**ESTEP 2025 Annual Event**
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Udine (ITALY)

How decarbonisation, digitisation and circular solutions forge the sustainable European steel future?

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# NOZZLE CLOGGING IN STEEL CONTINUOUS CASTING
## multi-phase multi-physics simulations

ESTEP
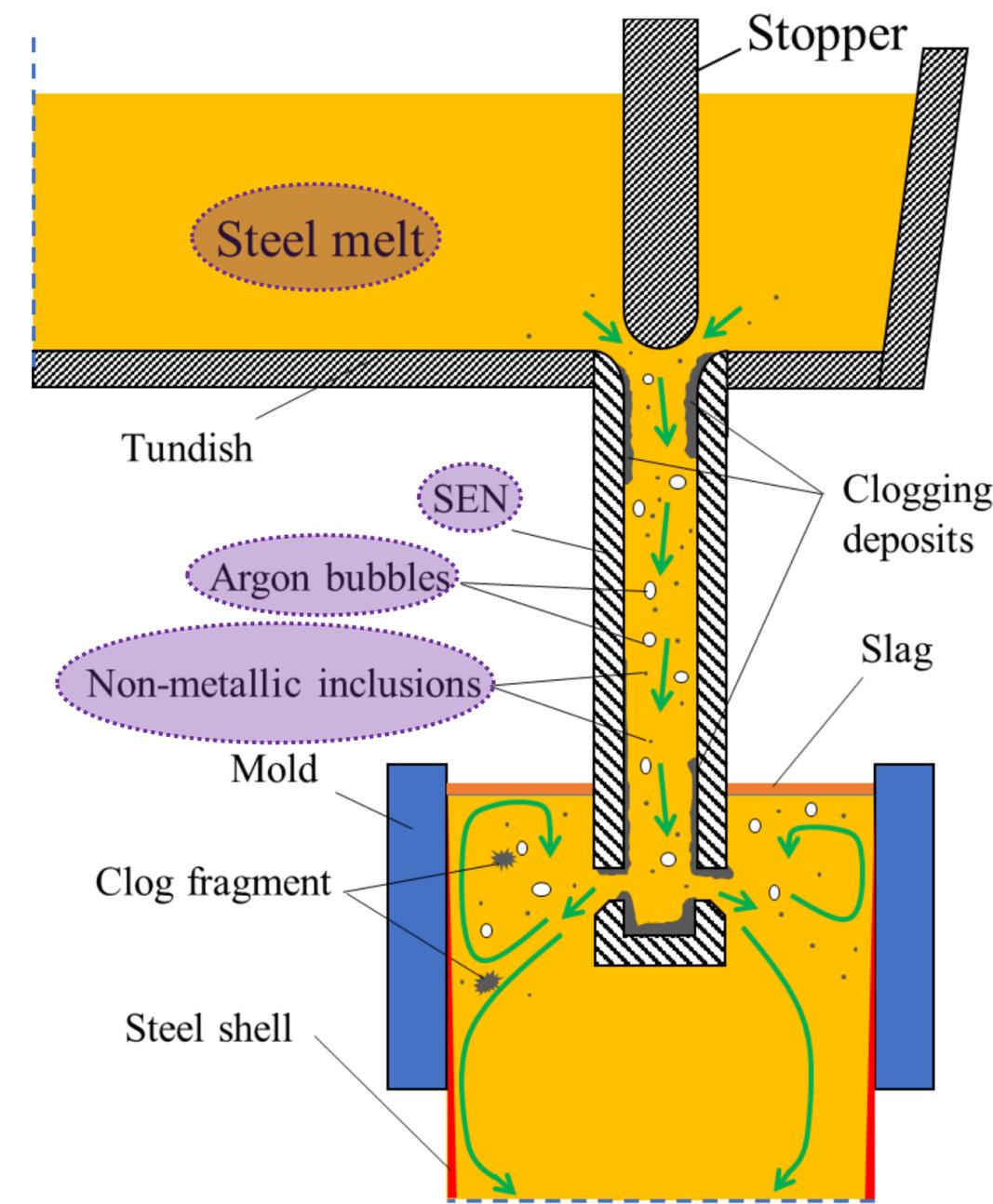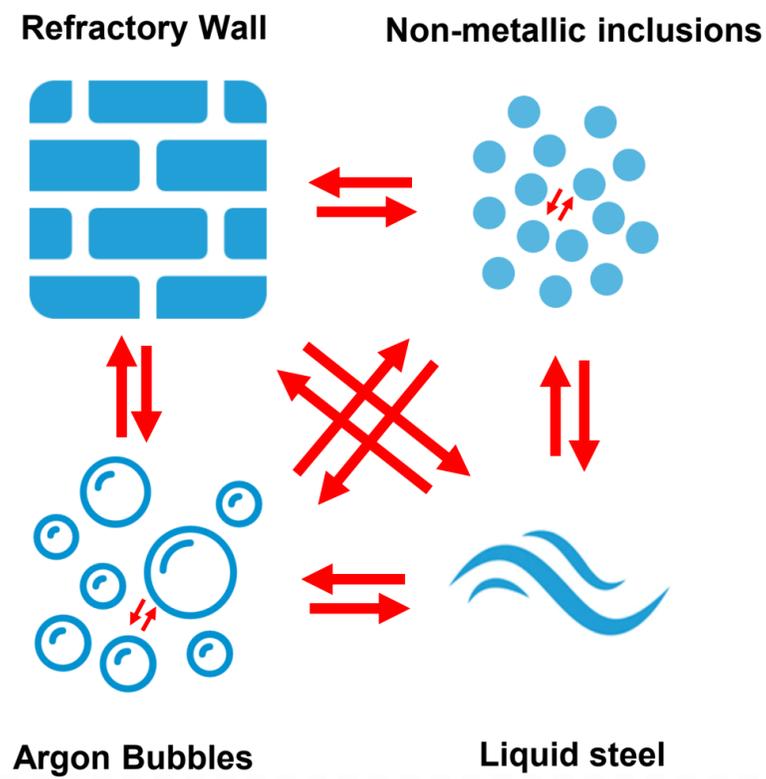European Steel Technology Platform

