Effect of Vibration Parameters of Electromagnetic Dynamic Plastics Injection Molding Machine on Mechanical Properties of Polypropylene Samples

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ABSTRACT: Dynamic injection processing experiments have been carried out on polypropylene using the self-made electromagnetic dynamic plastics injection molding machine, and the effects of the vibration force field on mechanical properties of molding samples are studied, namely, the influence of vibration frequency and vibration amplitude on the mechanical properties of samples are researched by using tensile testing, impact testing, differential scanning calorimeter (DSC) and scanning electronic micrograph (SEM) techniques. The results show that the tensile strength and impact strength are both enhanced and the melting point shifts toward the higher temperature, which facilitates the perfection of crystal. The best vibration parameters for processing polypropylene using electromagnetic dynamic plastics injection molding machine are that frequency is from 3 to 9 Hz and amplitude is from 0.1 to 0.4 mm. J Appl Polym Sci 102: 972–976, 2006

Key words: electromagnetic dynamic; polypropylene; vibration force field; injection molding; mechanical properties

INTRODUCTION

Polymer processing is one of the most significant approaches to increase the properties of the polymer materials. Recently, the vibration technique has been applied to polymer processing and gained a lot of investigations.[1–8] The vibration energy introduced into polymer processing affects the molecular movement and the rheological behavior of the polymer melt, which affects the mechanical properties of the final products.

To date, several types of melt vibration techniques have been investigated. For example, Lemelson[9] used ultrasonic to control the solid processing of plastics melt within the cavity and increased the strength and physical properties of molded parts. Ibar[10,11] introduced vibration into injection molding when polypropylene (PP) was molded. The results showed that the elongation rose 80%, and the yield strength and modulus were increased greatly. Allen and Bevis[12–14] (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 increased the strength of molded parts and eliminated the effect of weld line. The electromagnetic dynamic plastics injection molding machine invented by Qu[15–18] is another example utilizing vibration technique, which is based on the idea that polymer behavior can be changed by the vibration force field. In this kind of injection molding machine, the vibration force 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. The novel injection molding machine has significant advantages, such as low-energy consumption, low-injection pressure, and melt apparent viscosity, when compared with those of the conventional injection molding machine.[19,20]

Although many progresses have been developed in the vibration techniques, most of these are introduced into polymer melt in packing pressure. In our experiment, a novel self-made vibration injection molding apparatus is used, in which the vibration force field is applied to the entire procedure of polymer plasticating and injection molding process. The purpose of the work is to study the mechanical properties of polypropylene under the different vibration parameters, using the novel injection machine.

EXPERIMENTAL

Materials

The sample material used in this work was polypropylene (PP) in the form of pellets and with a trade-

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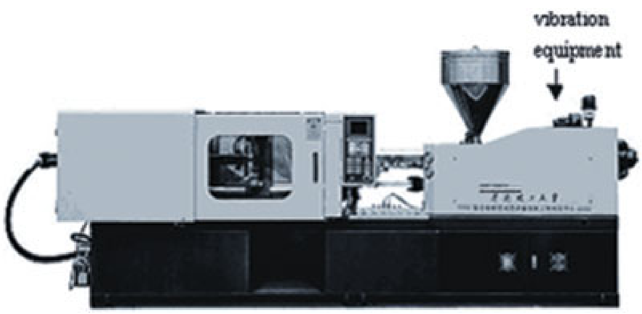

Figure 1 DPII-90 electromagnetic dynamic plastics injection molding machine. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

mark T30S (MFI = 3.0 g/10 min), spinning grade, supplied by the Wu han Phoenix, China.

Apparatus

The apparatus used in this experiment was a self-made electromagnetic dynamic plastics injection molding machine (model DPII-90), shown in Figure 1. The electromagnetic dynamic plastics injection molding machine is different from the traditional injection molding machine. The barrel and screw were inserted into the motor cavity, which was specifically designed. The schematic diagram is shown in Figure 2. The screw can rotate periodically along with the rotor induced by the electromagnetic coil. At the same time, back side of the screw was fixed to the metal plank of electromagnetic driver, which made screw vibrate in the axial direction along with the metal plank. The rotation of rotor and vibration of plank were adjusted by current. The diameter of screw is 38 mm, and the L/D ratio is $20:1$. The processing parameters are listed in Table I. A vibration velocity was superimposed on the steady processing by the axial vibration of screw. The vibration amplitude and frequency can be adjusted independently by the control pane.

