



USING OPENFOAM TO SUPPORT THE DESIGN OF PROFILE EXTRUSION DIES

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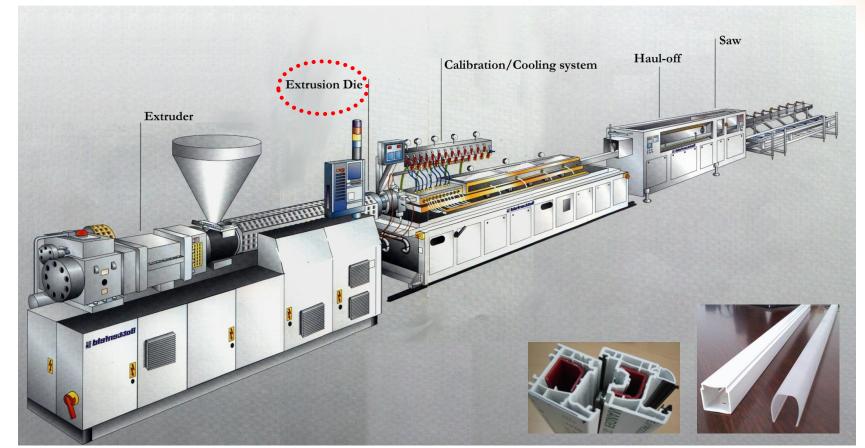
Outline

Introduction

- § What is polymer profile extrusion?
- § What is a balanced flow?
- § How is flow balance evaluated?
- § How is the flow simulated?
- § Optimization strategies
- Workflow
- Optimization loop implementation
- Case Study
- Case Study Demonstration



Introduction - What is polymer profile extrusion?





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Introduction - What is a balanced flow?

Die land cross-section Velocity contours Extrusion run Unbalanced Balanced

OS Carneiro, JM Nóbrega (Editors) , Design of Extrusion Forming Tools, Smithers Rapra Technology, ISBN 9781847355171, 2012. JM Nóbrega, OS Carneiro, FT Pinho, PJ Oliveira International Polymer Processing, 2004

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Introduction - How is flow balance evaluated?

ES1	IS1
	ES2

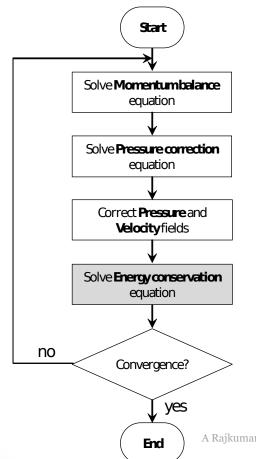
Objective Function

$$F_{obj,i} = rac{rac{Q_i}{Q_{ ext{target}}} - 1}{\max\left(rac{Q_i}{Q_{ ext{target}}}, 1
ight)}$$

$$F_{obj} = rac{\sum\limits_{\mathit{ES+IS}} \lVert F_{obj,i}
Vert_{\mathit{A}_{target,i}}}{A_{\mathsf{target},tot}}$$



Introduction - How is the flow simulated?



Methodology Employed

Energy conservation equation (Steady State)

$$\nabla \cdot (\boldsymbol{U}T) - \nabla \cdot \left(\frac{k}{\rho c_p} \nabla T\right) = \frac{1}{\rho c_p} \boldsymbol{\tau} : \nabla \boldsymbol{U}$$

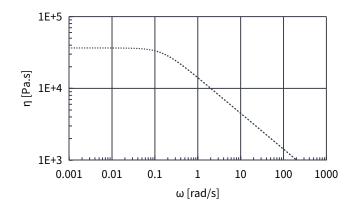
OpenFOAM Code

```
Solve
    fvm::div(phi,T)
   - fvm:: laplacian (DT, T)
 =(1/c_p)* (tau && grad U)
```

A Rajkumar et al., An Open-source framework for the CAD of Complex Profile Extrusion Dies, International Polymer Processing, 33, 2018

Introduction - How is the flow simulated?

Rheological model



Bird Carreau + Arrhenius Law

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

Shift Factor

$$a_T = \exp\left(\frac{E}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

Property	Value	Unit
η_0	36569	Pa·s
η∞	0	Pa⋅s
λ	6.667	S
n	0.501	[-]
аТ	1611.356	J/mol
T _{ref}	170	C°
ср	970	J·K-1·kg-1

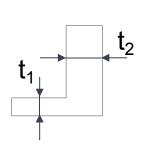


Introduction - Optimization Strategies?

Die Flow Channel Final Profile Haul-off **Optimisation** Required **Strategy Speed Profile** ST1 thickness t_2 V_3 t_2 t₁ ST2 length

Introduction - Optimization Strategies?