DIGIMET

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HIC SUNT FUTURA

# SEN clogging in steel continuous casting

**Multiphase and Multiphysics phenomena**

- Turbulent flow
- Chemical reactions
- Transport, attachment and detachment of particles
- Solid-liquid-gas interface

**Clogged SENs from steel plants**

Severe (left[1]) and mild (right[2])

**Main phases**

Refractory Wall      Non-metallic inclusions

Argon Bubbles      Liquid steel



Stopper

Steel melt

Tundish

SEN

Argon bubbles

Non-metallic inclusions

Mold

Clog fragment

Steel shell

Clogging deposits

Slag

# Numerical simulation of SEN clogging



**Late-stage of clogging [1]**

- ➤ Growth of porous network (clog) due to the deposition of solid non-metallic inclusions
- ➤ Two-way coupling between the clog growth and the melt flow
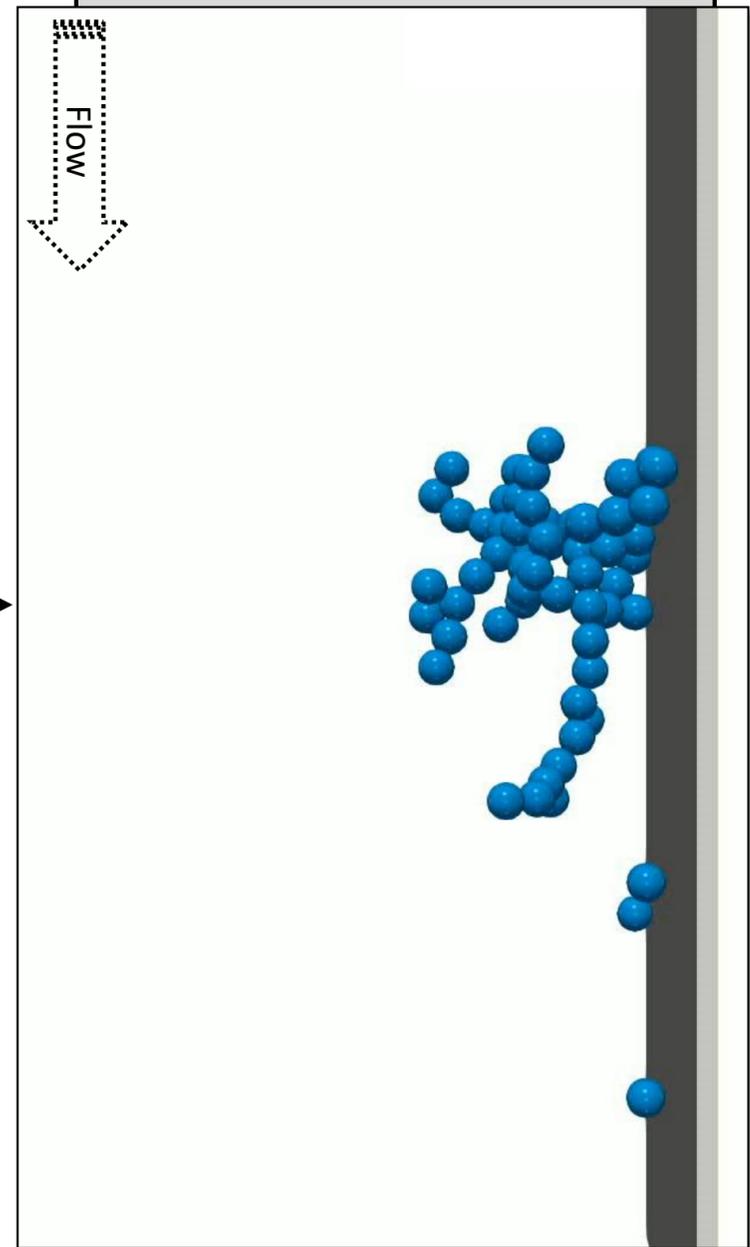- ➤ Random bulges reflecting the effects of turbulent flow

