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Numerical modeling of tribological phenomena: Products and processes

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Outline

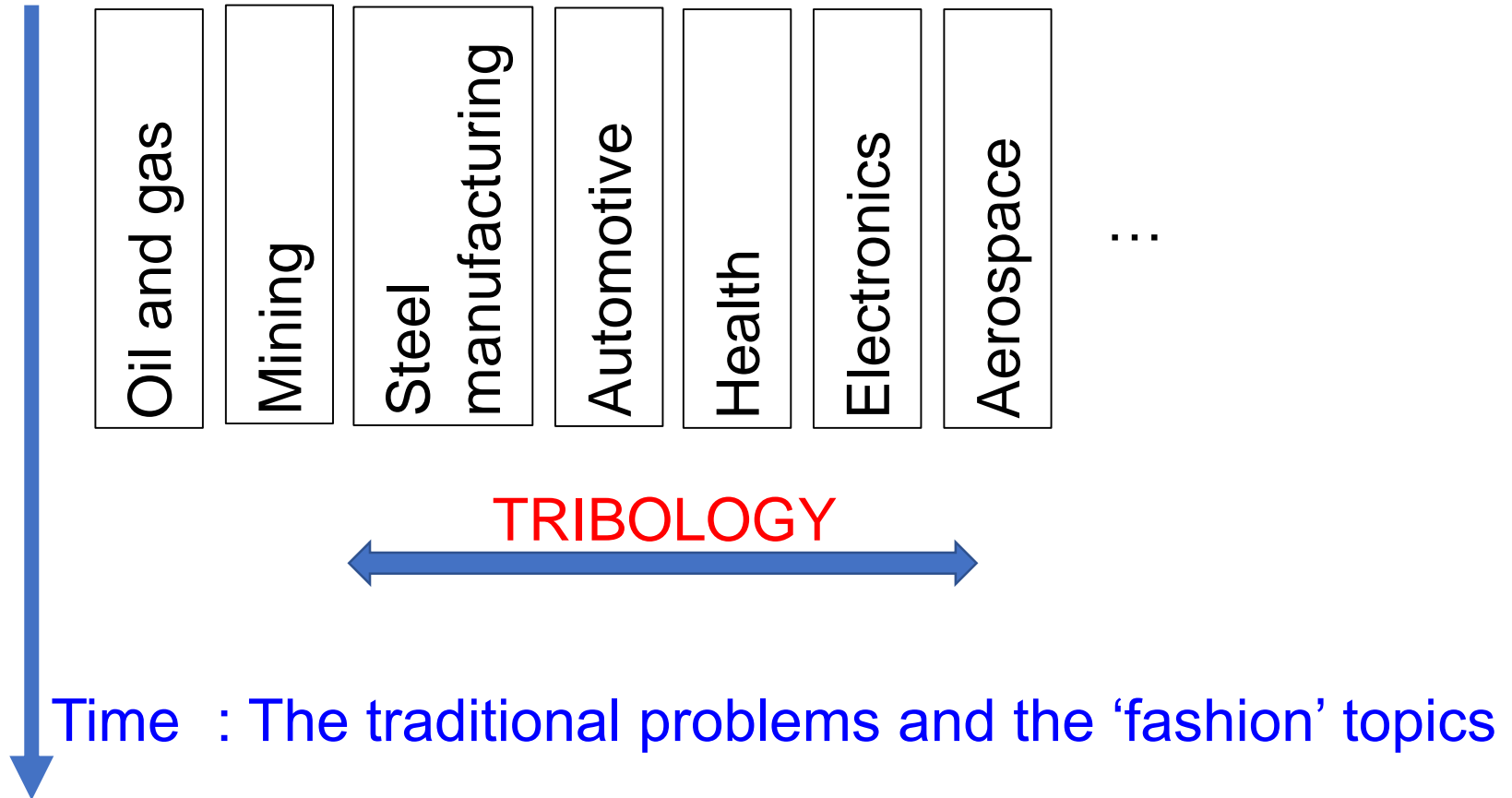
- Tribology
- Multi-scale approach
- Case study – Materials for rolling mill rolls
- Case studies – Processes
- Conclusions
- Acknowledgements



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Tribology



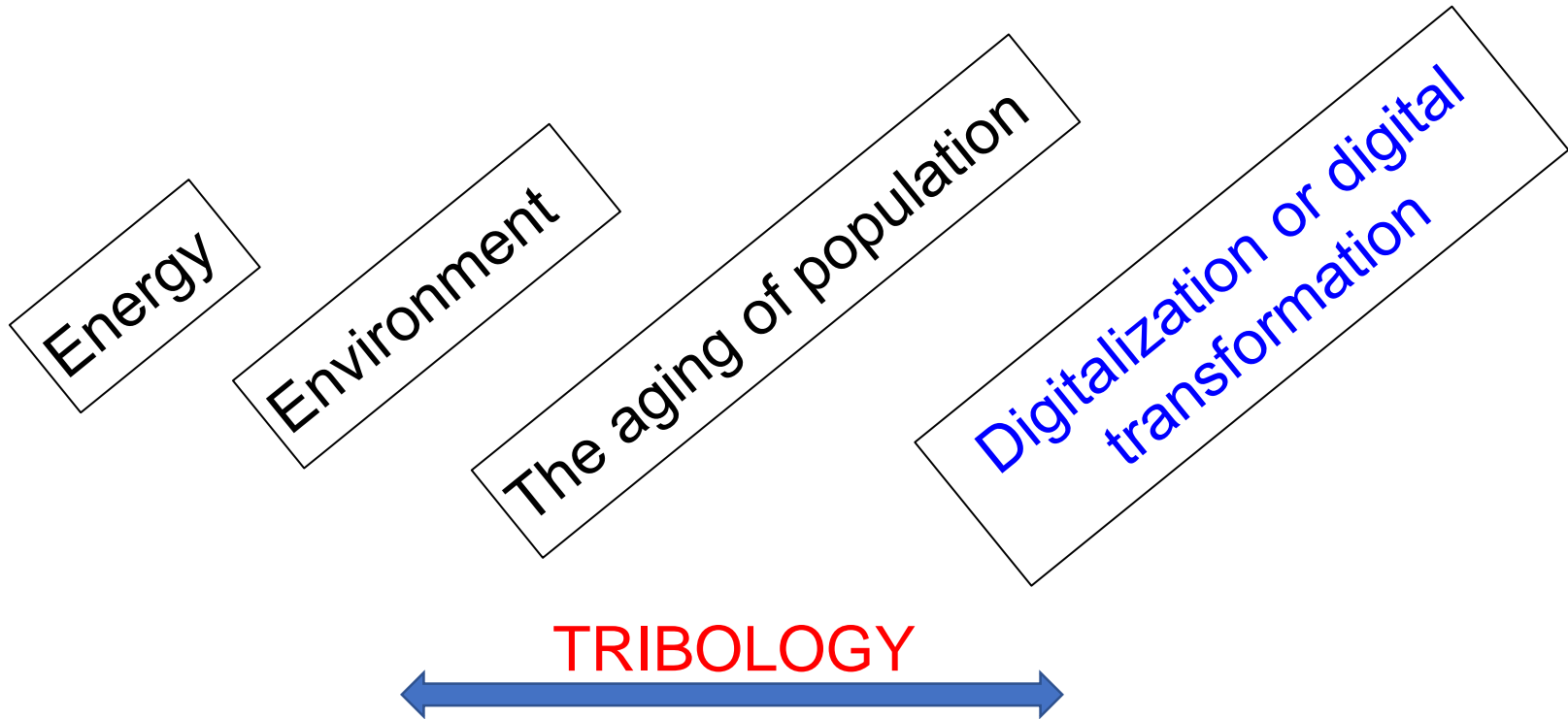


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Tribology

- A few current challenges





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Tribology

- Digitalization: “the conversion of text, pictures, or sound into a digital form that can be processed by a computer”
- In tribology: Simulation/reproduction of tribological phenomena
 - Identify materials with better tribological behavior: **Products**
Alternative for trial and error approach
 - Identify parameters for better manufacturing: **Processes**



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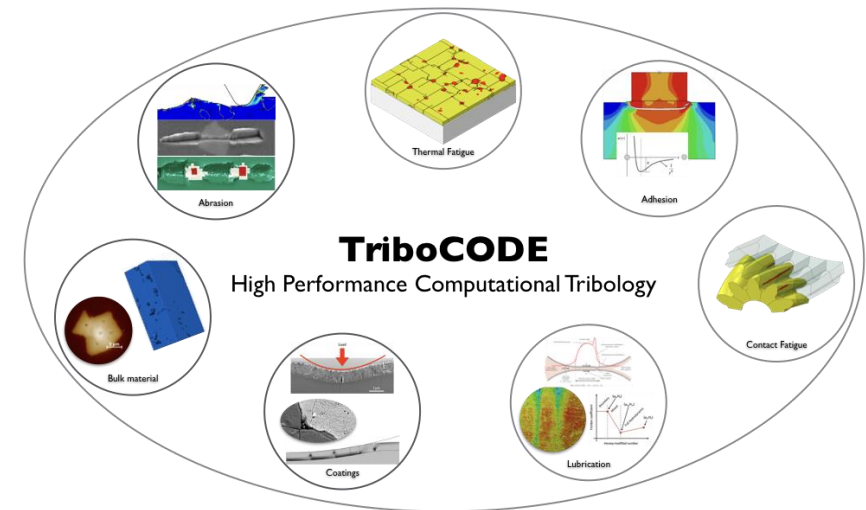
Surface Phenomena Laboratory

- Tribology group established in 1994
- Strong interaction with industry, universities and research institutes

Tribological and characterization tools



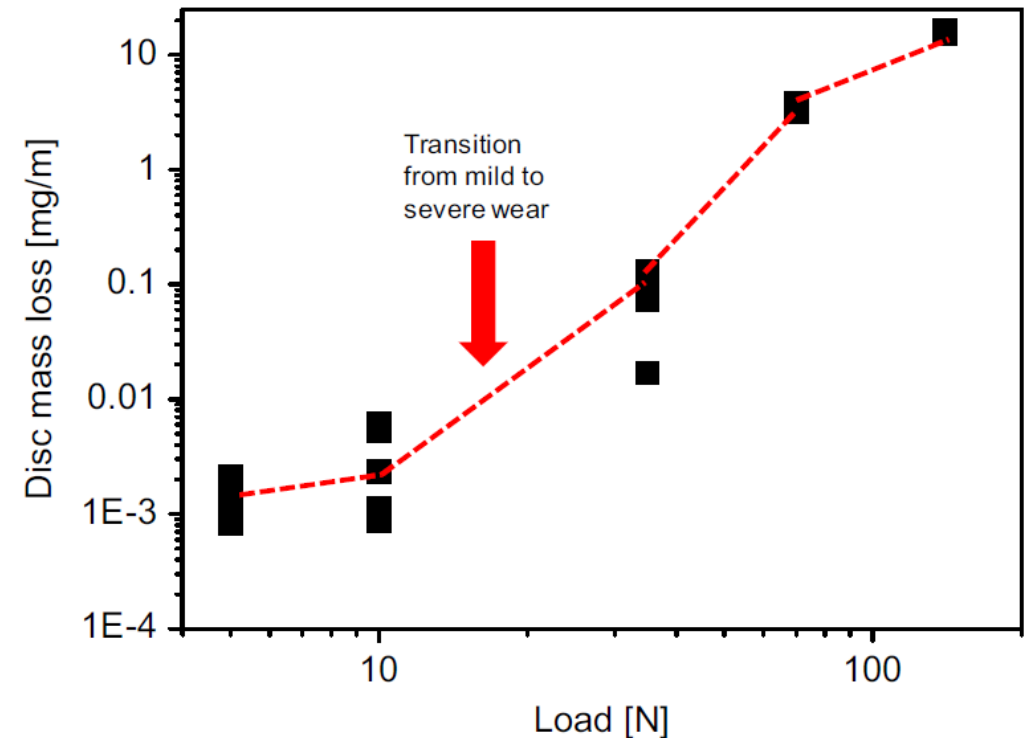
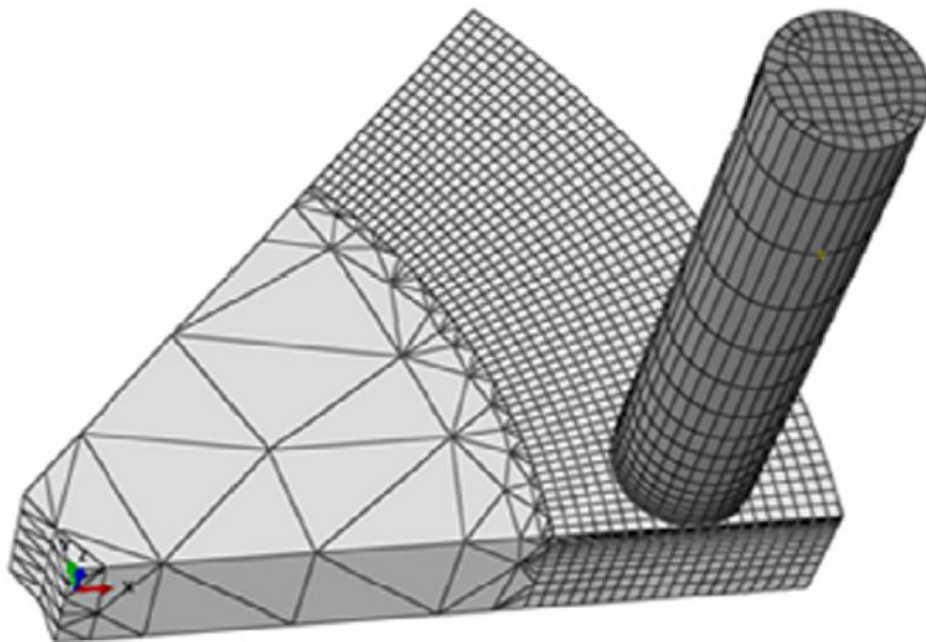
Modeling





