20th OpenFOAM Workshop 2025

Automatic Optimization 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
- Implementation
- Case Studies
- Demonstration

Introduction

What is polymer profile extrusion?

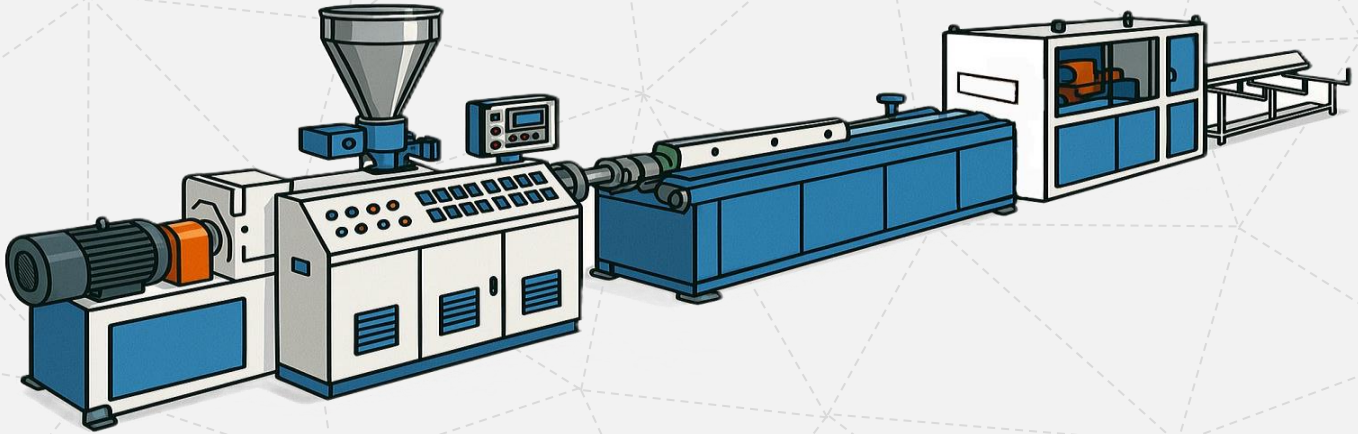
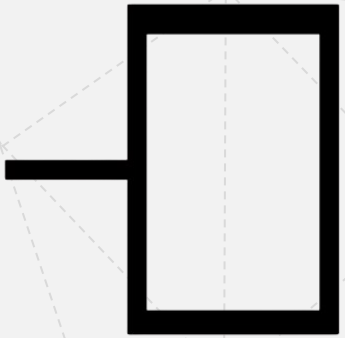


Image generated with ChatGPT

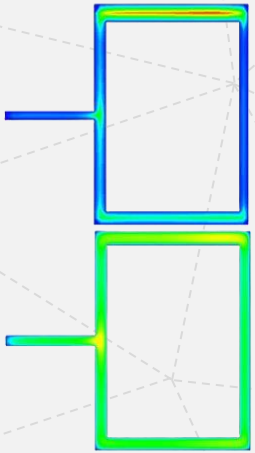
Introduction

What is a balanced flow?

Die land cross-section



Velocity contours



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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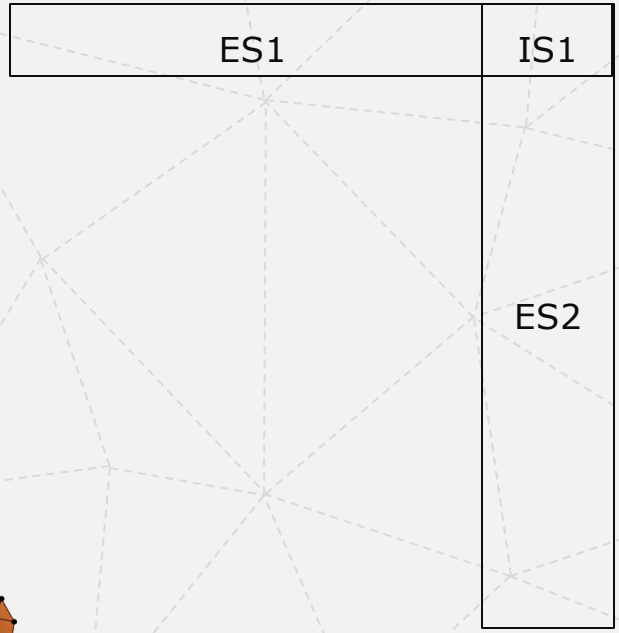
Introduction

How is flow balance evaluated?