Sample preparation

The samples of vibration injection molding were cooled to the room temperature (23°C) in air. The

TABLE I
Processing Parameters of Electromagnetic Dynamic Plastics Injection Molding Machine

Processing parameters	Parameters value
Injection pressure (Mpa)	90
Packing pressure (Mpa)	60
Melt temperature (°C)	190/200/210
Mold temperature (°C)	40
Packing time (s)	30
Cooling time (s)	25
Vibration frequency (Hz)	0–20
Vibration amplitude (mm)	0–0.4

mold temperature was controlled at 40°C through a thermolator that supplied heated oil to the mold in a closed loop network of hoses. The experiments were performed at a range of vibration parameters. The sketch of mechanical test specimen is shown in Figure 3.

Tensile testing

The universal tensile testing machine (Model INSTRON 5566, INSTRON, American) was used for tensile testing at room temperature (23°C), at a crosshead speed of 50 mm/min. The direction of test was parallel to the direction of melt flow.

Impact testing

The pendulum impact testing machine (Model POE2000, INSTRON corp. American) was used for impact testing.

Thermal analysis

The thermal analyses were performed using a differential scanning calorimeter (NETZSCH DSC-204). The samples were heated at a rate of 10°C in the temperature range of 25–220°C in a nitrogen atmosphere. Each sample was weighed ~5 mg. All results were recorded for the first heating of the samples.

The relative degree of crystallinity can be calculated using the formula

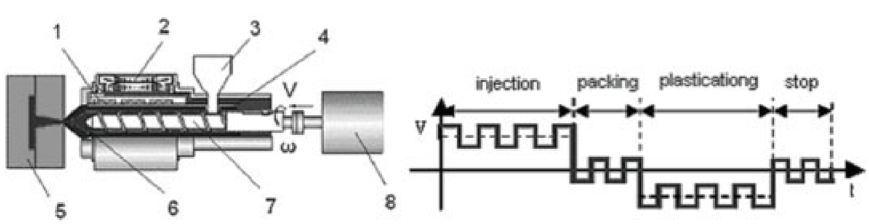

Figure 2 Schematic diagram of electromagnetic dynamic plastics injection molding equipment. 1, heater; 2, coil of electromagnetic driver; 3, hopper; 4, barrel; 5, die assembly; 6, melt; 7, screw; 8, electromagnetic dynamic driver. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

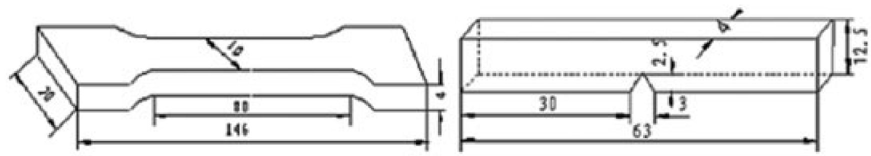

Figure 3 Sketch of mechanical test specimen. Sketch of (a) tensile test specimen (b) impact test specimen.

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

where the ΔH_f is the melt enthalpy of sample and the ΔH_{fc} is the melt enthalpy of the 100% crystal of PP, 209 J/g.

The DSC peak separation technique was adopted using the PEAK SEPARATION software provided by NETZSCH in the DSC-204 equipment.

Scanning electronic micrograph

A small sample was cut from the impact fracture bar and the structure was examined on a Philips XL-300 SEM.

