Effects of the Vibration Parameters of a Hydraulic, Dynamic Injection-Molding Machine on the Properties of Low-Density Polyethylene Samples in a Plasticating Process

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ABSTRACT: A novel, self-made, hydraulic, and dynamic injection-molding machine was used to mold low-density polyethylene samples in a standard sample mold. These samples were tested for tensile strength, density, differential scanning calorimetry, and energy consumption of the molding process to explore the influences of the vibration frequency and amplitude on the properties of the products. The results show that the maximum tensile strength was enhanced by 6.1%, the density was higher by 0.34%, the melting point moved to a higher temperature by 1.7°C, and the power consumption of the whole molding process was lowered by 7.5% when the vibration was imposed. The changing regularity is presented. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 117: 1208–1212, 2010

Key words: differential scanning calorimetry (DSC); injection molding; polyethylene (PE)

INTRODUCTION

Plasticating equipment is among the core configuration of injection-molding machines; product quality, the efficiency of injection molding, and machining costs are influenced directly by plasticating capability. Recently, the vibration technique has been applied to polymer processing and has been widely investigated.[1–6] The vibration field is introduced into a polymer melt, and the molecular movement and rheological behavior of the polymer melt is affected by the recurrence of melt vibration, which controls the micromechanism of the product. The mechanical properties of the final products are improved by the control of the micromechanism without any plastic additive.[7–13]

To date, several types of melt vibration techniques have been investigated. For example, Ibar and Lemelsonl[14] 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. Lemelson[15] used ultrasonic waves to control the solid processing of plastic melts within the cavity and increased the strength and physical properties of molded parts. Allen and Bevis[16–18] (Brunel University) used their invention of the multilive feed molding apparatus to introduce shearing oscillation into the melt flow within the cavity and found that it increased the strength of the molded parts and eliminated the effect of the weld line.

Although much progress has been made in vibration techniques, most of these are introduced into the polymer melt in packing pressure. The hydraulic, dynamic injection-molding machine invented by Qu[19–22] is another example that uses the vibration technique, which is based on the idea that polymer behavior can be changed by the vibration force field. In this kind of hydraulic injection machine, the vibration field is applied to the solid conveying, plasticating, melting, injection, and packing pressure of the entire molding process by the axial vibration of the screw, in which the vibration parameters of each molding process can be adjusted separately. The novel injection-molding machine has significant advantages, such as a low energy consumption, a low injection pressure, and a melt apparent viscosity comparable to the conventional injection-molding machine.[23,24]

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TABLE I
Characteristic Parameters of LDPE

Trademark	Melt flow index (g/10 min)
1I50A	40

The purpose of this study was to examine the influence of the regulation of the properties of low-density polyethylene (LDPE) by the changing of the vibration parameters in the plasticating process under otherwise identical conditions.

EXPERIMENTAL

Materials

The LDPE used in this study was provided in the form of pellets, supplied by China Petroleum and Chemical Corp. (Beijing Yanshan Petrochemical, Ltd., Beijing, China). The parameters are shown in Table I.

Apparatus

The apparatus used in this experiment was a self-made, hydraulic, dynamic injection-molding machine (model HD-980). This hydraulic, dynamic injection-molding machine was different from the traditional injection machine. The low-speed and high-torque hydraulic motors were applied in plasticating, and the screw rotated, driven by a hydraulic motor shaft by ball bearings. The axial pulsing of the screw was achieved by a back-pressure valve superposing a rectangular current signal; thus, the whole plasticating process was accomplished in pulsed pressure. The vibration amplitude and frequency were adjusted independently by control of the signal of the back-pressure valve. The hydraulic, dynamic injection machine is shown in Figure 1. The diameter of the screw was 32 mm, the length/diameter ratio was 24.8 : 1, and the clamp force was 980 kN.

Figure 1 HD-980 hydraulic, dynamic injection-molding machine.

Sample preparation

The samples' standard was given at room temperature (23°C). The mold temperature was controlled at 40°C through a thermolator, which supplied heated oil to the mold in a closed-loop network of hoses. The experiments were performed under a range of vibration parameters. A sketch of the mechanical test specimen is shown in Figure 2.

