The Effect of Vibration Injection Molding on Mechanical Properties of Polyolefin Parts

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ABSTRACT: In this paper an experimental study of vibration field effect on molded polymers specimens is carried out. A self-made vibration injection device is employed to mold the experiment samples. In the experiment some polyolefin materials are investigated, and property tests for the specimens are carried out. The results show that the tensile strength of high-density polyethylene (HDPE) and polypropylene (PP) have an obvious increase, but polystyrene (PS) does not. The effect of vibration on the strength is related to the temperature, pressure, and gate. Lastly, the test results are analyzed and conclusions are presented. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 91: 1514–1518, 2004

Key words: polyolefin; injection molding; mechanical properties

INTRODUCTION

During polymer melt molding, introduction of force field may bring the effect to the rheology, transition of aggregation, and crystal structure of molded parts. Vibration field is a kind of force field that can be introduced. By introduction of vibration during molding, the quality of molding parts can be improved.

Eight years ago, Lemelson[1] used ultrasonic to control the solid processing of plastics melt within the cavity and increased the strength and physical properties of molded parts. Ibar[2–4] introduced vibration into injection molding when PP was molded. The results showed that the elongation rose 80%, and the yield strength and modulus increased greatly. Allen and Bevis[5–7] (Brunel University) used their invention of the Multi-Live Feed Molding apparatus to introduce shearing oscillation into the melt flow within the cavity and found that it increases the strength of molded parts and eliminates the effect of weld line. Michadi and Galuschka [8] invented the vibration injection technique of Push-Pull, which was used to study glass-reinforced LCP.[9,10] The results show that tensile strength and bend modulus increased 420 and 270%. Shen et al. (Sichuan University, China)[11–14] used their invention of the OPTIM vibration technique to mold high-density polyethylene (HDPE), polypropylene (PP), and acrylonitrile–butadiene–styrene copolymer (ABS) and found that the tensile strength of HDPE parts increased from 23 MPa of nonvibrated to 93 MPa of vibrated, PP from 32 to 58 Mpa, and ABS from 46 to 54 MPa. Yu-Cheng et al. (South China University of Technology, China)[15] used a screw-applied vibrating technique to mold PP, HDPE, and polystyrene (PS) and found that the tensile strength of the parts increased 18.3, 22, and 16%.

The vibration type introduced into polymer melt may be classified into three types: ultrasonic, shear vibration, and pressure vibration. Most of these are single vibration types. In our experiment, a novel self-made vibration injection mold apparatus was used, which is an assembly of shear and pressure vibration. In the past, we have studied the effect of the vibration on rheology of polymer melt with this apparatus.[16] This paper is its continuity. In this work, we studied the relationship between the tensile strength (yield and breaking) of the molded samples under conditions of vibration and different vibration parameters.

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EXPERIMENTAL

Apparatus

The injector was a self-made vibration injector. The melting device was a single screw extruder (model SJ-30X25B; Shanghai Extruder Machinery Factory, China; screw diameter: 30 mm; ratio of screw length and diameter: 25:1; power: 5.5 kW; screw speed of

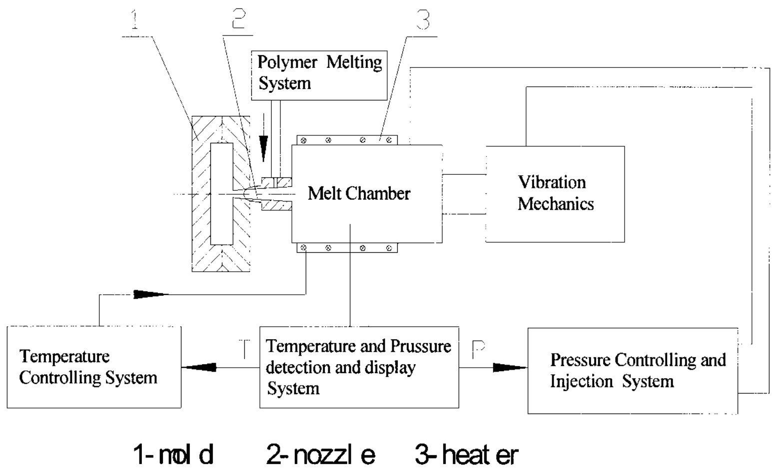


Figure 1 Vibration molding apparatus.

revolution: 13~200). The mold was a self-made standard sample mold. The test instrument was an Autograph (model AG-10TA; Japan).

