

Numerical Simulation of Distributive Mixing Characteristics in the Pin Barrel Extruder

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Abstract: In the process of rubber extrusion, the produce of viscous heat, thermal transport and power consumption are all related to the mixing behavior of material in extruder. In this paper, numerical analyses have been carried out to study the flow and mixing behavior of the fluid in the new type of pin barrel extruder. Results show that the shorter the row pitch of pins is, the larger average mixing strength has, for example, the row pitch of pins is 48mm, 60mm, 72mm, 84mm and 96mm, the average mixing strength is respectively increased by 70%, 52%, 40%, 36% and 22% than that of conventional extruder. Meanwhile, it's also found that a decrease in row pitch of pins increases mean square deviation of mixing strength at any point but reduces extrusion flow rate. Moreover, the more the number of pins in each row is, the larger average mixing strength has. When the number of pins in each row is 4, 6 and 8, average mixing strength is respectively increased by 35%, 41% and 54%. The conclusions obtained here can provide a better reference to optimize pin layout for pin barrel extruder.

Keywords: mixing, mixing strength, pin barrel extruder, numerical simulation

1. INTRODUCTION

The pin barrel extruder becomes the main product in the cold feeding rubber extruder due to its simple structure, low cost, reliable running, convenient operation and reasonable ratio of performance to cost. But the design method of pin barrel extruder named as trial and error design is still semi-empirical^[1-4], which means that much time and high cost are needed for the development. Therefore, in order to improved design efficiency and quality, the engineers are mainly concerned about whether a new type of optimum structure can be put forward after comparison of mixing effect for different structures is quickly made based on numerical calculation and analysis, then some experiments are carried out to verify the mixing effect.

Numerical analysis approach has been applied by several workers^[5-7]. For example, the flow and mixing efficiency of the cross-section of screw channel with different type of pins in screw was computed by Yao weiguang^[5], based on Newtonian 2D fluid models. However, previous analyses are not general enough to understand the actual 3D flow behavior in extruder by using simplified 2D models.

Therefore, mixing effect of viscous fluid in the conventional extruder as well as pin barrel extruder is needed to evaluate based on 3D model, and variables which effect flow behavior of materiel, such as the number of pin rows, the number of pins in each row, screw speed et al, are carried out to offer a route to optimize the pin barrel extruder.

2. ANALYSIS MODEL OF FLOW FIELD

2.1 Geometrical Model

Φ90 conventional extruder and pin barrel extruder are considered in the numerical analysis. In contrast to studying the influence of the number of pins and the row pitch of pins on flow field, some geometric parameters, such as root radius of screw channel, outer radius, width and helix angle of screw flight, width and depth of screw channel et al, have the same size for both structures.

Based on periodic structure of extrusion segment in extruder, computing models are established to study flow fields and mixing effect. Fig.1 is one of the geometrical models in which the material is input from

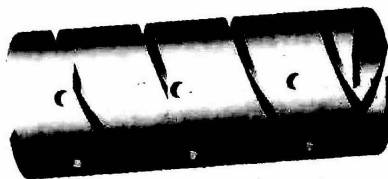


Figure 1: A typically geometrical

model. The material enters from the left side (inlet) and is extruded from the right side (outlet), computing length which at least two rows of pins are necessary to be included is 216mm, namely the length of two spirals. Moreover, row pitch of pins is 72mm and the number of pins for each row is 6, the distance between the first row of pin and right side is 36mm, meanwhile, double helix for screw is considered.

The clearance gap between the barrel inwall and the flight excircle is assumed zero in order to be easily analyzed and displayed flow field as well as mixing strength, which will have no influence on the

comparative study of flow field and mixing effect that are mainly concerned and discussed in this paper.

A series of models with different geometrical variables and values shown in Table 1 are conducted for numerical simulation of flow field and mixing effect.