RESULTS AND DISCUSSIONS

Effect of vibration frequency on the mechanical properties of PP

Figures 4 and 5 show the effect of vibration frequency on tensile strength and impact strength respectively. *A* and *f* represents the vibration amplitude and the vibration frequency, respectively. The experimental results show that the tensile strength increases sharply with increasing vibration frequency under the same vibration amplitude, and then, with further increase in frequency, the tensile strength decreases slightly. The tensile strength reaches to the maximum value in frequency f = 4 HZ under the four different amplitudes. The maximum increment of tensile strength is 7.03%, from 32.14 Mpa of the steady sample to 34.4 Mpa of the sample obtained at vibration frequency f = 4 Hz and vibration amplitude A = 0.05 mm. Figure 5 shows the impact strength also has the best value under different frequency. The impact strength increases slightly when vibration frequency is low. When vibration frequency is 8 Hz, the impact strength reaches to a maximum value of 9.7 kJ/m^2. But, the impact strength also decreases when vibration frequency is 10 Hz. So, the PP is processed using the electromagnetic dynamic plastics injection molding machine, the optimal vibration frequency is 3–9 Hz.

Effect of vibration amplitude on the mechanical properties of PP

Figures 6 and 7 show the effect of vibration amplitude on tensile strength and impact strength, respectively. The experimental results show that the tensile strength is 32.14 Mpa without vibration. Under the vibration force field, the tensile strength increases sharply in the range of amplitude 0–0.05 mm in the same frequency; subsequently, with increase in amplitude, the tensile strength increases slowly. In Figure 7,

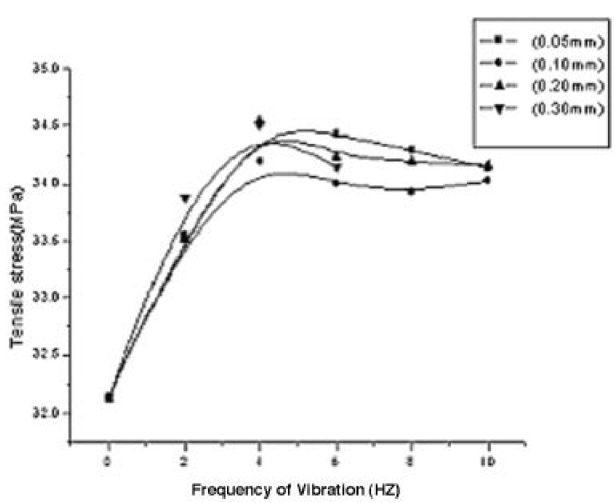

Figure 4 Tensile strength of PP under different frequency.

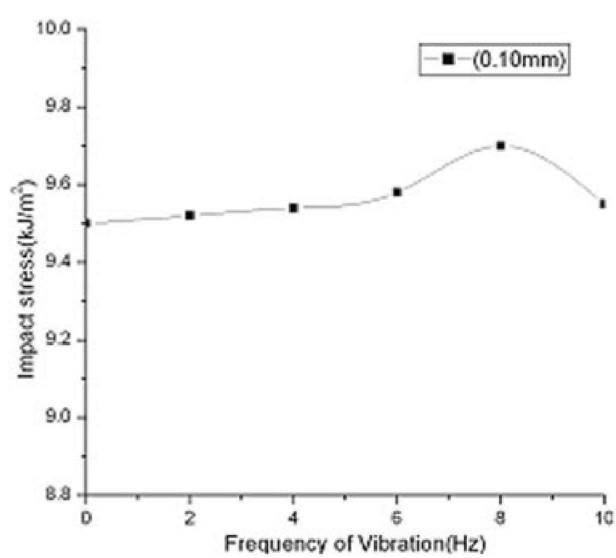

Figure 5 Impact strength of PP under different frequency.