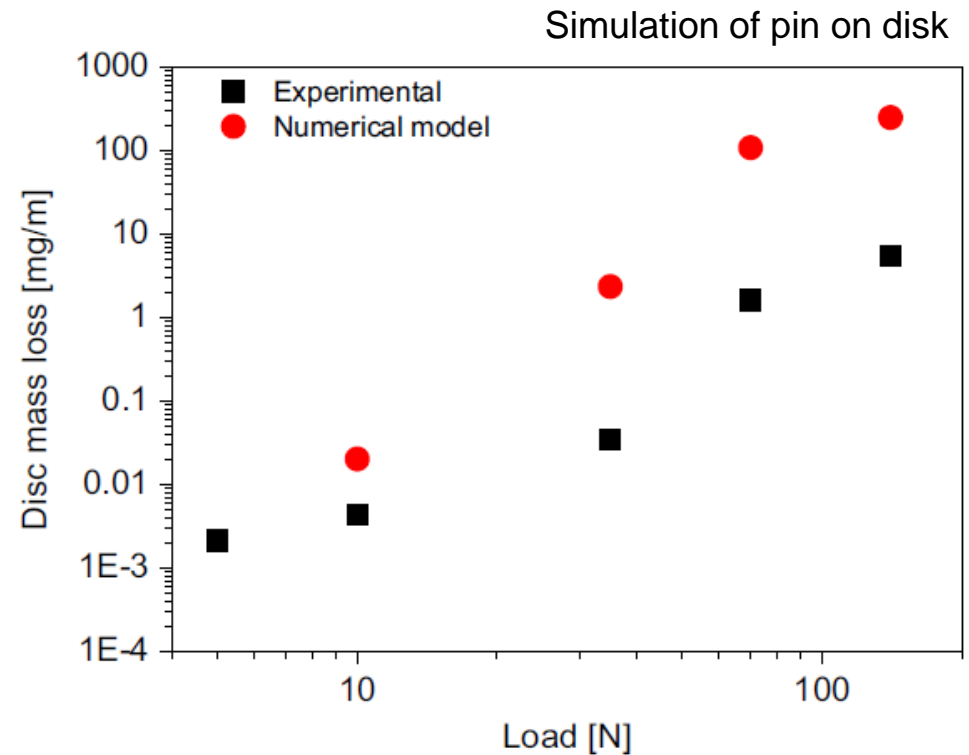
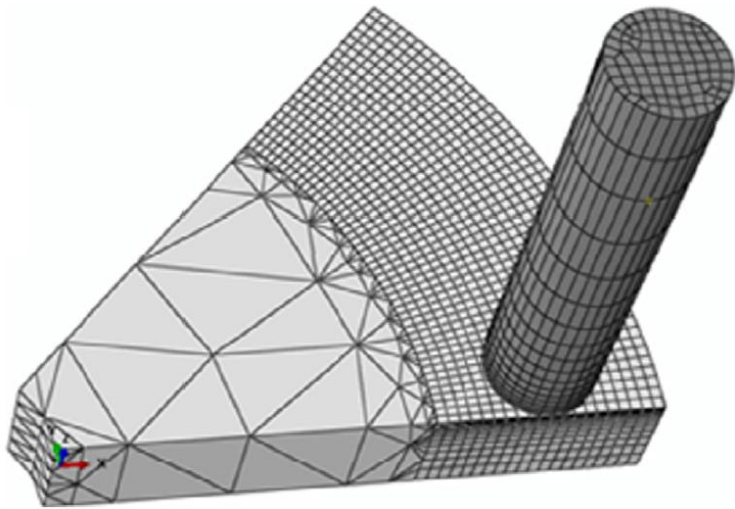
Multi-Scale Approach

- Simulation of pin on disc
- Wear **rates** measured experimentally





Multi-Scale Approach



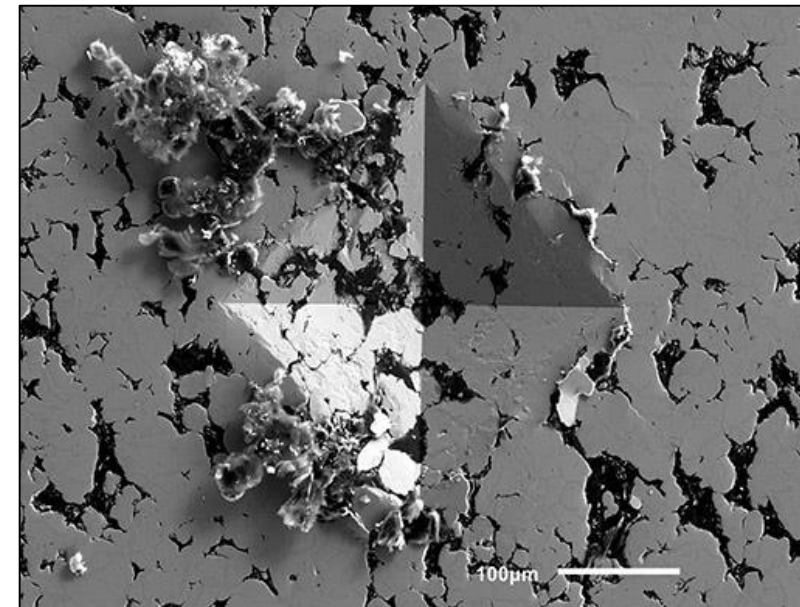
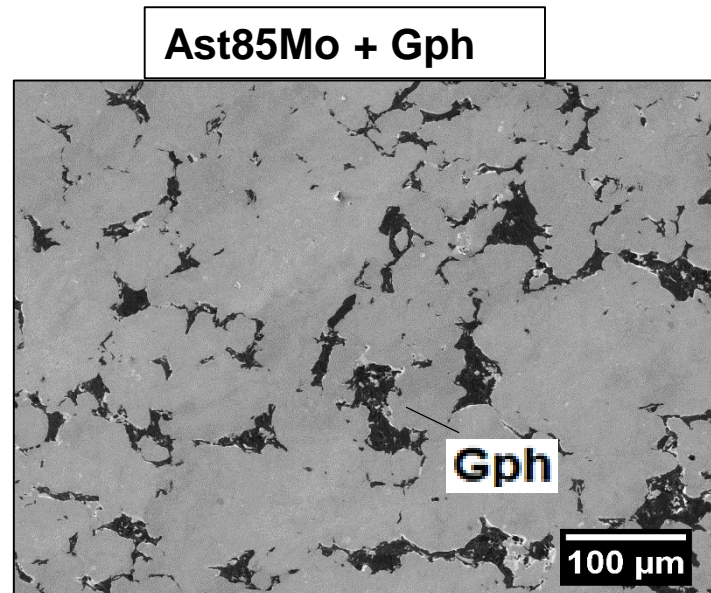


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Multi-Scale Approach

- Challenge in the numerical reproduction of tribological phenomena: **Scales**
 - Tribological behavior is **not** defined **only** by **hardness**



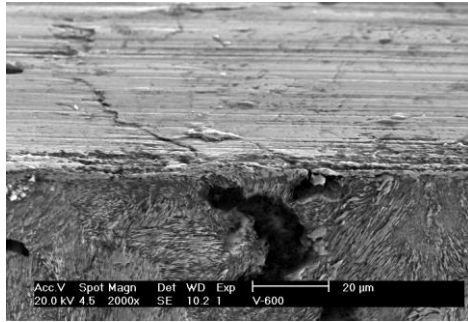


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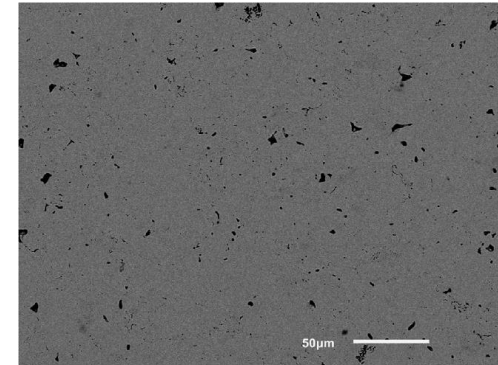
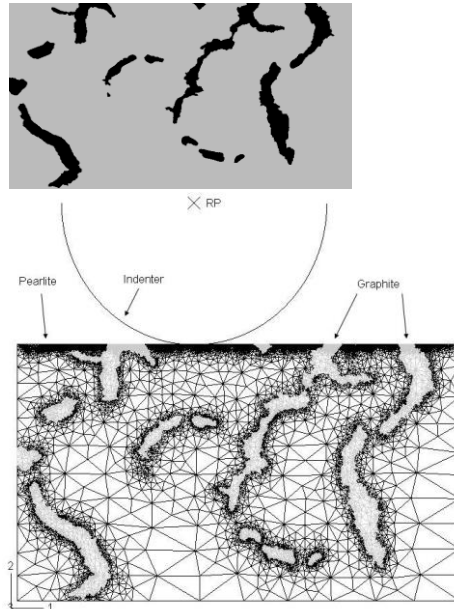


Multi-Scale Approach

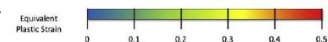
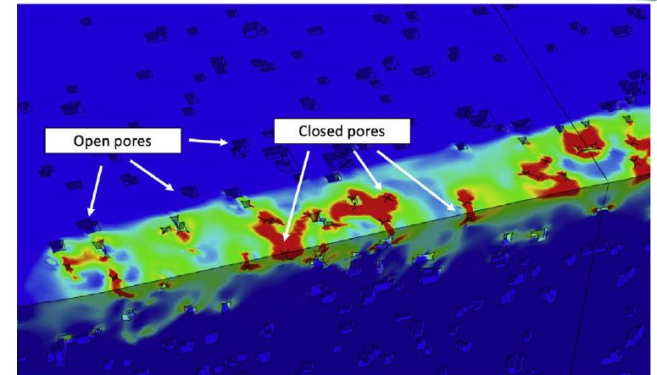
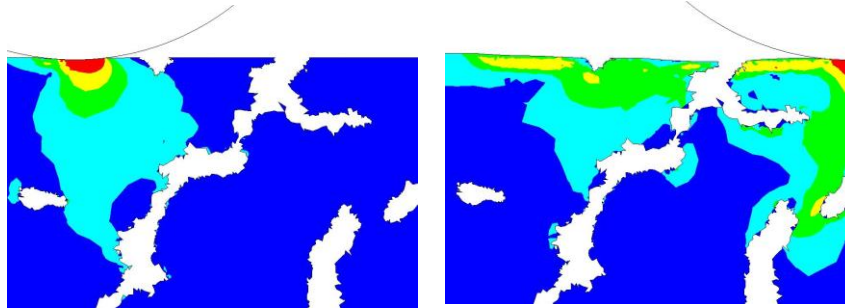
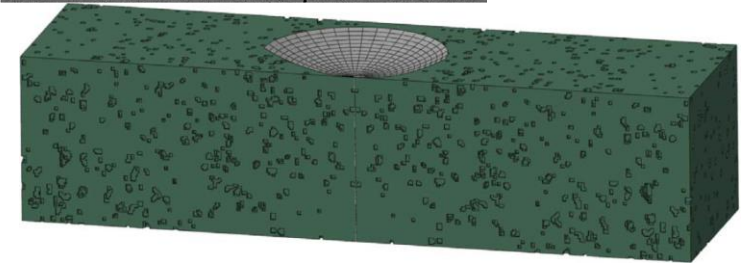
- Effect of structure and load