Table 1: Variables used for computing models

Variables	Values
Material viscosity μ [Pa · s]	27580
Width of screw channel [mm]	54
Depth of screw channel [mm]	15
Width of groove of screw flight [mm]	14
Helix angle of screw [°]	20
Reverse pressure difference [MPa]	1.0
Rotational speed [rpm]	60
Density ρ [kg/m ³]	920
Pin diameter [mm]	10
Pin length [mm]	13.5
Row pitch of pins	48,60,72,84,96
Number of pins in each row	0,4,6,8
Root radius of screw [mm]	30
Outer radius of screw [mm]	45
Screw flight width [mm]	6

2.2 Meshing and Boundary Conditions

After the geometrical models are set up, they are meshed and set boundary conditions by software GAMBIT. For the preprocessing, the finite element mesh is made of unstructured and hexahedral element with numbers varying from 470000 to 560000 depending on the screw model.

For solving the Navier-Stokes equation with FLUENT, different boundary conditions are applied. The no-slip boundary conditions are imposed at the fluids which contact with inwall of barrel and with the surface of pins, so that all velocity components are zero for those fluids. But the fluids which are in the root of screw channels and in the flank of flights and rotate with the screw have the same rotational speed as screw, namely 15, 30, 45, 60rpm, respectively. At the inlet, the pressure is set zero, while outlet pressure is assigned 0, 1, 2, 4, 6, 8 and 10MPa, respectively. And the free velocity is given at the inlet and outlet.

The simulation results are considered to be converged when the residual error is less than 0.0005. After all preprocessing are completed, the numerical analyses of flow field are then carried out by FLUENT.

Total 68 models with different geometrical structures given by Table 1 and various boundary conditions are simulated.

3. COMPARISON OF NUMERICAL RESULTS FOR THE CONVENTIONAL AND PIN BARREL EXTRUDER

Fig.5 gives the average mixing strength on the cylindrical section as a function of radius for the $\Phi 90$ conventional extruder and pin barrel extruder, mixing strength is gradually increased from the cylindrical section of screw root to the screw excircle, and the

rate of increase is faster near the outer cylindrical section of screw, which shows the shallower screw channel is, the better mixing effect has. These are in accord with the fact.

In addition, it can be seen from Fig.2 that mixing strength is locally larger on the cylindrical section of $r=0.032m$, in fact, larger mixing strength should be on the cylindrical section of $r=0.0315m$ due to higher shear action by pins on the cylindrical section, so the numerical analysis is reasonable.

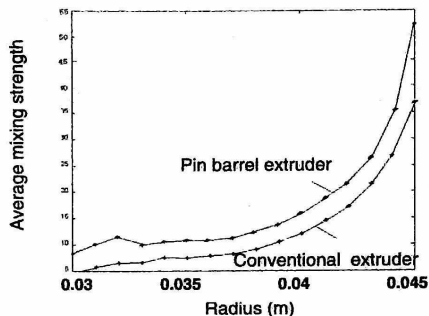


Figure 2: The average mixing strength on the cylindrical section as a function of radius for the $\Phi 90$ conventional extruder and pin barrel extruder

In addition, it can be seen from Fig.2 that mixing strength is locally larger on the cylindrical section of $r=0.032m$, in fact, larger mixing strength should be on the cylindrical section of $r=0.0315m$ due to higher shear action by pins on the cylindrical section, so the numerical analysis is reasonable.

Furthermore, Fig.2 also shows that the average mixing strength on the same radius cylindrical section of pin barrel extruder is larger than that of conventional extruder, for example, the average mixing strength is increased by about 30%-55% when the row pitch of pins is 72mm and the number of pins for each row is 6, among which the mixing strength on the cylindrical section of screw outer radius has an important influence on the whole mixing strength.

Therefore, a calculation methods provided by the paper is reasonable according to the numerical analyses of mixing strength distribution and the average mixing strength.

4. INFLUENCE OF PIN LAYOUT ON THE MIXING EFFECT AND EXTRUSION MASS FLOW

It is very important to investigate the influence of pin layout on mixing effect and extrusion mass flow, because it can guide to optimize design for the layout of pin in barrel extruder and operation parameters.