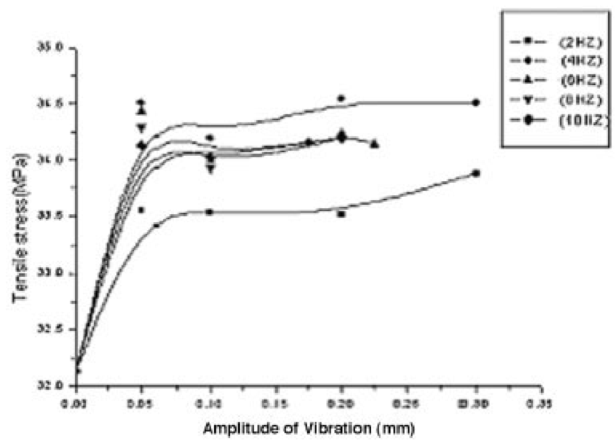

Figure 6 Tensile strength of PP under different amplitude.

the impact strength increases slightly with the increase of vibration amplitude. When the vibration amplitude is 0.4 mm, the impact strength reaches to maximum value. When the PP is processed using the electromagnetic dynamic plastics injection molding machine, the optimal vibration amplitude is more than 0.1 mm. From the aforementioned analysis, the phenomenon demonstrates that the amplitude also has the effect on the mechanical properties of PP as the frequency. But, the effect of the frequency on the mechanical properties of PP is much obvious than that of the amplitude.

Thermal analysis

The results of DSC heating scans for the samples in the different vibration parameters are shown in Figure 8, where the curve a exhibits the fusion thermogram of the sample under the steady condition, the curves b–d show the fusion thermogram of the samples in different vibration parameters. In Figure 8, the shape of

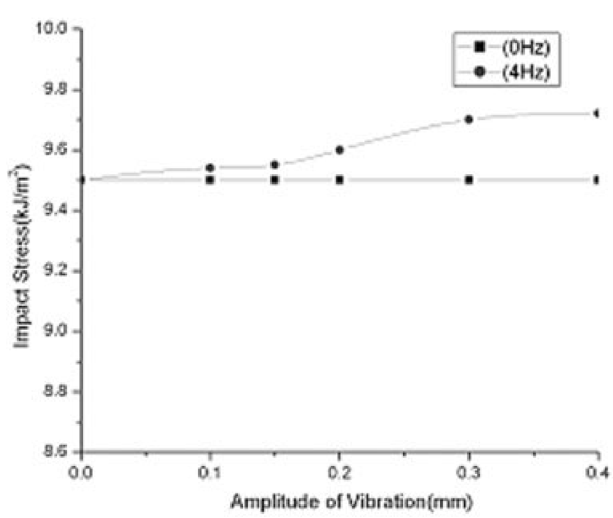

Figure 7 Impact strength of PP under different amplitude.

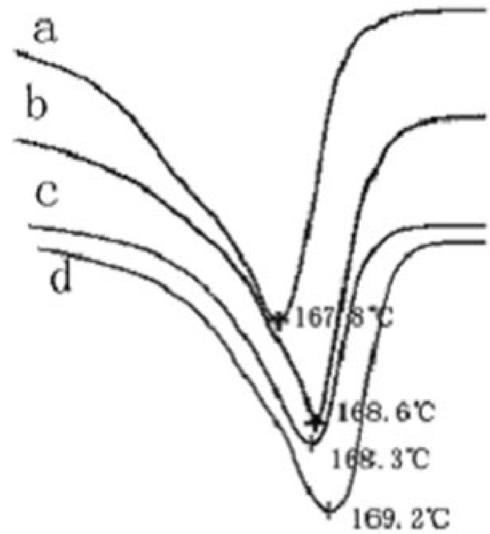

Figure 8 DSC curves of the samples with different vibration conditions a, 0 Hz; b, 4 Hz, 0.02 mm; c, 6 Hz, 0.05 mm; d, 10 Hz, 0.05 mm.

melting peak is very similar, but with increase of the vibration frequency and amplitude, the melting point shifts toward the higher temperature. The various melting parameters determined from fusion scans are given in Table II. The sample under the steady condition exhibits only a sharp peak at 167.8°C, but the peaks of the samples in different vibration parameters exhibit broader shapes than the curve a. Compared with the original sample in the steady condition, all melting points of the samples under vibration conditions increase from 167.8 to 169.2°C. The mechanical properties of the sample mainly depend on the change of polymer morphology and crystal kinetics. Since melting peak area obtained from the DSC is directly proportional to the degree of crystallinity, it is shown that the vibration force field has slightly effect on the degree of crystallinity that increases from 41.6 to 43.9%. Therefore, the increase in melting peak may be due to the vibration in crystal perfection, which affects the mechanical properties of PP samples. Because no new crystal had formed and no obvious increase of the degree of crystallinity, we think that the essential reason of the improvement of mechanical properties of samples is that average crystalline size decreased.

