Experimental study on the demolding force in Micro Metal Injection Molding

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Abstract

In this paper experimental study on the demolding force needed to eject micro structures in Micro Metal Injection Molding (μMIM) is conducted. Injection molding is done on a variotherm mold mounted on a Battenfeld injection molding machine and demolding force measurement is done on an Instron tensile testing machine. Green part is a round disc of ϕ16 mm and thickness 1.5 mm with an array of ϕ100 μm × height 200 μm micro structures at the center. The experimental results are in good accordance with the previous analysis results.

Index Terms

Demolding, micro structure, μMIM

I. Introduction

Currently the production of micro structures and microparts is dominated by materials based on silicon or polymers [1]. Plastic micro structures and microparts can be successfully and economically produced by micromolding technologies such as micro injection molding and hot embossing. However, for many applications, more challenging production of metal micro structures and microparts are required due to their superior mechanical properties and thermal stability. Micro metal injection molding (μMIM) is a potential process for the mass production of complex metal micro structures and microparts [2-5]. Some application areas are in micro drive technology (microgear), medical technology and hard metal mold insert for micro plastic injection molding [3-5]. Micro metal injection molding (μMIM) is a miniaturized variant of conventional metal injection molding process (MIM). It has the same four main processing steps as MIM (mixing, injection molding, debinding and sintering), as illustrated in Figure 1[6]. The metal powder is mixed with a binder system that mainly includes thermoplastic polymers. The mixture called feedstock is then injection molded (similar to plastic injection molding) into the required shape, the binder removed (debinding) and the powder sintered to full density incorporating certain shrinkage.

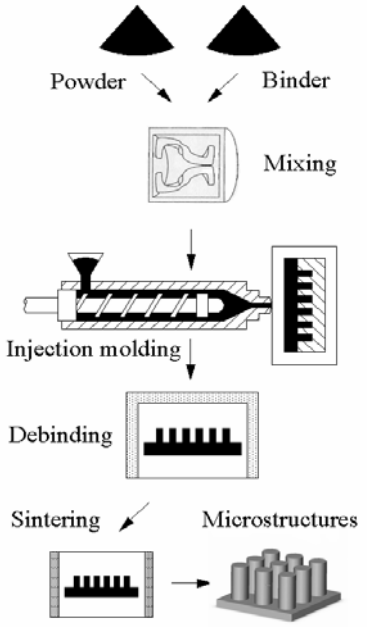

Figure 1 Processing steps of μMIM

In μMIM injection molding is a key step in which high quality green (i.e. molded) part and micro structures must be injection molded, otherwise the subsequent two processing steps can not be continued. Further, the defects in subsequent processing steps may also originate from the injection molding step in case of poor injection molding quality.

Experimental work found that during demolding (ejecting green part out of mold cavity) the micro structures broke easily, especially in the case of high aspect ratio micro structures [1, 7]. The fabrication of high aspect ratio micro structures fails due mainly to the feedstock which is too soft or brittle to withstand the demolding force [1, 2]. Additionally, the vertical sidewall of the microcavity and the lack of draft angle (i.e. the angle of taper that facilitates removal of the micro structures) on the microcavity increase the difficulty in demolding. Only with small sidewall roughness, can demolding be carried out without any draft angle [1]. To facilitate demolding, different strategies were investigated to improve the yield of the μMIM process. Reducing the surface roughness of the sidewall of the microcavity is one possibility, as this reduces the friction at the sidewall

and molded micro structure interface during demolding [8]. Another strategy is the enhancement of the mechanical strength of the molded micro structure. This can be achieved by using high strength polymer binder systems. However, such binder system also increases the viscosity of the feedstock making the molding of micro structures more difficult [9]. Although some demolding problems and remedies in μMIM were mentioned before, a theoretical and experimental analysis of micro structure demolding is needed and conducted.

II. EXPERIMENTS

Demolding denotes the process during which green part and micro structures are ejected out from mold cavity and microcavities after the feedstock cools and solidifies and mold opens. The schematic drawing of the demolding of the micro structures is shown in Figure 2. In this paper, green part in the analysis is a round disc of ϕ16 mm and thickness 1.5 mm with an array of ϕ100 μm × height 200 μm micro structures at the center (24 × 24, totally 576 micro structures). Accordingly, a silicon mold insert with 24 × 24, totally 576 cylindrical microcavities is mounted in the fixed half mold to form the mold cavity along with the movable half mold.

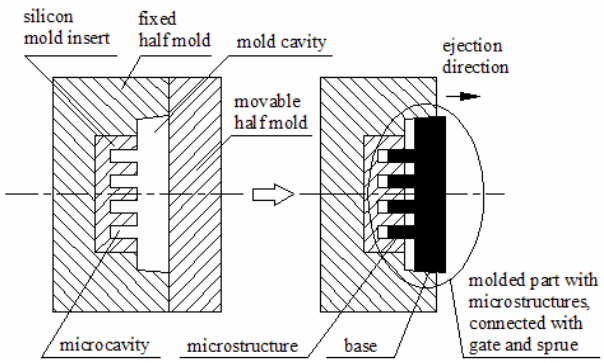

Figure 2 Schematic drawing of demolding of micro structures

Although demolding happens after packing and cooling phase, the demolding behavior is affected by the packing and cooling history of the feedstock during injection molding process. Based on the PVT properties of the feedstock and injection molding process, theoretical analysis of the demolding of micro structures was conducted in the previous paper [5]. In this paper, experiment is designed to measure the demolding force during demolding.

