed in the literature [1]. White and German [6] studied solids loading and its effect on dimensional variation. The 316L feedstock used in their experiment had solids loadings of 65, 67 and 69 vol%. It was found that as solids loading increased, the shrinkage and dimensional variation decreased. Using *in-situ* molding techniques, parts were sintered to a tolerance of less than ±0.1% for all dimensions.

The dimensional capability of powder injection molding is often cited as ±0.3% (Kulkarni [2], for example), ranging from ±0.15% to ±0.5% (Vonderohe *et al.* [3]), compared to conventional P/M processes that are usually accurate to ±0.1%. The dimension of a part with a nominal dimension of 10 mm and a tolerance of 0.3% would therefore range from 9.97 to 10.03 mm. Dimensional tolerances of ±0.3% are the industry standard, although Hens and Grohowski [4] report tolerances better than ±0.1%. However, few technical details have been provided with these statements.

Experimental Design

Two different solids loadings (65% and 60%) for two different powder types (Type 1: spherical, Type 2: irregular) were investigated in this portion of the study. In the overall project, other process parameters are investigated in a DOE (design of experiments) study, where a wide variety of parameters including powder characteristics, compounding techniques, molding parameters, and sintering parameters are studied. In this part of the DOE, two different powder types (different particle shapes) and two different powder sizes were examined in the green and debound states and their dimensional variability was evaluated.

Before the actual DOE experiments were started, a baseline process for the experiments was set up. In this baseline process, a wax/polymer-based binder system was used, compounded in a twin-cam compounder, molded on a hydraulic 55 ton injection molding machine, and solvent-debound in heptane.

Figure 1 shows a drawing of the PIM component used for this study. With each DOE condition, the dimensions of 120 parts were measured using a SmartScope and their variability was calculated. A gauge R&R was carried out prior to the experiments in order to check the repeatability and reproducibility of the dimensional measurements. The error was found to be within the acceptable limit and independent of the operator.

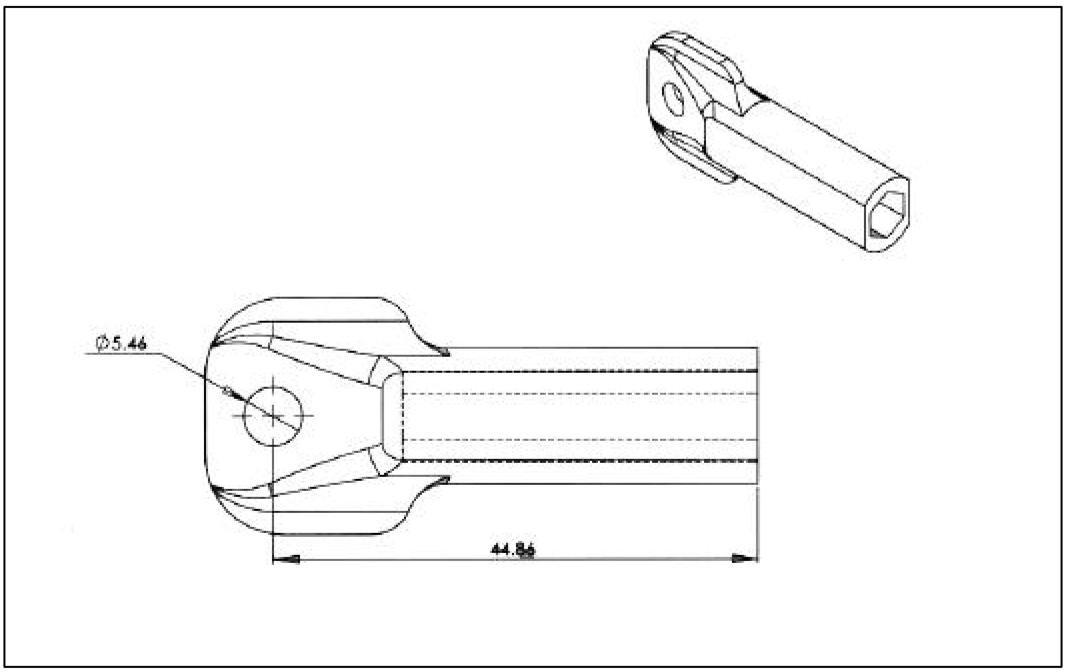

Figure 1: Drawing of the PIM component

As-Molded Components (Green Parts)

The dimensions (length, core diameter) of the components were measured after molding and solvent debinding and a statistical analysis was performed. The dimensions studied were the length of the parts (tool dimension 44.86 mm) and a core hole diameter (tool dimension 5.46 mm).

