

Numerical simulation and experiment on effect of ultrasonic in polymer extrusion processing

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Abstract. The influence of ultrasonic wave on the flow field parameters and the precision of extruded products are studied. Firstly, the effect of vibration power on the average velocity of the outlet, the average viscosity of the die section, the average shear rate and the inlet pressure of the die section were studied by using the Polyflow software. Secondly, the effects of ultrasonic strength on the die temperature and the drop of die pressure were studied experimentally by different head temperature and different screw speed. Finally, the relationship between die pressure and extrusion flow rate under different ultrasonic power were studied through experiments.

1. Introduction

Extrusion technology can be molded almost all of the thermoplastic, not only continuous production, but also high production efficiency, so the polymer processing methods occupy a very important position [1,2].

However, the quality of plastic products are affected by the performance of the plastic itself, In the molten state, the macromolecular structure of the polymer chains have a great influence on the stress of the melt viscosity, elasticity and relaxation method. Most linear polymers in the molten state, showed irregular macromolecular chains. Therefore, in the extrusion process, the molecular chain clusters flow through the die when there is extended orientation problem: When the melt flow out of the mold, part of the melt molecular chain elasticity recover, and tend to be line-like, then there will be squeeze swelling phenomenon.

In recent years, as a new energy, ultrasonic energy is often used into conventional processing method [3]. When the intensity is high, it can interact with its acoustic media, change or even destroy the original nature and structure of its acoustic media, this time called power ultrasound [4-6]. At present, domestic and foreign scholars use ultrasonic researches in the field of polymer processing, which are mostly around the ultrasonic impact on polymer melt rheological properties to improve the quality of molding process.[7] When the ultrasonic wave is added to the polymer solution, it can cause the polymer molecular chain to break into macromolecule radicals, and it will change the rheological properties of the polymer melt, and ultimately change the material processing properties and product properties.

In this paper, the rheological behavior of polymer melt under vertical superimposed ultrasonic vibration is studied. Firstly, the effects of ultrasonic wave on the average velocity inlet pressure,



average shear rate and the average viscosity of the die were analyzed by numerical simulation. The effect of ultrasonic wave on the head temperature, extrusion pressure and flow rate were studied by ultrasonic assisted extrusion experiment.

2. Simulation

2.1 The Establishment of Geometric Model

Using the capillary die for numerical simulation, circular cross-sectional, the size is shown in Figure 1.

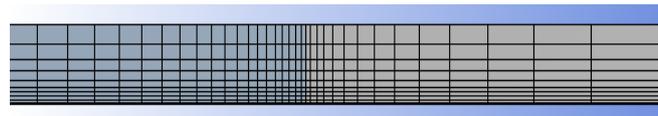
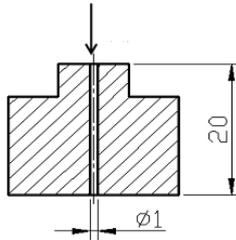


Figure 1. a sectional view of a capillary die

Figure 2. Local enlargement view of finite element model Boundary connection

This article uses Ansys own meshing method for structural meshing, and locally refine the die segment and the free segment boundary grid, as shown in Figure 2.

2.2 Mathematical Model

Ultrasonic assisted extrusion process is different from the traditional steady-state extrusion process, which is a cyclical dynamic forming process. In the process of ultrasonic assisted extrusion, due to the introduction of ultrasonic vibration field, The physical parameters (such as inlet flow rate, boundary conditions and material parameters) that characterize the melt flow are time-varying during the melt flow and are transient problems. Combining the basic theory of polymer rheology and the actual situation of melt flow in capillary die, the following assumptions are made[8]:

- (1) the melt in the mold will do the full development of laminar motion;
- (2) the melt is an incompressible non-Newtonian power law fluid;
- (3) ignore the effects of gravity and inertia;
- (4) do not consider the effect of wall slip on melt flow

The basic equation for incompressible melt flow:

Continuity equation:

$$\nabla v = 0 \quad (1)$$

Equation of motion:

$$\nabla \tau - \nabla p = 0 \quad (2)$$

Where v —speed, m/s, t —time, s, p —pressure, Pa ρ —density, kg/m^3 , τ_{ij} —Stress deflection, Pa.

