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The Shrinkage Behavior and Surface Topographical Investigation for Micro Metal Injection Molding

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Abstract. Metal injection molding (MIM) is a near net shape manufacturing technology that can produce highly complex and dimensionally stable parts for high end engineering applications. Despite the recent growth and industrial interest, micro metal molding is yet to be the field of extensive research especially when it is compared with micro molding of thermoplastics. The current paper presents a thorough investigation on the process of metal injection molding where it systematically characterizes the effects of important process conditions on the shrinkage and surface quality of molded parts with micro features. Effects of geometrical factors like feature dimensions and distance from the gate on the replication quality are studied. The influence of process conditions on the achievable roughness for the final metal parts is discussed based on the experimental findings. The test geometry is characterized by 2½D surface structures containing thin ribs of different aspect ratios and thicknesses in the sub-mm dimensional range. The test parts were molded from Catamold 316L with a conventional injection molding machine. Afterwards, the parts were de-binded and sintered to produce the final test samples. Among the different process parameters studied, the melt temperature was the most influential parameters for better replication and dimensional stability of the final part. The results presented in the paper clearly show that the shrinkage in metal part is not uniform in the micro scale. It depends on the feature dimensions and also on the process conditions. A thin section of the part exhibits higher relative shrinkage compared with a thicker section. Based on these findings, it can be concluded that a micro part molded by MIM process will have higher relative shrinkage compared to a macro part made with the same process.

Keywords: Metal injection molding, Process condition, Shrinkage, Replication.
PACS: 81.20.Hy

INTRODUCTION

Metal injection moulding (MIM) combines the advantage of injection moulding and powder metallurgy [1]. The process utilizes a feedstock of micro metallic powder and a polymer binder that results into metallic products with density of about 98% of the solid material. The economic advantage of metal injection molded parts arises from volume production, near-net shape manufacturing, part complexity and dimensional stability [2]. Due to these process and cost advantages, MIM can be an extremely suitable process for mass production of metallic micro parts. The process has already found many applications in the area of micro manufacturing, but further research and through understanding of the effects of the process conditions on surface, shrinkage and other mechanical properties will open up exciting application areas for MIM. The aim of the current paper is to experimentally characterize the effects of moulding conditions on surface replication, moulding quality and part shrinkage in the micro dimensional level. Shrinkage is one of the critical issues for micro metal injection moulding. A special emphasis is given to study the shrinkage behaviour where the uniformity of the shrinkage and geometrical effects on the shrinkage are experimentally characterized. The effects of physical location of the moulding gate on shrinkage and surface quality are also studied.

MATERIALS AND METHODS

The test geometry used for the experiment was 2½D structures containing a number of thin ribs (walls/channels) having different thickness and aspect ratios. The dimensions and specifications of the part are shown in the Figure 1 (picture A and B- all dimensions are in mm). The parts were mainly divided in three different sections based on the distance from the gate, namely: close to the gate (cg), middle from the gate (mg) and far from the gate (fg). For some investigations an additional section – (mgt) was considered as this section had the thinnest wall thickness (150 µm) on the entire geometry. The sections are marked in the 2D drawing of the following figure and metrological investigations were carried out on these sections which will be discussed later.

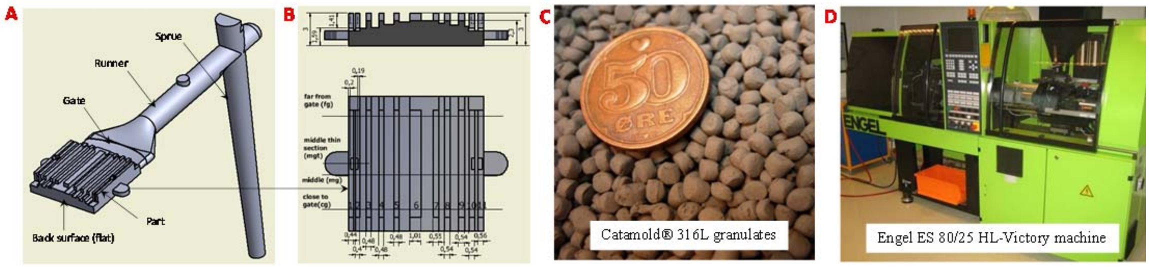

FIGURE 1. Test geometry used for the experimental investigation of metal injection moulding (picture A and B), Catamold grannulates (picture C) and injection moulding machines used for the experiment (picture D).