Typical results from one numerical simulation with reverse pressure difference of 1.0MPa, screw speed of 60 rpm, the number of pins in each row of 6 are discussed here. Fig.3 and Fig.4 respectively indicate the row pitch of pins as a function of average mixing strength ratio and mean square deviation ratio of pin

barrel structure to the conventional structure with calculating geometrical length of 216mm.

Fig.3 shows reducing row pitch of pins have the effect of increasing the average mixing strength and mean square deviation because mixing effect is strengthened when row pitch of pins is decreased, namely the number of pins is increased. At the same time, there exists larger difference between mixing strength at every point and the average mixing strength, which means the mean square deviation increases due to large mixing strength near to pins and the groove of flights. The effect of pins will be decreased with the increment of row pitch of pins, if row pitch of pins is continuously increased to as none-pins, then the average mixing strength and mean square deviation are just like that of the conventional extruder.

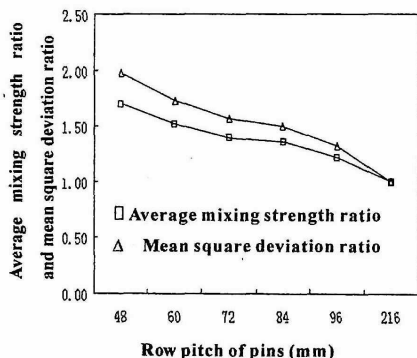


Figure 3: Influence of the row pitch of pins on the average mixing strength and mean square deviation in the case of reverse pressure difference of 1.0MPa, screw speed of 60 rpm, the number of pins in each row of 6

For example, the row pitch of pins shown in Fig.3 is 48mm, 60mm, 72mm, 84mm and 96mm, the average mixing strength is respectively increased by 70%, 52%, 40%, 36% and 22% than that of conventional extruder. Notice that the average mixing strength is decreased obviously when the row pitch of pins is longer than 84mm, so it should not be longer than 84mm for $\Phi 90$ pin barrel extruder.

It can be seen from Fig.4 that an increase in the row pitch of pins implies a larger extrusion mass flow rate. And it is increased slowly when row pitch of pins is longer than 60mm, but it is reduced evidently when row pitch of pins is equal to 48mm, therefore, row pitch of pins should not be shorter than 60mm in order to get suitable extrusion mass flow rate. So the row pitch of pins should be varied from 60mm to 84mm after considering the effect of row pitch of pins on the average mixing strength and extrusion mass flow rate.

Fig.5 and Fig.6 respectively illustrate the influence of the number of pins in each row on the average mixing strength, mean square deviation and the mass flow rate of material in the case of reverse pressure

difference of 1.0MPa, screw speed of 60 rpm and the row pitch of pin of 72mm. Vertical coordinate in Fig.8 represents the ratio of mixing strength and mean square deviation in pin extruder to those in conventional extruder with none of pin.

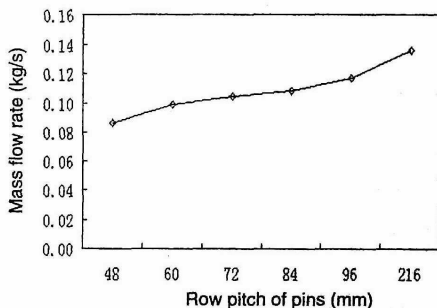


Figure 4: Influence of row pitch of pins on the mass flow rate of material in the case of reverse pressure difference of 1.0MPa, screw speed of 60 rpm and the number of pins in each row of 6

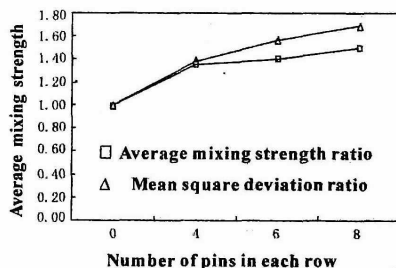


Figure 5: Influence of the number of pins on the average mixing strength and mean square deviation in the case of reverse pressure difference of 1.0MPa, screw speed of 60 rpm and row pitch of pins of 72mm