**Early-stage of clogging [2]**

- ➤ Formation of initial layer of oxides (with thickness of δ) on the steel-refractory wall due to the chemical reactions
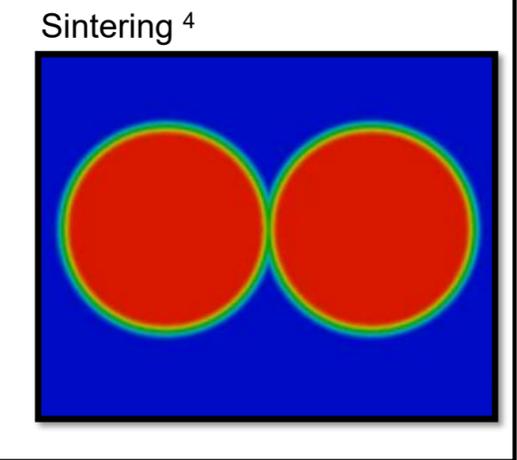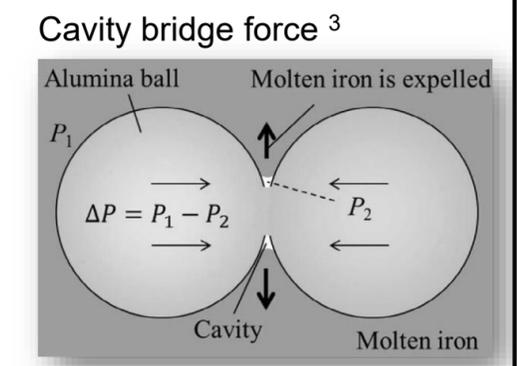
Clog thickness (mm)
0.0 — 1.0