The material used for this metal injection moulding trial is Catamold 316L, a ready-to-mould and commercially available granulates from BASF, Ludwigshafen, Germany. After sintering, this material can produce parts in stainless steel 316L [3]. The machine used for moulding was an Engel ES 80/25 HL-Victory type machine with screw diameter of 18 mm. The standard Catamold granulates and injection moulding machine are also shown in Figure 1.

For the moulding of the channel part a “one-factor-at-a-time” approach was used. Different experimental runs were made by changing one parameter at a time. Table 1 lists the moulding parameters for different injection moulding runs. The injection parameters recommended by material manufacturer were termed as reference parameters and the part moulded with these parameters were named reference parts. In other three experimental trials melt temperature, mould temperature and packing pressure were changed one at a time keeping other parameters same as the reference parameters. The debinding and sintering processes were performed at Sintex A/S, Hobro, Jutland, Denmark. After moulding, debinding and sintering the part were ready for metrological investigation.

TABLE (1). Moulding plan and injection parameters used for the moulding of Catamold 316L.

	Experimental Runs			
Parameters	Reference parameters	High melt temp (200 °C)	High mould temp (138 °C)	Low pack pressure 600 bar
Melt Temp, (°C)	180	200	180	180
Mould Temp (°C)	128	128	138	128
Input Injection Speed (mm/s)	79	79	79	79
Packing Pressure (bar)	900	900	900	600
Cooling Time (s)	10	10	10	10

RESULTS AND DISCUSSION

Both the green and sintered parts are analyzed for roughness, shrinkage and morphological investigations. Figure 2 shows the pictures of test part. The part after moulding and before sintering is termed as green part and part after sintering is called sintered part. For the roughness measurement Alicona Infinite Focus was used. The flat back surface of the test parts were chosen for the roughness measurement (shown in Figure 3). For coordinate measurement an Optical Coordinate Measuring Machine (Optical CMM- Demeet 220) was used. For morphological and microscopic investigations a Scanning Electron Microscope (SEM- JEOL JSM-5000) and an Optical Microscope (Olympus GX 41) were used. The channel part contains 11 different channels. To avoid the redundancy of the measurement data, 3 different channels were selected and geometrical measurements were done in 4 different locations as mentioned before: close to gate (cg), in the middle of the part (mg), the thin section in the middle of the part (mgt) and far from the gate (fg). The measured feature was the width of wall no: 1, 2 and 3 for both green and sintered parts as well as to the relevant sections of the mould. Figure 1 shows the measured channels, positions as well as the nominal dimensions of the geometry. The measurements are presented with a code, for example W1cg (Wall 1 close to gate).

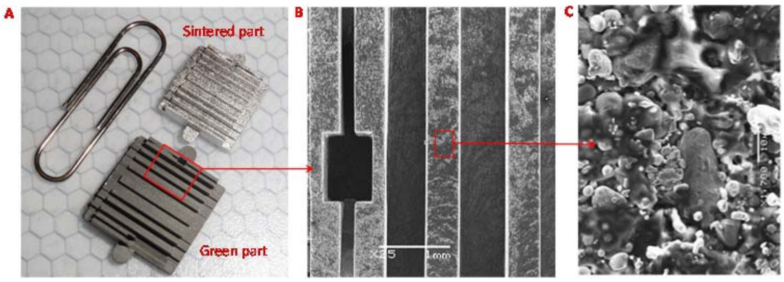

FIGURE 2. Test parts - green and sintered part (picture A), surface of a green part (picture B) and magnified view of the surface showing the distribution of the metal particles on the surface (picture C).

Investigation on surface roughness

As mentioned before for roughness measurements the flat back surface of the test geometry was chosen. Measurements were done in three different locations (as presented in Figure 3). Roughness measurement was done according to ISO 4288 standard.

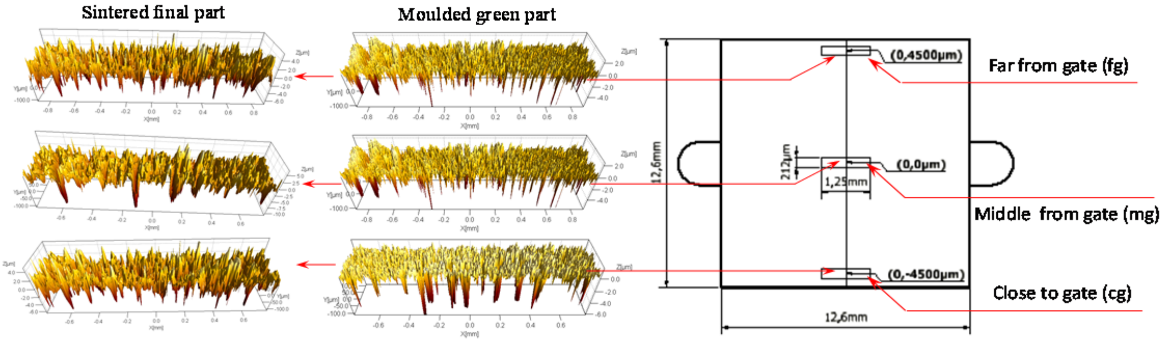

FIGURE 3. Roughness measurement positions and 3D views of the surface on green and sintered part.