Objective Function

$$F_{obj,i} = \frac{\frac{Q_i}{Q_{target}} - 1}{max\left(\frac{Q_i}{Q_{target}}, 1\right)}$$

$$F_{obj} = \frac{\sum_{ES+IS} \| F_{obj,i} \| A_{target,i}}{A_{target.tot}}$$

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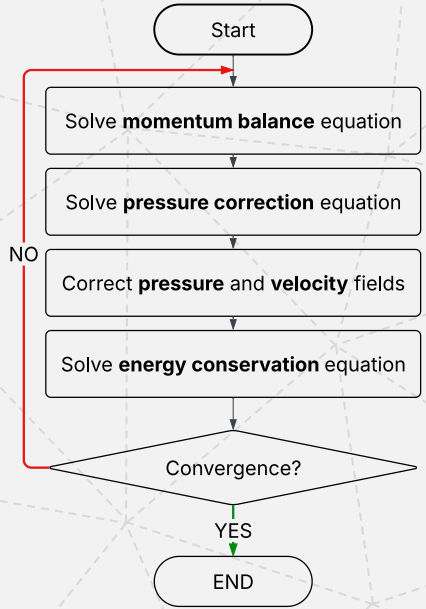
Introduction

How is the flow simulated?



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

```
fvScalarMatrix TEqn
(
    fvm::div(phi , T)
    - fvm::laplacian(DT , T)
 == (1/cp)*(tau && gradU)
);
```

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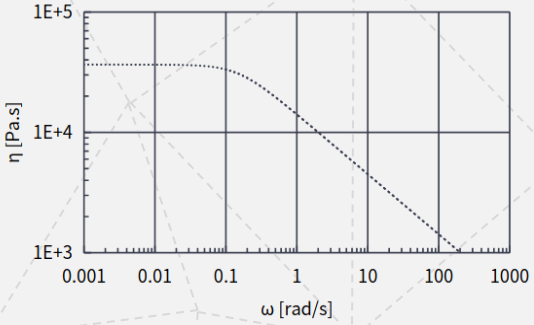
A Rajkumar et al., An Open-source framework for the CAD of Complex Profile Extrusion Dies, International Polymer Processing, 33, 2018

Introduction

How is the flow simulated?

Rheological model

Bird Carreau + Arrhenius Law

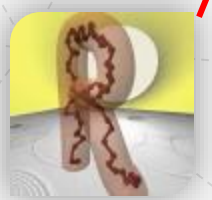


$$\eta(\dot{\gamma}, T) = a_T \eta_\infty + \frac{a_T(\eta_0 - \eta_\infty)}{\left(1 + (a_T \lambda \dot{\gamma})^2\right)^{\frac{1-n}{2}}}$$

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	$Pa \cdot s$
η_∞	0	$Pa \cdot s$
λ	6.667	s
n	0.501	$[-]$
a_T	1611.356	J/mol
T_{ref}	170	C°
c_p	970	$J \cdot K^{-1} \cdot kg^{-1}$