Figure 1 shows the vibration injector. It consists of the polymer melting system, temperature and pressure detection system, temperature controlling system, pressure controlling system, mold, and vibration mechanics. The temperature and pressure during the experiment are controlled by a temperature and pressure display and control system. An extruder is used to melt the polymer materials.

EXPERIMENTAL

Materials

High-density polyethylene (HDPE, grade PE-LA-50D1012) was provided by Lanzhou Chemistry Ltd. (China). Polystyrene (PS, grade B-1) was made in Taiwan China. Polypropylene (PP, grade F401) is from Gansu Langang Chemistry Ltd. (China).

EXPERIMENTAL

Method

First, polymer material is packed into the extruder and melted; the melted polymer is then transported into the vibration chamber. After keeping the temperature of the melt in the chamber for a period of several minutes, the vibration device starts. After vibration for 1 min, the melt is molded under the condition of continuous vibration and a given pressure. All molded samples are then tested for tension by an Autograph test instrument according a standard program.

Effect of vibration on the mechanical properties of PP

Figure 2 shows the yield strength curves of PP standard specimens through vibration injection under the

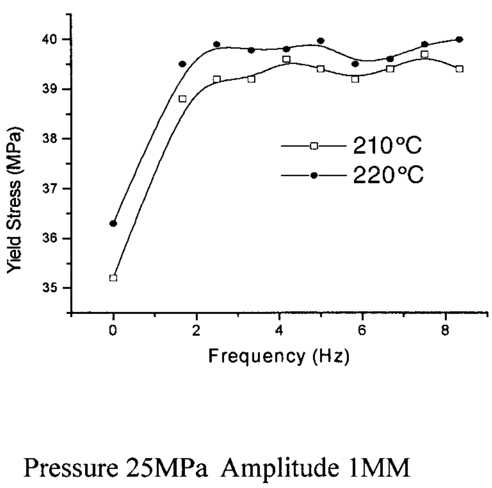


Figure 2 Yield strength curves of PP under differing frequencies.

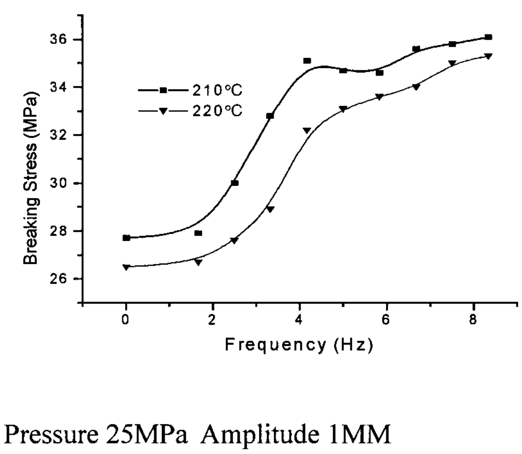


Figure 3 Breaking strength curves of PP under differing frequencies.

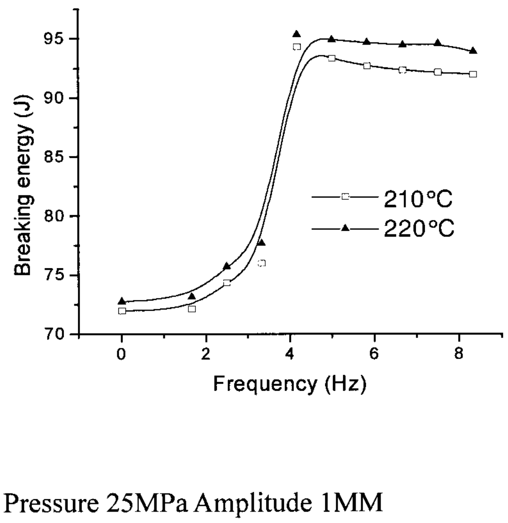


Figure 4 Breaking energy curves of PP under differing frequencies.