Demolding force is measured on an Instron tensile testing machine (Model 5569). The demolding force needed to eject all the 24 × 24 (totally 576) micro structures can not be measured directly as there exists frictional force between the base of the green part and the wall of the mold cavity. An indirect method is used to measure the demolding force as shown in Figure 3.

Firstly, green part with micro structures is injection molded using a specific packing pressure. The demolding force needed to eject the green part with micro structures is measured at a specific demolding temperature as shown in Figure 3(a). The peak value (F_1) in the upper curve is the maximum demolding force at the onset of the movement of micro structures. Secondly, the silicon mold insert with microcavities is replaced by a silicon mold insert without microcavities. Accordingly, a disc with the same dimensions as the base of the green part with micro structures is injection molded using the same molding parameters. Then the demolding force needed to ejecting the disc is measured as shown in Figure 3(b).

The peak value (F_2) in the lower curve is the maximum demolding force at the onset of the movement of the disc. Finally, the difference between these two demolding forces is the demolding force of 24 × 24 (totally 576) micro structures in the case of the specific packing pressure.

During the experiment of measuring demolding force, the mold is maintained at the demolding temperature by heating cartridges. The mold half with the ejection system and green part with micro structures is detached so that the ejection pins are exposed. During the course of detaching the mold, any contact with the ejection pins is strictly avoided. Then place the mold half with the green part onto Instron tensile testing machine, make sure the mold half is secured and the top surface is horizontal (using spirit level). Green part with micro structures is ejected out at a speed of 2 mm/s that is equal to that used on injection molding machine.

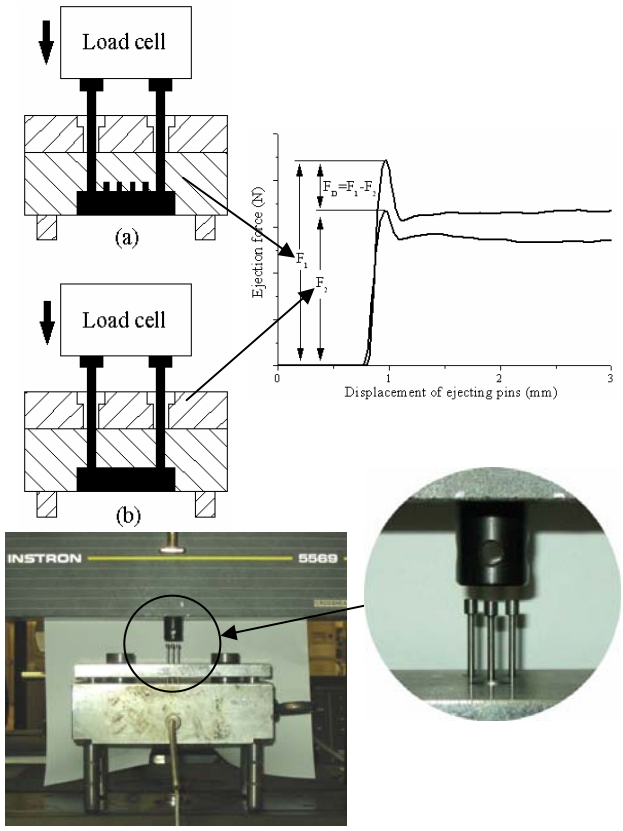

Figure 3 Schematic drawing of ejection force measurement

The maximum demolding force for ejecting micro structures molded at packing pressure of 120 bar is shown in Figure 4. The measured demolding force value is in accordance with the theoretical ones. Their discrepancy is within 25% of the measured values.

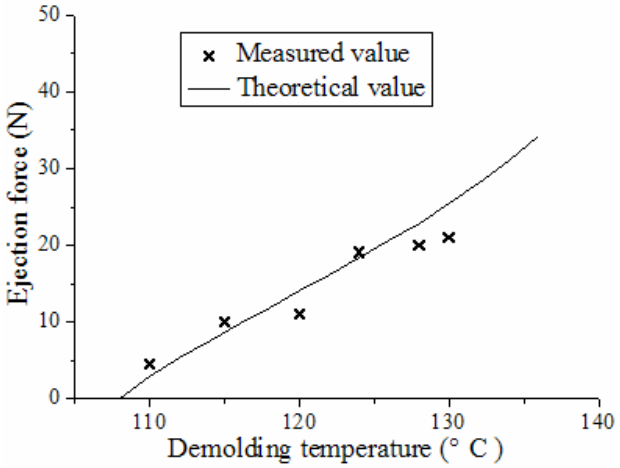

Figure 4 Theoretical and experimental demolding force

III. Conclusion

In this paper, an indirect measuring experiment is designed to measure the demolding force during ejection of the array of micro structures in μMIM. The experimental results are in accordance with the theoretical value.

Acknowledgment

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