TABLE II
DSC Result of PP Samples Under Different Vibration Conditions

Frequency (Hz)	Amplitude (mm)	Melt point (°C)	ΔH_f (J/g)	Crystallization(%)
0	0	167.8	87.00	41.6
4	0.02	168.6	90.49	43.3
6	0.05	168.3	89.10	42.6
10	0.05	169.2	91.79	43.9

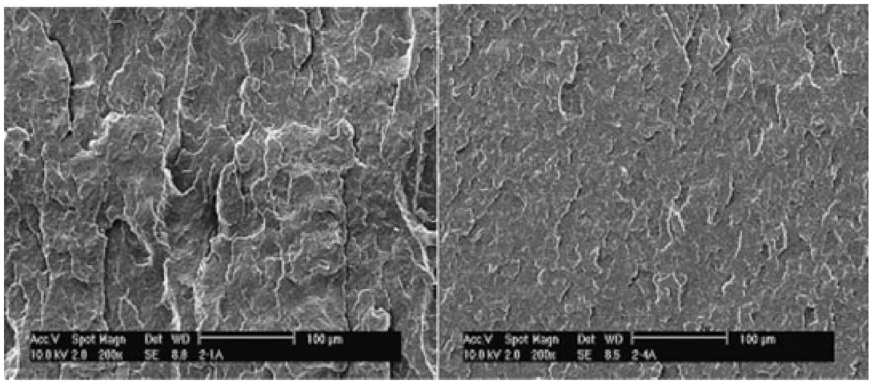

Figure 9 SEM micrographs of impact break cross-section of PP sample (200×) (a) $f = 0$, $A = 0$ (b) $f = 4$ Hz, $A = 0.1$ mm.

SEM investigation

Figure 9 shows the scanning electron micrographs of impact break cross sections of PP sample in the steady and vibration conditions, respectively. Figure 9(a) corresponds to steady molding and Figure 9(b) corresponds to dynamic processing. Figure 9 shows that the impact break cross sections of PP sample is not obvious breakpoints, but is the sheet and tiny break surface. By comparing the Figures 9(a) and 9(b), it was found that the break lines of the impact cross sections of PP sample in vibration condition ($f = 4$ Hz, $A = 0.1$ mm) is more uniform and compact than in the steady condition. The pattern of break for PP sample is close to the brittle fracture.

Compared to the steady molding, the regularity of crystal region of PP sample is improved under the vibration force field. The break sheet is denser on the impact cross sections and the distribution is more uniform. The break configuration shows that the impact break energy of the sample is higher under the vibration force field, which is accordant to the experimental data of impact. The break configuration and the improvement of the impact break energy also shows that the vibration force field can affect the crystalline structure of PP and improve the degree of crystallinity. Thus, the break cross section is smoother and the break lines are more uniform. According to the smooth break cross section and uniform break lines of impact, we think that the spatial arranging sequence of molecular chain is enhanced under vibration force field. So, the mechanical properties of samples improved macroscopically.

CONCLUSIONS

Compared to the conventional injection molding, the tensile strength of PP samples is enhanced to a certain extent by using the novel electromagnetic dynamic plastics injection molding machine, because the vibration force field is applied to the entire molding process. The effect of vibration frequency on the tensile strength is much obvious than that of vibration amplitude. The tensile strength is close to linear increase under low-vibration frequency and vibration amplitude. When the vibration frequency is less than 3 Hz and vibration amplitude is less than 0.1 mm, the impact strength decreases than the steady sample. But, with further increase in vibration frequency and vibration amplitude, the impact strength is improved. So, for the novel electromagnetic dynamic plastics injection molding machine, the best vibration parameters for processing PP is from 3 to 9 Hz and amplitude is from 0.1 to 0.4 mm.

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