Flow
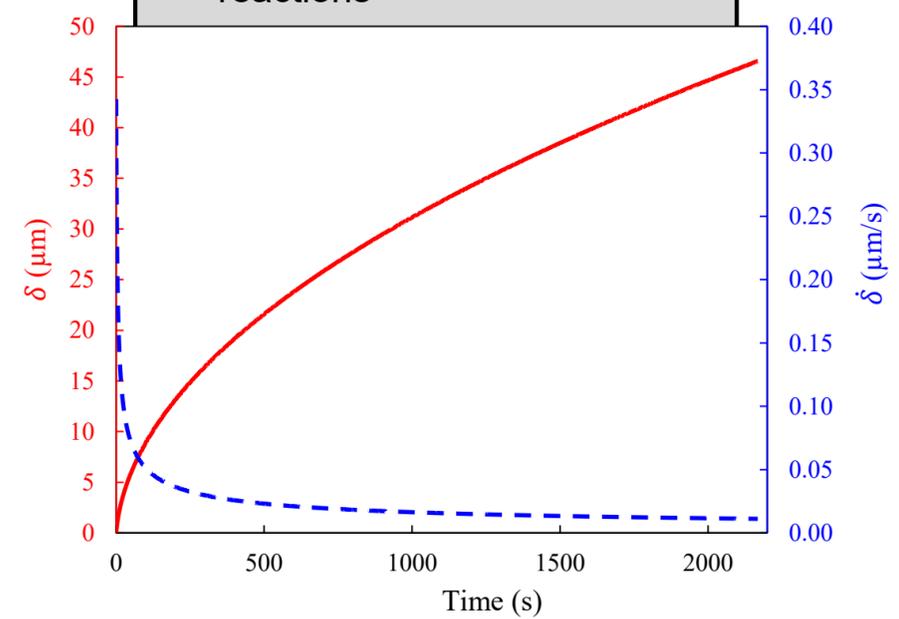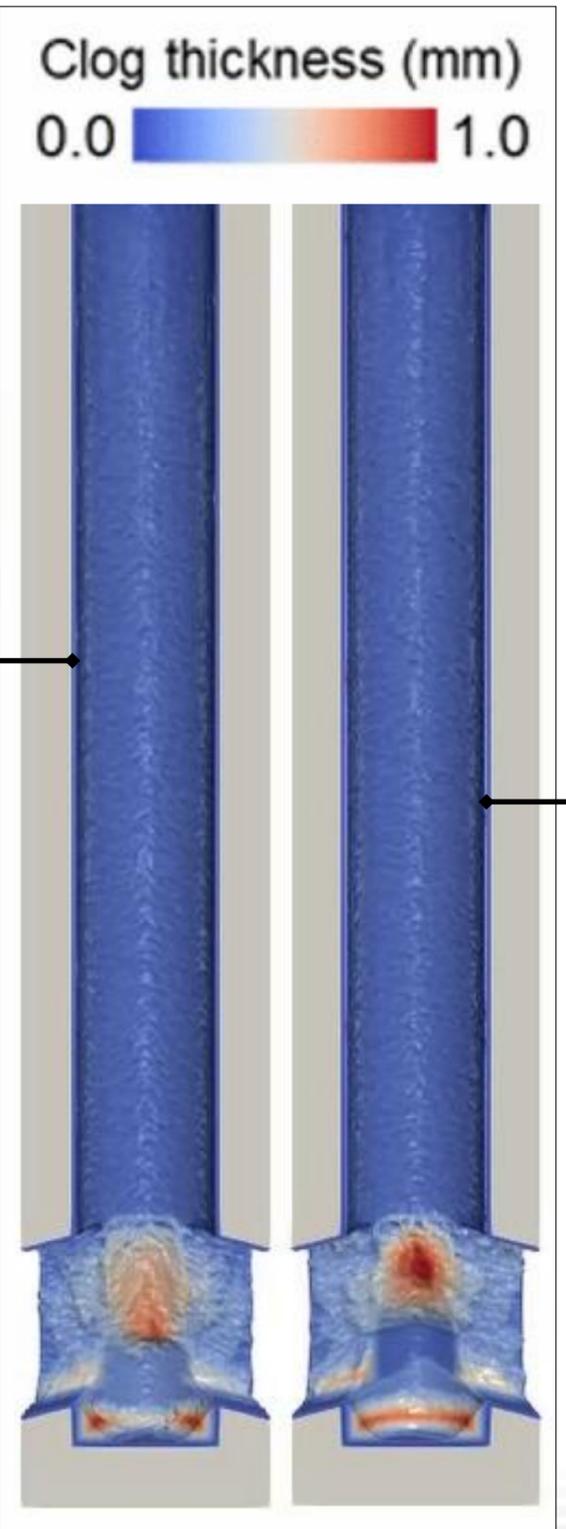
**Microscopic simulation**

- ➤ Coupled CFD-DEM simulation of inclusion deposition and clog network formation

**Critical forces/bons considered in particle-particle interactions**

Cavity bridge force [3]

Alumina ball    Molten iron is expelled
$P_1$
$\Delta P = P_1 - P_2$    $P_2$
Cavity    Molten iron

Sintering [4]