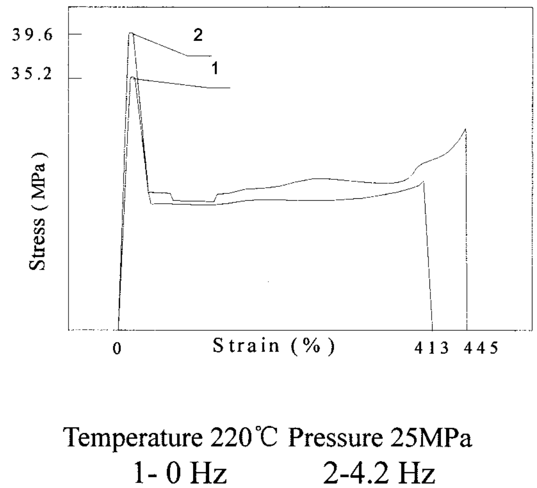


Figure 6 Stress versus strain curves of nonvibration and vibration injection-molded samples of PP.

varying conditions. As Figure 2 shows, when the frequency varies from 0 to 4.2 Hz, the yield strength curve with temperature 220°C occurs from 35.2 MPa (f = 0 Hz) to 39.6 MPa. During this period, the strength increases faster following vibration frequency. Comparing the last volume with its primary volume, there is a 12.5% increase; after that point, the yield strength changes slowly. The curve under the temperature of 210°C has the similar varying regularity. Its strength is higher than that of 220°C at the same point. According to the results shown above, polymer melt vibration injection has an obvious effect on yield strength of the specimen using our vibration device.

Figure 3 shows the relationship plots of PP between strength at break and melt vibration frequency. The curve may be divided into three stages. In the first stage (0–1.6 Hz), it varies slowly. In the second stage (1.6–4.2 Hz), it varies faster. In the third stage (>4.2 Hz), it varies slowly again. The strength reaches its peak when the frequency is about 4.2 Hz. The peak volume is 35.1 MPa. It increases 26% compared with the beginning. At the highest point of 8.3 Hz, it is 36.1 MPa and increases 30%.

Figure 4 shows plots of PP breaking energy versus vibration frequency. The breaking energy increases slowly at the interval of 0~3.3 Hz, changes strongly at the interval of 3.3~5 Hz, and approaches the highest point at about 4.2 Hz. At this point, the breaking energy is 94.3 MPa. After 5 Hz, the breaking energy decreases slightly following vibration frequency. The largest increase in volume of the breaking energy is 30%.

The breaking energy characterizes the tenacity of a material. Therefore, the enhancement of the specimen

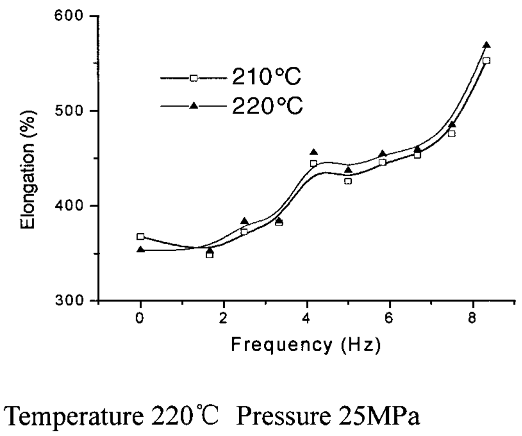


Figure 5 Breaking elongation curves of PP under differing frequencies.

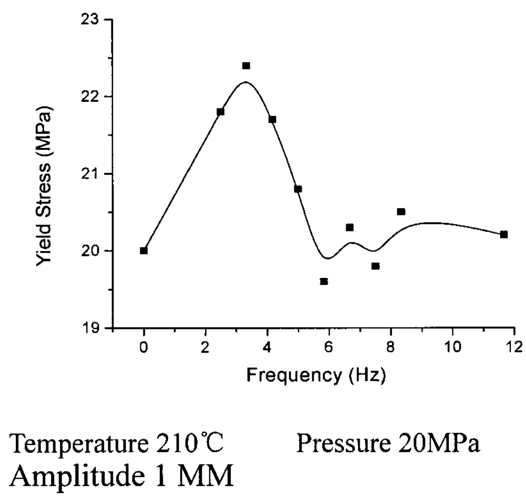


Figure 7 Yield strength curve of HDPE under differing frequencies.