https://reptate.readthedocs.io/

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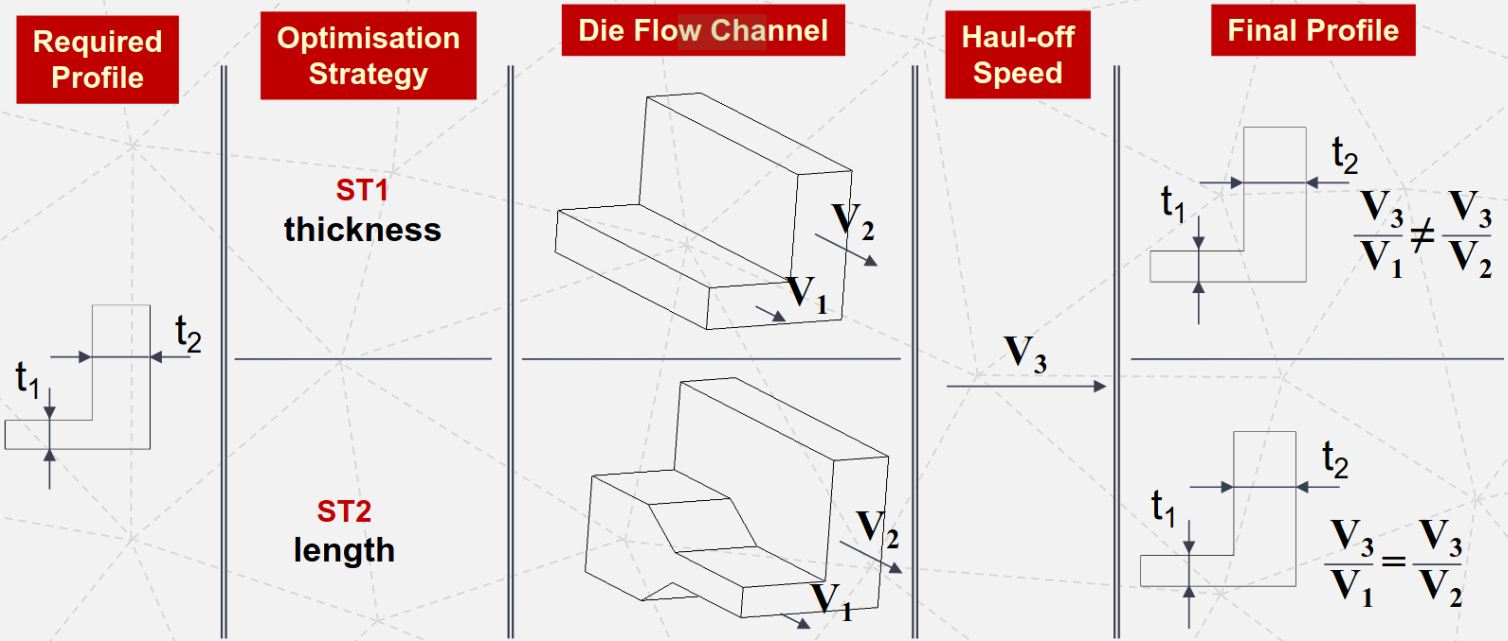
Introduction

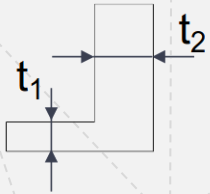
Optimization strategies?



Introduction

Optimization strategies?

