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Response of Cavity Pressure to Vibration Parameters During VAIM Process

Xiaochun Yin, Guangjian He, Qu Jinping (✉)

The National Engineering Research Center of Novel Equipment For Polymer Processing, South China University of Technology, Guangzhou 510641, China
E-mail: mxcyin@163.com; fax: +86-208-711-2503

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Summary

In this study, a new type of vibration-assisted injection molding machine was introduced including the principle, structure and application. The responses of cavity pressure to the piston rod vibration amplitude and vibration frequency were discussed in detail. The cavity pressure oscillation frequency was the same with the piston rod frequency. The piston rod vibration frequency had little effect on cavity pressure oscillation amplitude. The cavity pressure oscillation amplitude increased with the increase of piston rod amplitude. The introducing of vibration forces field shortened the filling time, postponed the gate-frozen time and quickened the pressure build up process. More materials could be packed into the mold as the mean cavity pressure was higher which improved the quality of the products.

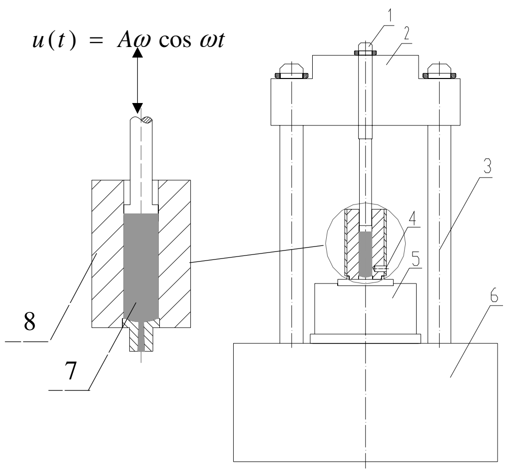
Introduction

Injection molding is a cyclic process. Each cycle has four stages [1,2], that is to say, plastication, injection, holding/packing and cooling. During the process, cavity pressure and polymer melt temperature determine the evolution of the polymer melt inside the cavity. The cavity pressure plays an important role in determining the quality of the molded parts, particularly, its dimensions, dimensional stability, mechanical behavior, and surface quality. The high quality demand for injection molded products as well as the broader application range of injection-molded parts had brought about great changes to the injection molding process. Some new molding techniques had surfaced that make use of specific pressure profiles prior to or during molding to control the flow pattern and/or the internal structure and morphology of the plastic as it was being shaped. Among them, one novel technique is to control the filling and packing parameters by using introducing vibration forces field into the mold that caused melt vibration/oscillation. They were sometimes called "Melt Manipulation" techniques [3]. Examples of these techniques that have been investigated include the SCORIM process [4,5], the moving Boundary process [6], the push-pull process [7,8], the RHEMOLDING process [9,10], the mold rotation molding process [11,12], vibration-assisted injection molding process [13,14,15] and electromagnetism injection molding process [16,17]. At the same time, there are some researches about the influences of vibration forces on melt viscosity during processing. Wong and Isayev [18,19] studied the influence of the vibration field on the polymer melt by an extruder with a vibration device. Their experiments further demonstrated that the influence degree on the rheology of the polymer melt is relative to the direction of flow of the melt and the vibration applied. When the flow direction of the polymer melt is parallel with the vibration, the effect is much stronger than is the orthogonal superimposition. Qu Jin ping et al. [20,21] studied the influence of vibration amplitude/frequency on the polymer melt viscosity by using a non-affine network model. And also they explained the influences in terms of entanglement density. These researches had shown that such techniques might solve or subdue the problems existing in injection molding process and improve the quality of molded parts. However, there were very few reports about the actual response of cavity pressure to the vibration parameters that affect the parts quality greatly. In this study, experiments about the response of cavity pressure to the piston rod vibration parameters during filling and packing were carried out and the results were listed in the following paragraphs.