Figures 2 and 3 show the dimensional variation in the core hole and the component length of the green components, respectively. The graphs show a line drawn across the box at the median. The bottom of the box is at the first quartile (Q1) value, and the top is at the third quartile (Q3) value. The whiskers are the lines that extend from the top and bottom of the box to the adjacent values. The adjacent values are the lowest and highest observations that are still inside the region defined by the following limits:

lower limit: (Q1 - 1.5 (Q3 - Q1))

upper limit: (Q3 + 1.5 (Q3 - Q1)).

Outliers are points outside of the lower and upper limits and are plotted with asterisks (*). Figure 2 shows that for the core hole all the outliers are smaller than the mean dimension, which is probably due to the occurrence of flash.

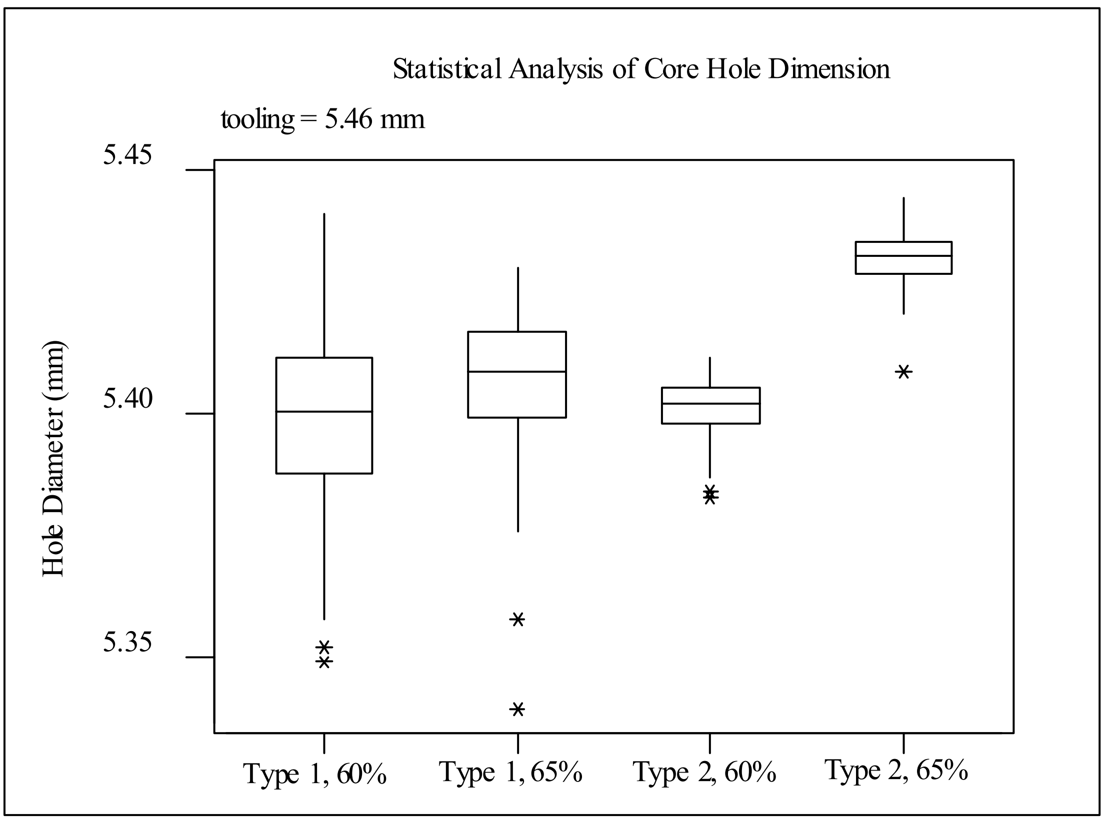

Figure 2: Variability of core hole dimension (green components)

For both powder types, the shrinkage of the molded components with 65% solids loading was smaller than that of the components with 60% solids loading (see Tables 1 and 2). However, the dimensional variation for Type 2 powder (irregular) was substantially smaller than that for Type 1 powder.

