DESIGN OF EXTRUSION DIE FOR PLASTIC PROFILE USING ANSYS POLYFLOW SOFTWARE

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Abstract

Extrusion is one of the most widely used processes for polymer processing. Example: extrusion is a technique for producing film, pipe, sheet, profiles, cable and coatings in coextrusion process. The main tool used in this process for the manufacturing final shape product is die. The task of this article is to design the last part of extrusion die (die land) for plastic profile, using numerical simulation. In this paper was presented methodology of numerical simulation for the die design. A commercial computer fluid dynamics program Ansys Polyflow was used to design the die passage. The objective of the simulation is to determine the die passage that results in a balanced mass flow exiting the die that closely matches the target profile. The die land shape modification with using optimization algorithm is very helpful to obtain geometry and dimension of extrudate desired profile.

Keywords: profile extrusion, die design, die land, inverse die design, simulation Ansys Polyflow,

1. Introduction

Extrusion is one of the main processing methods for production of thermoplastic parts. It is used to manufacture pipes, films, fibers, cables, wires, and various continuous profiles [8]. In each type of extrusion, the polymer is forced through a die to create the desired shape [11]. Extrusion dies vary in shape and complexity to meet the demands of the product being manufactured. There are five basic shapes of products made with extrusion dies: 1) sheet dies; 2) flat-film and blown-film dies; 3) pipe and tubing dies; 4) profile extrusion and 5) co-extrusion dies. Furthermore, each product type has unique hardware downstream of the die to shape and cool the extruded melt [9].

In extrusion die design there are two main issues to be solved: how to make the flow distribution more uniform and how to anticipate post-extrusion effects. Trial and error procedures have been the common base to design these tools. The main objective to achieve when designing a new die is to reach the best possible production rate at the highest quality product level with dimensional accuracy, aesthetics and mechanical performance [2,4,6].

Predicting the required die profile to achieve the desired product dimensions is a very complex task and requires detailed knowledge of material characteristics and flow and heat transfer phenomena, and extensive experience with extrusion processing [9]. Design of the dies for extrusion of products having complicated cross sectional shapes is still an art rather than a science. Die design for a new product is developed on the basis of previous experience and experimentation. In many case costly experiments and in-plant trials can be replaced by numerical simulation [1,6]. Several commercial polymer flow simulation programs are used for profile die

design today. For example: Ansys Polyflow, Flow 2000, Dieflow, HyperXtrude [10]. Numerical simulation has the potential to uncover important interior details of the extrusion process, such as velocity, shear stress, pressure, and temperature fields in the region of interest, which is not possible to do experimentally [9,12]. Typically, designers know the requested shape of the final profile but do not know the corresponding die shape. The required die shape can be determined by method inverse die design. For example Ansys Polyflow program implements an ''inverse extrusion'' solution algorithm, which computes the shape of the die exit (die land profile) required to achieve the target profile dimensions at the exit of the free surface domain. The program solves for the shape of the die land that will achieve the target profile after die swell occurs [5,9,11]. In the design stage it is important that die land length profile should be average 10 times longer than the thickness of thick extrudate portion place to relax the viscoelastics stresses in the melt before leaving the die and forms the shape of the extrudate leaving the die. The die land profile has the required shape to compensate for extrudate deformation after the die (die swell and drawdown) and yield the desired shape downstream [9].

2. Ansys Polyflow CFD software capabilities

Ansys Polyflow is a finite element computational fluid dynamics (CFD) program designed primarily for simulating applications where viscous and viscoelastic flows play an important role. The flows can be isothermal or non-isothermal, two- or three-dimensional, steady-state or time-dependent. Ansys Polyflow is used primarily to solve flow problems in polymer and rubber processing, food rheology, glass-work furnaces, and many other rheological applications. This program can perform a number of complex calculations such as multi-domain simulations, coextrusion of several fluids, three-dimensional extrusion and time-dependent calculation of free surfaces [14].

