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Development of Numerical Tools to Aid the Design of Complex Geometry Profile Extrusion Dies

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ABSTRACT

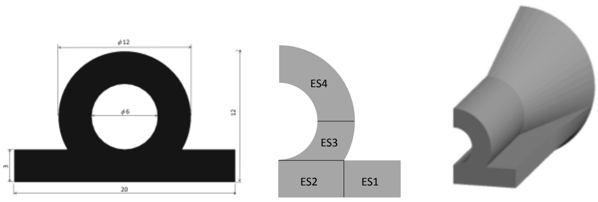
The research team of this work is involved since the mid-nineties on the development of computational tools to aid the design of profile extrusion dies. Initially, the numerical code employed was based on structured meshes that limited its application to simple geometries. The work planned in this PhD programme comprises the development of a numerical modelling code able to deal with unstructured meshes and its application on the design of profile extrusion dies comprising complex cross sections.
In its current state the numerical code under development is able to model de flow of generalized Newtonian fluids inside flow channels using unstructured meshes.
This paper describes briefly the current state of the developed code and illustrates its application in a case study involving the design of a profile extrusion die comprising a complex cross section.

NUMERICAL MODELLING CODE

For modelling purposes the Navier Stokes equations for incompressible generalized Newtonian fluids, under isothermal conditions, were considered, where the shear viscosity is a function of the second invariant of the rate of deformation tensor using a Bird-Carreau law.
The governing equations were discretized following the Finite Volume Method procedure for unstructured meshed, as described elsewhere (Versteg and Malalasekera 2007), for collocated unstructured meshes and a SIMPLE based iterative procedure.

CASE STUDY

The numerical modelling code described in the previous section was used to optimise the flow distribution in a profile extrusion die required to produce a complex profile, whose cross section is illustrated in Fig. 1a. Due to symmetry, just half of the geometry was modelled, as shown both in the cross section geometry, Fig. 1b, and in the flow channel geometry used for the first trial, Fig. 1c.



(a) (b) (c)

Figure 1 – Case study geometry: (a) cross section of the profile (dimensions in mm); (b) half of the cross section considered for the computational model, showing the division into Elemental Sections; (c) typical flow channel geometry

The 3D geometry of the flow channel (Fig. 1c) was meshed with tetrahedrons and triangular prisms in convergent and constant cross section regions, respectively.
Following the methodology described in (Nóbrega et al. 2003), the flow distribution was monitored by the division of the profile cross section into 4 Elemental Sections (ES), illustrated in Fig. 1b. The performance of a specific solution was evaluated using the following objective function:

$$F_{obj} = \sum_{i=1}^{N_{ES}} \left(1 - \frac{Q_i}{Q_{obj,i}} \right)^2 \frac{A_i}{A} \quad (1)$$

were Q_i and $Q_{obj,i}$ are the current and required (objective) volumetric flow rates of a specific ES, respectively, A_i and A are the area of each ES and of the total cross section, respectively, and N_{ES} the number of ES. In this way the objective function value is always positive and reduces as the flow distribution is improved, being zero for a perfectly balanced extrusion die.

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The polymer melt employed in the numerical runs was modelled using a generalized Newtonian constitutive equation (Bird-Carreau), being the required parameters obtained by the rheological characterisation of a commercial grade of a polypropylene homopolymer (Nóbrega et al. 2004).
For the search of a geometry that promotes a better flow distribution, the results obtained in a specific trial were analysed in order to determine the subsequent modifications (promoted by the user) in the cross section of the final region of the flow channel. This process mimics the usual optimisation procedures employed experimentally (Nóbrega et al. 2003).
The different geometries and respective flow distributions for the trial geometries tested are illustrated in Fig. 2.

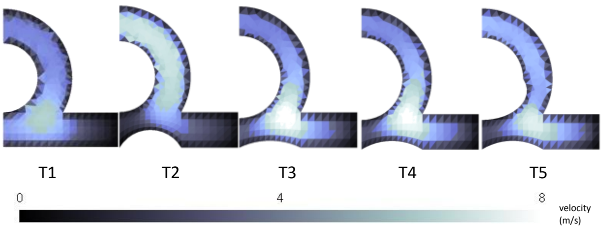
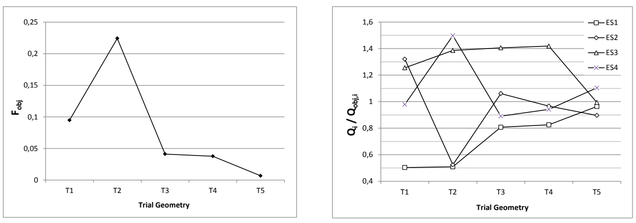


Figure 2 – Outlet cross section of the flow channel for the tested trials and contours of the outlet flow distribution obtained

The improvements obtained during the design process can be evaluated by the evolution of the objective function and the ratio between the actual and objective flow rates, obtained in each ES, illustrated in Fig. 3.



(a) (b)

Figure 3 – Results obtained for the trial geometries: (a) objective function and (b) ratio between actual and required flow rate per ES

CONCLUSION

In this work the a 3D numerical modelling code, based on the Finite Volume Method, able to model the flow of Generalized Newtonian Fluid with unstructured meshes, was described and used in a profile extrusion die design problem.
The results obtained allow to conclude that the numerical code developed is able to deal with the flow of polymer melts in complex geometrical problems, being, therefore, a valuable tool for the design of complex profile extrusion dies.

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