

Effect of Vibration on Rheology of Polymer Melt

ZHENG YAN,¹ KAI ZHI SHEN,¹ JIE ZHANG,¹ LI MIN CHEN,¹ CHIXING ZHOU²

¹ The State Key Laboratory of Polymer Materials Engineering, College of Polymer Science and Engineering, Sichuan University, Chengdu, Sichuan 610065, People's Republic of China

² Department of Polymer Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China

Received 10 May 2001; accepted 12 October 2001

ABSTRACT: In this article, under shearing vibration and pressure vibration, the rheological behavior of HDPE, ABS, and PS melts and the mechanical properties of molded parts are studied. The experimental results show that, under the vibration condition, the apparent viscosity of the polymer melt decreases with an increasing of the vibration frequency and amplitude applied. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 85: 1587–1592, 2002

Key words: melt; vibration; rheology

INTRODUCTION

The rheology of the polymer melt plays an important role in polymer processing. The behavior of a polymer melt can be changed greatly by applying an external stress field during processing. The vibration field is a kind of external stress field that can be used to control the processing behavior to obtain high-quality products. Some vibration techniques and apparatus have been developed^{1–5} to investigate such influences. The experimental results^{1,2} showed that the vibration has a great effect on the rheology of the polymer melt as well as on the physical properties of the parts molded under vibration. Wong and Isayev¹ studied the influence of the vibration field on the poly-

mer 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. Ibar studied the effect of vibration on the molding using rheomolding. The results indicated that the vibration has a great effect on the physical performance of the molded parts as well.^{2–6} For applying such vibration into injection-molding, Allen and Bevis created the multi-live feed molding technology.^{7–9} Also, we developed the oscillating packing injection-molding technology¹⁰ to study the strength of the molded parts. Those experiments all showed that the properties of the injection-molding parts could be improved by applied vibration. To investigate the mechanism of the vibration, we further designed a new vibration molding apparatus and presented our primary experimental results in a previous article.¹¹ In this present article, we show our recent experimental results in detail and compare them with our theoretical prediction.

Correspondence to: Z. Yan (yanzeng@mail.sc.cninfo.net).

Contract grant sponsor: National Natural Science Foundation of China; contract grant number: 29874025.

Contract grant sponsor: Special Funds for Major State Basic Research Projects of China; contract grant number: G1999064809.

Contract grant sponsor: Visiting Scholar Foundation of Key Laboratory in University of China.

Journal of Applied Polymer Science, Vol. 85, 1587–1592 (2002)
© 2002 Wiley Periodicals, Inc.

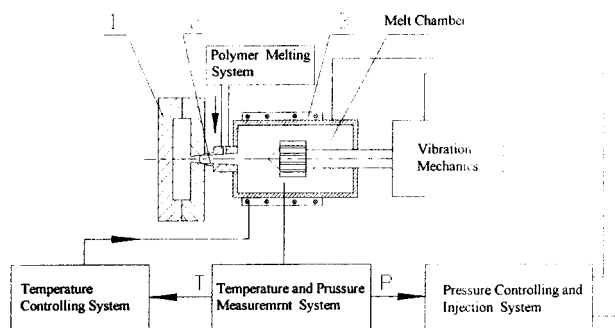


Figure 1 Vibration molding apparatus.

EXPERIMENTAL

Apparatus

Figure 1 shows our novel apparatus^{12,13} which can apply shearing and pressure vibration at the same time. The apparatus consists of several systems, such as for polymer melting, temperature detection and control, pressure detection and control, mold (or standard hole mold), injection, 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.

Materials

High-density polyethylene (HDPE, grade PE-LA-50D012) was provided by Lanzhou Chemistry Ltd. (China). Polystyrene (PS, grade B-1) and ABS were made in Taiwan. Polypropylene (PP, grade F401) is from Gansu Langang Chemistry Ltd. (China).

