Powder Technology 239 (2013) 389–402

Contents lists available at SciVerse ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Gas-assisted powder injection molding: A study about residual wall thickness

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ARTICLE INFO

Article history:
Received 8 October 2012
Received in revised form 12 February 2013
Accepted 14 February 2013
Available online 26 February 2013

Keywords:
Powder injection molding
Gas-assisted injection molding
Gas penetration depth
Residual wall thickness
Stereolithography cavity

ABSTRACT

The effects of processing variables on gas penetration depth and residual wall thickness (RWT) of gas-assisted injection molding (GAIM) parts were investigated for polypropylene (PP) and 316L stainless steel powder feedstock (SUS316). The processing variables were melt temperature, shot size, gas pressure, and gas delay time. By using a Taguchi L_9 array, the results were compared with the previous work. Mold material was also investigated by molding with both aluminum and Stereolithography (SLA) mold inserts at varying temperatures. The most significant parameter affecting RWT was melt temperature for PP and gas delay time for SUS316. Additionally for SUS316, it was found that gas penetration depth and RWT were decreased with increasing mold temperature. While both computer simulation and experimental validation were carried out, the results from simulations failed to consider the effect of thermal conductivity differences between SLA and Al cavities due to lack of a coupled analysis capability in its module.

1. Introduction

The injection molding process is one of the most popular manufacturing methods due to the capability to produce a high volume of precision parts using a wide range of plastic materials. The cycle time is also significantly less compared to the other manufacturing techniques. As with the material flexibility of injection molding, powder injection molding (PIM) has presented an effective and mature technology able to produce parts of complex geometry through injecting metal or ceramic powder blends in place of plastic into the cavity [1–3]. The PIM allows the fast cycle time and low cost production of small-sized complex components consistently with high dimensional accuracy.

Gas-assisted injection molding (GAIM) is a modification of the conventional injection molding and a method of pressurizing an injection molding part with gas in order to provide the necessary packing force to produce a quality injection molded part [4]. GAIM produces parts with hollow internal sections and this becomes particularly useful for PIM [5–7] as lower material usage is achieved. Required time for debinding processes can be reduced as well [8]. Despite the advantages, the GAIM process with powder feedstock, i.e., gas assisted powder injection molding (GAPIM) process is not intensively studied. Also the effect of processing variables over GAPIM process is not well understood yet.

Epoxy cavities made by Stereolithography (SLA) were used in the prior experiments by Lee et al. [7] due to low cost and easy fabrication. They found out that durability of SLA cavities can be significantly increased by the application of GAPIM due to reduced injection pressure in the experiments [9]. However, use of metal cavities is necessary in order to accomplish mass production and commercialization. Accordingly, this research will focus on the effects of the processing parameters such as melt temperature, shot size, gas pressure, and gas delay time on gas penetration depth using an aluminum (Al) cavity insert. Simulations and experiments were conducted to find the effects of processing variables and the results were compared to the previous study using an SLA cavity. Furthermore, residual wall thickness (RWT), an important parameter for commercial application of GAPIM, was investigated. The effect of mold temperature on gas penetration and RWT was also studied.

1.1. Background

Karatas et al. [10] recently studied the moldability of various feedstocks used in PIM. It was mentioned that feedstocks used in PIM have high thermal conductivity which leads to fast solidification and as a result, very high injection rates were required. The high injection rates promoted the accumulation and separation of binder in sudden direction changes in the cavity during injection molding. This separation caused defects in the sample which become apparent during debinding and

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http://dx.doi.org/10.1016/j.powtec.2013.02.032

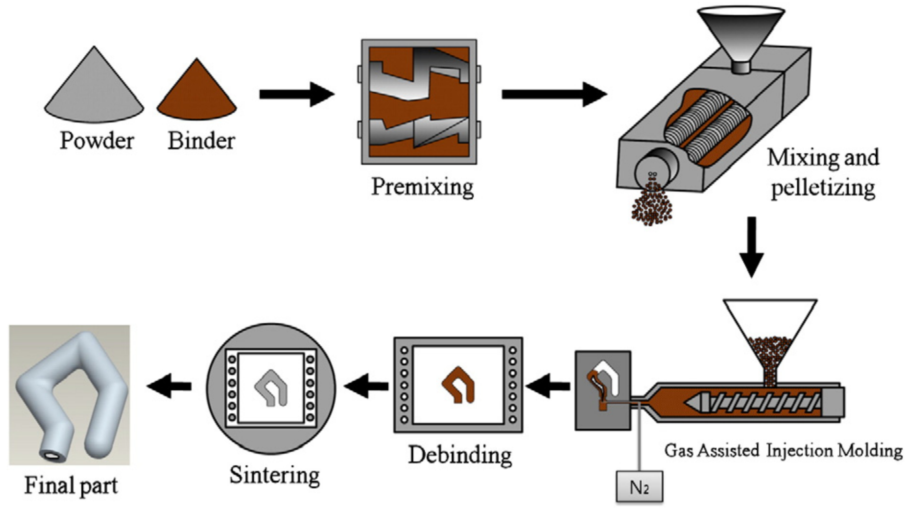

Fig. 1. Schematic diagram of GAPIM process.