Ansys Polyflow consist of few interdependent modules used to prepare analyze geometry, define data, calculations and presents results. Typical flowchart for numerical simulation was presented on figure 1.
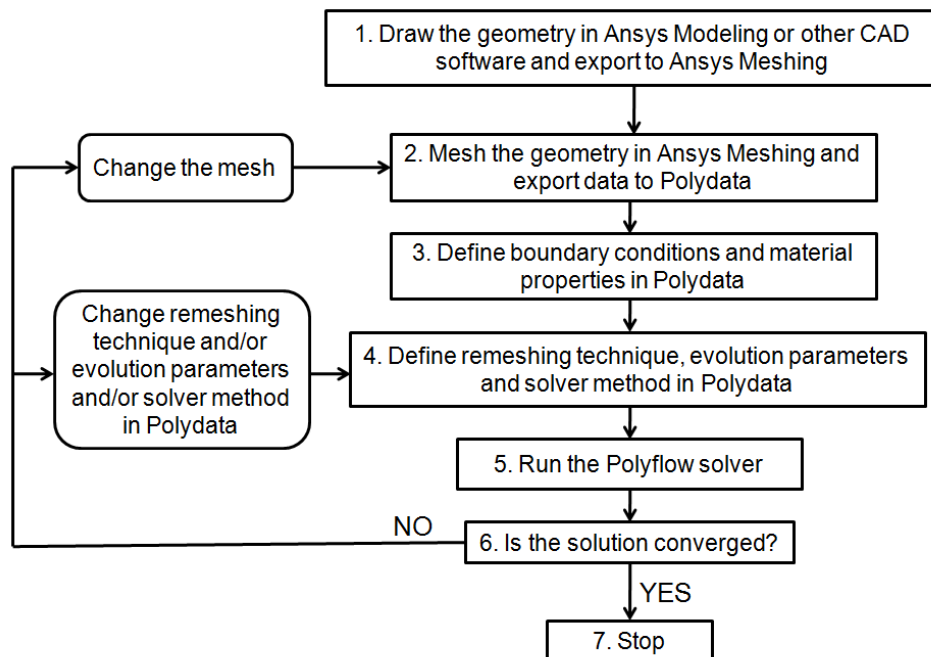

Fig. 1. Flowchart for numerical simulation using Ansys Polyflow [14]

3. Modeling and numerical algorithm of die design

This problem deals with the flow of a Newtonian fluid through a three-dimensional die. The design process begins with a target product shape. In this work, the product is a hollow chamber profile (Fig. 2a) – 40 mm x 50 mm rectangular cross section with inside 5 mm rib. Due to the symmetry of the die, only one-half of the passage is modeled as shown in Fig. 2b. In our case we considered only a die land profile, which is one of the most important tooling place in extrusion process, because it must cope with the phenomena occurring in the course of flowing plastics – to compensate for extrudate deformation after the die and yield desired shape downstream [9]. The domain for the problem is divided into four sub-domains (as shown in Fig. 2b: Sd.1, Sd.2, Sd.3, Sd.4) so that specific remeshing algorithms can be applied in each sub-domain to accurately predict the die profile. Subdomain 1, 2 and 3 represent the die where the fluid is confined, while subdomain 4 represent the extrudate that is in contact with the air.
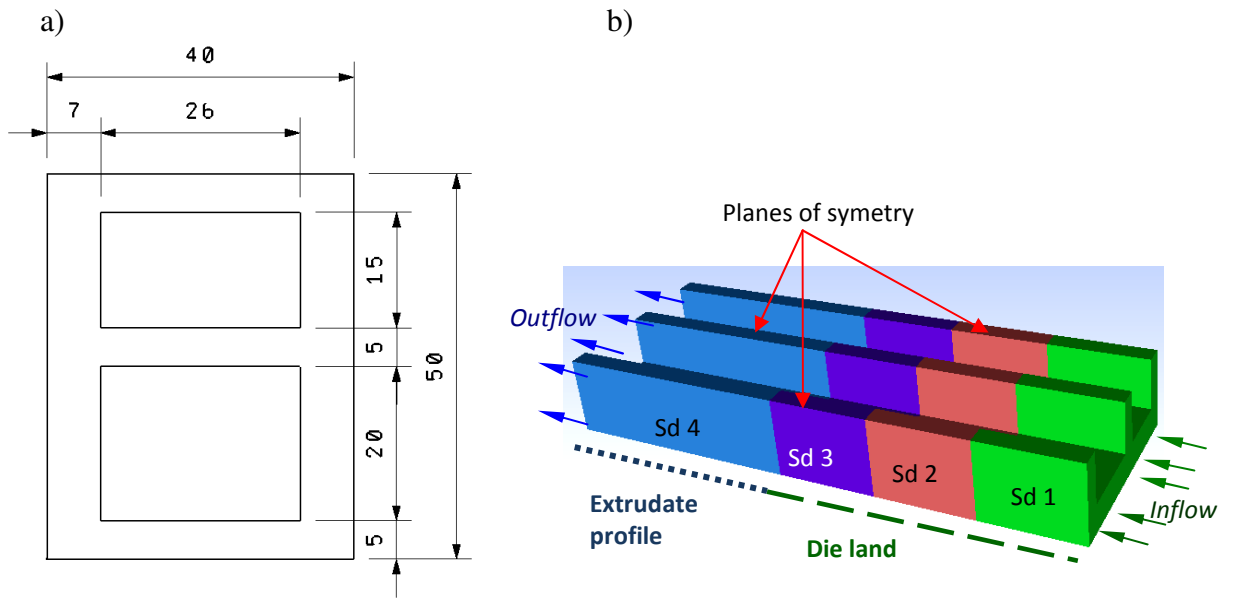