Experimental

Vibration-assisted Injection Machine

To study the responses of cavity pressure to the piston rod vibration parameters during injection molding process experimentally, a facility was developed that applies mechanical vibration to the melt during injection molding process by vibrating the piston rod. The cavity pressure changes homologous to sinusoidal. Oscillation pressure gradients with none-zero means were generated within the flow domains during filling and packing stages by the mechanical vibration of the piston rod. The schematic diagram of the vibration-assisted injection-molding machine used in the experiment was shown in Figure 1. As shown in Figure 1, during the filling and packing stages the piston rod keeps vibrating at given frequency and amplitude. As the piston rod vibrating, vibration forces were induced and introduced into the mold



1 piston rod, 2 vibration device, 3 pillar, 4 thermocouple, 5 mold, 6 housing, 7 melt, 8 barrel

Figure 1 Schematic Map of Vibration-Assisted Injection Machine through the polymer melt. The vibration forces affect the shear stress and the hydrostatic pressure, which eventually influence flow pattern of the melt and the molecular orientation /relaxation during filling and packing stages.

During the filling stage, the two pillars move downwards at a constant velocity u_0 relative to the housing so as to keep the constant average injection velocity. $A\sin\omega t$ was a superimposed vibrating displacement on the piston rod. A and f are the vibration amplitude and vibration frequency respectively; ω is the circular frequency of vibration ($\omega = 2\pi f$). So the displacement of the piston rod as a function of time during filling was

$$S(t) = u_0 \cdot t + A\sin(\omega t) \quad (1)$$

Where $S(t)$ is the instantaneous displacement of the piston rod. Accordingly, the absolute velocity of the piston rod during filling stage was:

$$u(t) = u_0 + A\omega\cos(\omega t) \quad (2)$$

During the packing stage, the piston rod keeps vibrating as the pillars move downwards very slowly. By this way, vibration forces were induced through the mechanical vibration of the piston rod and superimposed onto the melt in mold. Oscillation pressure gradient was generated within the flow domains during filling and packing stages through melt vibration. The vibration amplitude and frequency of the piston rod could be adjusted expediently from the control panel.

Injection Mold and Pressure Measurement Device

A center-gated disc-shaped mold as illustrated in Figure 2 was used for injection molding. Three plates mainly constituted the mold, that’s to say, a simple superior plate, an inferior plate that contains sprue bushing and an interchangeable plate contains cavity. The cavity plate could be changed according to the shape and dimension of the parts.

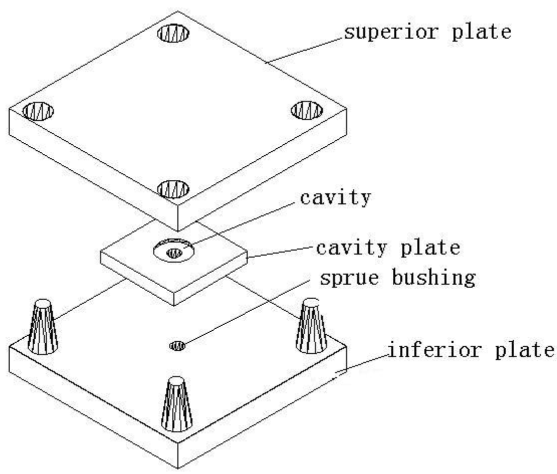
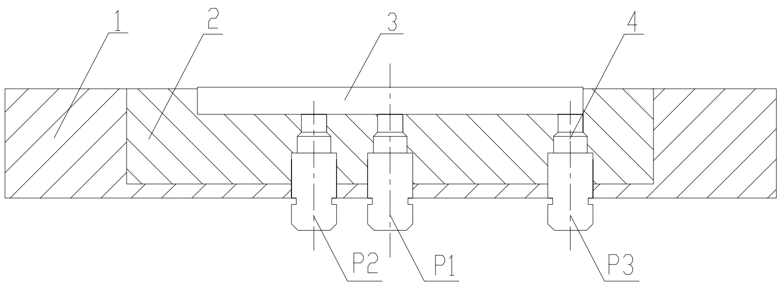


Figure 2 Center-gated Disc-shaped Mold

As shown in Figure 3, three pressure transducers were embedded in the mold along radial direction. These three pressure transducers monitored the changes of the cavity pressure. P1 denotes cavity pressure at the gate, P2 denotes cavity pressure at r=30mm, P3 denotes cavity pressure at the far end of the mold.