Testing

Vibration amplitude and frequency online collection

The data-collection system (model DEWE-BOOK-16, Dewetron Corp., Graz, Austria) was used for vibration amplitude and frequency online collection. The standard software applied in the collection system is DEWESoft (Dewetron Corp., Graz, Austria).

Tensile testing

A universal tensile testing machine (model Instron 5566, Instron Corp., Norwood, MA) was used for tensile testing at room temperature (23°C) at a crosshead speed of 50 mm/min.

Thermal analysis

The thermal analyses were performed with a differential scanning calorimeter (Netzsch DSC-204, Bavaria, Germany). The samples were heated at a rate of 10°C/min in the temperature range 25–160°C in a nitrogen atmosphere. Each sample was approximately 5 mg. All results were recorded for the first heating of the samples.

The relative degree of crystallinity (X_c) was calculated as follows:

$$X_c = \frac{\Delta H_f}{\Delta H_{fc}} \times 100\%$$

where ΔH_f is the melt enthalpy of the sample and ΔH_{fc} is the melt enthalpy of the 100% crystal of PP (293 J/g).

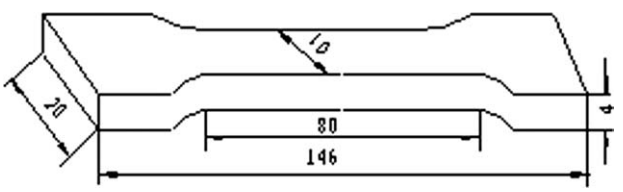

Figure 2 Sketch of the tensile test specimen.

The differential scanning calorimetry (DSC) peak separation technique was adopted with the Peak Separation software provided by Netzsch Corp. in the DSC-204 equipment.

Energy consumption testing

An digital energy consumption instrument (model WT1600, Yokogawa Corp., Tokyo, Japan) was used for the testing of energy consumption.

Density testing

A specific gravity tester (model SartoriusAG, Sartorius Corp., Goettingen, Germany) was used for density testing at room temperature (23°C); its precision was 0.1 mg/cm^3.

RESULTS AND DISCUSSION

Effects of the vibration parameters on the mechanical properties

Figure 3 shows the effects of the vibration amplitude on the tensile strength at different frequencies. The experimental results show that the tensile strength increased with increasing vibration amplitude under the same vibration frequency, and then, with increasing the amplitude further, the tensile strength decreased slightly. The tensile strength increased first and decreased slightly later but reached a maximum value quickly at last at a frequency of 8 Hz. This showed that the tensile strength was most sensitive at a frequency of 8 Hz. The tensile strength reached a maximum value at a frequency of 8 Hz under different frequencies. The maximum increment of tensile strength was 6.1%, from 8.13 MPa of the steady sample to 8.63 MPa of the sample obtained at a vibration frequency of 8 Hz and a vibration amplitude of 0.39 mm. From Figure 3, the else rule was found: The tensile strength increased quickly when the vibration amplitude was lower. The tensile strength of all of the vibration samples improved over that of the no-vibration samples.

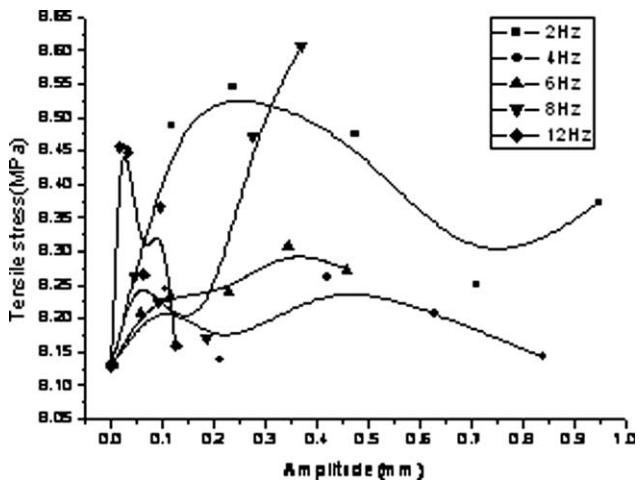

Figure 3 Tensile strength of the LDPE samples at different frequencies versus the amplitude.