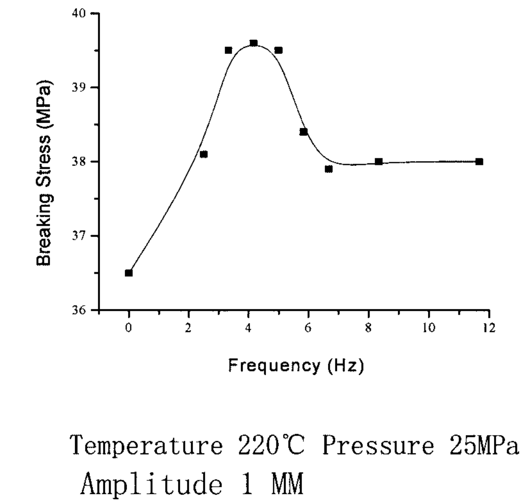


Figure 8 Breaking strength curve of HDPE under differing frequencies.

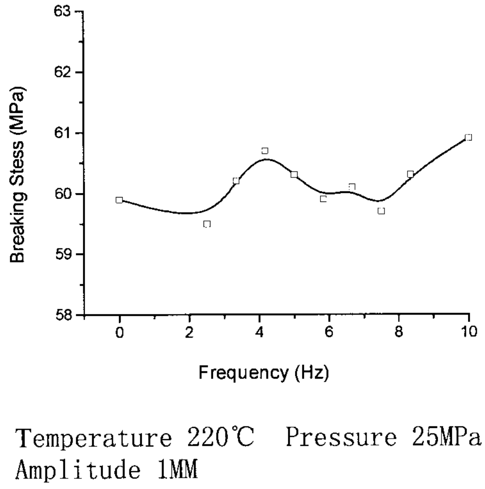


Figure 10 Breaking strength curve of PS under differing frequencies.

means the enhancement of its property of impact resistance.

Figure 5 shows relationship curves of PP between breaking elongation and vibration frequency. It shows that the whole changing trend of breaking elongation is enhanced. The plot illustrates that, following the increase of frequency, the plasticity of the sample increases. Figure 6 is the tensile curve of PP. It is observed that the area under the vibrated sample curve is larger than that under the nonvibrated sample. This indicates that the vibrated sample has greater plasticity than the nonvibrated sample.

Figure 7 shows the yield strength curve of HDPE under differing frequency at 210°C. In the primary stage, 0~3.3 Hz, it increases quickly. The yield strength reaches its highest volume at the point of 3.3 Hz. The volume is 22.4 MPa and the rise is 12%. After that point, it drops to about 20 MPa and a peak appears on the curve. Following this, the change of the yield strength trend slows. These results showed that the melt vibration has an effect on the yield strength of the HDPE.

A relationship curve of HDPE between the breaking strength and vibration frequency is presented in Figure 8. Figures 7 and 8 are of similar regularity. A peak appears near the point of 4.2 Hz with a volume of 39.6 MPa on Figure 7. Compared with the nonvibrated condition, the break strength increases 8%. After the peak point, the break strength changes slowly at around 38 MPa.

Figure 9 is the yield strength curve of PS under differing frequencies. The figure shows that vibration

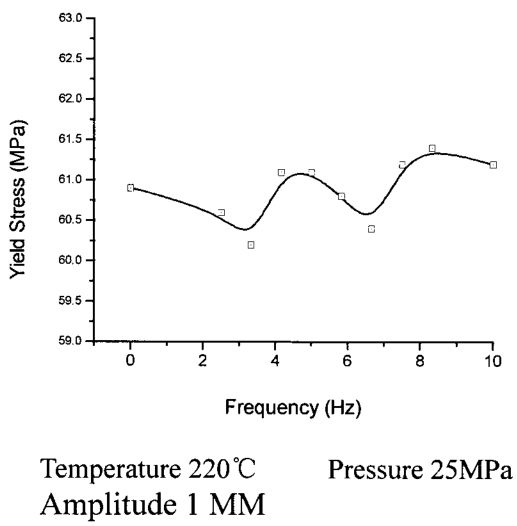


Figure 9 Yield strength curve of PS under differing frequencies.