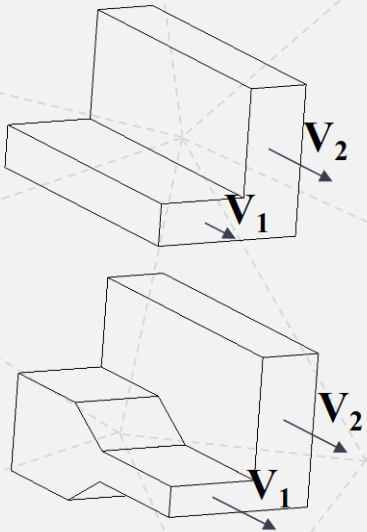
Required Profile



Optimisation Strategy

ST3
length
+
Thickness

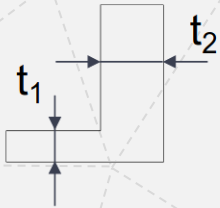
Die Flow Channel



Haul-off Speed

V_3

Final Profile



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

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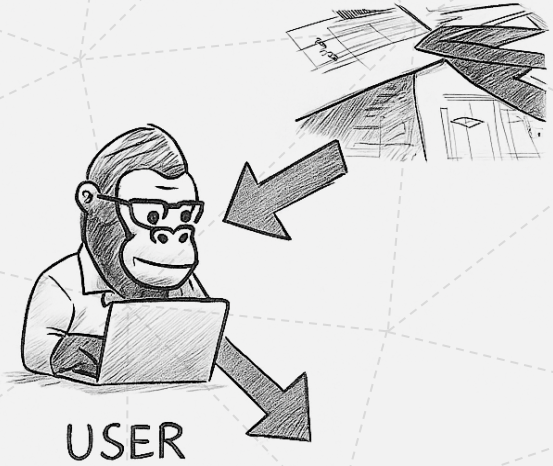
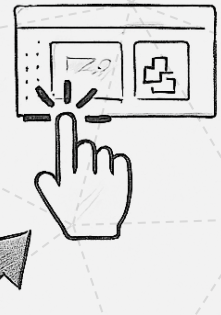
Workflow

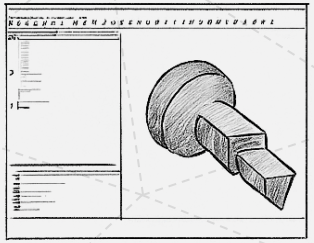
AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES



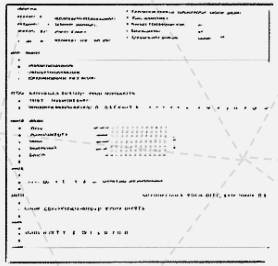


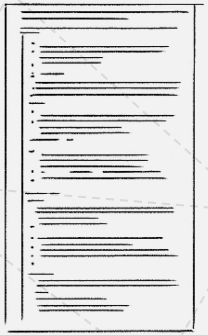
DAKOTA
Explore and predict with confidence