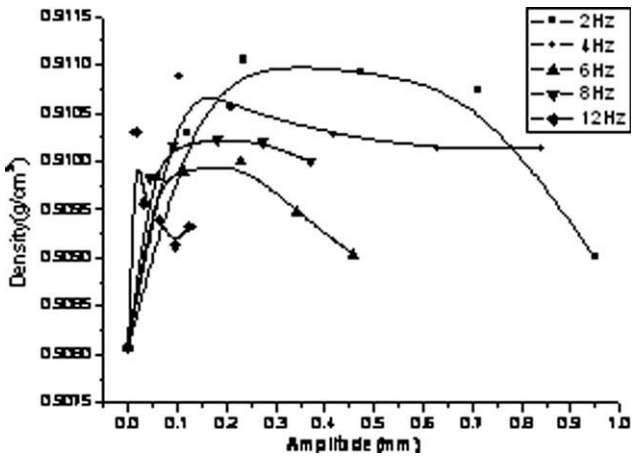

Figure 4 Density of the LDPE samples at different frequencies versus the amplitude.

Effects of the vibration parameters on the sample density

Figure 4 shows that the sample density improved evidently with imposed vibration. With increasing vibration amplitude, the samples density reached its maximum value and later decreased slowly under the same frequency. The sample density reached its maximum values of 0.9081 g/cm^3 for the steady sample to 0.9112 g/cm^3 for the sample obtained at a vibration frequency of 2 Hz and a vibration amplitude of 0.24 mm. The maximum increment of density was 0.34%. The influence was relatively great on the sample density in low-frequency molding. The more the melt was filled to the mold by periodical changes of pressure in the packing pressure process, the more compacted the product was. The sample density also improved.

Thermal analysis

The results of the DSC heating scans for the samples in different vibration parameters are shown in Figure 5, where curve a exhibits the fusion thermogram of the sample under steady conditions, and curves b, c, d, and e show the fusion thermograms of the samples under different vibration parameters. In Figure 5, the shape of melting peak is very similar, but, with increasing vibration amplitude, the melting point shifted toward a higher temperature. The various melting parameters determined from the fusion scans are given in Table II. The sample under the steady conditions exhibited only a sharp peak at 106.6°C, but the peaks of the samples with different

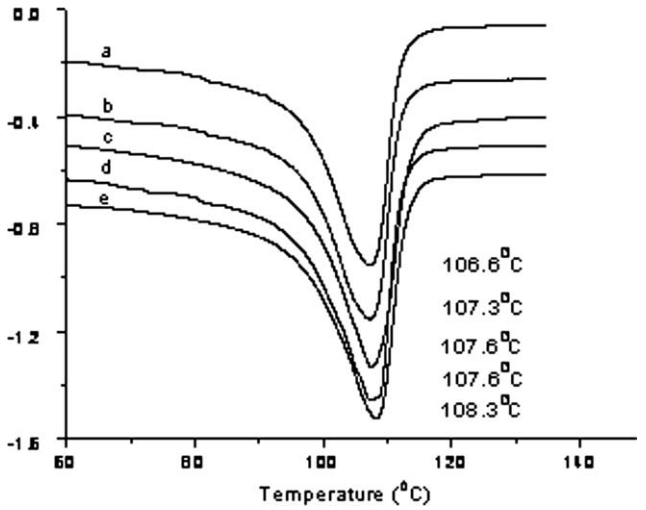

Figure 5 DSC curves of the LDPE samples with different vibration amplitudes.