The constitutive equation of the melt is Ostwald's power-law constitutive equation, The power-law constitutive equations commonly used in polymer melt processing proposed by Ostwald and de Waele [8] can be used to describe this shear thinning behavior of polymer melts. The power law constitutive equations are as follows:

$$\tau = K \dot{\gamma}^n \quad (3)$$

Where τ is the shear stress, Pa; K is the melt viscosity coefficient, $\text{Pa} \cdot \text{s}^n$; $\dot{\gamma}$ is the shear rate, s^{-1} ; n is the non-Newtonian index. The parameters used in Table 1.

Table 1 .Consistency Coefficient K and Non-Newtonian Index at Different Ultrasonic Power n

Ultrasonic power(W)	Consistency coefficient(Pa. s ⁿ)	Non - Newtonian index n
0	15217.68	0.35846
300	13216.45	0.4578
500	10015.23	0.5632
800	8996.47	0.6835

2.3. Effect of Vibration Parameters on Flow Field during Ultrasonic Vibration Extrusion

In order to study the effect of ultrasonic vibration parameters on the physical field of polymer melt extrusion, the results of Polyflow can be statistically analyzed. That is, to calculate the mean of the instantaneous value of each parameter in a vibration period. This can be more directly observed the impact of ultrasonic vibration parameters on the physical field. In order to be closer to the actual situation, this section simulates the distribution of the physical fields within 1 minute and processes the results. The simulation results are shown in Fig.3.

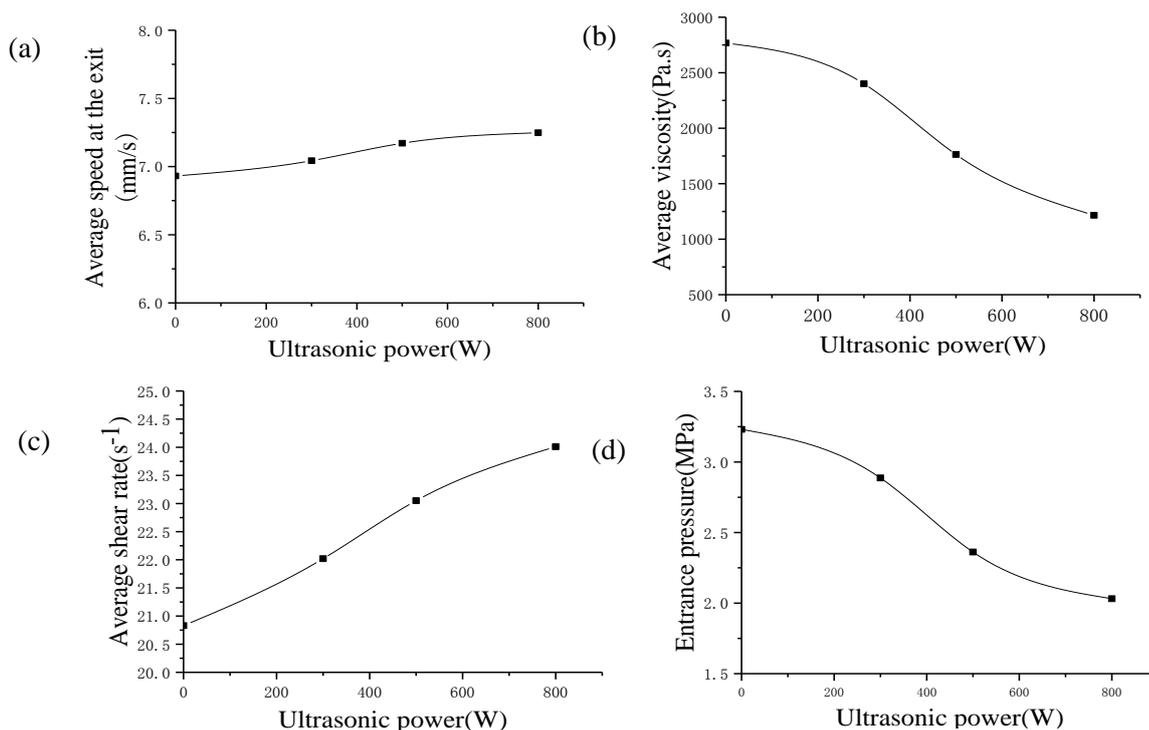


Figure 3 .The relationship between the mean of the parameters of the flow field and the vibration power in one cycle.(a) The average speed at the exit (b) Average viscosity of die module (c) Average shear rate of die (d) Entrance pressure

It can be seen from Fig. (A) that the ultrasonic velocity has little effect on the average velocity of the outlet section when the extrusion volume flow rate is constant during a cycle. Figure (b) shows the average viscosity statistical plot over the entire cross section of the melt in a die during a cycle. It can be seen from the figure that, with the increase of the ultrasonic power, melt viscosity decreased rapidly.

