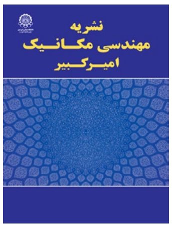

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Numerical and Experimental Investigation of Non-Newtonian High Viscosity Flow Field in Multi Materials Extrusion Process

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ABSTRACT: Predicting and reducing of the rubber cross-section dimensions after exiting die channel are of great importance in the design process of extrusion die. In this research, the effect of velocity distribution at the die exit on the rubber dimensions is experimentally and numerically studied with the aid of finite volume method. Three-dimensional simulation of non-Newtonian high-viscosity flow was performed to predict the distribution of velocity and pressure in the die channels. Recognizing the soft and hard materials boundaries in the multi-material cross-sections, the two-phase volume of fluid method is employed. The viscosity of melted rubber flow in the die is calculated by interpolating the experimental data obtained from Rubber Process Analyzer apparatus based on least squares method. A comparison between primary (with nonuniform profile) and modified dies shows more precise dimensions of the modified die. In the narrow portions of the profile in the vicinity of wide regions, because of the impossibility of achieving a uniform velocity distribution, the produced cross-section is smaller than the design value. In addition, optimizing channel geometries by the employed numerical method reduces the pressure loss in the modified die by 40% in comparison with that of the primary designed die.

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1- Introduction

Rubber strips are widely used in automobile industries as an insulator for dust, rain and sound. The accurate dimensions of rubber weather strips, plays an important role in their performance. On the other hand, due to non-linear behavior of rubber, its flow in die channels and the geometry complexity, the production of rubber parts in extrusion processes is very complicated. The numerical investigations can facilitate design of the forming die and production process [1, 2]. To the best of author's knowledge, the three-dimensional behavior of non-Newtonian multi-phase polymeric fluids has not been studied with the aid of Finite Volume Method (FVM) yet. In this research, the effect of velocity distribution at the die exit on the rubber dimensions is numerically studied to predict the distribution of velocity and pressure in the die channels.

2- Methodology

The weather strip includes two different materials; the flexible material (127R) and the inflexible one (129C) (see Fig. 1 (a)). The existence of two materials with different properties and inlet temperatures makes the analysis of this mold much more complicated in compared with mono-material ones. There are two common methods of achieving co-extruded materials: feed block manifolds and multi-manifolds within dies [3]. The major disadvantage of the first method is that it produces irregular flow patterns, because of the long traveling of melt streams before the die exit. Therefore, multi-manifold dies are picked, which keep the melt streams separated till just before the die exit. The die is made up of four plates (Fig. 1 (b)). The first plate is the bottom die plate into which the extruder flow enters. After passing the channels of second and third runner plates, the flow enters the fourth plate named the form plate. This plate is usually shaped in the desired outlet. To achieve a desired profile, any final modification should be carried out on the form plate.

Regarding the importance of the flexible and inflexible materials boundary in the multi-material sections, for predicting the boundary, a two-phase volume of fluid (VOF) model was employed. Viscosity of molten rubber flow in the die is calculated from interpolation of data obtained from the Rubber Process Analyzer (RPA) system [4], based on the least squares method. The melted rubber is a non-Newtonian fluid and its shear viscosity maybe considered as a product of shear rate $\eta 0(\gamma)$ and temperature H(T) functions. Among the various models for $\eta 0$ and H, the power law and Arrhenius law (non-Newtonian power law) models are respectively chosen as [5]:

$$\eta_0(\gamma) = k_0\, \gamma^{n-1} \tag{1}$$

$$H(T) = e^{([-\alpha(T-T0)])} \tag{2}$$

where n, k, α and T0 are power law index, consistency index, energy of activation and reference temperature, respectively. The conservative equations are solved using Fluent commercial code, so as the equations are integrated over control volumes located around each node of the grid. The convective terms are discretized by applying the power law scheme and diffusive

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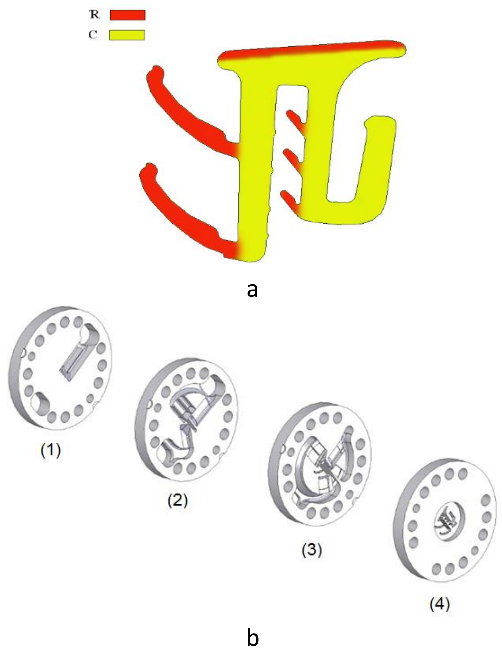

Fig. 1. a) Flexible and inflexible boundaries in the strip section, and b) the die plates arrangements

terms by the central difference scheme. Also, no slip condition was considered on the wall and in the two-phase model that was used to determine flexible and inflexible boundaries.