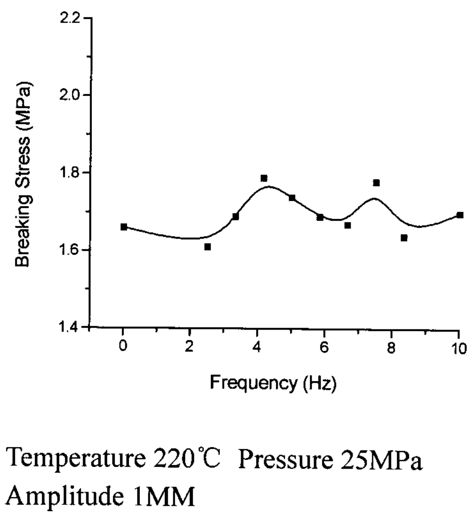


Figure 11 Breaking energy curve of PS under differing frequencies.

has no obvious effect on the yield strength of PS molded parts.

Figure 10 is the relationship curve of PS between breaking stress and vibration frequency. It shows that vibration molding has no obvious effect on the strength of PS at the breaking point.

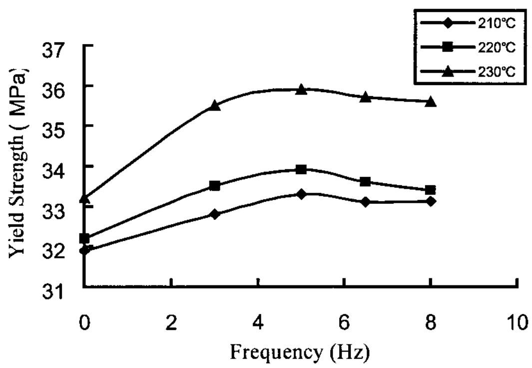
Figure 11 is the energy curve at the breaking point of the vibrated sample of PS. With change of vibration frequency, the energy waves are within a small extent. This illustrates that vibration has no effect on the plasticity of PS.

Test results of samples molded with different gates

Figures 12 and 13 are the relative curves of yield strength with different gates in molding. From Figures 12 and 13, we observe that, when molding with different gates, the strength of the samples is varied. The temperature for molding also affects the specimens.

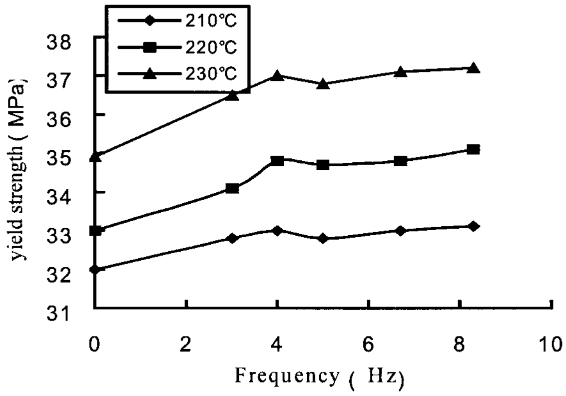
CONCLUSION

1. Vibration injection can increase the yield strength of HDPE and PP specimens, but PS does not have a significant effect.



Pressure 26MPa, Nozzle diameter 3 mm
Gate: 2mm long, 2mm width, 4mm depth

Figure 12 PP yield strength curves.



Pressure 26MPa, Nozzle diameter 3 mm
Gate: 2mm long, 2mm width, 2mm depth

Figure 13 PP yield strength curves.

2. Vibration injection can increase the strength at the breaking point of HDPE and PS specimens, but PS cannot.
3. The effects of vibration on mechanical properties of specimens vary with different materials.
4. The effect of vibration on the mechanical properties of HDPE and PP has a sensitive interval.
5. The effect of vibration is related to the gate size of the mold.

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