Figure (c) shows the statistical curve of the average shear rate on the entire cross section of the melt in a cycle. It can be seen from the figure that with the increase of the ultrasonic power, the shear rate of the melt in the capillary die increases gradually. Figure (d) shows the average pressure statistics at the inlet of the die during a cycle. With the increase of ultrasonic power, the pressure at the inlet of the die is obviously reduced.

3. Experiment of ultrasonic assisted micro-extrusion

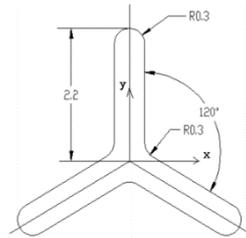


Figure 4. shape and size of die

The low-density polyethylene (LDPE) trilobal microstructure was extruded by ultrasonic - assisted micro - extrusion device. The changes of die temperature, die pressure, extrusion flow rate and dimensional precision of extruder were analyzed after ultrasonic pressure of different power intensity under different die temperature and extrusion speed. Size of trilobal -microstructure die shown in Figure 4.

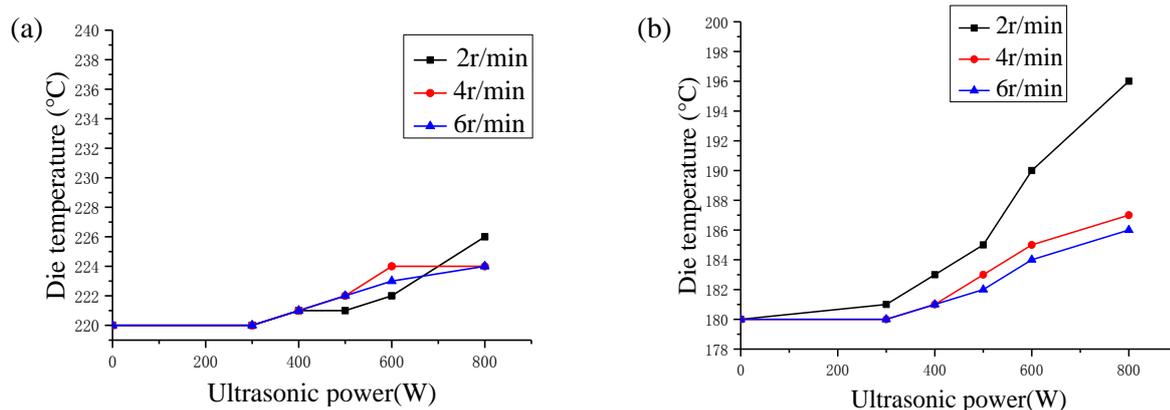
Experimental materials are the granular low-density polyethylene, South Korea's LG production, model is FB9500. A density of 0.954 g / cm³, a melting point of 112-120 °C, a decomposition temperature of about 300 °C and a melt index of 3.5 g / 10 min.

In order to test the effect of different processing temperature, screw speed and ultrasonic power on the melt extrusion process, the experimental scheme was designed when the head temperature was 180, 200 and 220 °C, respectively. Each processing temperature takes three kinds of screw speed at the head of each program, respectively 2r / min, 4r / min and 6r / min. The rheological data of the polymer melt at 0W, 300W, 400W, 500W, 600W and 800W were selected at each screw speed.

4. Effect of extrusion process parameters on forming accuracy

4.1 Effect of ultrasonic wave on extrusion die temperature

Figure 5 shows the effect of ultrasonic intensity on the melt temperature in the die at different experimental temperatures. It can be seen from the figure that when the extrusion temperature is between 180-220 °C, the melt temperature at the outlet of the die is increased with the increase of the ultrasonic power. The lower the head temperature, the greater the effect of ultrasonic on the melt temperature will be in the die. When the head temperature is between 200 °C - 220 °C, the effect of ultrasonic power on the mold temperature is very small.