For the analysis of the surface roughness two most relevant roughness parameters Sa and Sq were considered. Sa and Sq are the average and root mean square roughness respectively evaluated over the complete 3D surface. Figure 4 presents the comparative results of roughness values (Sa, Sq- plot A) for green parts, sintered parts and the mould. It is observed that the mould has the lowest roughness (Sa: 0.15 µm and Sq: 0.20 µm) and moulded green parts are rougher compared to the mould. There is a significant increase on the roughness values on the sintered parts in comparison with the green parts. The final metal part is about seven times rougher compared to mould surface and is about 1.5 times rougher compared to the green part. Roughness variation among different process condition is not significant but high mould and melt temperature tend to reduce the surface roughness compared to the recommended process conditions.

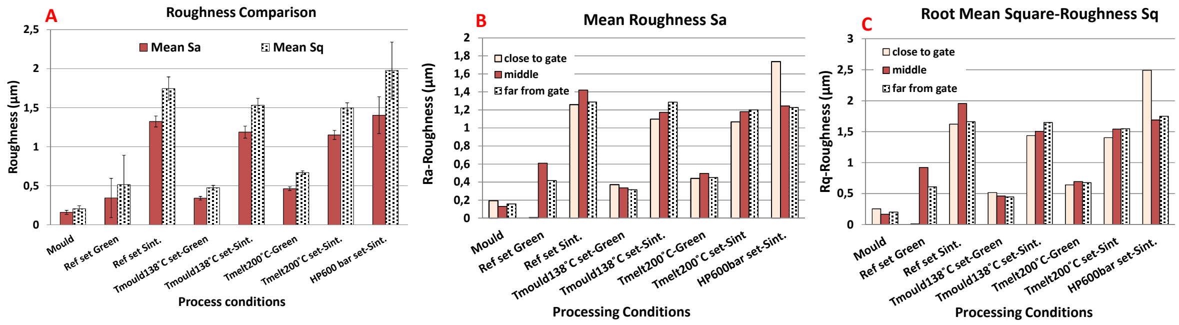

FIGURE 4. Results of roughness measurements on the mould, green and sintered parts for different process settings (plot A), roughness comparison among green, sintered parts and mould in three positions (plot B and C).

When the roughness in three different areas are compared, green parts show a higher surface roughness close to gate, the mould also has higher roughness close to the gate (presented in Figure 4- plot B and C). But the sintered parts do not share the same trend; the roughness at the distal section of the part is the highest in comparison with the two other sections in the parts. The source of this behavior originates from the distribution of metal particles in the polymer binder. The density of metal particles is lower at the far end of the part and the relative amount of plastic binder is higher. This is caused due to the heavy weight of the metal particles and inertia effect also due to the different flow characteristics of metal and polymer. Low density of the metal particles and higher percentage of plastic binder makes the part rougher following the steps of debinding and sintering.

Shrinkage investigation

The results of the coordinate measurement are presented in Figure 5 (plot A) where the widths of the walls are measured at various locations. The measurement shows that the width of the same channel is not equal at different sections of the parts (for example the measurement results of W1cg, W1mg and W1fg). The width of the wall is bigger close to the gate and less in the section far from the gate. This means, at the same channel of the final part, the shrinkage is higher at the far end from the gate and close to the gate the shrinkage is less. Among the different process conditions, the high melt temperature is found to be the dominating factor that can reduce the shrinkage. It is found that the highest shrinkage of the sintered parts moulded with higher melt temperature (Tmelt 200˚C) is 23.4% whereas the part made with higher mould temperature (Tmould 138˚C) and with reference parameters have a maximum shrinkage of 28.4% and 32.4% respectively.