Required Profile

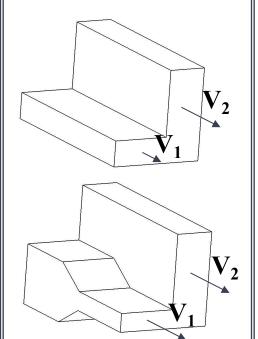


Optimisation Strategy

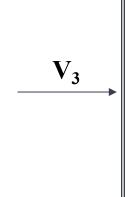
length + Thickness

ST3

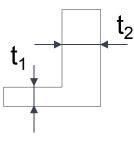
Die Flow Channel



Haul-off Speed



Final Profile

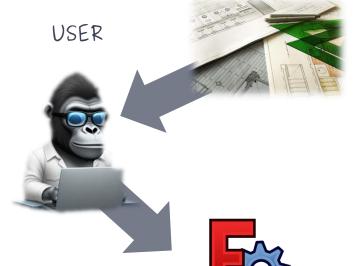


$$\frac{\mathbf{V_3}}{\mathbf{V_1}} \neq \frac{\mathbf{V_3}}{\mathbf{V_2}}$$





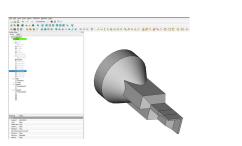
Workflow











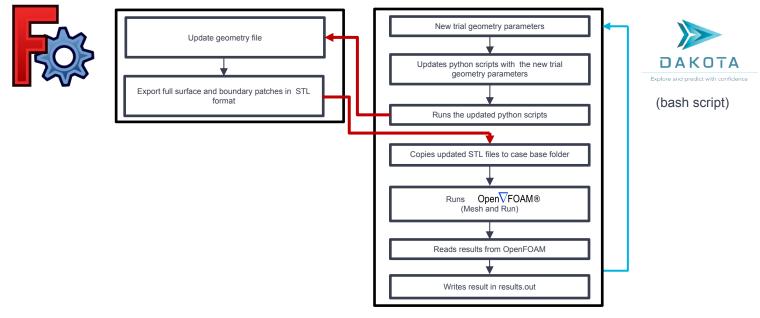






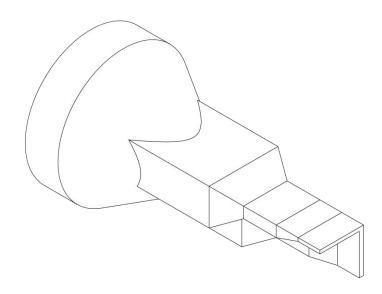
J.Vidal

Optimization loop implementation

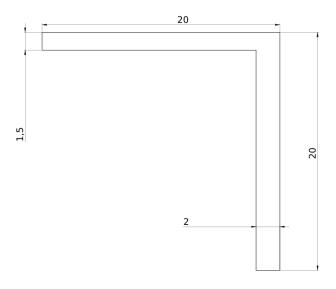




Case Study



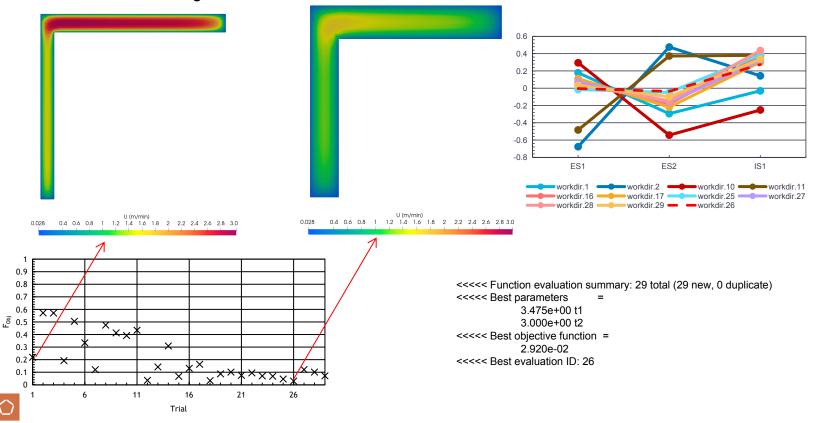
Flow Channel Geometry



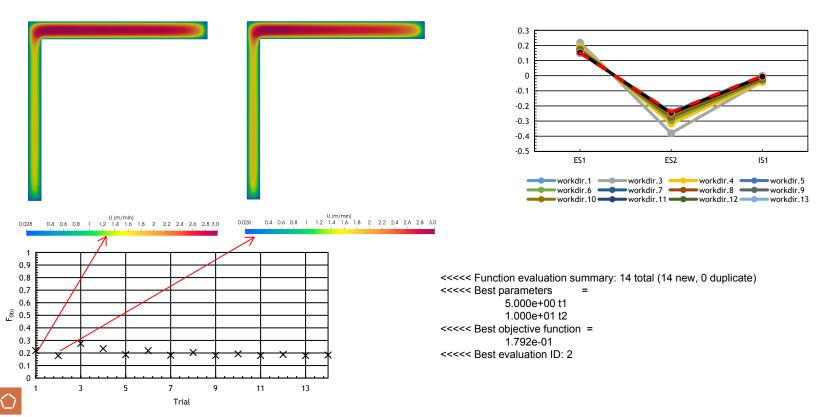
Profile Cross Section



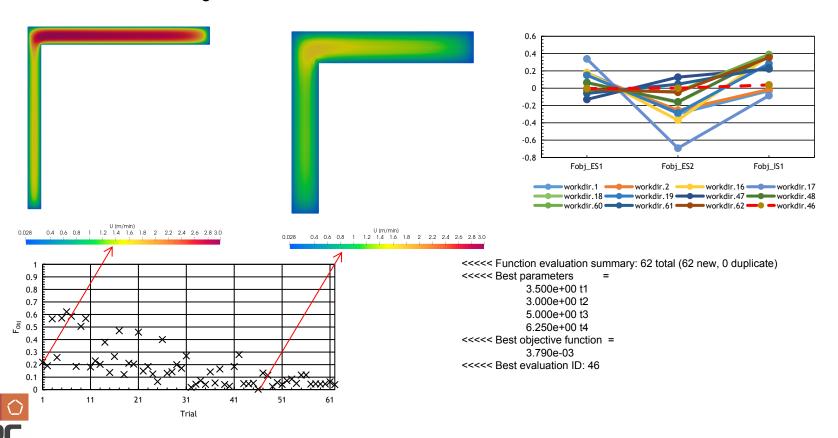
Case Study(ST1)



Case Study(ST2)



Case Study(ST3)



Case Study Demonstration(ST1)

- Requirements
- 3D modelling in Freecad
- OpenFOAM dictionaries setup
- Dakota dictionaries setup
- Launching the optimization