Graphite flakes completely or partially covered



Spark Plasma Sintered (SPS) Fe-C-Mo



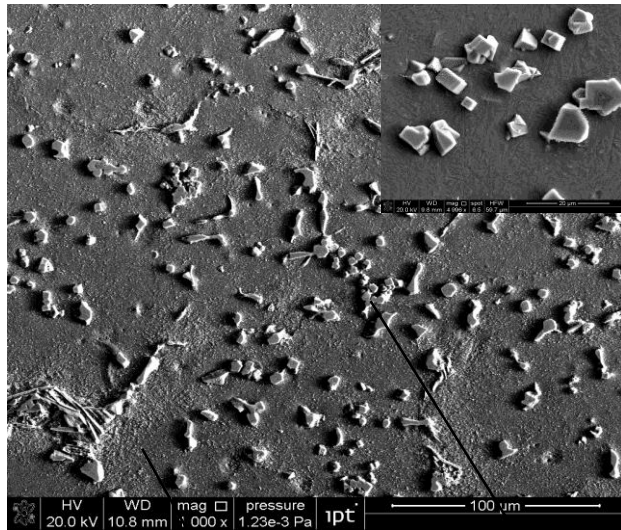


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Microstructural Modeling

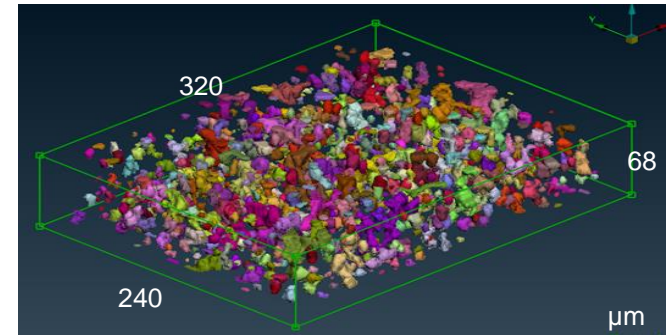
Cast Nb-bearing HSS



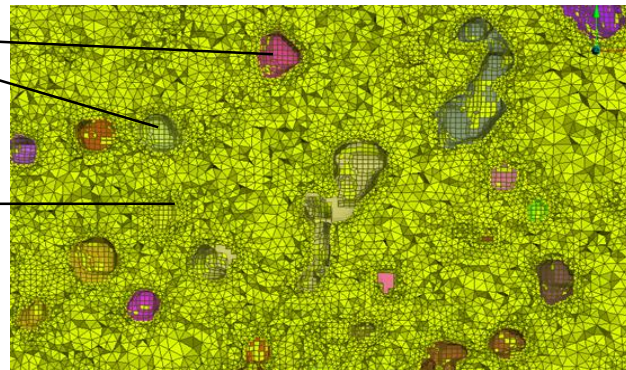
- ✓ SEM planar micrograph
- ✓ 45 slices
- ✓ Distance $\cong 1.5 \mu\text{m}$



Digitalizing (3D)

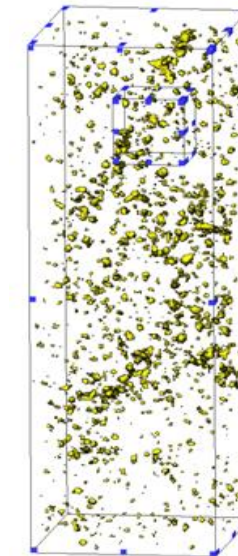


X-ray
Microtomography



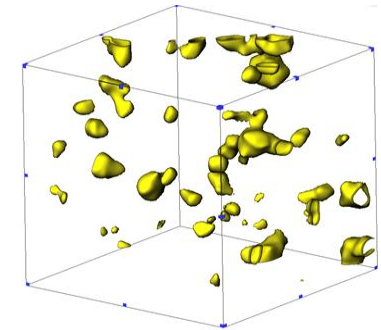
MC carbide

Matrix
(tempered martensite)



250 X 300 X 750 μm^3

Meshing

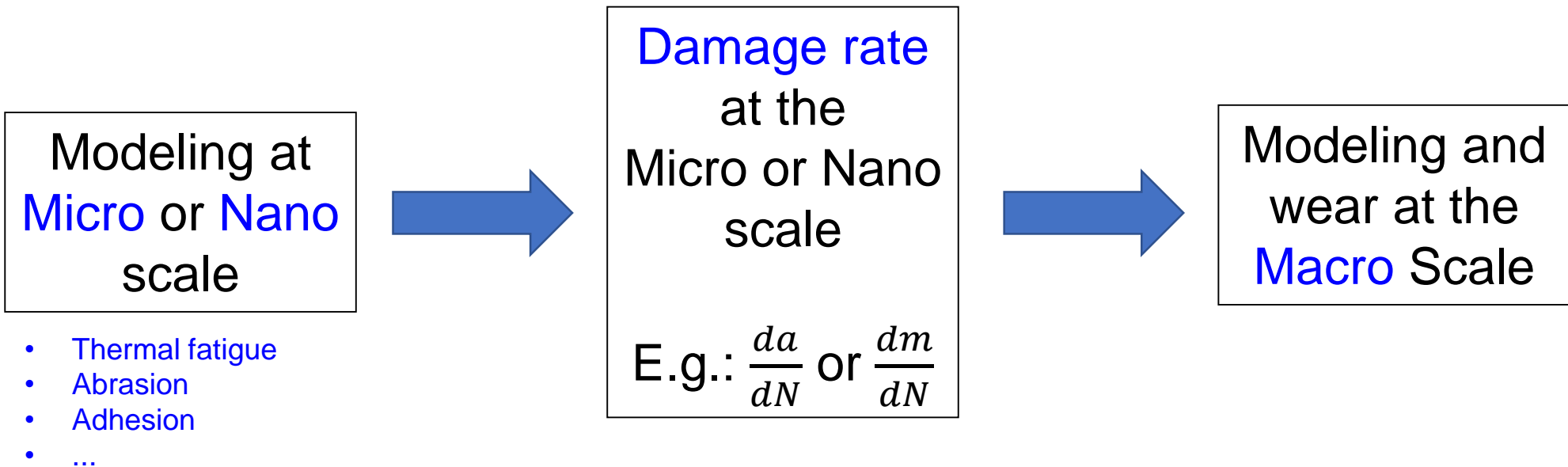


97 X 97 X 97 μm^3



Multi-Scale Approach

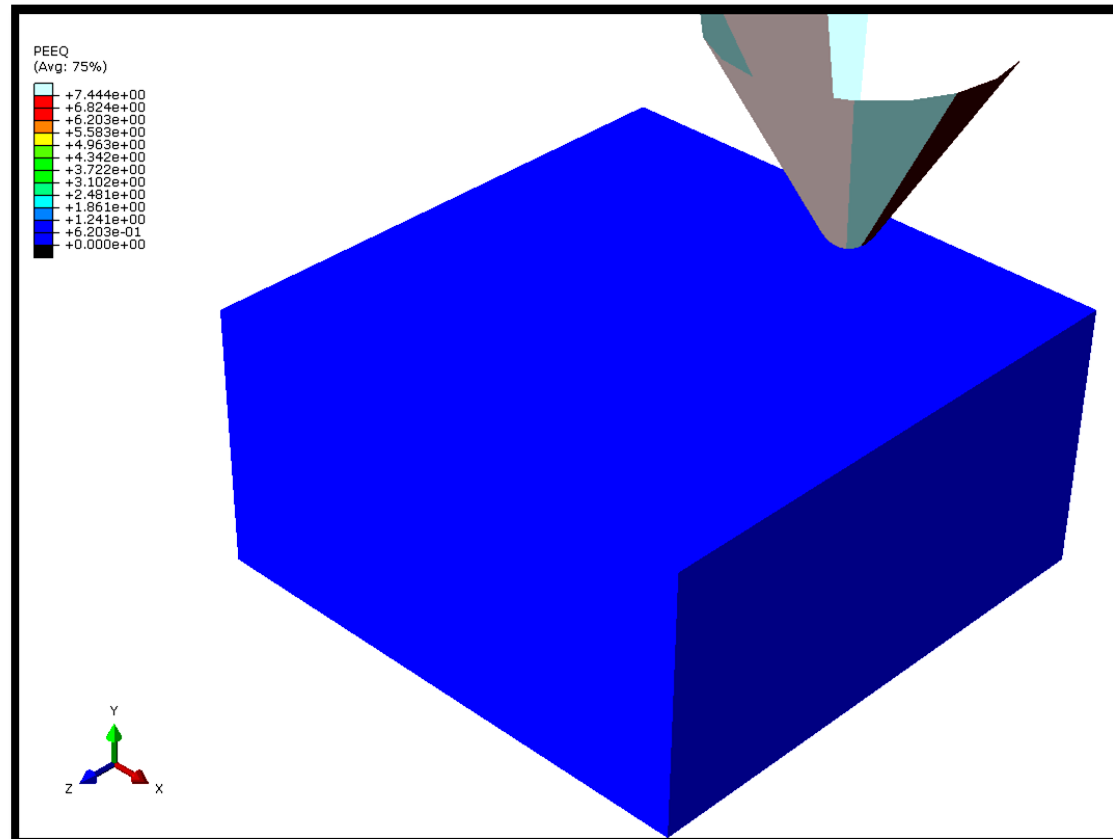
- Challenge in the numerical reproduction of tribological phenomena: **Scales**