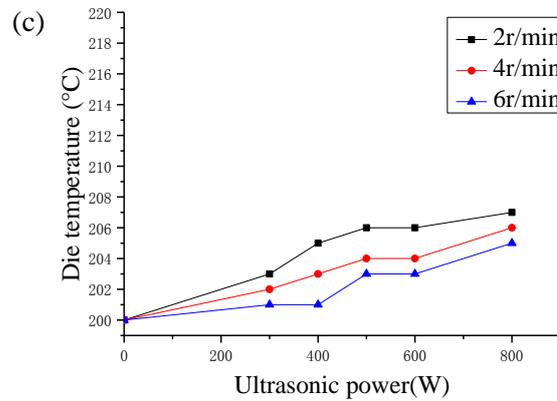


Figure 5. The effect of ultrasonic intensity on the die temperature at different head temperatures.(a) The head temperature is 180 °C (b) The head temperature is 200°C (c) The head temperature is 220°C

4.2 Effects of Ultrasonic on Extrusion Pressure and Flow

Figure 6 shows the effect of ultrasonic intensity on the pressure drop of the extrusion die when the extrusion temperature is constant and the screw speed is different. In the figure, ΔP is used to denote the relative descent value of the die pressure under the action of ultrasonic waves: In the formula, P is the die pressure when no ultrasonic wave is applied, and P_u is the die pressure at the time of applying ultrasonic waves.

$$\Delta P = \frac{P - P_u}{P} \tag{4}$$

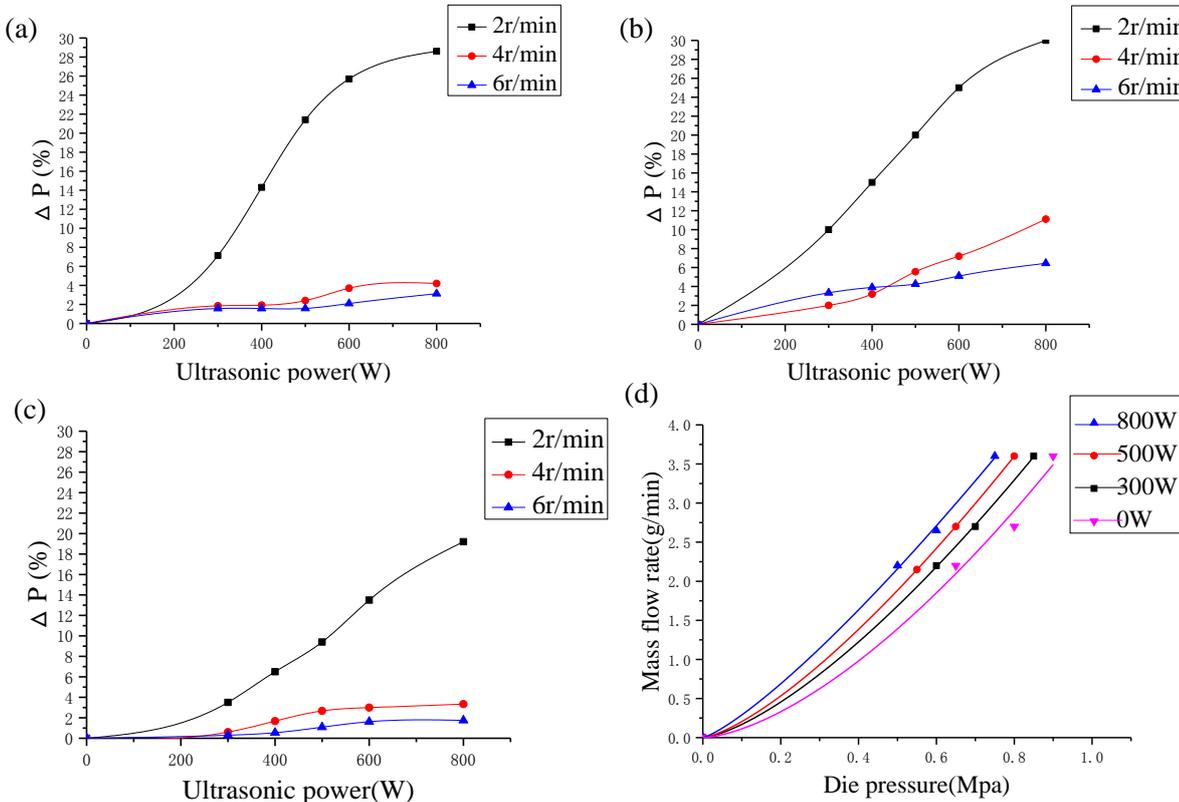


Figure 6. The effect of ultrasonic intensity on the pressure drop of the die at different head temperatures. (a) The head temperature is 180 °C (b) The head temperature is 200 °C (c) The head temperature is 220 °C (d) The relationship between die pressure and extrusion flow