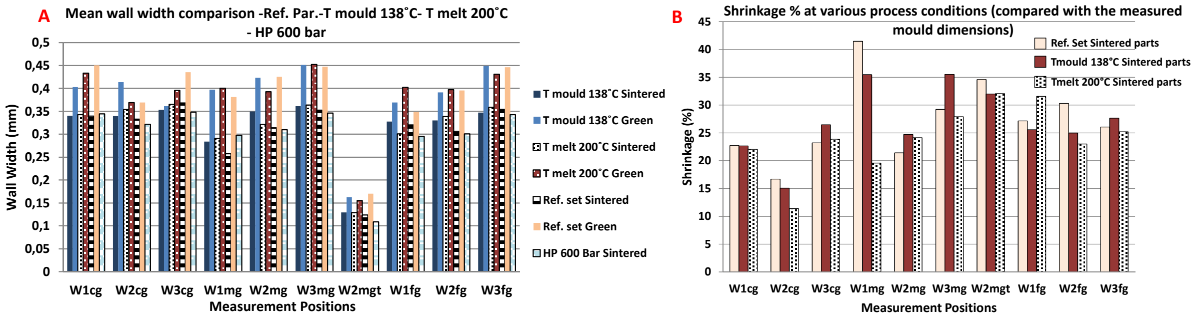

FIGURE 5. Results of CMM measurements on the channel widths based on different part location and different process conditions (plot A), Shrinkage comparison of sintered part made with different parameter with respect to measured mould dimensions (plot B) .

The percentage of shrinkage of the final sintered parts is presented in Figure 5 (plot B). Shrinkage percentage close to the gate is lower compare to the far section. Among different walls, the thinnest wall is wall 2 at the middle section (W2mgt) and the maximum amount of shrinkage for all different conditions is observed with this wall. The average shrinkage of this section is about 33%. The reason for high shrinkage with the thin channel is explained with the melt flow characteristics of the metal granulate. When melted granulates flow through a micro channel or thin channel the flow resistance is higher. This high flow resistance obstructs the entrance of metal particles but the polymer binder in the melt can flow relatively well in the narrow cavity or small part. Due to this, the narrow channels or micro cavities are filled with relatively higher amount of plastic material with less density of metal particles which at the end result into higher shrinkage of the sintered parts.

Morphological investigations

The cross sections of the sintered metal parts were examined under optical microscope to investigate on the porosity distribution. Figure 6 (picture A and B) shows the porosity distribution in the middle of the part at two different locations. Here no significant different in porosity distribution is observed- the porosity distribution observed close to the part surface and inside the core of the part is basically the same.

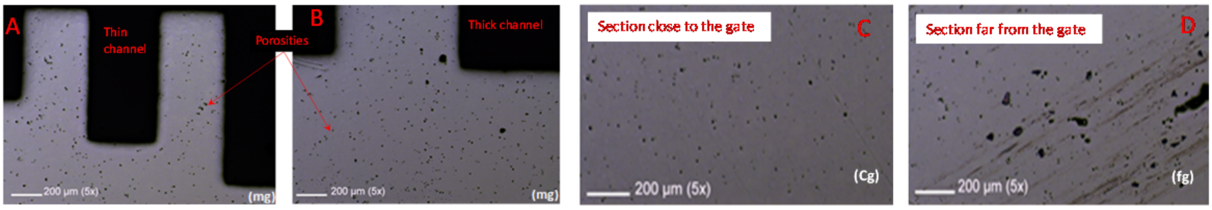

FIGURE 6. Porosity distribution in the middle section of a sintered part (pictures A and B). Pictures C and D show difference in porosity at two sections- the section nearing to the gate has much less porosity compared to the section lying far from the gate.

At different sections of the parts different degree of porosities were observed. For example picture C and D of Figure 6 shows two pictures at specific locations of the part: one close to the gate and other far from the gate. Cross section located far from the gate has more porosity compared to the section located far from the gate. This fact agrees with the observation made on the green parts where relative amount of binding polymer was higher in the sections laying far from the gate. Presence of more binding material in the metal matrix results in the higher amount of porosity after debinding and sintering.

CONCLUSION

This paper investigates on the surface properties and shrinkage behaviour of injection moulded metallic parts in the micro dimensional level. The results presented in the paper clearly show that the shrinkage in metal part is not uniform at the micro scale. It depends on the process conditions; it also depends on the feature dimensions. A thin section of the part exhibits higher relative shrinkage compared with a thicker section. From this observation, it can be concluded that a micro part molded by MIM process will have higher relative shrinkage compared to a macro part made with the same process. The morphological investigation shows difference in morphological structures depending on the distance from the gate. High melt and mould temperature help to reduce the porosity and the part shrinkage. The amount of porosity far from the gate is significantly higher compared to the section close to the gate of the part.

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