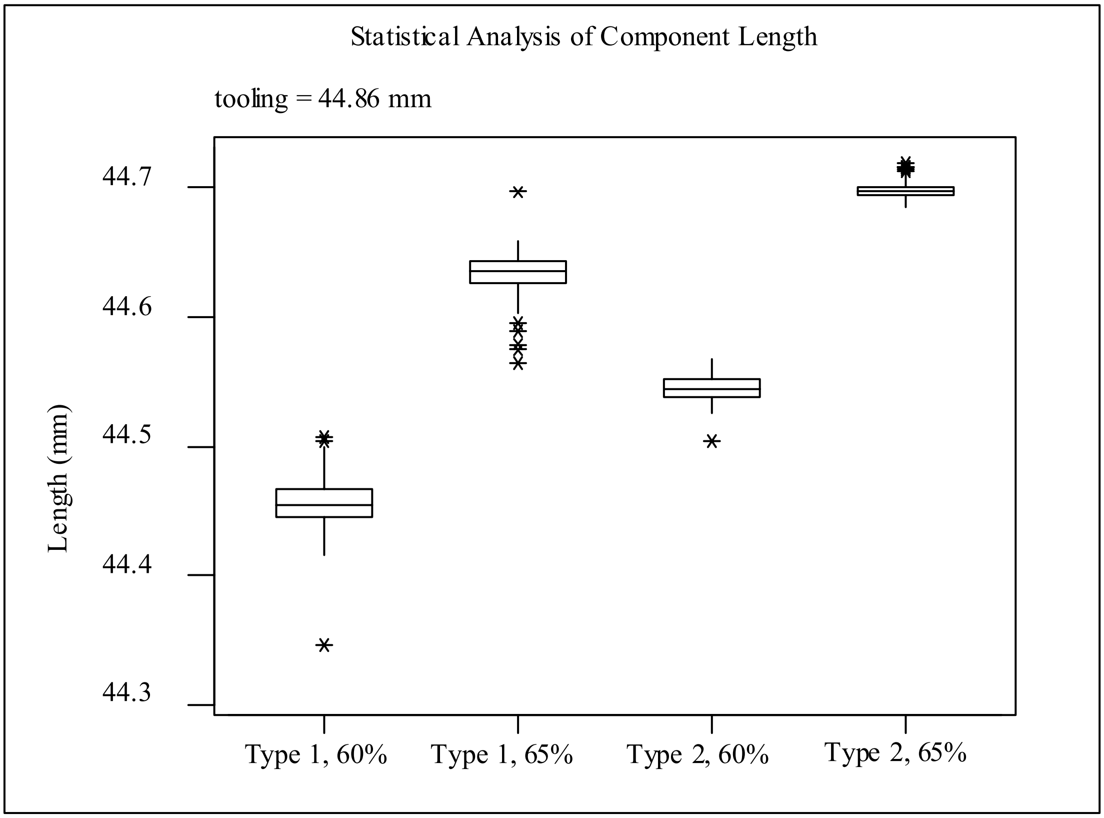

Figure 3: Variability of length (green components)

For both powder types and solids loadings, the variation in the length was smaller than that in the core hole. The experiments showed a difference between the average shrinkage of the core dimension and the shrinkage of the length dimension of the component for both solids loadings. Tables 1 and 2 summarize the average shrinkage and dimensional variation of the different powders at different solids loadings.

Table 1: Shrinkage after molding and debinding

Feedstock	Core hole (green) [%]	Length (green) [%]	Length (debound) [%]
Type 1, 60%	1.12	0.90	0.85
Type 1, 65%	0.99	0.50	0.44
Type 2, 60%	1.08	0.70	0.64
Type 2, 65%	0.54	0.35	0.30

Table 2: Dimensional variability after molding and debinding

Feedstock	Core hole (green) [%]	Length (green) [%]	Length (debound) [%]
Type 1, 60%	0.33	0.05	0.06
Type 1, 65%	0.28	0.04	0.05
Type 2, 60%	0.11	0.02	0.04
Type 2, 65%	0.10	0.01	0.02

