ON THE AUTOMATIC DIE DESIGN FOR THE EXTRUSION OF THERMOPLASTIC PROFILES

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Introduction

The rheological design of extrusion dies must consider the flow developed through the die channel and the influence of post-extrusion phenomena. For the particular case of non-axisymmetric profile extrusion dies, the flow must be balanced in order to guarantee uniform melt velocity at the die exit contour.
Currently several software are available for modelling the flow in extrusion dies [1-5]. Despite being powerful modelling tools, they only consider some of the relevant phenomena and the design process is not fully automated. It is already possible to define the die land contour to obtain a specific profile, considering the effect of the post-extrusion die-swell [6-7]. However, the referred formulations do not consider, for example, the problem of flow balancing, which is rarely referred in the literature [8-11]. Therefore, there is still a need to develop an algorithm integrating all the relevant aspects in order to enable the automatic die design optimisation [9,12].
In this work a methodology to automatically balance the flow in profile extrusion dies is presented and illustrated considering the most relevant region of the die.
Due to the complexity of the problem and the need to perform several simulations to reach the final solution, a fully three-dimensional finite volume based software [13] was used to solve the algorithm, to reduce the correspondent computational cost [14].

Methodology

In the methodology proposed the die is defined by three main zones: i) an adapter, to perform the transition from a circular section to a section similar to that required for the parallel zone; ii) a pre-parallel zone connecting the adapter and the parallel zone, used to control accurately the flow distribution at the die exit; iii) a final parallel zone.
The process involves two different strategies: in a first attempt, the geometric variables (illustrated in Figure 1) are successively modified until flow balancing is reached. The final geometry is than checked in terms of practical feasibility. If the resulting L (length)/t (thickness) of the most restrictive sub-sections is lower than the advisable value, the process is restarted using another approach (considering flow separation).

Case study

The problem illustrated in this work refers to the extrusion die shown in Figure 1. The study of the flow balance concentrates on the three sub-sections (Sa,Sb,Sc) that have different thickness and, therefore, different flow restriction. The problem was modelled using several geometries, as shown in Table 1, using the two strategies to balance de flow: with (WSi) and without (NSi) flow separation. The polymer used in the simulations is a polypropylene whose rheological behaviour was modelled by a Bird Carreau constitutive equation. The flow rate was imposed in order to obtain an average velocity of 100 mm/s at the die exit. The average velocity computed for each sub-section is shown in Figure 2. In Figure 3 the velocity iso-lines correspondent to two limit cases are presented. The required flow distribution was reached using both strategies. However, it should be noted that the NS approach leads to unacceptable parallel zone L/t values.

Conclusion

A methodology for flow balancing was presented and applied. It was concluded that when the thickness of the sub-sections are significantly different the use of flow separators might be a reasonable solution.

References

1. Polyflow, Fluent Inc.
2. Diecalc, Rapra Technology Ltd.
3. G. Menges, M. Kalwa, J. Schmidt, *Kunstst.*, **77** (1987) 797-803
4. J. Vlachopoulos, P. Behncke, J. Vlcek, Adv.Polym.Tech., 9 (1989) 147-156

5. D. H. Sebastian, R. Rakos, Adv.Polym.Tech., 5 (1985) 333-339
6. H. –P. Wang, Plastics Technology, February (1996)
7. V. Legat, J. M. Marchal, Int. J. for Numerical Methods in Fluids, **16** (1993) 29
8. J. Svábík, T. Mikulenta, M. Manas, J. W. Busby, PPS Europe/Africa Region Meeting, Gothenburg, Sweden, 1:p:13, 1997
9. J. Sienz, I. Szarvasy, J. Pittman, E. Hinton, R. Sander, PPS Europe/Africa Region Meeting, Gothenburg, Sweden, 1:13, 1997
10. M. P. Reddy, E. G. Schaub, L. G. Reifschneider, H. L. Thomas, Design and Optimisation of Three Dimensional Extrusion Dies Using Adaptive Finite Element Method, SPE-ANTEC, New York, 1999
11. J. Svábík, L. Placek, P. Sáha, Intern. Polymer Processing, **XIV**, 247 (1999)
12. O. S. Carneiro, J. A. Covas, Plast. Rubb. Comp. Proc. Appl. , **24** (1995) 79-87
13. P. J. Oliveira, F. T. Pinho, G. A. Pinto, J.Non-Newtonian Fluid Mech., **79** (1998) 1-43
14. S. –C. Xue, N. Phan-Thien, R. I. Tanner, J. Non-Newt. Fluid Mech., 74 (1998) 195