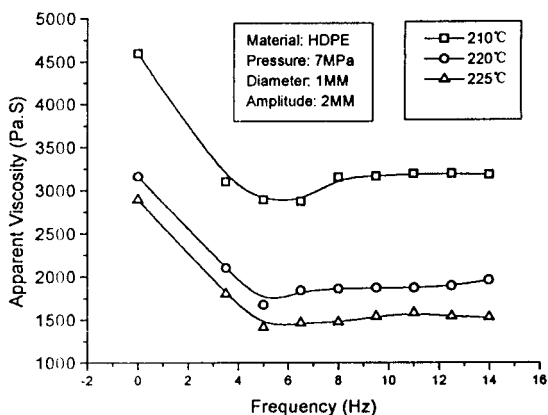


Figure 2 HDPE melt apparent viscosity curve versus frequency at different temperatures.

Table I Experimental Results for HDPE Melt

Temperature (°C)	Frequency (Hz)	Viscosity (Pa S)	Max Decrease of Amplitude (Pa S)	Percent (%)
210	5.5	2722	1873	40.8
220	5.2	1522	1613	51.0
225	5.2	1538	1354	53.2

Rheology Study

The procedure of measuring the viscosity of polymer melts under vibration is as follows: First, polymer materials are melted in an extruder. Then, the polymer melt is transported into the melt chamber of the vibration device and vibrated. During vibration, the melt is extruded out through a standard rod die. Thus, the rheological parameters of the polymer melt studied can be obtained according to the *in situ* measurement and subsequent calculation.

HDPE Melt Vibration Experiment at Different Temperatures

HDPE was used in this study. The experiment was carried out at different temperatures and pressures. The correspondent rheological parameters were measured by changing the vibration frequency. Figure 2 gives an HDPE melt apparent viscosity curve versus the frequency at different temperatures. The results show that the apparent viscosity of the HDPE melt decreases greatly when the vibration frequency increases. The viscosity reaches a minimum value at about 5.2–5.5

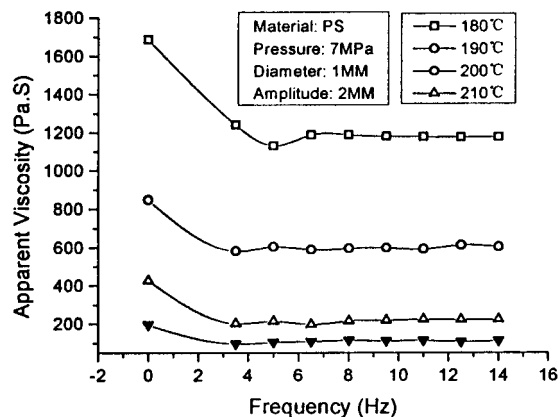


Figure 3 PS melt apparent viscosity curve with frequency at different temperatures.

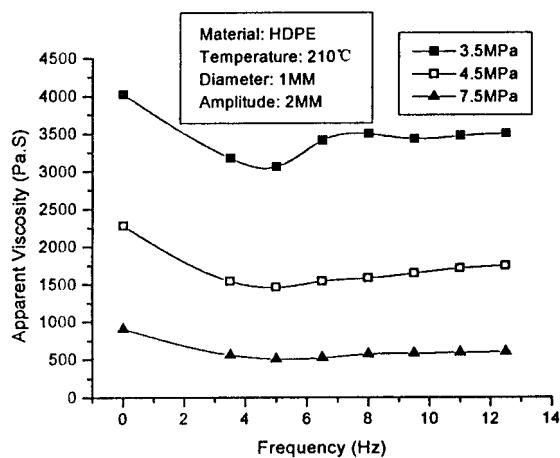
Table II Experimental Results for PS Melt

Temperature (°C)	Frequency (Hz)	Viscosity (Pa S)	Max Decrease of Amplitude (Pa S)	Percent (%)
180	5.2	1075	611	36.2
190	4	553	296	34.9
200	4	170	258	60.3
210	4	83	113	42.3
220	4	58	38	39.6

Hz and increases again very slowly over this critical point. The changing rate and amplitude of the curves is different under different temperature conditions. The minimum viscosity, maximum decrease of amplitude, and decreased percentage at different temperatures are shown in Table I. It is obvious that the rate of decrease and amplitude of the apparent viscosity of the HDPE melt rely on the operating temperature under the condition of melt vibration.