Fig.5 shows that an increase in the number of pins in each row causes larger average mixing strength and mean square deviation when row pitch of pins, reverse pressure and screw speed are constant. For example, when the number of pins in each row is 4, 6 and 8, the average mixing effect is respectively increased by about 35%, 41% and 54% than that of conventional extruder. But the mean square deviation is increased faster than the average mixing strength especially when the number of pins is more than 4, which means that mixing strength difference between the mean square deviation and average mixing strength at any point in flow field is larger, so the number of pins should be limited. It is found in Fig.6 that the influence of the number of pins in each row on the mass flow rate of material is not evident when there are more than 4 pins in each row. Therefore,

when pin barrel extruder is designed, row pitch of pins should be properly increased and some more pins may be added to each row in order to obtain a larger extrusion mass flow rate under the condition of same mixing effect. Considering the influence of the number of pins in each row on mixing strength and extrusion mass flow rate, 6-8 pins are suitable in each row.

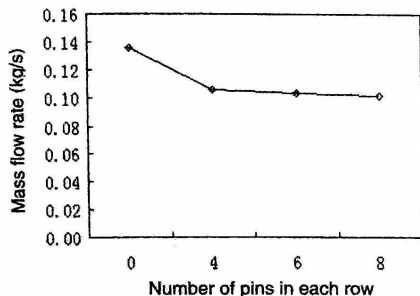


Figure 6: Influence of the number of pins in each row on the mass flow rate of material in the case of reverse pressure difference of 1.0MPa, screw speed of 60 rpm and pin pitch of 72mm

Average mixing strength shown in Fig.7 is proportional to screw speed as the number of pins is the same, and reducing the number of pins in each row from 8 to 0 has the effect of gradually decreasing average mixing strength in the case of pin pitch of 72mm and reverse pressure difference of 1.0MPa.

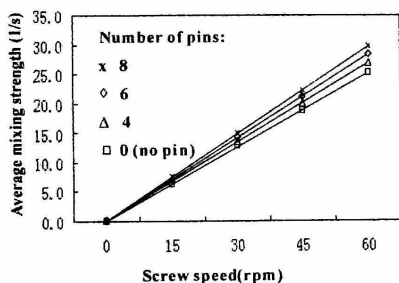


Figure 7: Relationship between average mixing strength and screw speed with various number of pins in the case of pin pitch of 72mm and reverse pressure difference of 1.0MPa

5. CONCLUSIONS

- 1) The structure which makes fluid have larger deformation rates will strengthen mixing effect.

- 2) A shorter row pitch of pins in pin barrel extruder has the effect of increasing average mixing strength. Numerical analyses find that the row pitch of pins is 48mm, 60mm, 72mm, 84mm and 96mm, the average mixing strength is respectively increased by 70%, 52%, 40%, 36% and 22% than that of conventional extruder. But a decrease in row pitch of pins also increases mean square deviation of mixing strength at any point as well as reducing extrusion flow rate. Considering every aspect, study demonstrates that row pitch of pins varied from 60mm to 84mm is suitable for $\Phi 90$ pin barrel extruder.
- 3) Average mixing strength will be increased with the increase of the number of pins in each row for pin barrel extruder. When the number of pins in each row is 4, 6 and 8, average mixing strength is respectively increased by 35%, 41% and 54% than that of conventional extruder. But increasing the number of pins in each row has the effect of increase mean square deviation of mixing strength although the influence is not quite evident, so the number of pins in each row should be ranged from 6 to 8 in each row to get a better performance for $\Phi 90$ pin barrel extruder.
- 4) Many factors would affect mixing effect, only the influence of pin layout is investigated here, so other factors need to be studied further. It can be anticipated that new type of rubber extruders with better mixing characteristics will be continually developed with the study going on.

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