1 Inferior plate, 2 Cavity plate, 3 Cavity, 4 Pressure transducer

Figure 3 Layouts of the Pressure Transducers in the Mold

Materials and Materials Processing

The material used in the experiments was injection grade High Density Polyethylene (HDPE, T30S) produced by Hunan Petrochemical Corporation. Its melt flow index is about 0.9 g/10min. Its density is 0.95 g/cm^3.

Experimental producer

A self-assembled injection-molding machine as illustrated in Figure 1 was performed in the experiments. The materials were melted at 210°C and molded into a center-gated disk-shaped mold (Figure 2). Mold temperature could be controlled through the use of a thermolator that supply heated oil in a closed loop network of hoses. The injection process parameters were listed in Table 1. The diameter of the disc is 120mm with a depth of 4mm. The vibration frequencies vary from 0 to 20Hz, and the vibration amplitudes vary from 0 to 0.25mm.

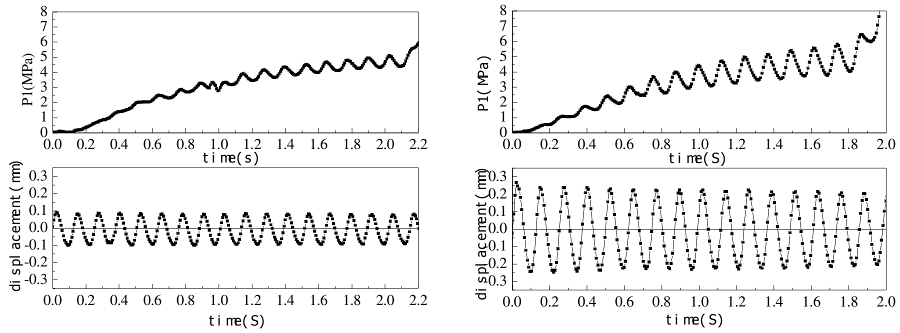
Table 1: Injection Parameters

Injection Velocity	Temperature of Barrel	Temperature of Mold	Injection time	Holding time
28.27cm$^{3/}$S	210°C	45°C	2S	3S

The pressure sensors attached with an amplifier were embedded in the mold as shown in Figure 3 for direct measurement of cavity pressures. The electronic signal was recorded by a personal computer in real time scale.