PS Melt Vibration Experiment at Different Temperatures

The results of the PS melt vibration experiments at different temperatures are shown in Figure 3. The curves show that the apparent viscosity of the PS melt decreases with increase of the vibration frequency. However, at different temperatures, the rates of decrease are different. The higher the temperature, the less the rate decreases. The changing tendency of the PS melt under vibration is similar to that of the HDPE

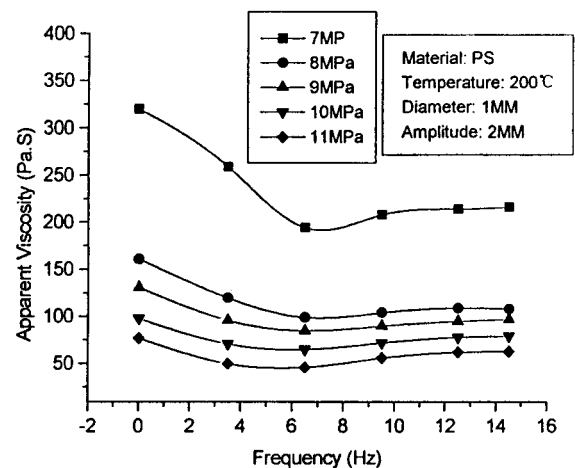
**Figure 4** HDPE melt apparent viscosity curve at different average pressures.**Table III Experimental Results for HDPE Melt**

Pressure (MPa)	Frequency (Hz)	Viscosity (Pa S)	Max Drop Amplitude (Pa S)	Percent (%)
3.5	5.5	2965	1055	23.9
4.5	5.2	1429	850	37.3
7.5	5.2	506	399	44.1

melt, that is, the apparent viscosity decreases quickly at the first stage until it arrives at a minimum value, then increases very slowly after this critical point. The lowest apparent viscosity, maximum decrease of amplitude, and decreased percent at the corresponding frequencies are shown in Table II. We know from the table that the critical frequency equals 5.2 Hz at $T = 180^{\circ}\text{C}$, which is the same as for HDPE. While at $190\text{--}220^{\circ}\text{C}$, the frequency is 4 Hz.

HDPE Melt Vibration Experiment at Different Average Pressures

Since the pressure is fluctuated during the experiment, we took its average value as the pressure parameter. Figure 4 presents the experimental results under different average pressure. When the vibration frequency varies from 0 to 5 Hz, the apparent viscosity decreases quickly, then reaches the lowest point, and after that increases slightly and eventually levels off. The lowest point of the apparent viscosity, maximum decrease of amplitude, and decreased percent at

**Figure 5** PS melt apparent viscosity curve under different average pressures.

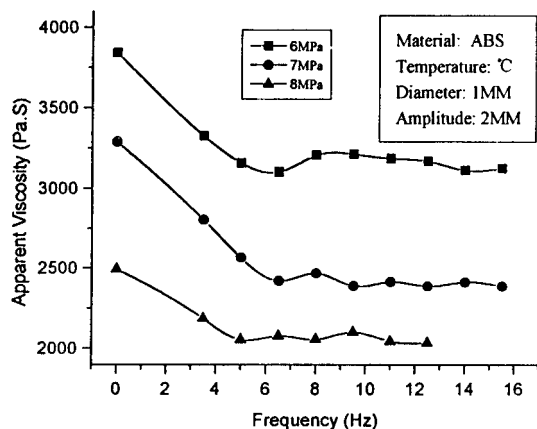


Figure 6 ABS apparent viscosity versus frequency at different pressures.

different pressures with the corresponding frequencies are shown in Table III. The experimental results have proved that the effect of the polymer melt vibration is relative to the average pressure.

PS Melt Vibration Experiment at Different Average Pressures

The experimental results of PS are shown in Figure 5.

ABS Melt Vibration Experiment at Different Average Pressures

The experimental results presented in Figure 6 show that the apparent viscosity of the ABS melt is relative to the average pressure applied on it. Under different average pressures, there is an apparent viscosity quickly decreasing region. Within it, the apparent viscosity decreases quickly with increase of the vibration frequency.

