FEA of flow field of short fiber and rubber composite material during extrusion process

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Abstract: Die structure is one of the most important factors that impacts short fibers orientation during extrusion process. As a result, the effects of two kind of die structure which is dam-die and expansion-die on flow field including pressure field, velocity field and the velocity of short fiber and rubber composite material during extrusion process has been researched by Polyflow. The FEA results about the flow field of the short fiber and rubber composite material indicate that, compared with the two kind of dam-die and expansion-die, the dam die is better for short fibers get orientation in rubber matrix during extrusion process than the expansion-die.

1. Introduction

Short fiber and rubber composite material has been a new kind of high polymer composite material, which has been researched deeply and used widely in recent years [1-12]. Moreover, some research results showed that if short fibers get orientation in the composite material, the rubber products using properties could be promoted. For tire products, if short fibers get orientation which means the orientation direction of short fibers is at the radial direction of tire, or at the thickness direction of tire tread, the wear resistance ability and tear resistance ability of tires could be promoted greatly. During the extrusion process of short fiber and rubber composite material, the die structure is one of the most important factors that impacts short fibers orientation. As a result, the effects of die structure on extrusion flow field of short fiber and rubber composite material have been researched by FEA method using Polyflow in this paper. The researched die structure were dam-die and expansion-die, and the analyzed flow fields were pressure field, velocity field and velocity vector.

2. Models for FEA

2.1 Physical model and FEM model

The physical model and FEM model should be established for FEA. The physical model is the die channel be filled with short fiber and rubber composite material, which have been shown in the Figure 1. The FEM model is the results of net dividing, which have been shown in the Figure 2.
2.2 Boundary conditions and physical parameters

The boundary conditions and physical parameters that have been set for the FEA process have been shown in the Table 1 and Table 2.

| Table 1. Boundary conditions of dies |
|-------------------------------------|
| Die flow amount ($mm^3/s$) | Velocity in the channel face ($m/s$) |
| 40 | 0 |

| Table 2. Physical parameters |
|-------------------------------|
| Density ($Kg/m^3$) | Milv Index | Material Viscosity ($Pa·S^n$) | Material Viscosity ($Pa·S^n$) | Relax time ($s$) |
| 1066 | 0.23 | 1000000 | 10 | 10 |

3. Analysis results and discussion

3.1 Pressure field

The effects of die structure on extrusion process pressure field of short fiber and rubber composite material has been shown in the Figure 3.
As what has been shown in the Figure 3, at the same extrusion conditions, it is obviously that the pressure field of dam-die is changing more intensely than that of expansion-die. The maximum pressure value of dam-die is about 2.3MPa, while the maximum pressure of expansion-die is 0.52MPa. Therefore, at the same extrusion conditions, on one hand, the dam-die could establish a higher die pressure for extrusion of short fiber and rubber composite material than that of expansion-die. Due to it is necessary to make rubber material with short fibers get compressed for short fibers get orientation in rubber matrix, so a higher die pressure is also needed. On the other hand, the dam-die pressure change is intense, which indicates that the rubber material could expand as fast as possible after passing the dam-structure, as a result, short fibers would turn to a bigger angle with the expanding of rubber material than the situation of rubber material expanding slowly. Therefore, the dam-die could establish a better pressure field for orientation of short fiber than dam-die or expansion-die.

### 3.2 Velocity field

The effects of die structure on extrusion process velocity field of short fiber and rubber composite material has been shown in the Figure 4.

As vividly shown in the Figure 4, at the same extrusion conditions, the velocity field of dam-die is steadier than that of expansion-die, which means the change of velocity value is not intensely. The maximum velocity value of dam-die is about 15.9mm/s, while the maximum velocity value of expansion-die is 25.3mm/s. Therefore, at the same extrusion conditions, not only could the dam-die have a bigger extrusion speed, which does not cut down the production ability of extruder, but also the velocity field of the dam-die is steadier. If the changing of velocity value is intense, such as the velocity field of expansion-die, the flow of rubber material with short fibers would generate turbulence, which would impact orientation of short fibers. So, the dam-die has a bigger velocity value and a steadier velocity field for the extrusion of short fiber and rubber composite material.

### 3.3 Velocity vector

Considering velocity is a vector, and the Figure 4 just showed the velocity value, without velocity direction, so the velocity direction has also been analyzed. The results have been shown in the Figure 5.
Figure 5. Effects of die structure on velocity vector

As what have been vividly shown in the Figure 5, the velocity direction could be seen directly together with the velocity value. Only considering the velocity direction, at the same extrusion conditions, the direction angle of dam-die is bigger than that of expansion-die, which means the short fibers turn direction of dam-die is better than that of expansion-die, which also means the dam-die could make short fibers get better orientation.

4. Conclusions
The conclusions about effects of die structure on extrusion flow field of short fiber and rubber composite material during extrusion process could be drawn as following,

1) At the same extrusion conditions, the dam-die could establish a bigger pressure field that changes intensely and a steadier velocity field that has a bigger velocity value than the expansion-die. Moreover, the velocity direction angle of dam-die is bigger than that of expansion-die.

2) Via FEA, the effects of die structure on extrusion field of short fiber and rubber composite material could be researched easily and directly without experiments, avoiding the bad effects of some experimental factors. Also, the design of die structure can be changed according to the FEA results, as a result, the design efficiency and quality can be promoted.

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References
[1] Nuttapong H, Sombat T and Taweechai A 2017 Improving the mechanical properties of short pineapple leaf fiber reinforced natural rubber by blending with acrylonitrile butadiene rubber Polymer Testing 57 94-100
[2] Pitchapa P, Sombat T and Taweechai A 2017 Comparative study of natural rubber and acrylonitrile rubber reinforced with aligned short aramid fiber. Polymer Testing 64 109-116
[3] Wang C S, Zhang D W and Bian H G 2011 Effects of Mixing Parameters on Properties of Short Fiber and Rubber Composite Material Journal of Functional Materials 42 1448-1452.
[4] Zhang D W, Wang C S and Lin G Y 2011 Effects of Rotor Speed on Manufacturing Process of Short Fiber-rubber Composite Material Advanced Materials Research 211 350-355.
[5] Li H T 2006 Development of Short Fiber-rubber Composite Material Modern Rubber Technology 32 5-12
[6] Wang C S, Liu C J and Bian H G 2009 Radial Orientation Mechanism and Experimental Research of Short Fiber in Tread Compound Journal of Donghua University 26 666-672.
[7] Liu L, Zhang L Q and Feng Z X 1999 Development of Green Tires China Rubber Industry. 46 245-248.
[8] Zhang D W, Wang C S and Lin G Y 2012 Effect of Die Structure on Radial Orientation of
Short Fiber in Tire Tread and its Performance Key Engineering Materials 501 247-252.

[9] Li L, Wang C S and Zhang Dewei 2014 Effects of Radial-Orienta- tion-Die Structure Parameters on Properties of Short Fiber and Rubber Composite Material, Journal of Donghua University 31 249-255

[10] Zainal Z and Ismail H 2011 Effects of silane coupling agent and dynamic vulcanization Journal of Vinyl and Additive Technology 17 245-253

[11] Rijpkema B 1994 The use of short fiber to reduce the rolling resistance of tires Plastomere Elastomere Duromere, 47 748-752

[12] Shirazi M, Talma A G and Noordermeer J W 2012 Viscoelastic properties of short aramid fibers-reinforced rubbers Journal of Applied Polymer Science 124 4671-77