Abrasion

- Phenomena – Abrasion, 3D analysis



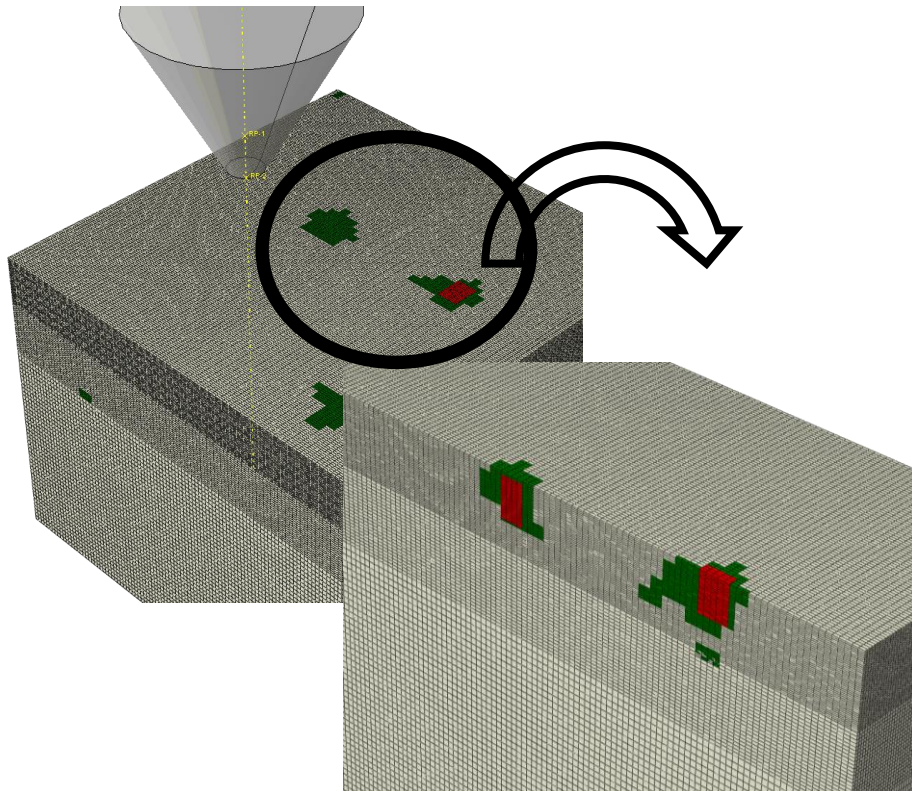
Homogeneous material



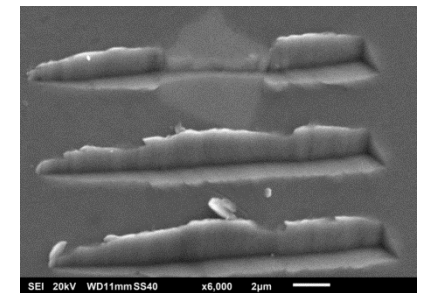
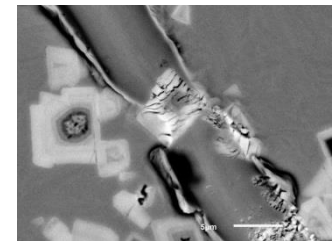
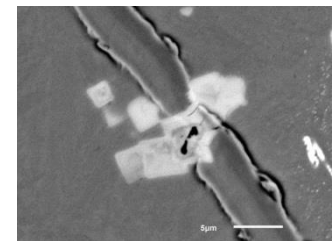
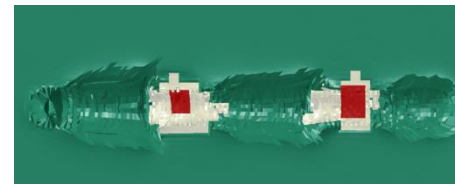
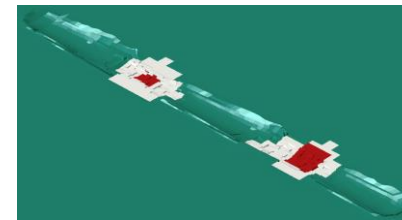
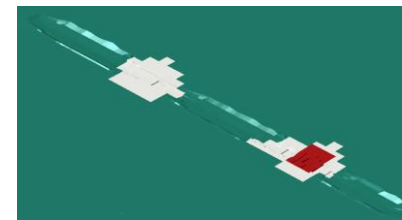
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Abrasion

- Phenomena – Abrasion, 3D analysis



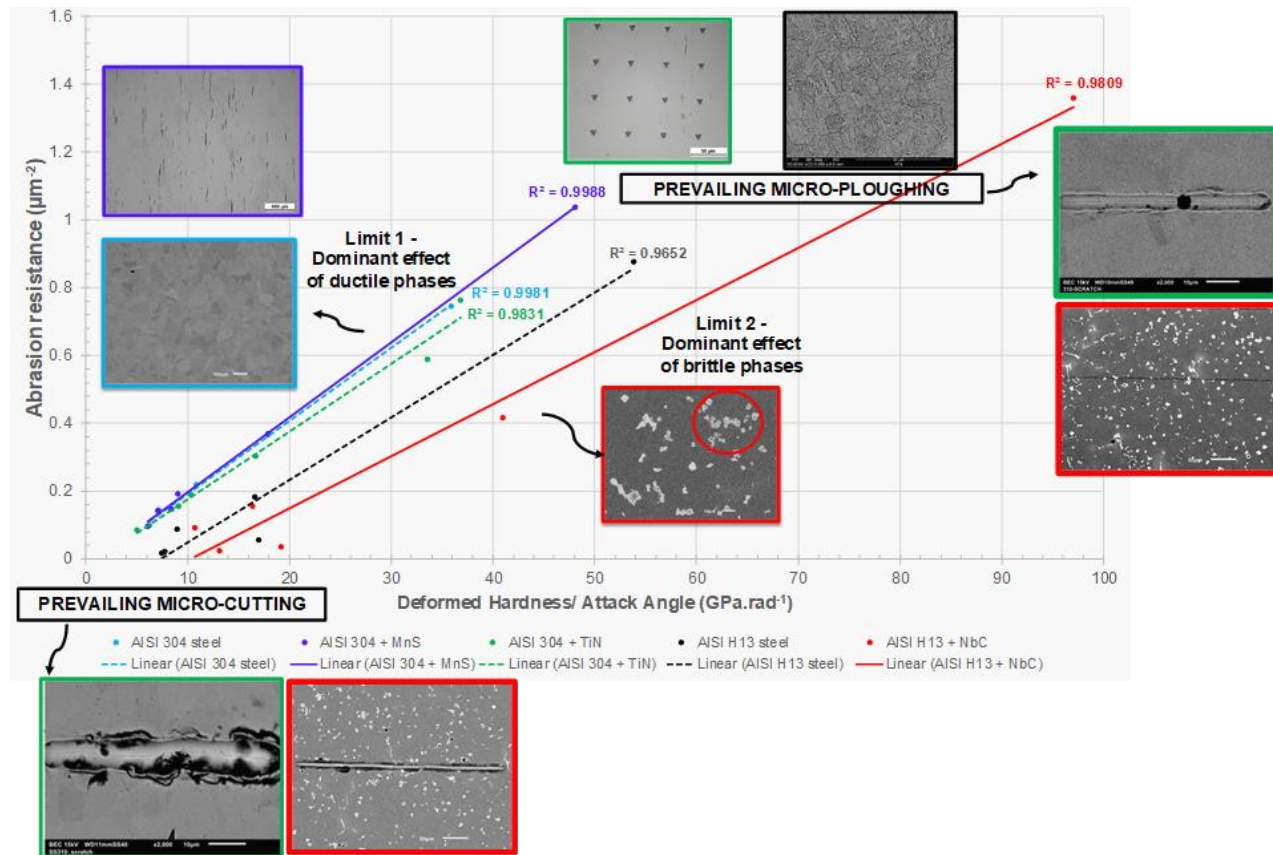
Heterogeneous material





Abrasion map

- Homogeneous and heterogeneous (2-phase) materials – Hard and soft matrices
 - higher slopes: mainly ductile
 - Lower slopes: mainly brittle
 - Micro-ploughing when abrasion resistance is high or when attach angle is small
 - Micro-cutting when abrasion resistance is low or when attach angle is large

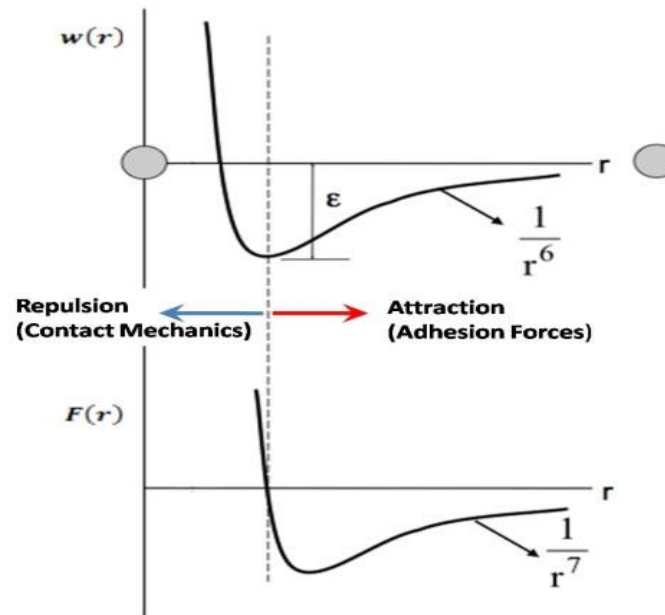
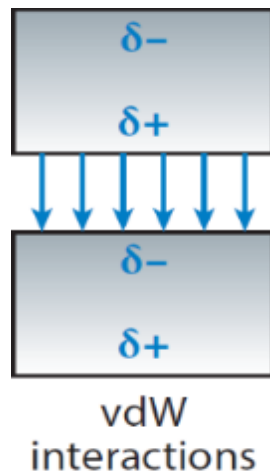




Adhesion

- Phenomena – Adhesion
 - Not available in most finite element software
 - Consider contributions to adhesion

$$F_{adh} = \underline{F_{vdW}} + F_{el} + F_{chem} + F_H + F_{cap} + \dots$$



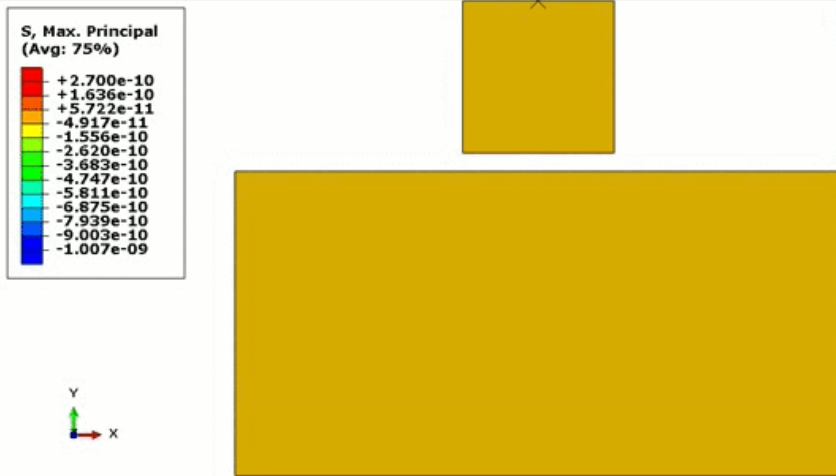
$$\Pi_{vw}(h) = -\frac{A_H}{6\pi h^3}$$

A_H – Hamaker constant

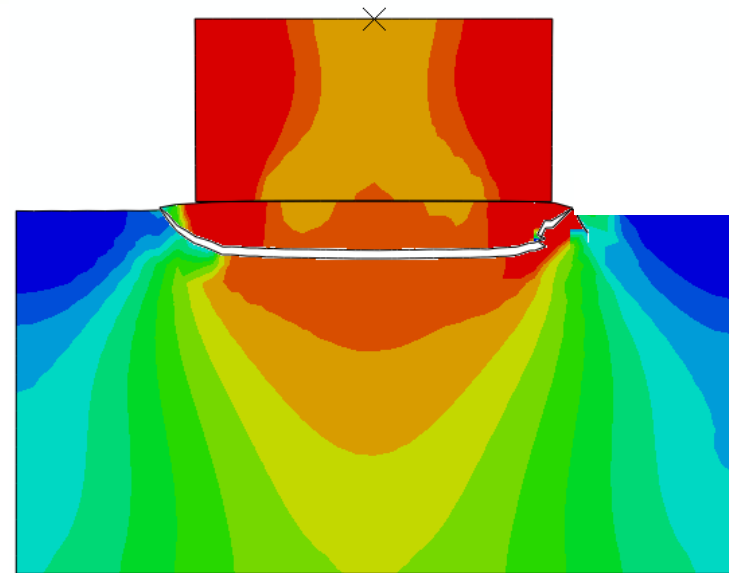
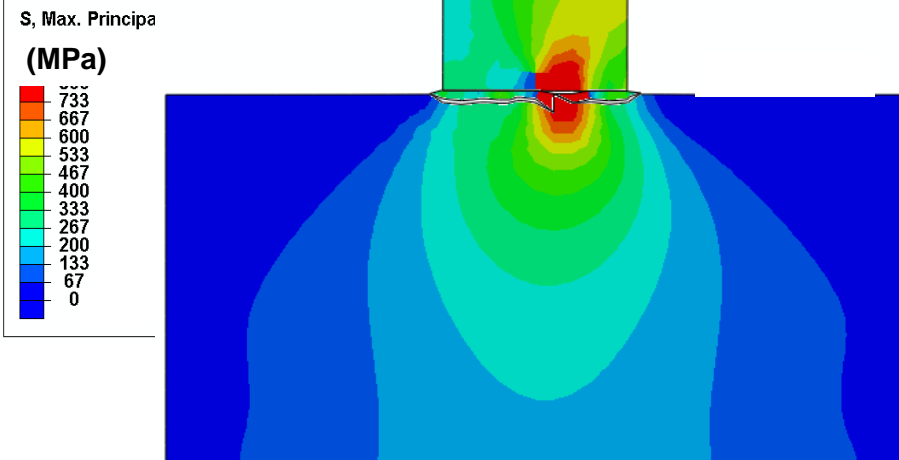
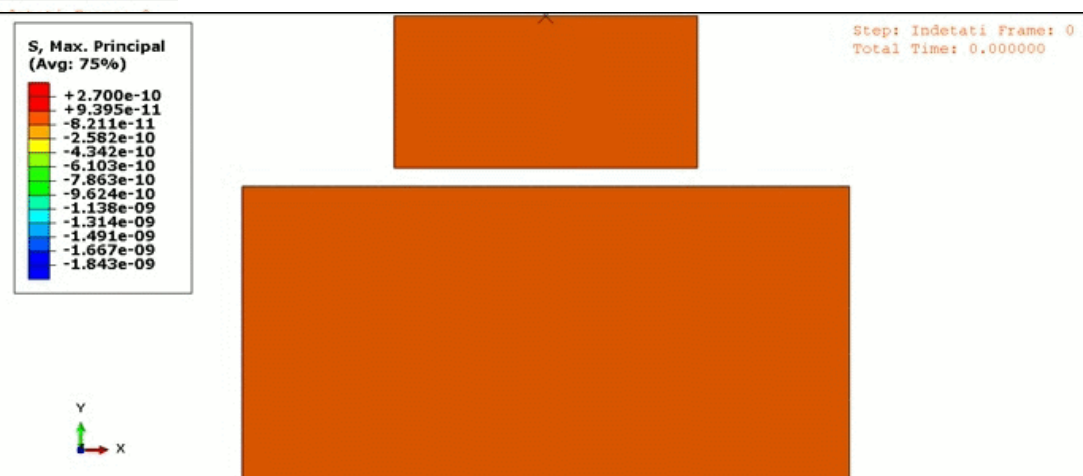