As can be seen from the figure 6, when the extrusion temperature between 180-220 °C, the ultrasonic can significantly reduce the extrusion die pressure. When the processing temperature is 180 °C, the screw speed is 2r / min and the ultrasonic power is 800W, the extrusion die pressure drop reaches 29%.

Figure 6 (d) shows the relationship between extrusion pressure and extrusion flow, which is under the extrusion temperature of 180 °C and different power of ultrasound. It can be seen from the figure that the extrusion flow increases with the increase of die pressure.

4.3 Effects of Ultrasonic on Extrusion Accuracy

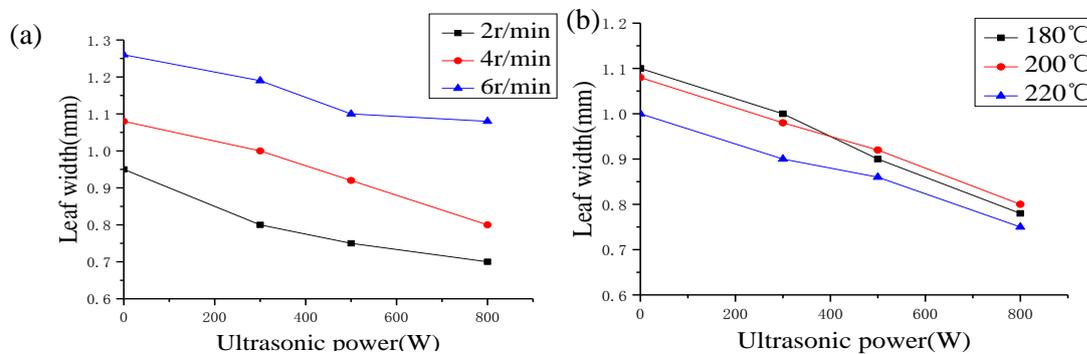


Figure 7. Size of extrudate at different ultrasonic power, (a) The relationship between ultrasonic power and leaf width at 200 °C (b) The relationship between ultrasonic power and leaf width at 4r / min

Figure 7 shows the size of the extrudate at different ultrasonic powers. Figure a) shows the impact of ultrasonic strength on the size of extrudates at different speeds when the head temperature is 200 °C. As can be seen from the figure, as it is with the head temperature of 180 °C, the ultrasonic can reduce the leaf width of the trilobical products, that is, to reduce the expansion rate of exports; When the ultrasonic power is constant, the leaf width of the trilobule product increases with the increase of the rotational speed of the screw.

Figure b) shows the effect of ultrasonic intensity on the size of the extrudate at different processing temperatures when the screw speed is 4r / min. It can be seen from the figure that the lower the temperature, the more obvious the effect of ultrasonic on the melt.

5. Conclusion

The simulation results show that the ultrasonic vibration can reduce the inlet pressure of the die, reduce the viscosity and shear stress of the melt in the die, promote the flow of the melt and reduce the resistance of the melt.

Through the experimental study, it was found that the melt temperature at the outlet of the die was increased with the increase of the ultrasonic power. The lower the head temperature, the greater the effect of ultrasonic on the melt temperature in the die. With the increase of the head temperature, the ultrasonic power has little effect on the die temperature. At the same time, the ultrasonic effect can obviously reduce the extrusion die pressure. When the processing temperature is 180 °C, the screw speed is 2r / min and the ultrasonic power is 800W, the extrusion die pressure drop reaches 29%. When the extrusion temperature is 180 °C, the extrusion flow rate increases with the die pressure rising.

Ultrasonic vibration can reduce the extrusion pressure, and can improve the extrusion yield and extrusion efficiency in low extrusion pressure. And ultrasonic vibration assisted extrusion can reduce the export of extruded outlet expansion rate and improve the dimensional accuracy of extruded products.

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Acknowledgments

This work was financially supported by the Hunan Province Key R & D program (application of basic research)(2015JC3008)