FreeCAD



OpenFOAM





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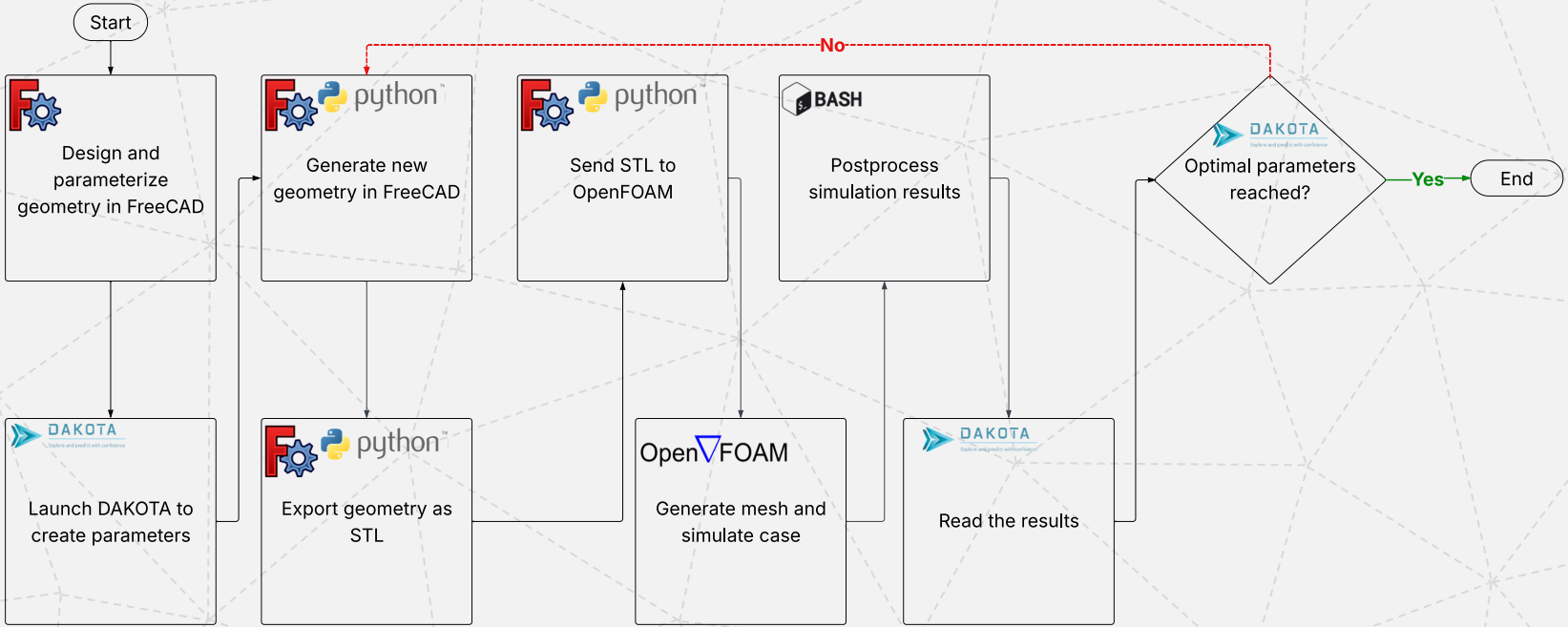
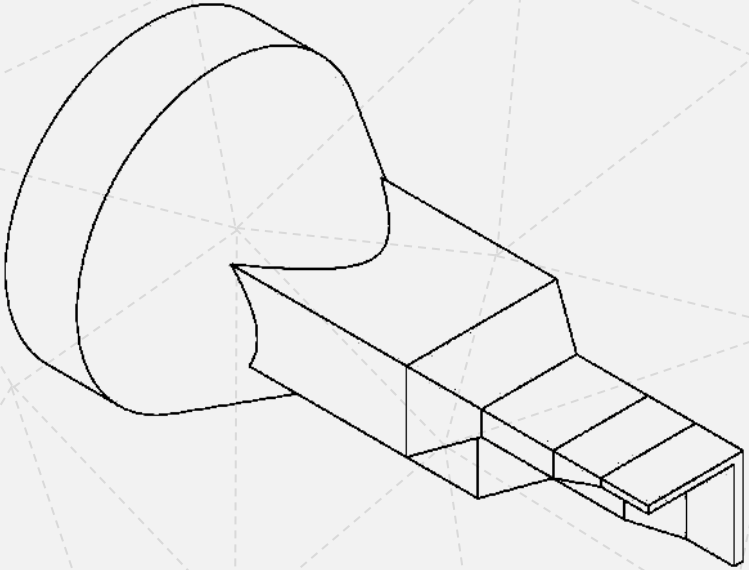
Implementation

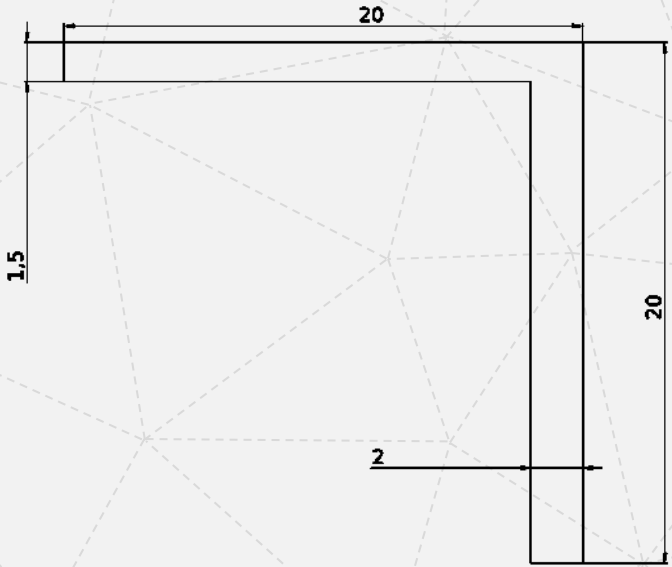
AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES



Case studies

AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES





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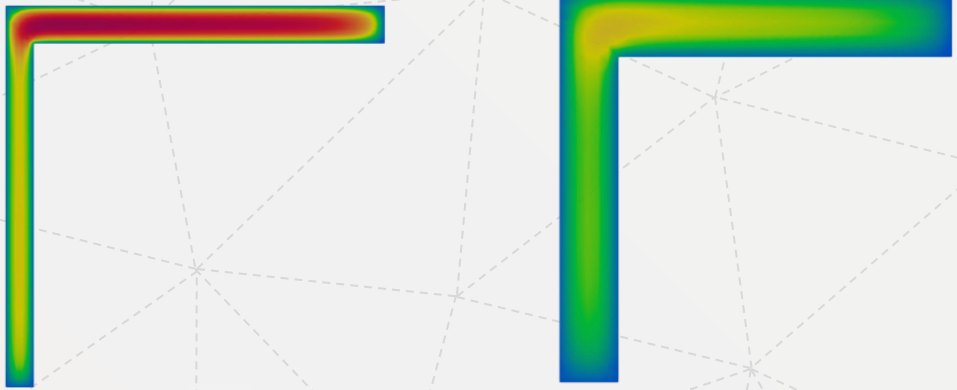
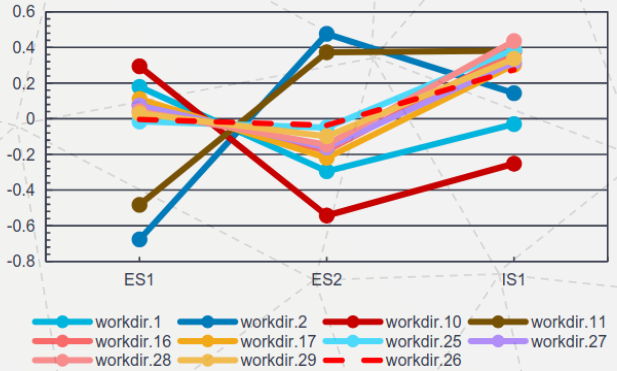
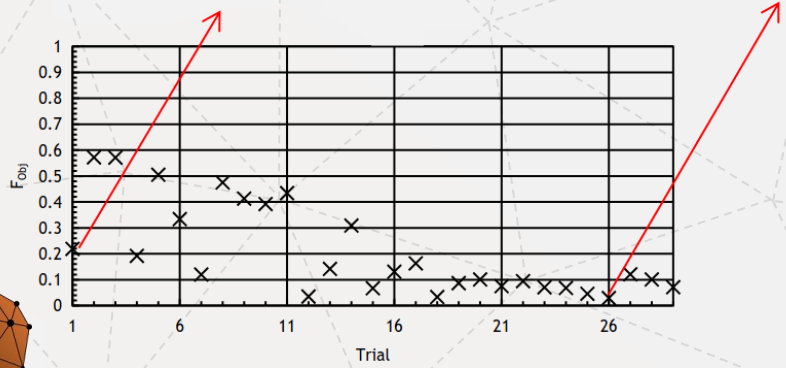
Case study(ST1)

AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES







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<<<<< Best parameters =
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3.000e+00 t2
<<<<< Best objective function =
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<<<<< Best evaluation ID: 26