Case Study Demonstration(ST1)-Requirements

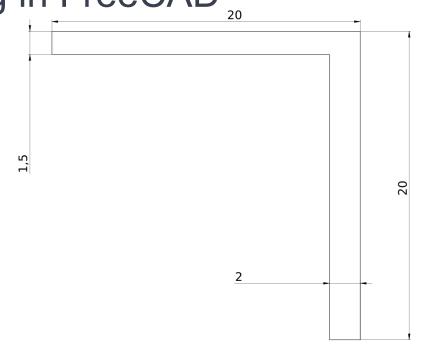
- Dakota 6.19¹
- FreeCAD 0.21.2²
- OpenFOAM® v2406
- Ubuntu/Windows(WSL)

1https://snl-dakota.github.io/docs/6.19.0/users/setupdakota.html#installing-for-linux-or-

2https://wiki.freecad.org/Getting started#Installing



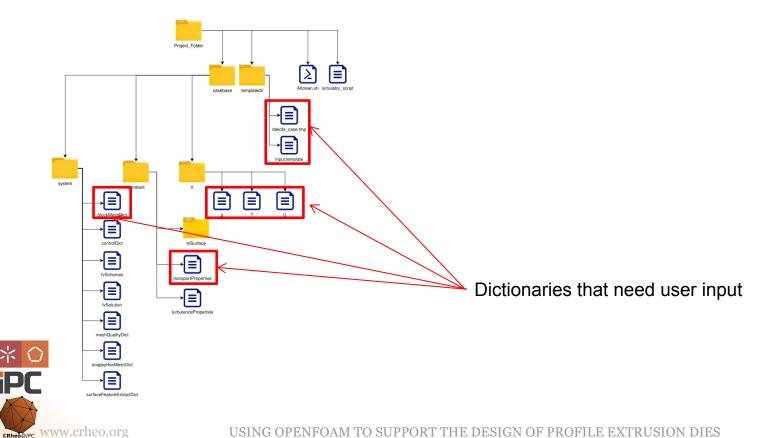
Case Study Demonstration(ST1)-3D modelling in FreeCAD





Profile Cross Section

Case Study Demonstration(ST1)-**Dictionaries Setup**

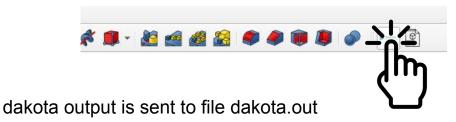


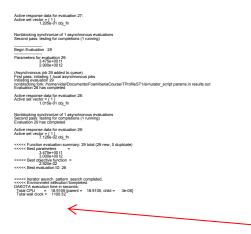
Case Study Demonstration(ST1)-Launching the optimization

Optional:

Add the macro to the toolbar.1







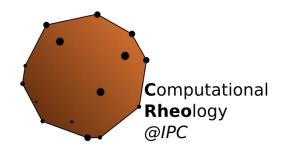
Optimized geometry



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1https://wiki.freecad.org/Customize_Toolbars

Course Material Repository



https://github.com/Computational-Rheology/FOAM-Iberia2024_ExtrusionDies





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THANK YOU!!