3- Results and Discussion

By a repetitive process of simulations and corrections, the final geometry of die exit was obtained. The result is compared with the initial geometry in Fig. 2. Comparison of the produced profile from initial die (with uneven profile) with that is obtained from the modified die indicates that much more precise dimensions are obtained by the modified die.

The results show that in narrow regions of the section located near wide regions, because of uneven distribution of the flow velocity, dimensions of the produced profile are smaller than values of design dimensions. Also, due to no geometrical restrictions in the numerical method, for the modified die with optimized channels geometry the pressure loss decreases over 40%.

Fig. 3 shows shear stress distribution on flow channels walls. Comparison of these results with those obtained for five different viscosity indicates that in the regions with low shear stress the flow viscosity increases highly. In addition, in the optimized die the flow channels exhibit more uniform shear stress in comparison with the primary die. Up to now, no similar design has been performed based on uniform distribution of shear stress on the die walls and viscosity criteria. But the results of this research show that the values of mixture viscosity through the path may be used for geometrical modification and the shear stress criterion may be used for varying the channel section at various paths of the flow. However, this needs more simulations and investigations.

4- Conclusion

In this paper, the extrusion process of rubber strips composed of two different materials is simulated using two-phase mixture model. The optimized geometry of die is obtained based on elimination of stationary points, shortening the flow path, elimination the regions with high viscosity, elimination of sharp corners by rounding the bent locations, reduction of stream time in the die and the most important, retaining the velocity balance at die exit. According to the results:

1- The two-phase Volume of Fluid (VOF) method is a suitable model for determining the boundary between flexible and inflexible materials in polymeric martial flow.

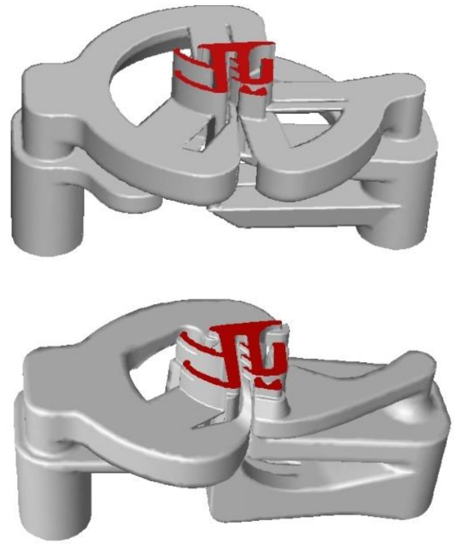

Fig. 2. Die exit geometry in initial (up) and modified (down) states

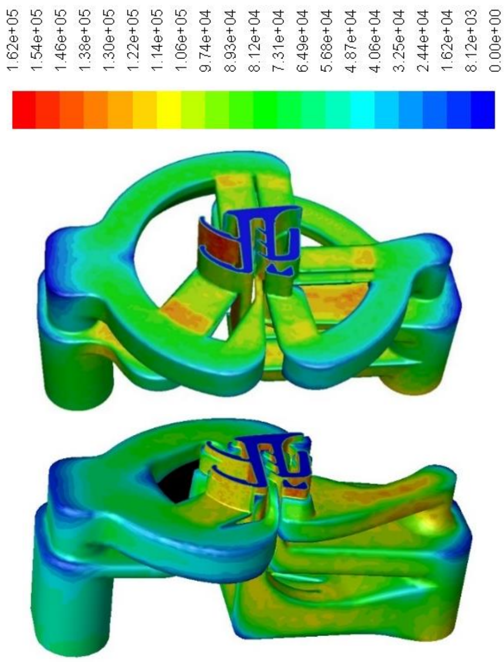

Fig. 3. Shear stress distribution in primary die (up) and modified die (down)

2- Velocity balance at die exit reduces considerably the cross-section deformations after exiting the die.

3- Increasing the flow channel diameter beneath the forming plate of die, can be a solution for velocity increase in narrow regions of profile.

4- In narrow regions neighboring a wide and open region, it is very hard to attain velocity balance. So, in order to achieve the desired dimensional accuracy, after testing the designed die, the dimensions should be modified in the forming palate based on shortening of these regions in the produced specimen.

5- Despite high complexity of the problem, including measuring fluid properties, calculating viscosity coefficients, modeling, etc., there is a very good agreement between the results and those obtained from experiment.

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