Solvent-Debound Components

A very similar dependence was observed for the solvent-debound parts as was observed for the green components (Figure 4). The variability after solvent debinding was observed to be slightly higher than after molding. This behavior is independent of the powder loading studied. The dimensional variability at 65% solids loading was, as already observed in the molded state, smaller than at 60%. This observation was independent of the powder type (round particles or irregular particles) and could be explained by the fact that at higher solids loadings the increased number of particle-particle contacts results in better shape retention of the component. For both 60% and 65% solids loading, a slight swelling occurred during solvent debinding which led to a decrease in the shrinkage of the components (see Tables 1 and 2). The swelling seems to be powder-independent and is therefore likely to be a binder-related process which caused a softening of the backbone binder component. Therefore, variability is also a result of the binder properties and composition.

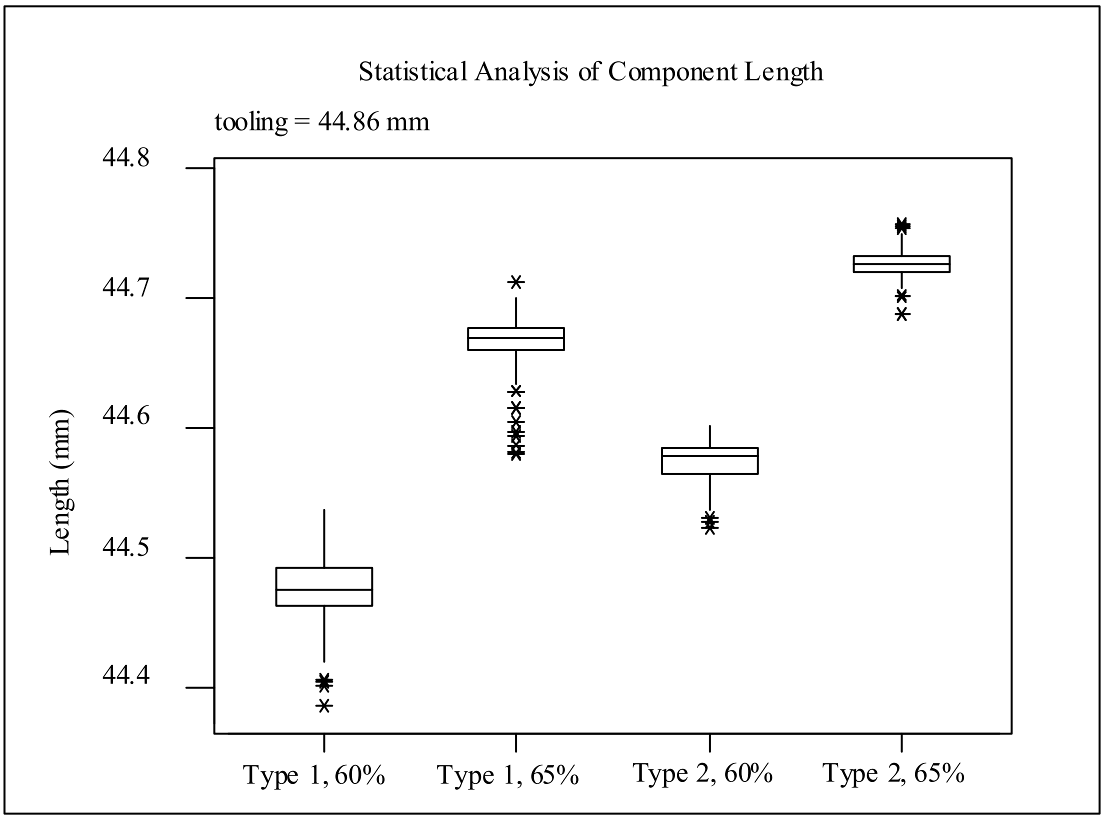

Figure 4: Variability of length (solvent-debound components)

Conclusions

Dimensional variability in the PIM process chain was studied in dependence on the solids loading of two different powder types. It was found that in the green and debound states both dimensional variability and shrinkage are smaller for higher solids loadings. Furthermore, components showed larger dimensional variability and less shrinkage after solvent debinding, suggesting that the components swell during solvent debinding, which increases variability. The shrinkage of a core hole dimension (and also its variability) was consistently larger than that of the component length, leading to the conclusion that the components are subject to anisotropic shrinkage.

References

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