1 Barati, et al., 2024, Powder technol
2 Barati et al., 2021, Metall. Mater. Trans. B.
3 Nakamato, 2014, ISIJ Int.
4 www.youtube.com/@SciTekGo

# Numerical simulation of SEN clogging

## Summary

➤ The clogging model provides a comprehensive framework of different phenomena:

- Turbulent flow
- Chemical reactions
- Transport, attachment and detachment of particles
- Effects of argon gas

➤ This model
- considers two-way coupling between clog growth and melt flow,
- validated by reproducing a laboratory and industrial experiments,
- considers *fluid dynamics*, *thermodynamics*, and *kinetics*,
- correlates *pressure* in addition to *velocity* and *turbulence* to clogging tendency.

**Simulated clog interface** [1]
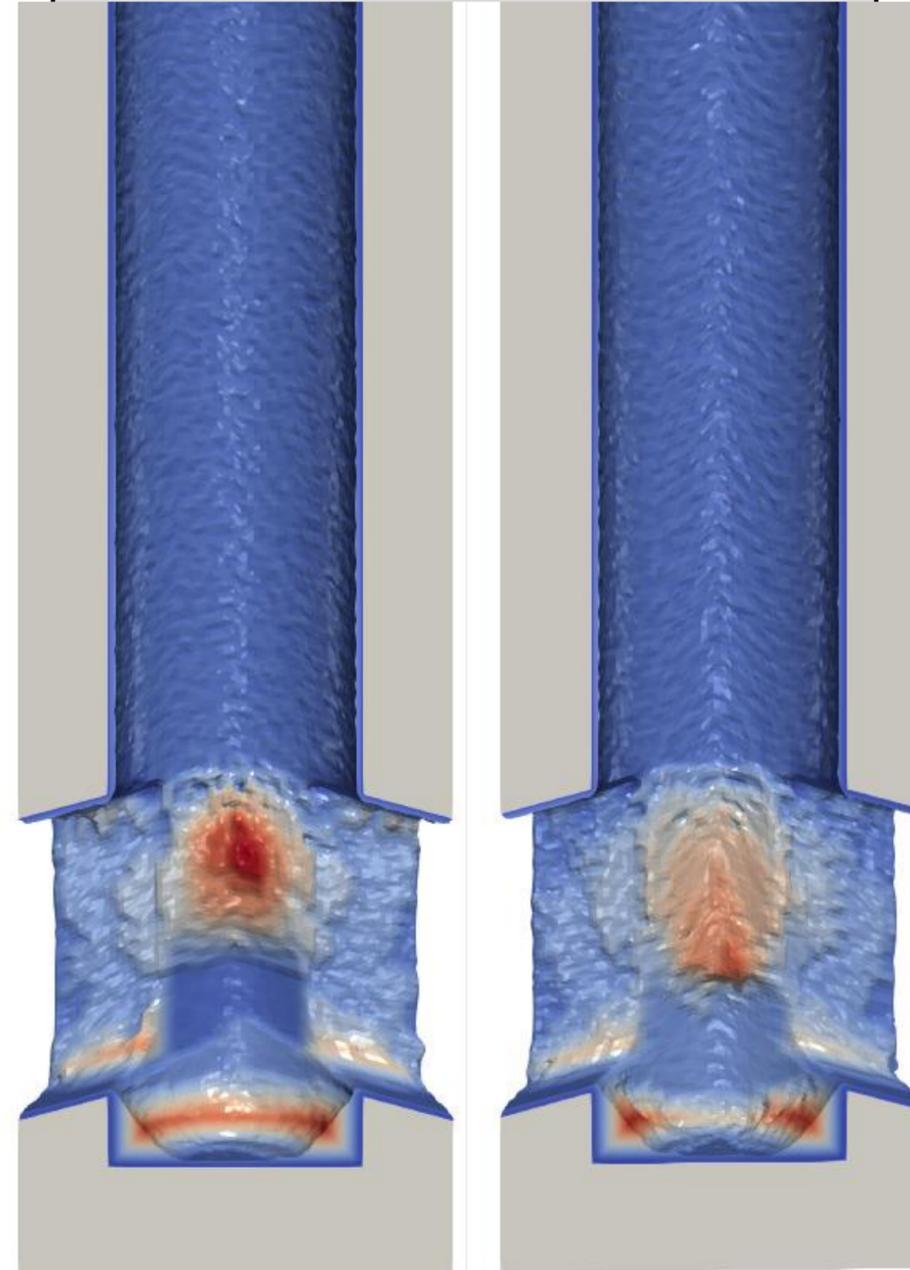
**Topography of clog interface in a clogged SEN in the plant** [2]
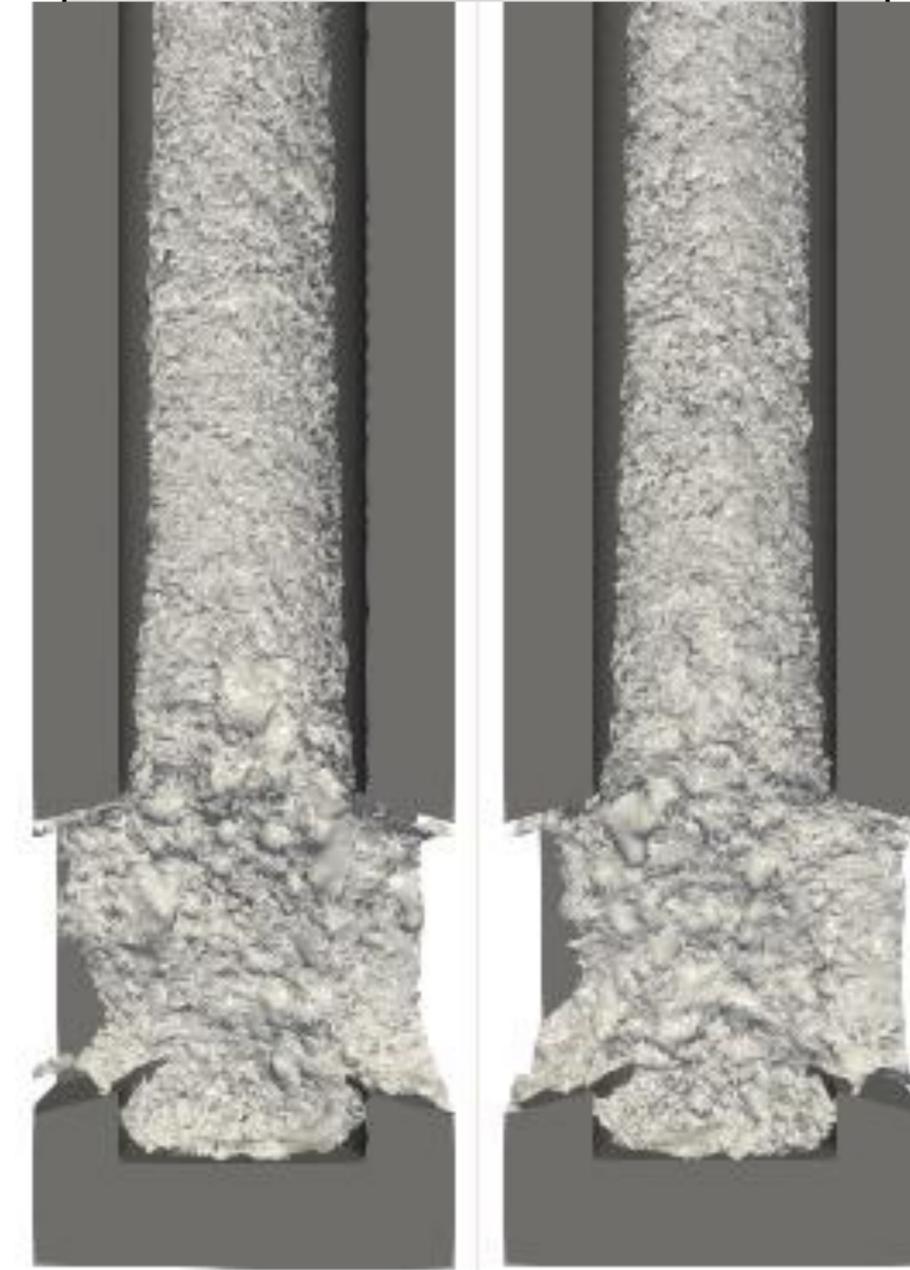


1 Barati, et al., 2024, CFD conference
2 voestalpine Stahl Linz GmbH