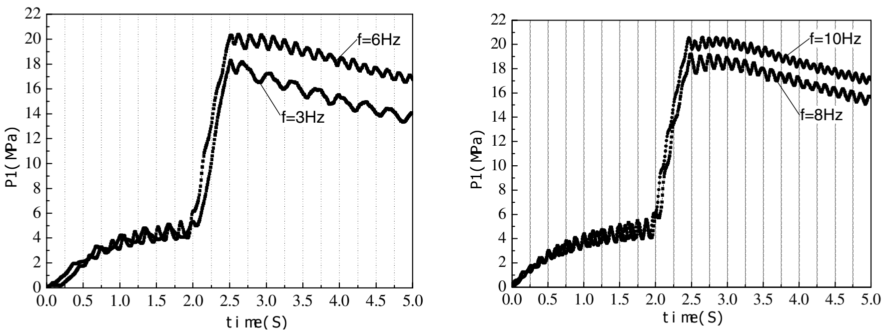
Results and Discussion

Response of cavity pressure to vibration parameters



(a) A=0.10mm, f=8Hz (b) A=0.30mm, f=8Hz

Figure 4 Response of Cavity Pressure to Vibration Amplitudes During Filling



(a) A=0.25mm (b) A=0.3mm

Figure 5 Response of Cavity Pressure to Vibration frequency

Figure 4 showed the responses of cavity pressure at different radial position in the mold to the vibration amplitude of the piston rod during filling stage. As presented in the Figure, the vibration forces had been actually superimposed onto the melt. The cavity pressure changed homologous to sinusoidal. The pressure oscillation amplitudes varied with the amplitudes and frequencies of the piston rod. The smaller the piston rod vibration amplitude, the smaller the cavity pressure oscillation amplitude. Figure 5 showed the response of cavity pressure at different radial position in the mold to the vibration frequency of the piston rod. As can be seen, the response frequency of the cavity pressure was the same with the vibration frequency of the piston rod. As illustrated in Figure 5, when the vibration frequency of the piston rod was 3,6, 8,10Hz, the pressure oscillation frequency was 3,6, 8,10Hz too. In conclusion, the vibration parameters of the piston rod had significant influence on cavity pressure and cavity pressure oscillation amplitude and frequency. The influence would be discussed in detail in following paragraphs.

Effect of vibration amplitudes on cavity pressure

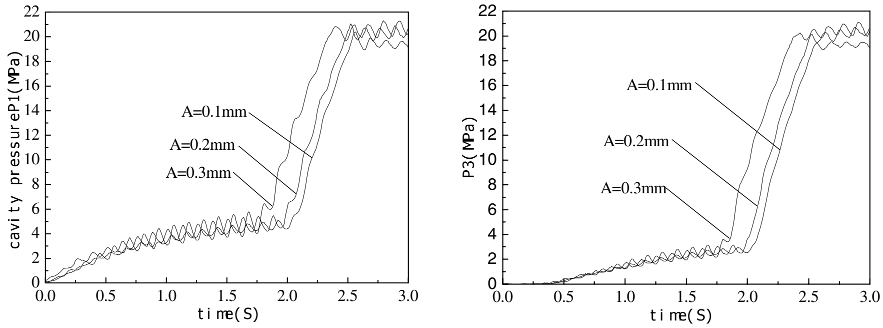


Figure 6 Response of Cavity pressure to different vibration amplitude while f is 8Hz

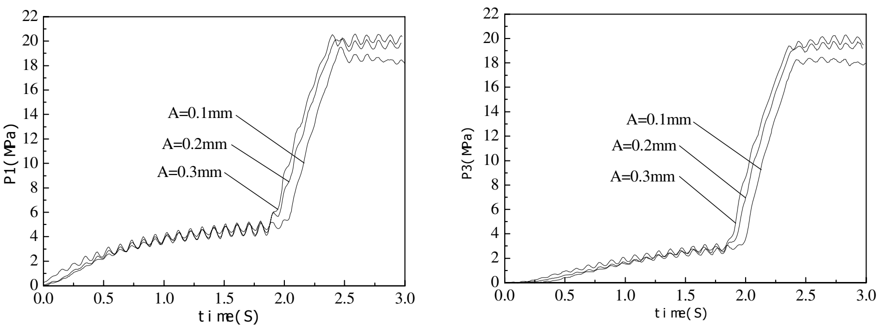
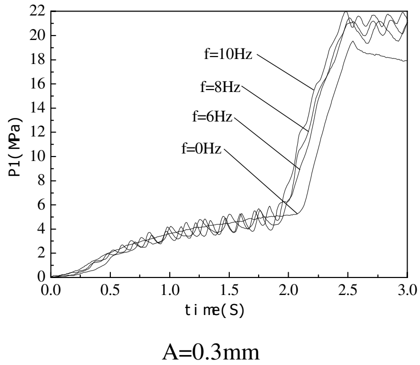


Figure 7 Response of Cavity pressure to different vibration amplitude while f is 10Hz

As illustrated in Figure 6 and Figure 7, the cavity pressure and pressure oscillation amplitudes increased with the increase of the piston rod vibration amplitudes for both frequencies 8Hz and 10 Hz. The cavity pressure built up much faster as the vibration amplitude increased. As can be seen from the Figures, the higher the vibration amplitudes, the higher the mean cavity pressure was. This could be explained from two aspects: firstly, introducing vibration forces into the mold decreased the viscosity of the melt and improved the melt flowability; Secondly, the oscillation pressure gradients within the flow domain generated more heat locally by inner friction, which postponed the gate frozen time and more melts were packed into the mold during the packing/holding stage.