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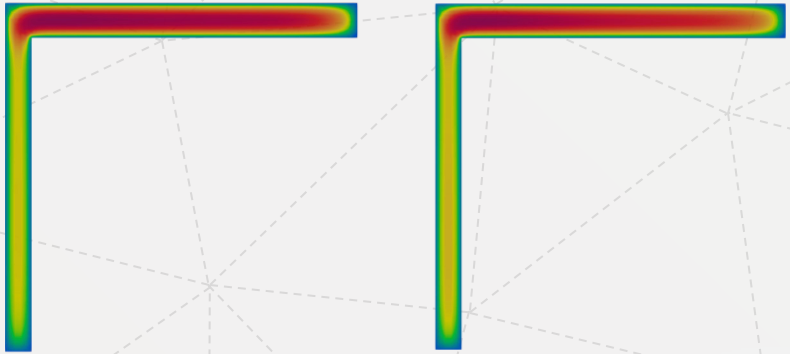
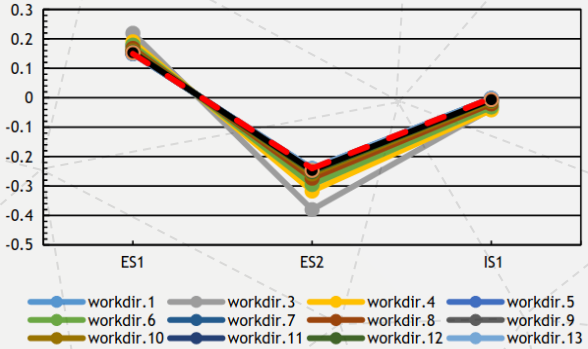
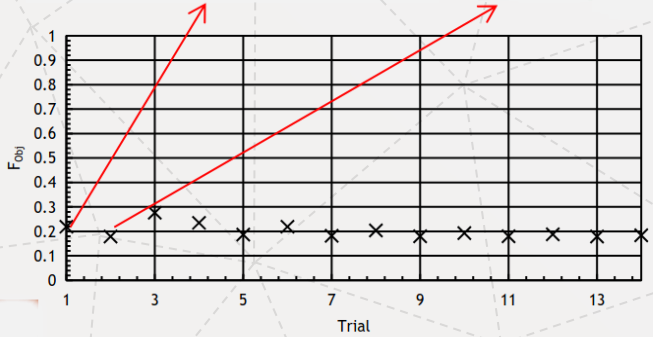
Case study(ST2)

AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES








```
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                1.000e+01 t2
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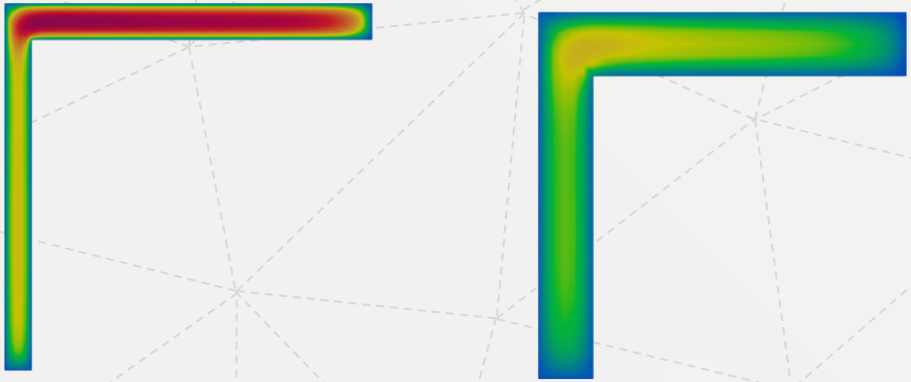
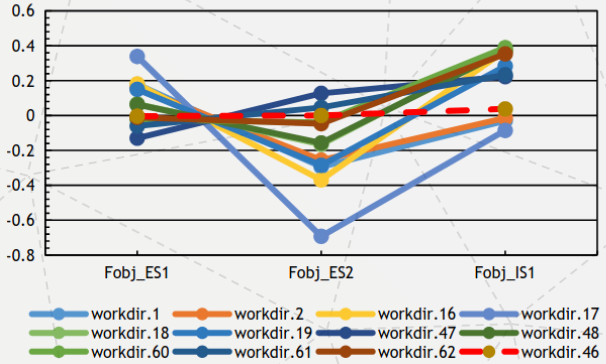
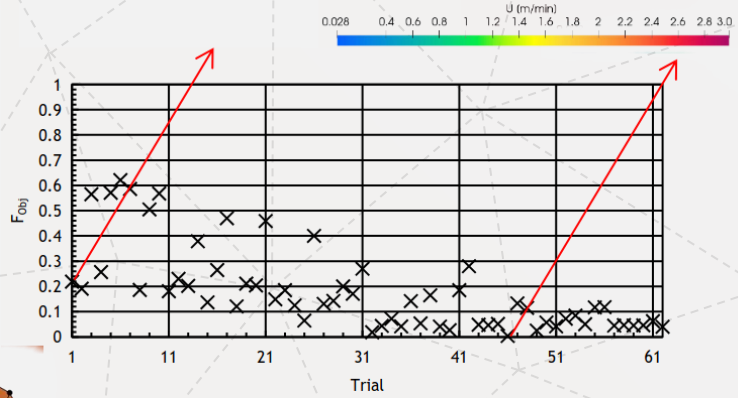
Case study(ST3)

AUTOMATIC OPTIMIZATION OF PROFILE EXTRUSION DIES







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3.000e+00 t2
5.000e+00 t3
6.250e+00 t4
<<<<< Best objective function =
3.790e-03
<<<<< Best evaluation ID: 46

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Requirements

1. Dakota 6.19
2. FreeCAD 0.21.2
3. OpenFOAM® v2406
4. Ubuntu/Windows(WSL)

Course Material Repository

https://github.com/Computational-Rheology/OFW20_ProfileExtrusionDies

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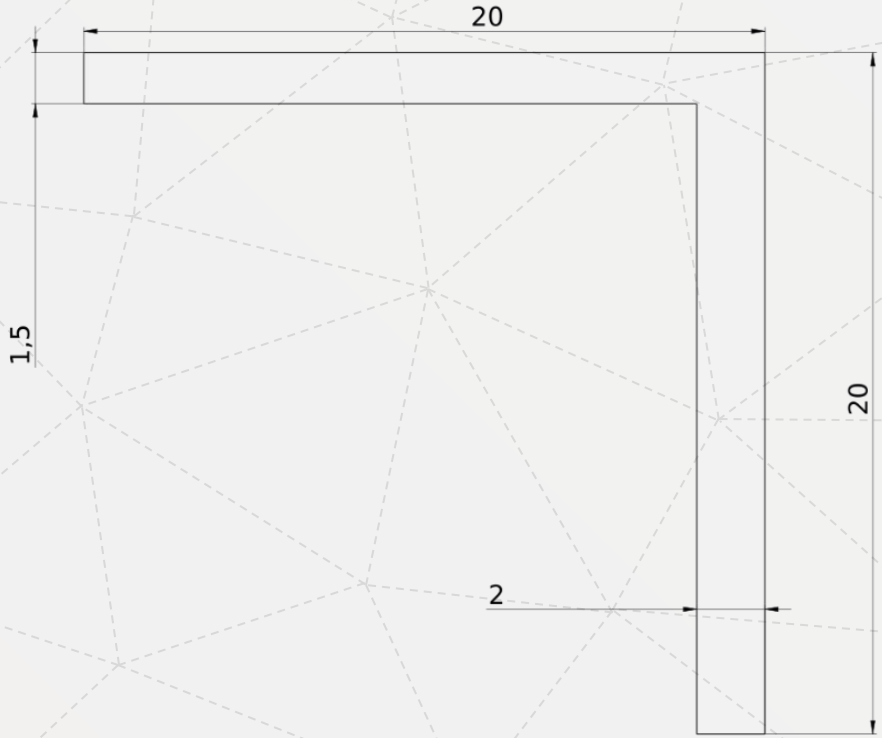
Demonstration

Geometry



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Thank you