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copper and copper



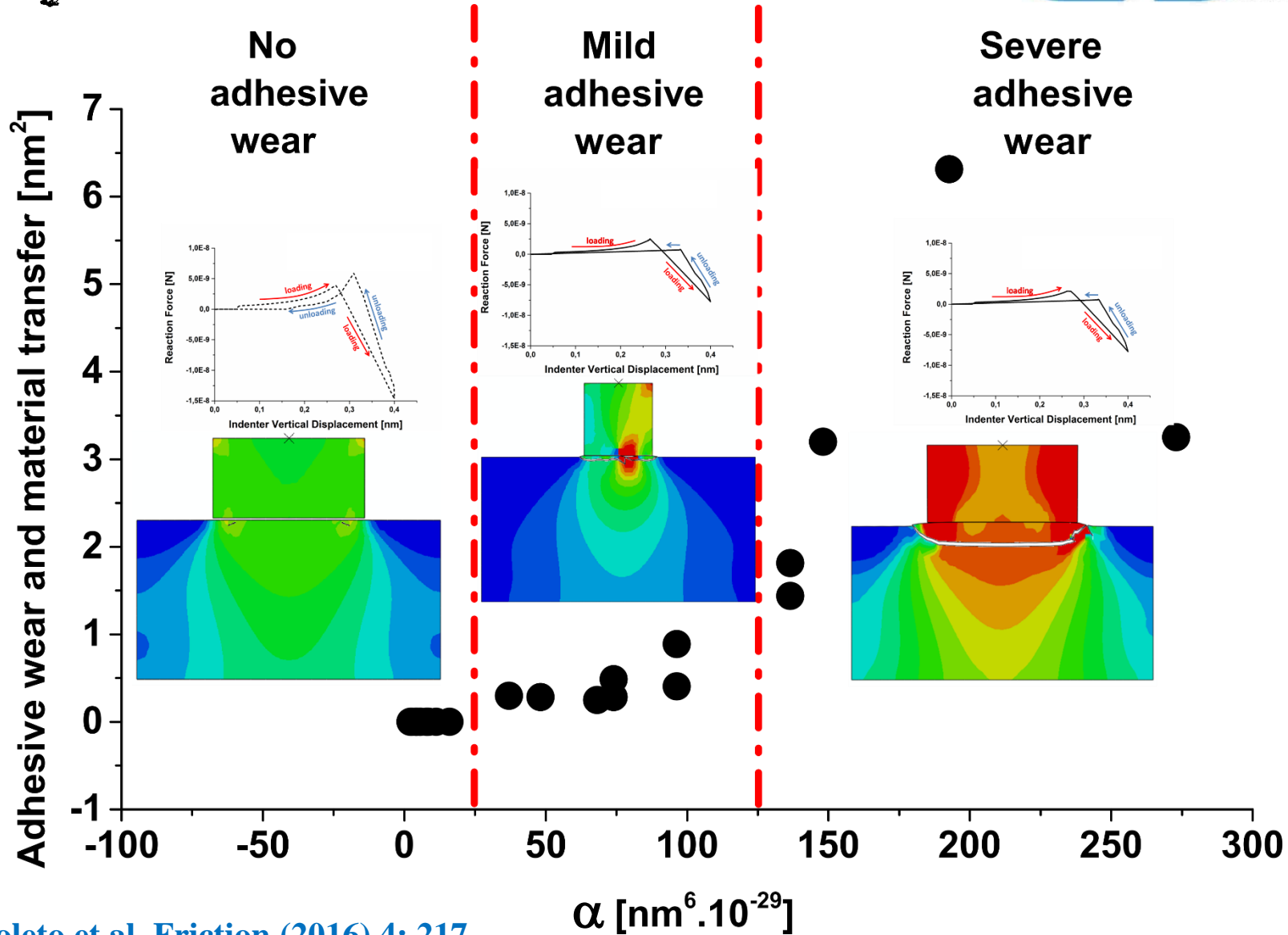
copper and copper





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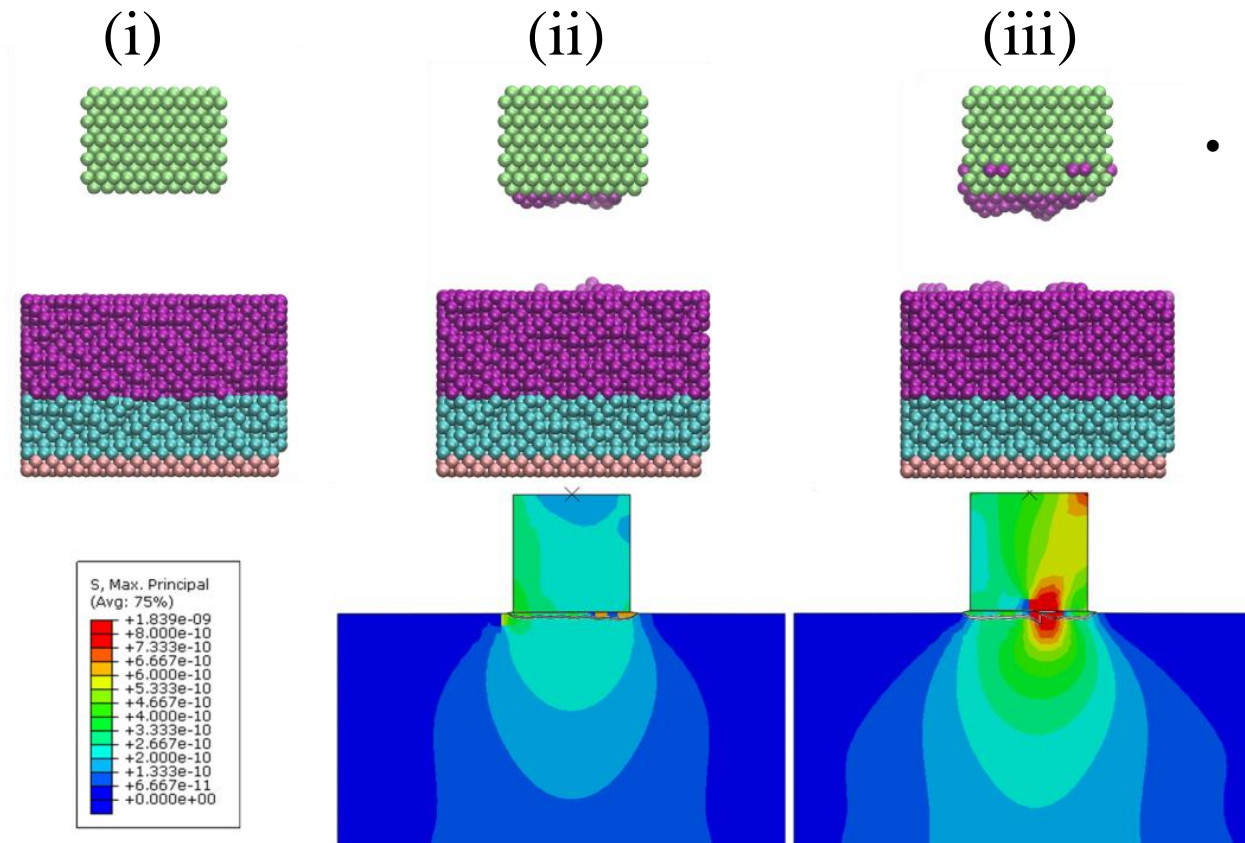
$$\alpha_{\text{adhesion}} = \frac{h_{\text{depth}} L_{\text{real}} A_{12}}{\left(E_{\text{slab}} / E_{\text{indenter}} \right) \sigma_{\text{failure}}}$$





Adhesion

- Copper surfaces



- There is a correlation between the amount of material adhered to the indenter in the MD and FEM simulations.

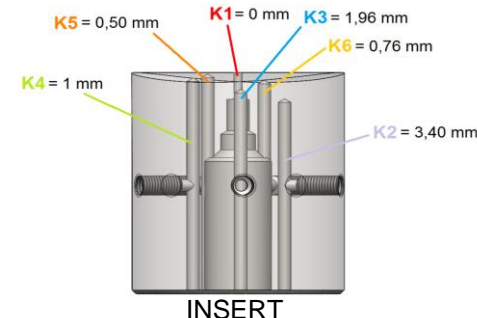
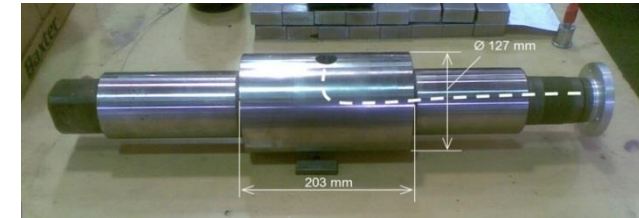
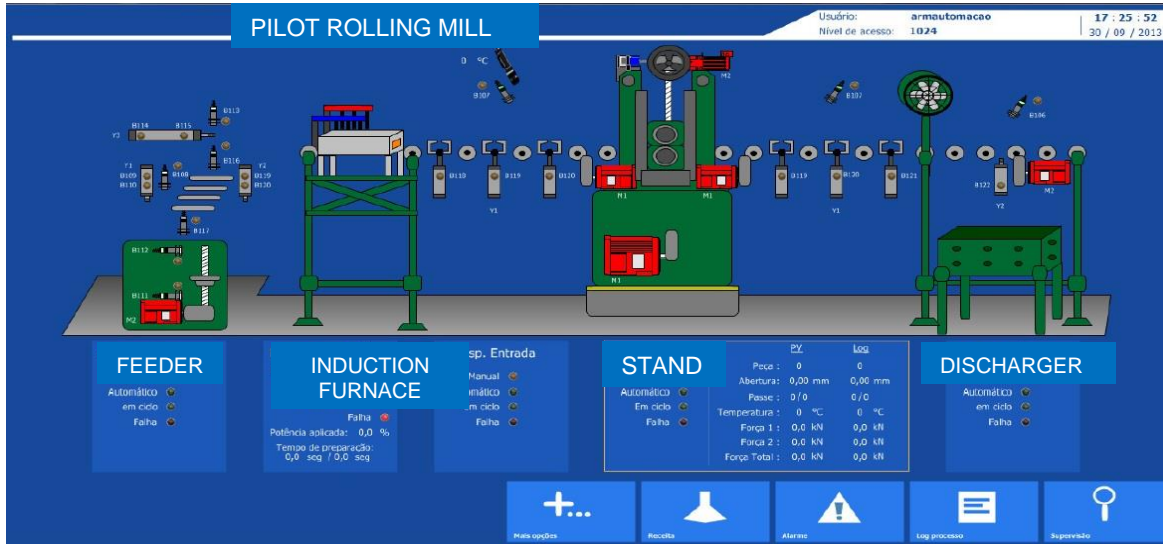
- The tendency of higher material transfer under conditions of higher penetration of the indenter continues in MD simulations