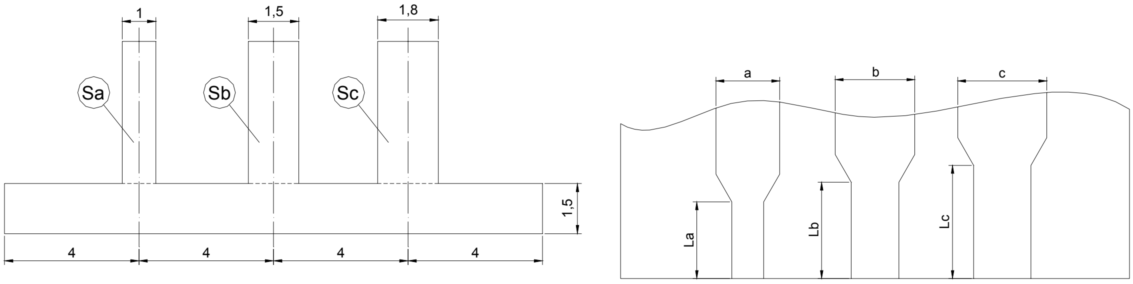

Figure 1- Parallel zone cross section and sub-sections considered for flow balancing control (left). Top view of the pre-parallel and parallel zones of the flow channel and variables used to create/modify their geometry (right). Dimensions in mm.

Table 1 – Sequence of simulations performed using each of the flow balancing strategies adopted (NSi - without flow separation; WSi – with flow separation). Dimensions in mm.

	NS1	NS2	NS3	NS4	NS5	WS1	WS2	WS3	WS4	WS5
L_a	7.0	3.5	1.0	1.0	1.0	7.0	7.0	5.0	5.0	5.0
L_b	10.5	5.0	3.0	3.0	3.0	10.5	10.5	10.5	10.5	10.5
L_c	12.6	6.0	4.0	4.0	4.0	12.6	12.6	12.6	12.6	12.6
a	3.0	3.0	4.0	3.5	3.2	3.0	3.0	2.6	2.0	2.2
b	3.0	3.0	3.0	3.0	3.0	3.0	2.3	2.3	2.3	2.3
c	3.0	3.0	3.0	3.0	3.0	3.0	2.2	1.8	2.2	2.0

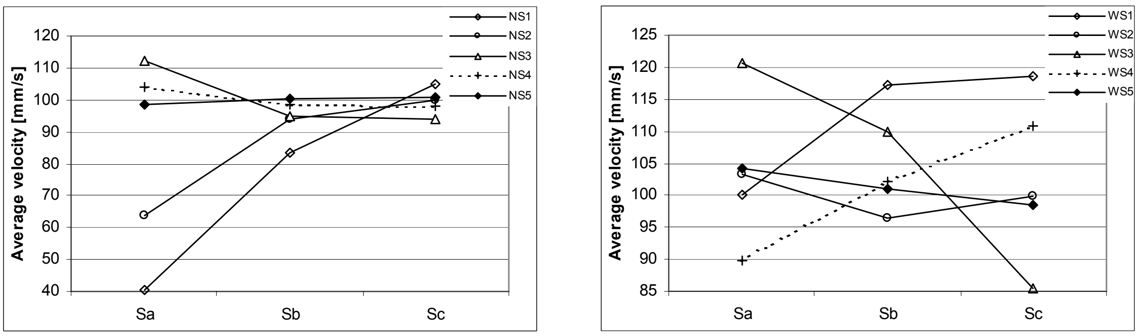

Figure 2- Average velocity computed for the three sub-sections (Sa, Sb, and Sc): (left) without flow separation; (right) with flow separation.

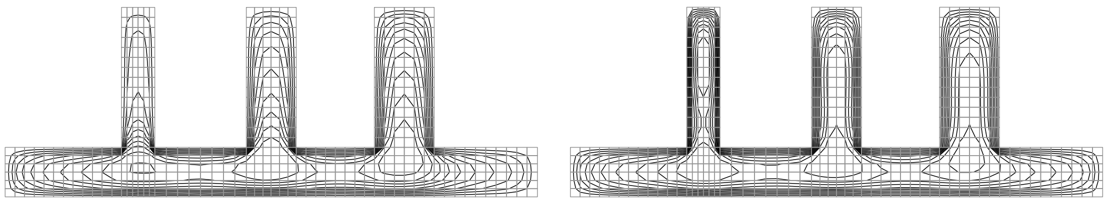

Figure 3- Iso-lines of velocity for simulations NS1 (left), initial trial, and WS5 (right), final balanced solution.