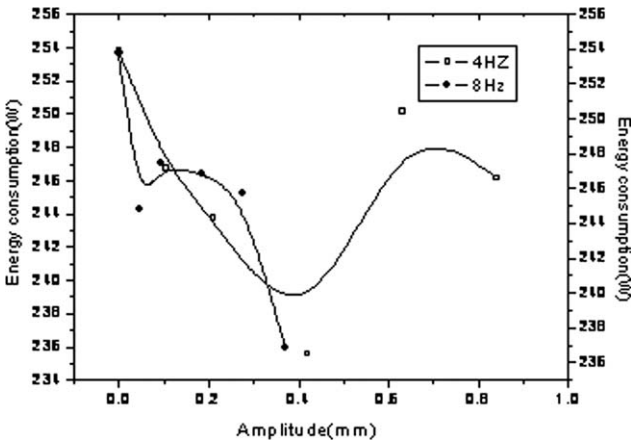

Figure 6 DSC curves of the LDPE samples with different vibration amplitudes (frequency = 4 Hz, amplitude a = 0 mm, amplitude b = 0.2 mm, amplitude c = 0.42 mm, amplitude d = 0.63 mm, amplitude e = 0.84 mm).

vibration parameters exhibited broader shapes than curve a. Compared with the original sample under the steady conditions, all melting peaks of the samples under vibration conditions increased, from 106.6 to 108.3°C. The mechanical properties of the sample mainly depended on the change of the polymer morphology and crystal kinetics. Because the melting peak area obtained from DSC was directly proportional to the degree of crystallinity, the vibration force field had a slight effect on the degree of crystallinity, which increased from 24.47 to 26.74%. Therefore, the increase in the melting peak may have been due to the vibration in crystal perfection, which affected the mechanical properties of the LDPE samples.

Energy consumption

To explore the effect of the vibration parameters in the plasticating process on the whole molding energy consumption, the digital energy consumption instrument was connected to a general import power supply of the injection-molding machine. We collected the energy consumption by changing the vibration amplitude and frequency in the plasticating process but keeping the other technical parameters invariable.

TABLE II
DSC Results for LDPE Samples Under Different Vibration Conditions

Amplitude (mm)	Melting point (°C)	ΔH_f (J/g)	Crystallization (%)
0	106.6	71.69	24.47
0.2	107.3	74.18	25.32
0.42	107.6	76.13	26.27
0.63	107.6	76.97	25.98
0.84	108.3	78.35	26.74

The results of the general energy consumption of the samples under different vibration parameters are shown in Figure 6. With increasing vibration amplitude at the same frequency, the general energy consumption dropped. When the frequency was 4 Hz, the general energy consumption dropped and reached a minimum value with increasing vibration amplitude, but when the vibration amplitude increased further, the energy consumption rose. The maximum decrement of energy consumption was 7.5%, from 254 W for the steady sample to 235 W for the single sample obtained at a vibration frequency of 4 Hz and a vibration amplitude of 0.42 mm in the range of the experiment.

Mechanism analysis

The experimental results indicate that the properties of the LDPE samples improved when a vibration force field was introduced into plasticating process. This could be explained as follows. The dissipation heat was generated by the instantaneous changing of the shear velocity and pressure with pulsed pressure introduced into plasticating process. In pulsed shear pressure, the product quality was improved because the blending of the melt accelerated, the difference in the temperature of the melt diminished, and the temperature of the melt became uniform. The polymer melt was periodically compressed and released; thus, an instantaneous impulse was obtained, and the macromolecule orientations were retained. Compared to the steady molding, the regularity of the crystal region of the LDPE sample was improved under the vibration force field. So, the mechanical properties of the dynamic molding samples were better than those of the steady samples. At the same time, the apparent viscosity of the polymer

melt dropped because of vibration shear action, and the flow state of the polymer melt changed. The screw plasticating driven power and the resistance of injection filling all decreased, so the general energy consumption dropped macroscopically.

CONCLUSIONS

Compared to conventional injection molding, the maximum increment of tensile strength and density of LDPE samples were 6.1 and 0.34% with our novel, hydraulic, dynamic, injection-molding machine because of the pulsed pressure introduce into the plasticating process. The melt point of the samples moved to a higher temperature by 1.7°C, which facilitated the perfection of the crystal. Furthermore, the whole molding resistance decreased with dynamic plasticating, and the general energy consumption dropped by 7.5%.

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