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Pilot operation - Rolling



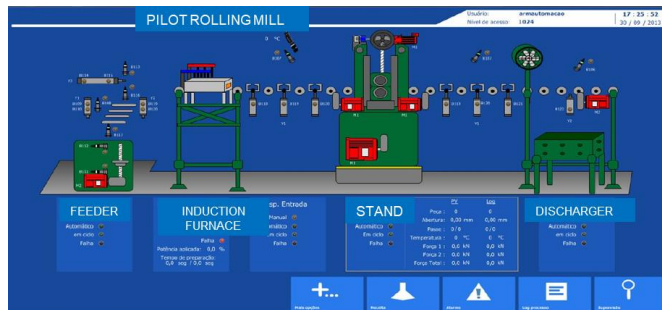
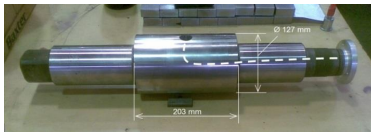
Thermocouples positioning



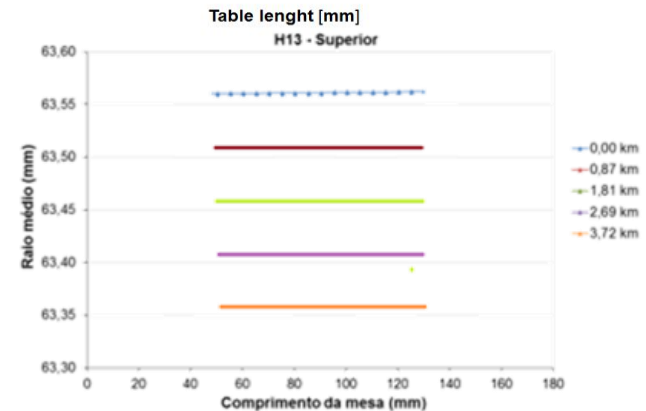
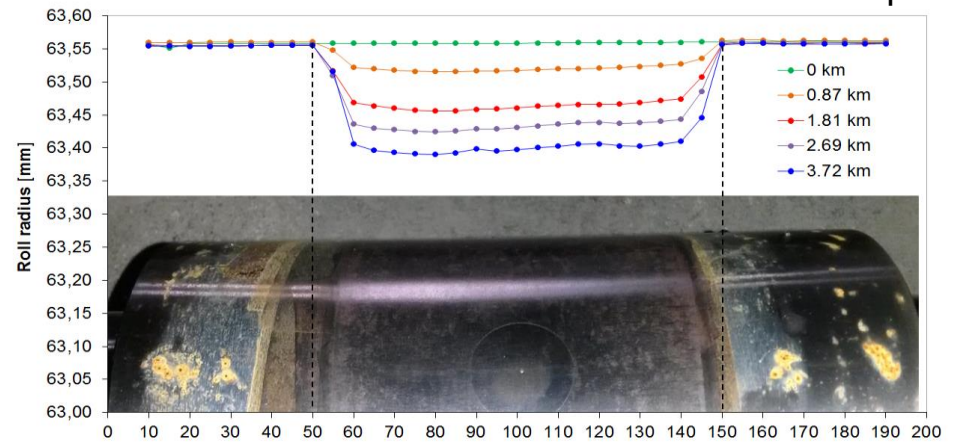
Case Study - Results

- Prediction of performance

Simulation of rolling in pilot scale mill



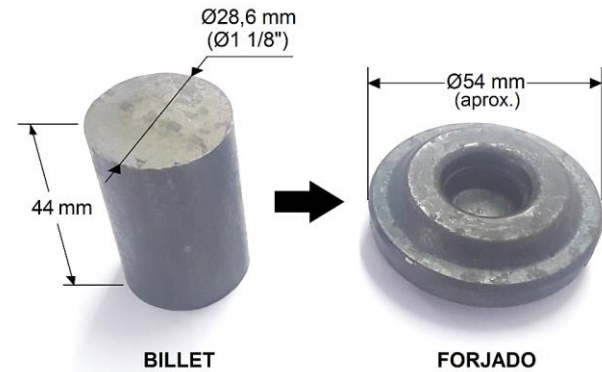
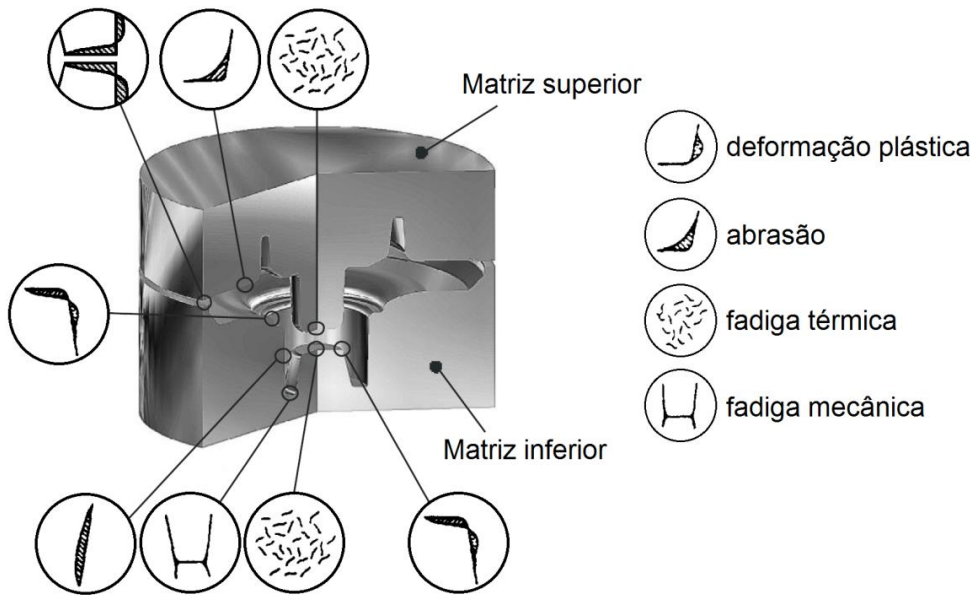
Experimental