However, the apparent viscosity changes slowly beyond that region. Under different average pressure conditions, the lowest point, ampli-

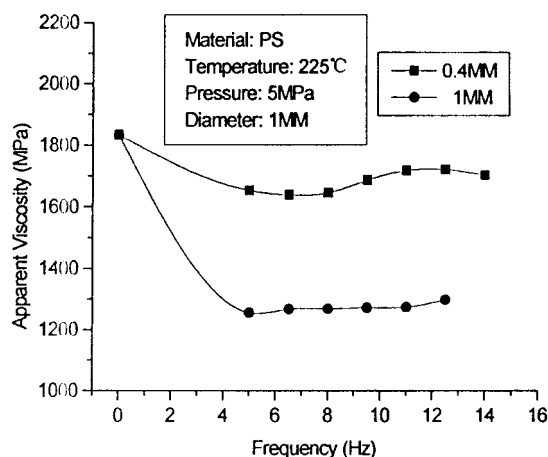


Figure 7 PS apparent viscosity and frequency curve under vibration of different amplitudes.

tude decreases and percent of the amplitude of the ABS melt at the corresponding frequencies are shown in Table IV. The experimental results for ABS also indicate that, under experimental conditions, the effect of the vibration on the apparent viscosity is relative to the average pressure applied on it.

PS Melt Vibration Experiment at Different Shearing Amplitudes

Our vibration apparatus can apply both shear vibration and pressure vibration at the same time. In the experiment, an experimental apparent viscosity and frequency curve under vibration can be acquired by only changing the amplitude of vibration. The resulting curves are shown in Figure 7.

The results show that the vibration amplitude has a great influence on the shape of the apparent viscosity–frequency curve. When other conditions are the same, the greater the amplitude, the more the curve decreases. The lowest point of the ap-

Table IV Experiment Results for ABS Melt

Average Pressure (MPa)	Frequency of the Lowest Point (Hz)	Volume of the Lowest Point (Pa S)	Viscosity Max Decrease of Amplitude (Pa S)	Percent of Max Decrease of Amplitude (%)
6	6.5	3103	739	19.2
7	6.5	2421	869	26.4
8	5	2054	439	17.6

Table V Experimental Results for PS Melt

Amplitude (MM)	Frequency (Hz)	Viscosity (Pa S)	Max Drop Amplitude (Pa S)	Percent (%)
0.4	6.5	1639	95	5.5
1	5.2	1237	497	28.7

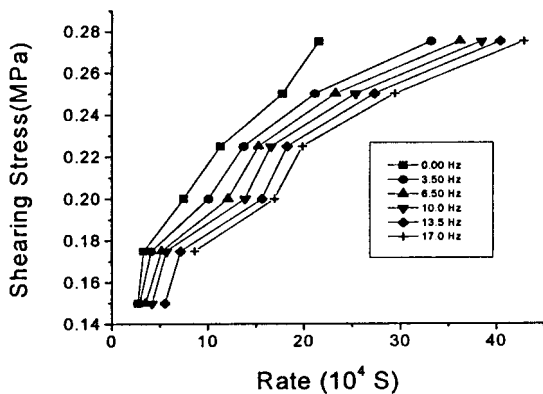
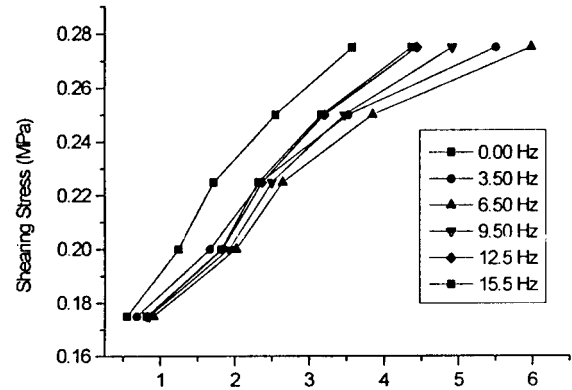
parent viscosity, maximum decrease of the amplitude, and the decreased percent at different amplitudes with the corresponding frequencies are shown in Table V.

Polymer Melt-flow Curve at Different Frequencies

The flow curves of the HDPE melt at different frequencies are presented in Figure 8. The flow curves of the PS melt are presented in Figure 9. The results reveal that the polymer melt-flow curves under vibration are different from those under no vibration. This also illustrates that vibration has an influence on the rheology of the polymer melt.