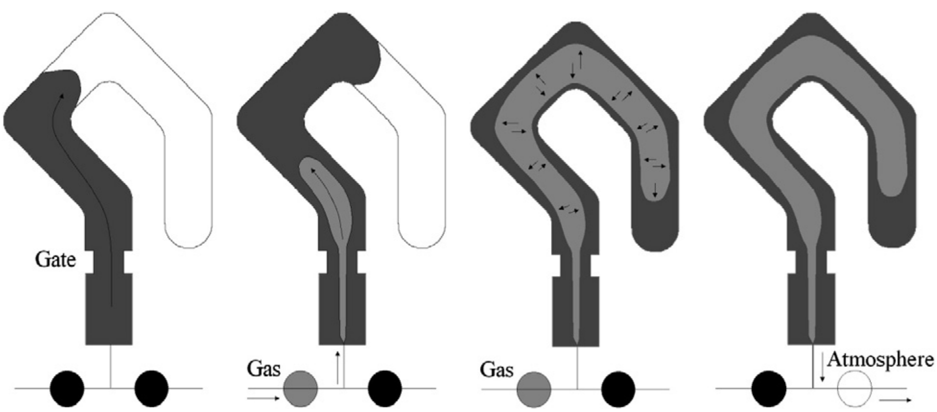

Fig. 2. Schematic diagram of GAIM.

sintering. In the experiment, the moldability increased with increasing injection pressure, temperature, and flow rate.

Urval et al. [11] investigated the influence of decreasing part thickness with accompanying increase in aspect ratios on the process parameters, including melt temperature, mold temperature, fill time and switch-over position. This was done using the Taguchi design method and a simulation tool (PIMSolver) [12]. It is reported that as less part thickness, higher melt temperature and mold temperature would be necessary to obtain complete parts due to the solidification rate increase. The mold temperature was considered to be the most critical parameter.

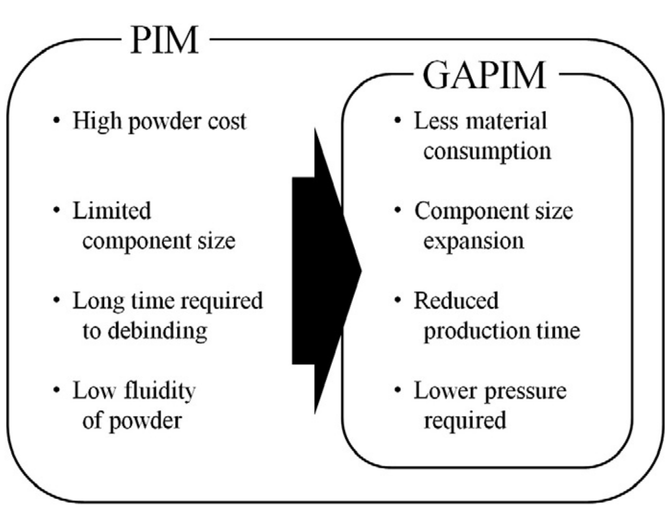

Fig. 3. Advantages provided by application of GAIM to PIM.

1.2. Gas-assisted injection molding process

GAIM technology has been increasingly adopted due to many advantages over conventional injection molding, such as reduction of injection-packing pressure, cooling time, and material usage. Injected parts have less sink mark, shrinkage, warpage, and residual stresses, resulting in better final production at lower costs [13–16]. GAIM is a technology which injects gas to form hollow cores in the thicker sections of the part [17]. Fig. 1 shows a schematic of GAPIM and Fig. 2 shows the process of GAIM in four stages.

At the first stage, a fixed amount of plastic melt is injected into the mold cavity, less than the full volume of the cavity, which is called as “short shot”. The injection pressure required is reduced due to short shot in the cavity as compared to conventional injection molding.

In the second stage, the nitrogen gas is injected and the plastic melt is displaced by applied gas pressure. It takes the path of least

Table 1
Material properties.

Property	PP	SUS316
Density (g/cm^3)	0.9	7.76
Specific heat capacity (J/kg-K)	2740	685
Thermal conductivity (W/m-K)	0.16	1.84
Thermal diffusivity (m^2/s)	0.65×10^{-4}	3.46×10^{-4}