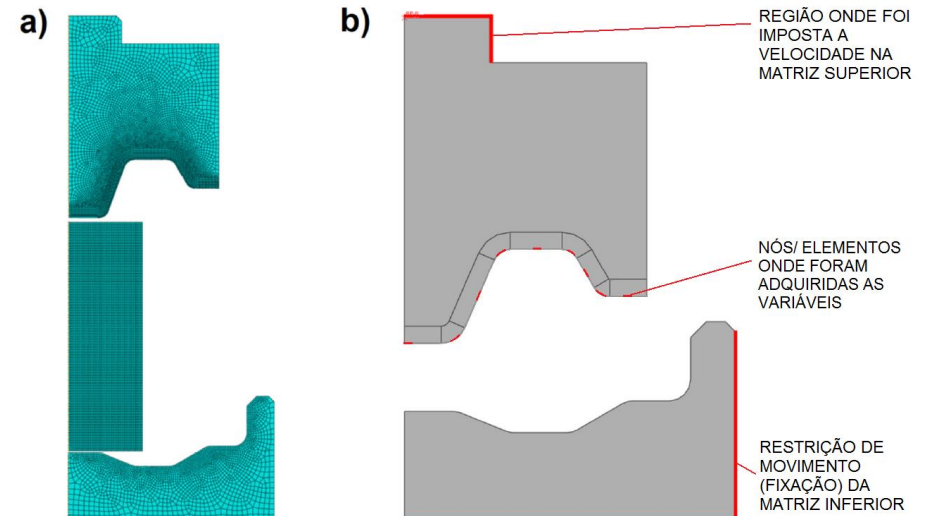
Numerical



Pilot operation - Forging

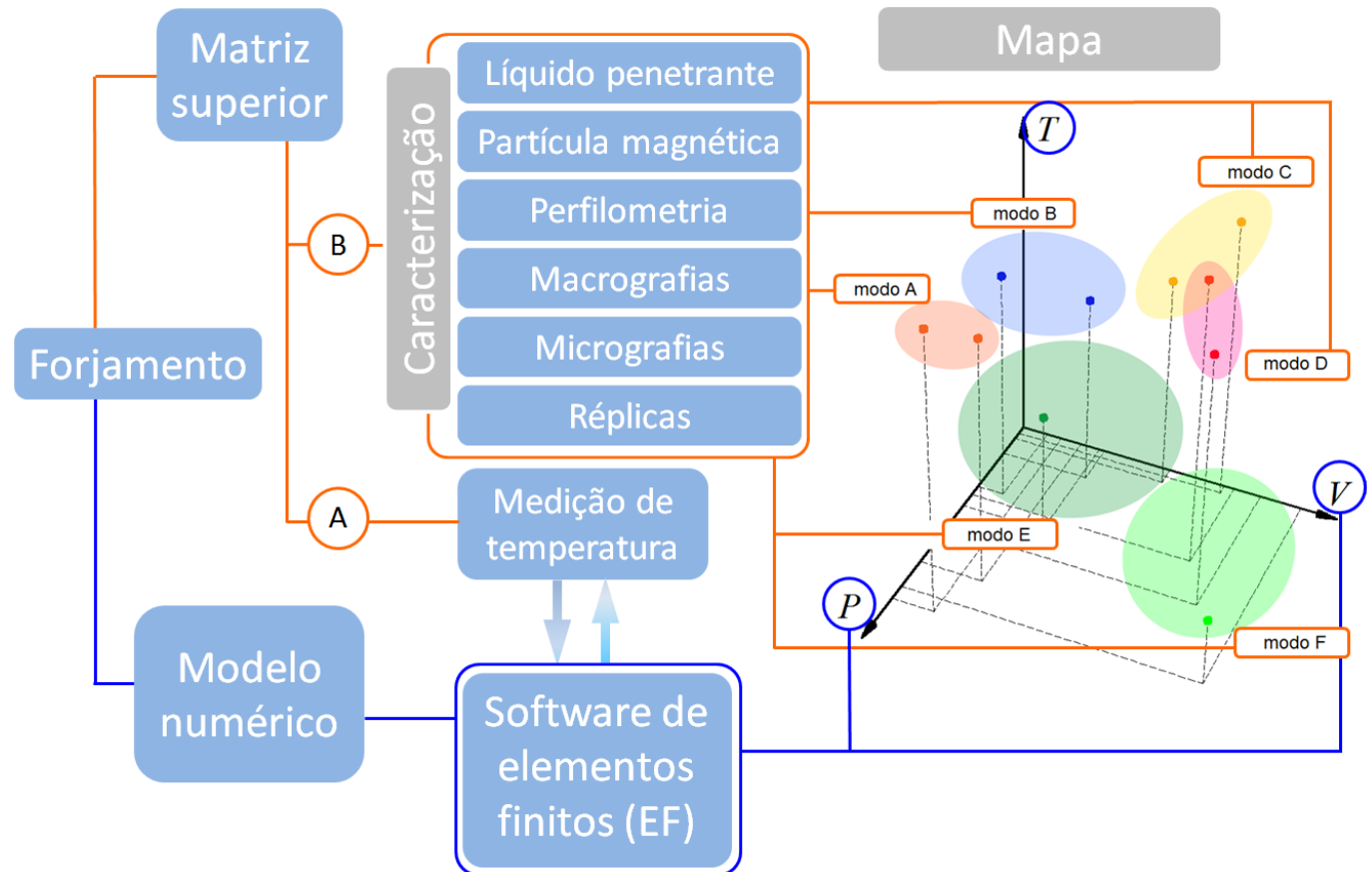


Obs.: sem escala



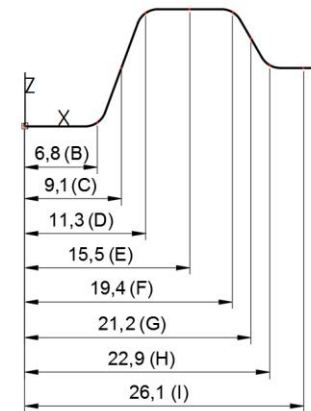
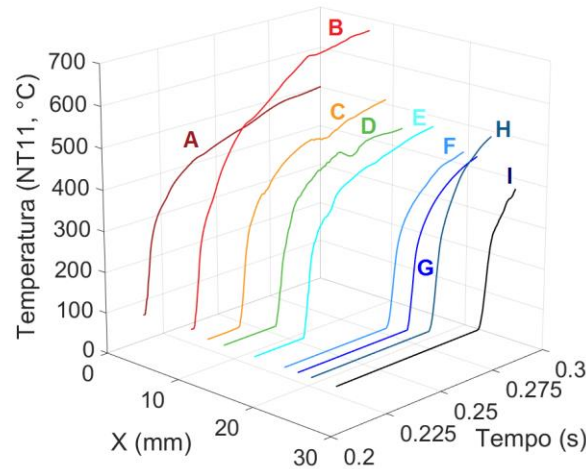
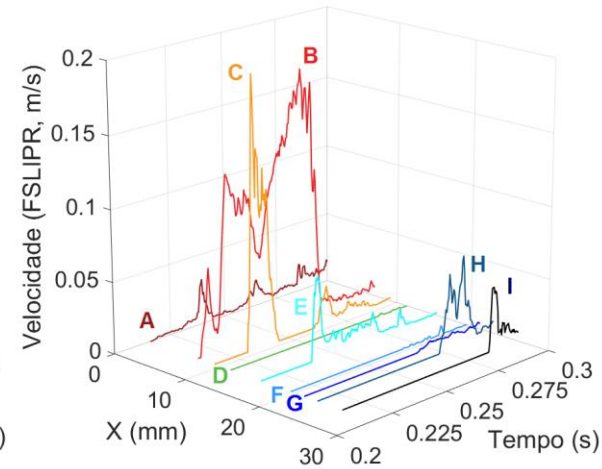
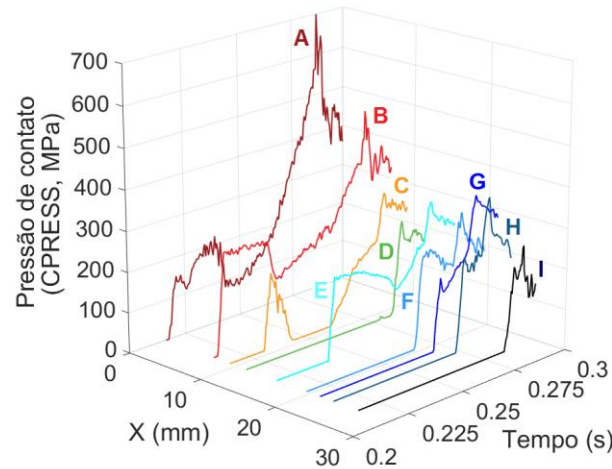


Pilot operation - Forging



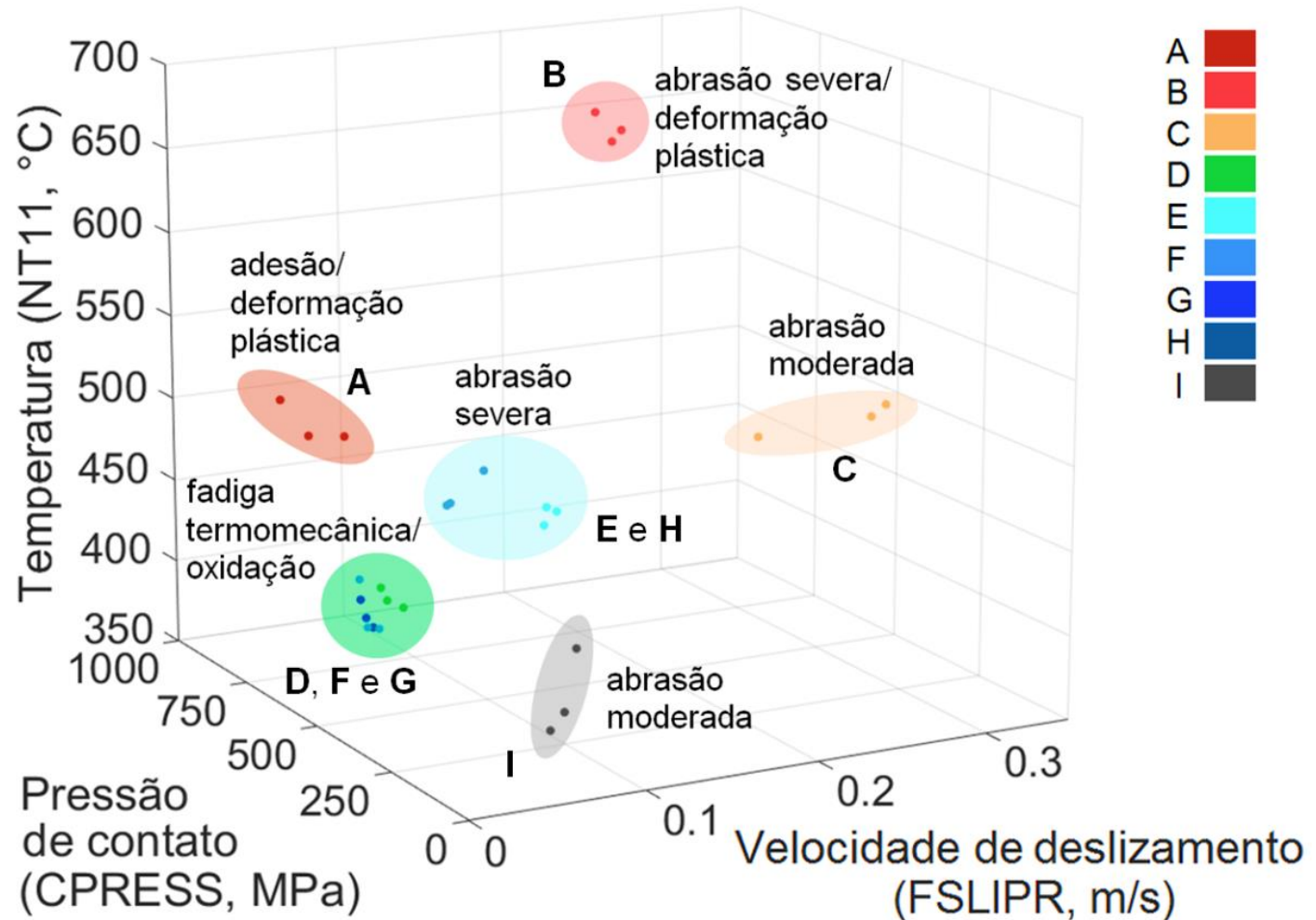


Pilot operation - Forging





Pilot operation - Forging





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- Tribology
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- Case study – Materials for rolling mill rolls
- **Case studies – Processes**
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Production of Bulk Components

- Example – By Powder Metallurgy
- Use of **solid lubricants**
 - To improve **performance**
 - To **facilitate machining**



<https://www.epma.com/spotlight-on-pm/sintered-camshaft-gear>

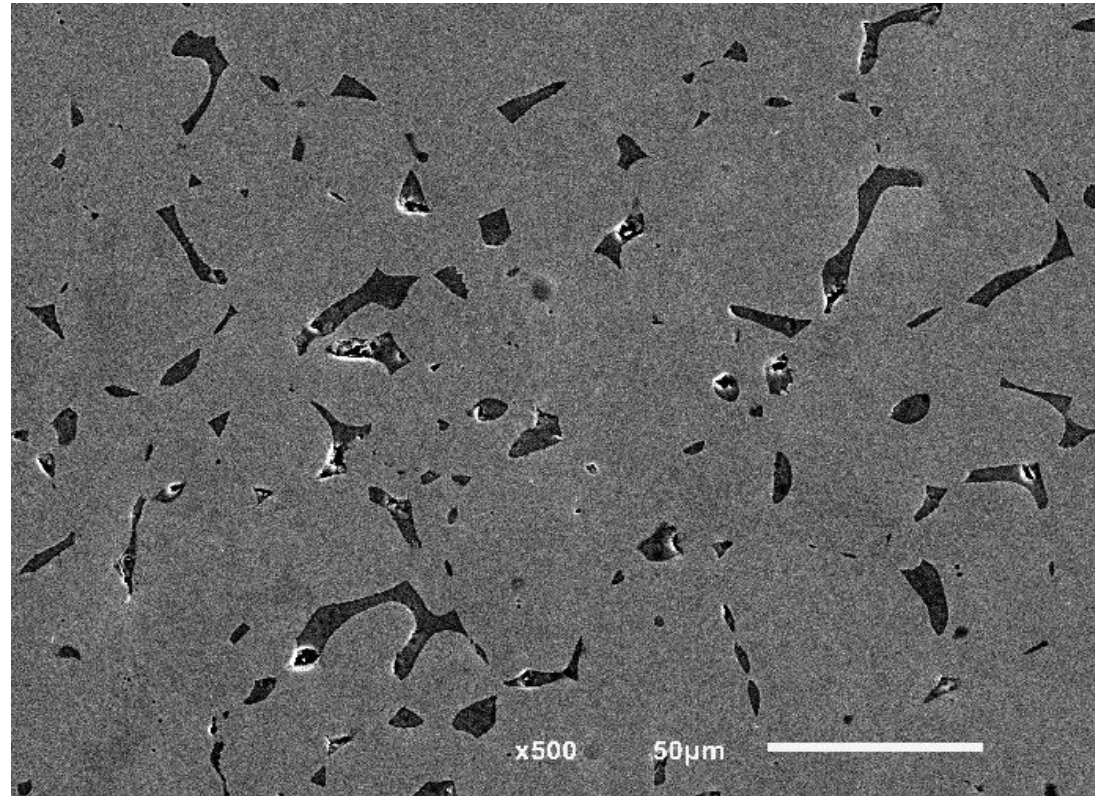


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Production of Bulk Components

- Materials produced by Spark-Plasma Sintering (SPS)



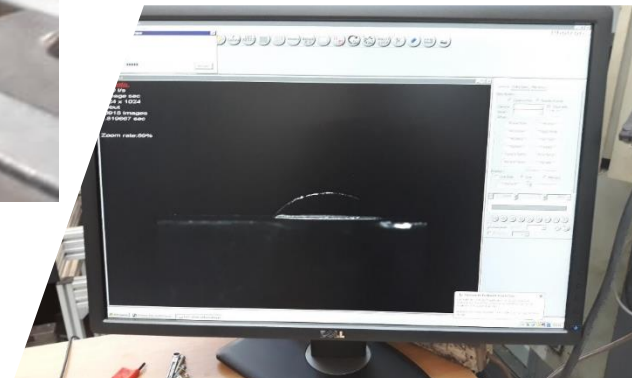
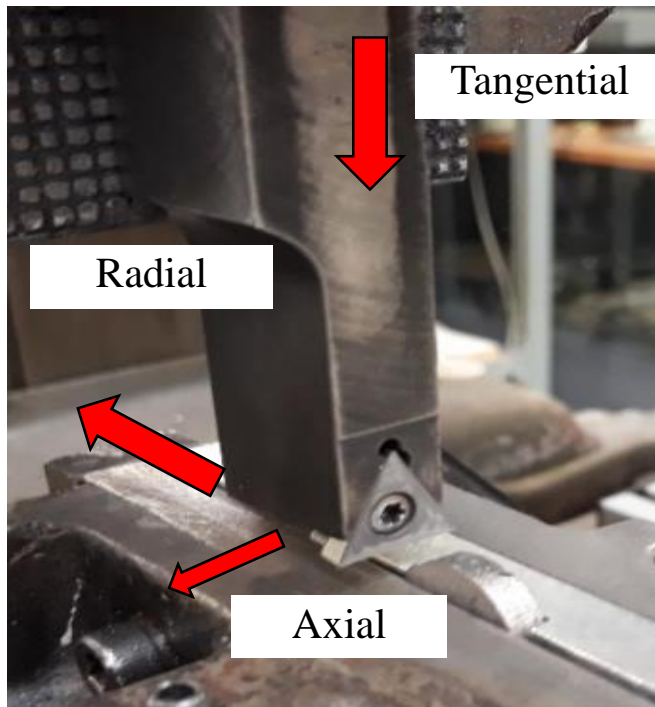


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Production of Bulk Components