Fig. 2. Considered model: a) dimensions of the profile, b) initial configuration implemented to the simulations

The objective of the simulation is to determine the die passage that results in a balanced mass flow exiting the die and an extrudate shape downstream of the die that closely matches the target profile. The shape of the die exit is determined by solving an inverse flow problem where the target profile is given as the downstream shape of the extrudate. The program computes the die exit shape that results in the target profile downstream of the die after melt velocities equalize in the free-surface region.

A HDPE is used as extrusion material in numerical simulations and the Bird-Carreau viscosity model is used to characterize the shear rate dependence of viscosity [14]:

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty) \cdot \left(1 + \left(\lambda \cdot \dot{\gamma} \right)^2 \right)^{\frac{n-1}{2}}, \tag{1}$$

where:
η – viscosity,
η_0 – zero share rate viscosity,
η_∞ – infinite shear rate viscosity,
λ – time scale,
n – power-law index.

In this study it was assumed that temperature distribution of polymer is uniform and equal 180°C and for this temperature related parameters for Bird-Carreau viscosity model equals: η_o= 5630 Pa·s, λ= 0,32, n= 0,64. The polymer melt flow is assumed to be incompressible [7,13,14]:

$$\nabla \cdot \nu = 0 . \tag{2}$$

Gravitational and inertial forces are neglected. The momentum equation yields a balance between viscous and pressure forces [13]:

$$\nabla \cdot p = \nabla \cdot \tau_{ij} . \tag{3}$$

In this study it is also assumed that viscoelastic effects were neglected. Fully developed velocity profile is assumed at the inlet Q = 10000 mm³/s, and no-slip boundary condition is applied at the die wall.

4. CFD simulation results and their analyses

CFD simulation was carried out to obtain target final hollow profile design under assumptions and parameters. In the first stage of simulation authors obtain the profile result without compensation Barus and other flow effects, what was shown in Fig. 3. Wrong shape of final product (inter alia) is caused by different local pressure and share rate during flow for the die passage. Other difficult during extrusion in this profile shape is different wall thickness (5 and 7 mm). Different local thickness caused faster flow polymer particles in thickness section (v=21,25 mm/s), what is showed in figure 3. Based on the results obtained from the first simulation, in next step with Polyflow implements an "inverse extrusion" solution algorithm, realized automatic calculation to obtain final desired shape. Program change the die land geometry (60 mm length) to find target final shape of our extrudate hollow profile in ten iterations. These results are visible in figure 4, 5 and 6. In each place of extrusion land observer can see how the polymer flow and see if they have example areas with a slow movement of polymer material, which can cause its local degradation. Final result of realized simulation was achieved.
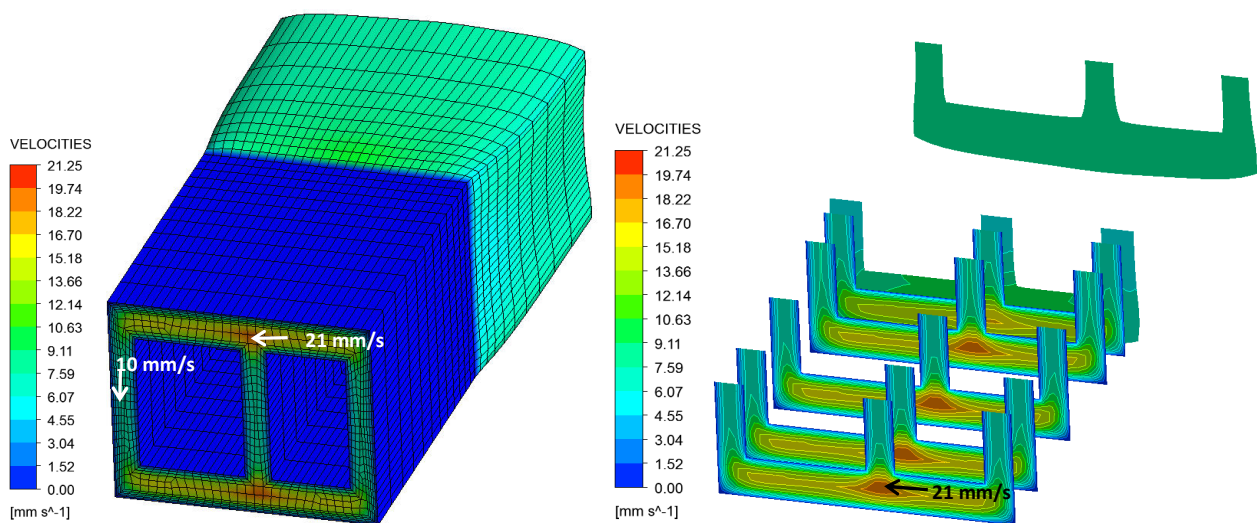