Effect of vibration frequencies on cavity pressure

As presented in Figure 8, the piston rod vibration frequency had little effect on the cavity pressure oscillation amplitude at fixed piston rod vibration amplitude. Near the gate, as the melt temperature was high that the viscosity of the polymer melt was low, the pressure oscillation amplitude near the gate (P1) was greater than that the pressure oscillation amplitude at the far end of mold (P3). Like the effect of vibration amplitude on cavity pressure, the cavity pressure built up faster with the increase of piston rod vibration frequency at given piston rod vibration amplitude. During the packing stage, the higher the vibration frequency, the higher the mean cavity pressure.



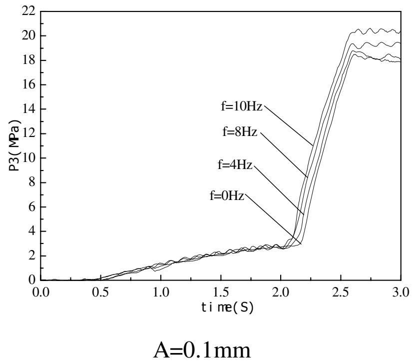


Figure 8 Response Of Cavity Pressure to Vibration Frequency at different amplitude

Effects of vibration parameters on filling time

Filling time is an important factor in determining injection molding process and the injection-molded parts quality. However, it is difficult to measure the actual filling time. In general, it can be approximately estimated from the cavity pressure at the gate. In this study, cavity pressure P1 is adopted to estimated filling time as shown in Figure 9.

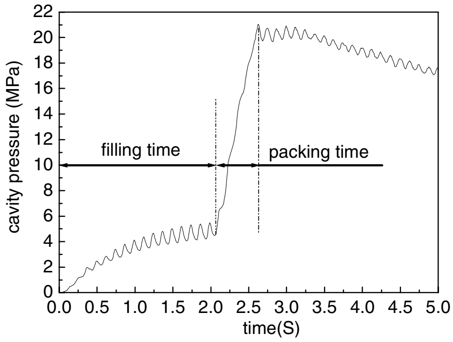


Figure 9 Sketch Map of Filling Time Calculation Method

According to the calculation method introduced in Figure 9, effects of vibration parameters on filling time can be obtained. As illustrated from Figure 5 to Figure 8, the filling time can be shortened with the increase of vibration amplitude or vibration frequency.

Conclusion

By introducing vibration force into the mold during filling and packing stage, oscillation pressure gradient with non-zero means was generated within the flow domains. The oscillation pressure reduced the melt viscosity and hence improved flowability. And also the oscillation pressure gradient postponed the frozen time of the gate that more materials could be packed into the mold that the cavity pressure was higher than that of conventional injection molding. According to the experimental results, the following conclusions were drown:

1) The cavity pressure oscillation frequency was the same with the frequency of the piston rod; the vibration frequency had little effect on cavity pressure oscillation amplitude. The cavity pressure increased with the increase of piston rod vibration amplitude.

2) The introducing of vibration forces into the mold during the filling stage decreased the viscosity of polymer melts so that the filling time could be shortened. And the time at which the pressure build up was completed occurred sooner with the increase of piston rod vibration amplitude of vibration frequency.

3) The introducing of vibration force into mold during packing stage postponed the gate frozen time that more materials could be packed into the mold hence the mean cavity pressure was higher than conventional injection molding. The mean cavity pressure increased with the increase of piston rod vibration amplitude and vibration frequency.

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