- Comparison of steel x composites



Operation:

Kistler cutting platform

Material:

- Astaloy 85Mo (Höganäs powder)
- Astaloy 85 Mo + MoS₂ – 2 wt.%
- Astaloy 85 Mo + MoS₂ – 4 wt%

Conditions of cutting:

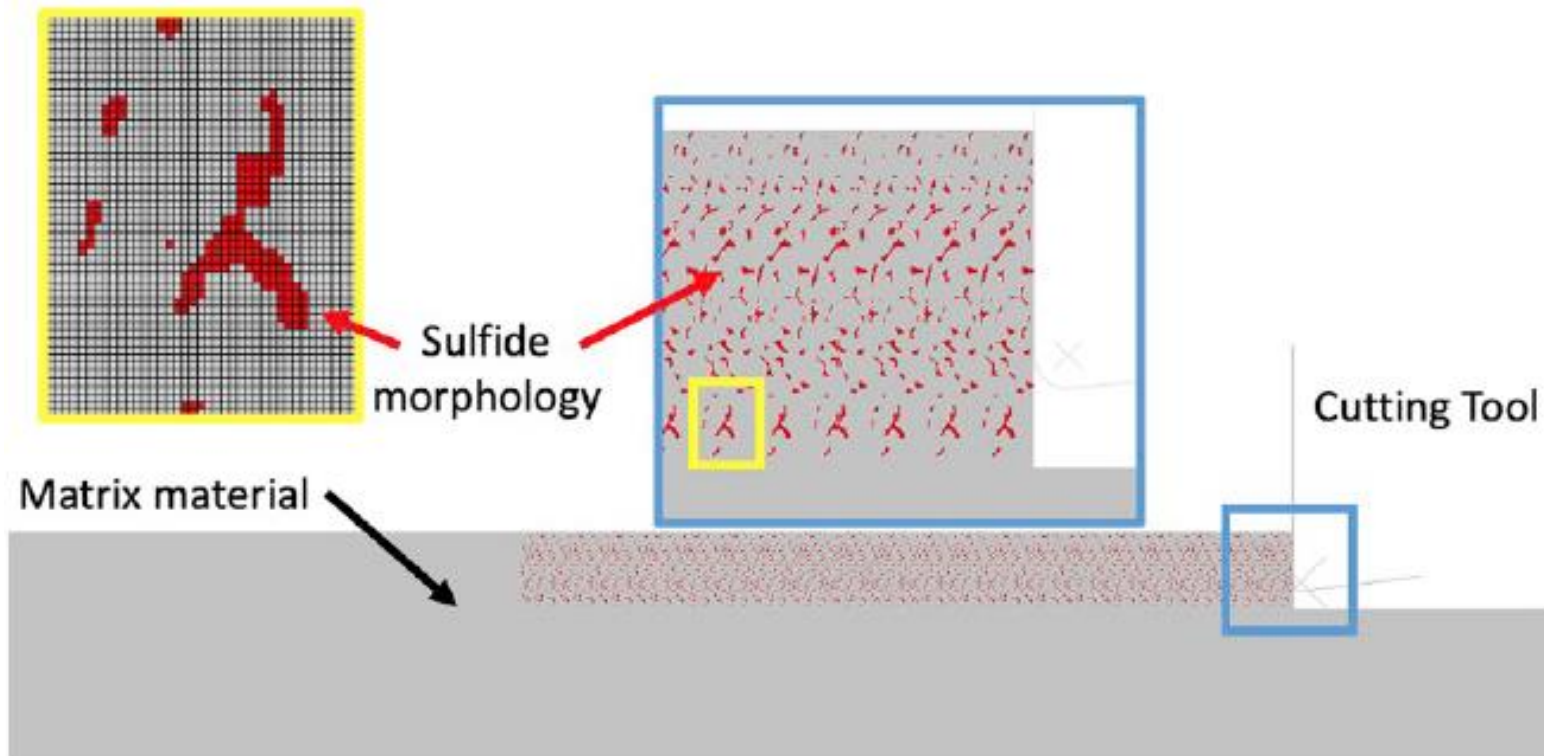
Speed: 32 m/min
50 m/min = 833 mm/s (**nominal**)
Depth: 0.15 mm and 0.2 mm
Length of cut: 14 mm aprox.

Data acquisition: 6000 fps



Production of Bulk Components

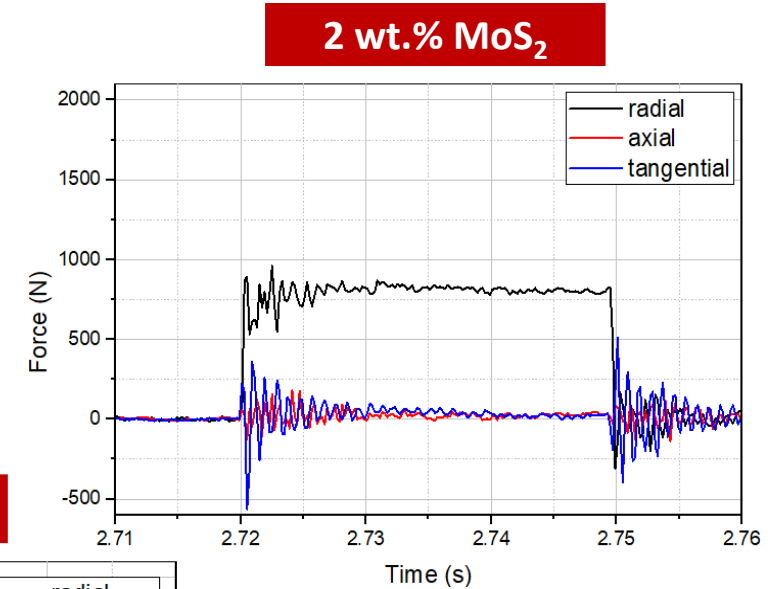
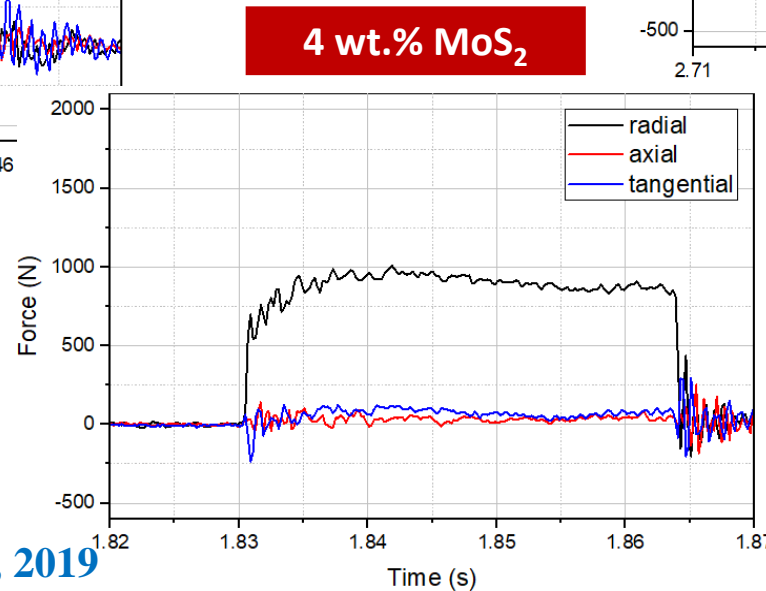
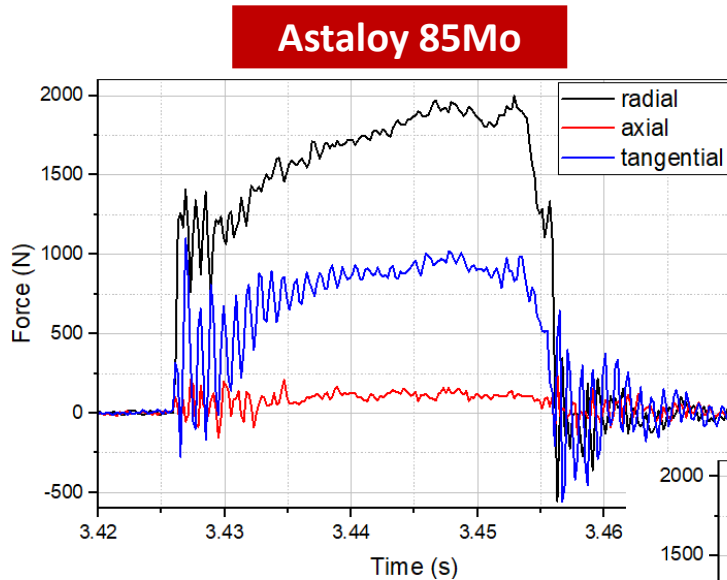
- Numerical analyses





Production of Bulk Components

- Cutting forces

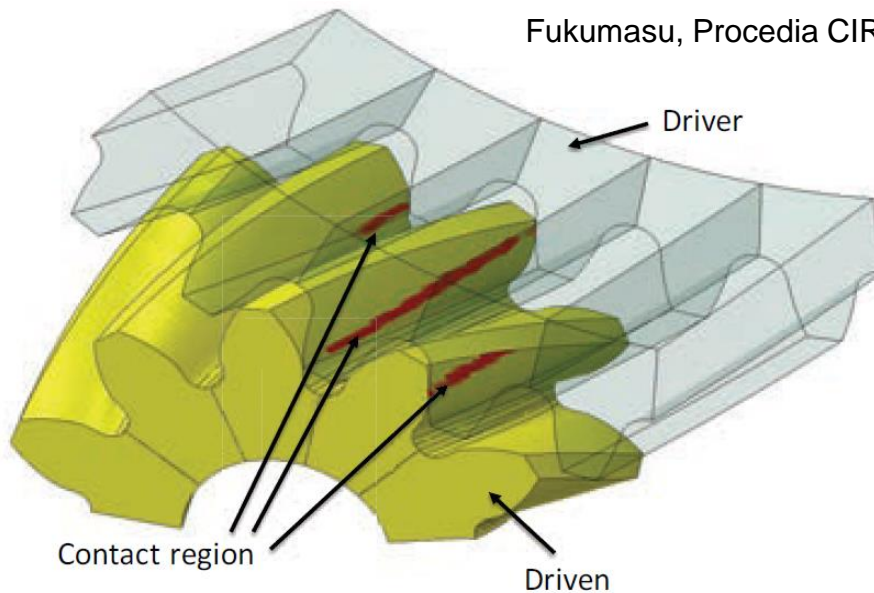




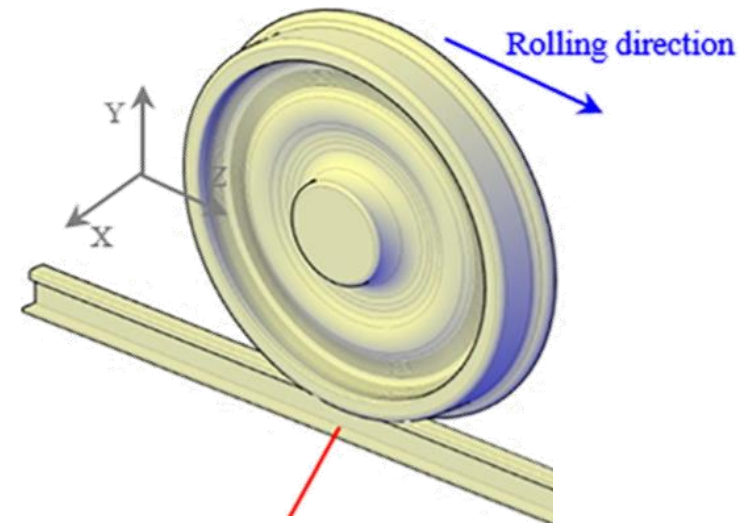
Other Applications

- Gears: Lubricated contact

Fukumasu, Procedia CIRP 2016



- Wheel – rail: Rolling contact fatigue





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Conclusions

- Modeling as an additional tool – Does not eliminate the need of experimental analysis
 - Modeling to predict behavior
 - For Materials Selection
 - For digital reproduction of given application
- Modeling may require
 - Analysis of individual phenomena at different scales
 - Ability to integrate phenomena and scales



Acknowledgements

- Brazilian Development Bank – BNDES
- IPT
- Gerdau Summit
- To all LFS team