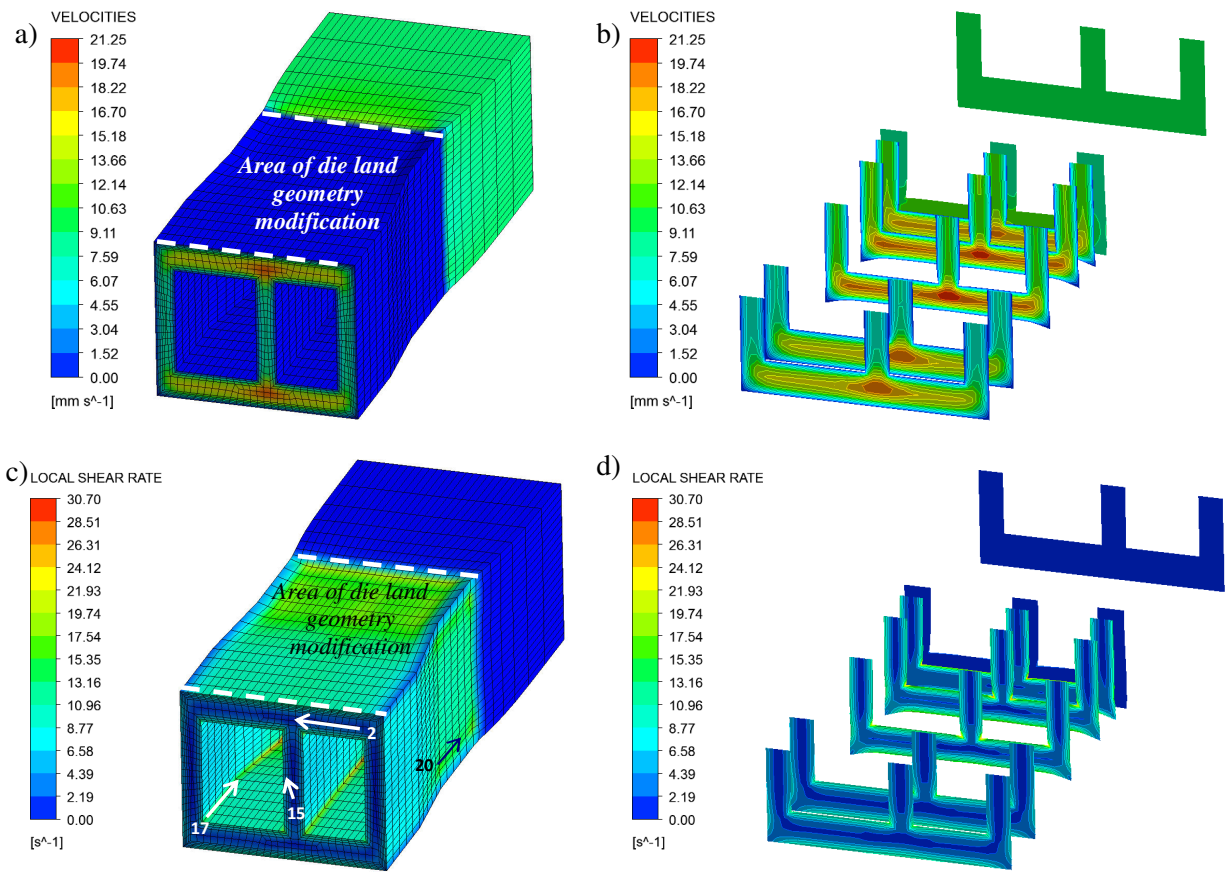Fig. 3. Velocity distribution for the die without optimized die land