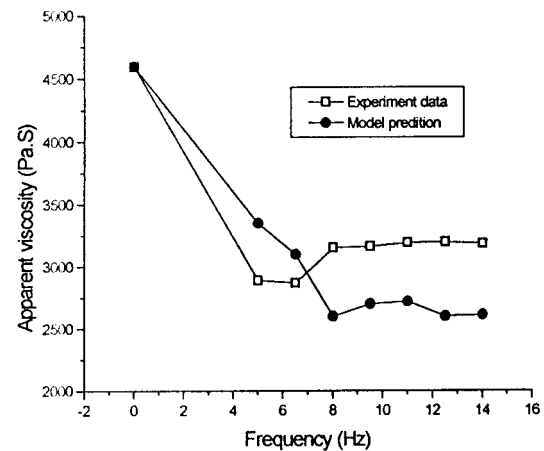
Simulation of HDPE Melt Apparent Viscosity Curve Under Vibration

A rheological model was used to simulate the flow field of the HDPE melt under vibration. This model was presented by Zhou.¹⁴ The simulation result is shown in Figure 10. The theoretic curve and experimental curve are both shown in the figure. In comparing the two curves, it is observed that the tendency of the simulation curve and the experimental curve is the same.

**Figure 8** Flow curve of HDPE melt under different frequencies.**Figure 9** Flow curve of PS melt under different frequencies.

RESULTS AND DISCUSSION

On the basis of the theory of the polymer molecule chain network model, the experimental results above can be explained as follows: Conceptually, polymer chains in the melt can be regarded as an intercrossed viscoelastic matrix and entangled to form chain networks. It is widely accepted that flow fields can destroy some of that entanglement, resulting in a viscosity reduction of the polymer melts. In a flow field of the polymer melt, the actions of disentanglement and entanglement exist at some time and form a dynamic equilibrium. Under a vibration condition, it is expected that the vibration force makes much easier the disentangling function at a superimposed vibration field. The result is that the total numbers of poly-

**Figure 10** Theoretical effect of the vibration frequency on the viscosity of the HDPE melt at 210°C.

mer entanglement points decrease and, hence, the viscosity of polymer melt decreases.

CONCLUSIONS

On the basis of the experimental results, some conclusions can be summarized as follows:

1. In general, the apparent viscosity of a polymer melt decreases with increase of the vibration frequency. There is a fast decreasing sensitive region of vibration for a certain material.
2. The apparent viscosity of the polymer melts decreases with the vibration amplitude.
3. The effect of the vibration field on the apparent viscosity of the polymer melt is relative to the temperature field and the pressure field of the polymer melt. The lower temperature and pressure applied result in a greater effect on the apparent viscosity.

REFERENCES

1. Wong, C. M.; Isayev, A. I. *Rheol Acta* 1989, 28, 2.
2. Ibar, J. P. *ACS Polym Prepr* 1980, 21, 215.
3. Ibar, J. P. *Fr. Patent* 906 532, 1979.
4. Ibar, J. P. *Fr. Patent* 8 002 620, 1980.
5. Ibar, J. P. *U.S. Patent* 7 906 532, 1979.
6. Ibar, J. P. *Mod Plast Int* 1995, Jan, 72.
7. Allen, P. S.; Bevis, M. J. *Plast Rubb Process Appl* 1987, 7, 3–10.
8. Allen, P. S.; Bevis, M. J. *Brit. Patent* 2170-140-B, 1995.
9. Allen, P. S.; Bevis, M. J. *SPE-ANTEC Tech Pap* 1993, 1, 442.
10. Guan, Q.; Shen, K.-Z.; Ji, J. *J Appl Polym Sci* 1995, 55, 1797.
11. Yan, Z.; Shen, K.; Song, D.; Zhang, J. *Chin Plast* 2000, 14, 63.
12. Yan, Z. *Postdoctoral research report of Sichuan University*, 2000.
13. Yan, Z.; Shen, K.; Zhang, J. *Chin. Patent Appl.* 01 214 285, 2001.
14. Zhou, C. X. *Chin Polym Sci* 1999, 17, 151–158.