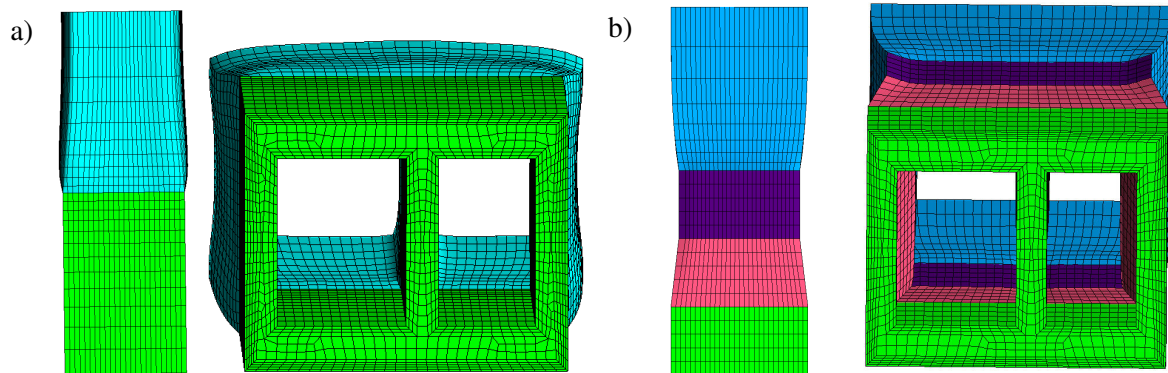*Fig. 4. Velocity (a, b) and local share rate (c, d) distribution fort the die with optimized die land*

Fig. 5. View of extrudate shape profile with: a) non-optimized shape of die land, b) optimized shape of die land
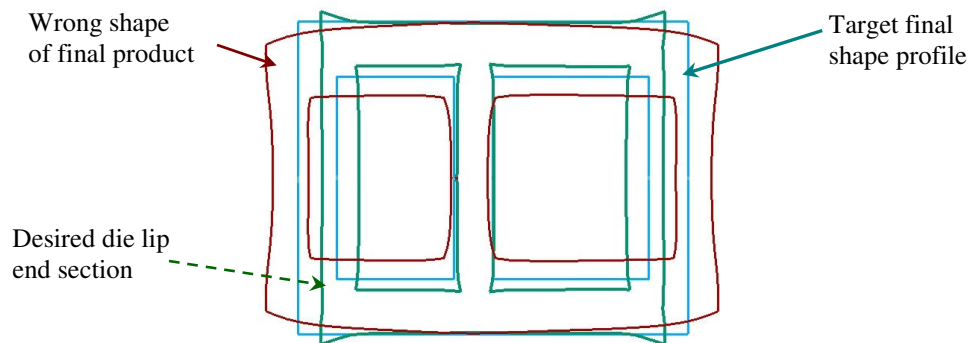

Fig. 6. A cross section in die lip section, compared with outlet section obtain from non-optimized shape of die land and optimized shape of die land

5. Final consideration and summary

Design of extrusion dies for plastic profile is a complex task because the extrudate final profile dimension depends not only on the die shape design, but also on the plastics properties and technological extrusion process parameters. Overall design of extrusion process should include each plate of extrusion dies: mounting, adapter, transition, preland and die land plate. It is important to know that two last plates have the most significant role in extrusion stage. In our study we only show the capabilities of geometry prediction in the last die land plate for the made an assumption. The powerful of Polyflow software is in predict of the preland and die land geometry for the individual complex geometry. Each simulation process is more shorter and more costly than trial end error iterations.

Engineering Polyflow simulation can provide crucial help to manufacturing extrusion tooling that must resolve critical issues related to reality of industry: cost and time savings in developing extrusion dies.

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