Coupling of CFD and a Material model for the assessment of incubation time and erosion rate

Kavitationsworkshop Drübeck

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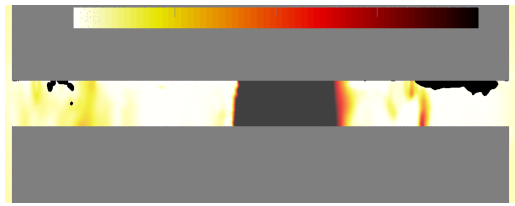
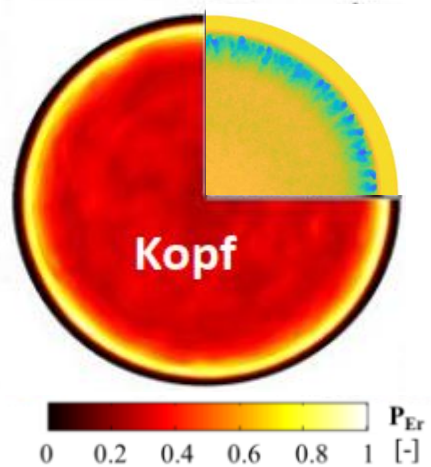
State of the art

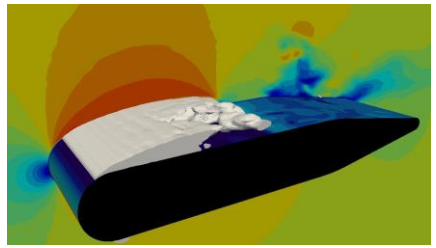
- CFD Erosion indicators: Exceeding of **pressure** p and **condensation rate** $\partial\alpha/\partial t$ threshold
- Erosion probability P_{Er} by statistical evaluation
- Assessment of **erosion sensitive wall zones** only, no material information

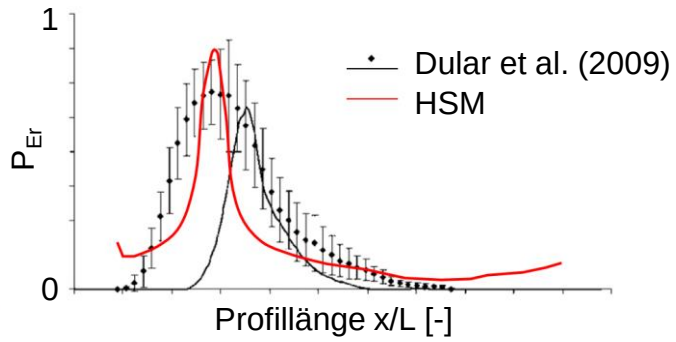
Sonotrode[1)]



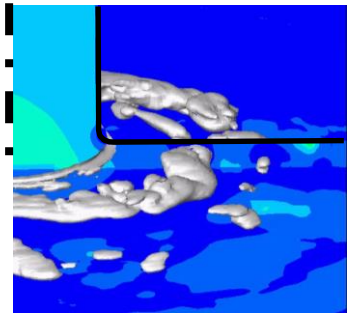


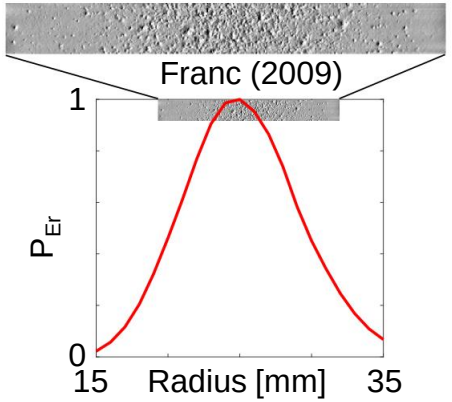
CLE hydrofoil[2)]



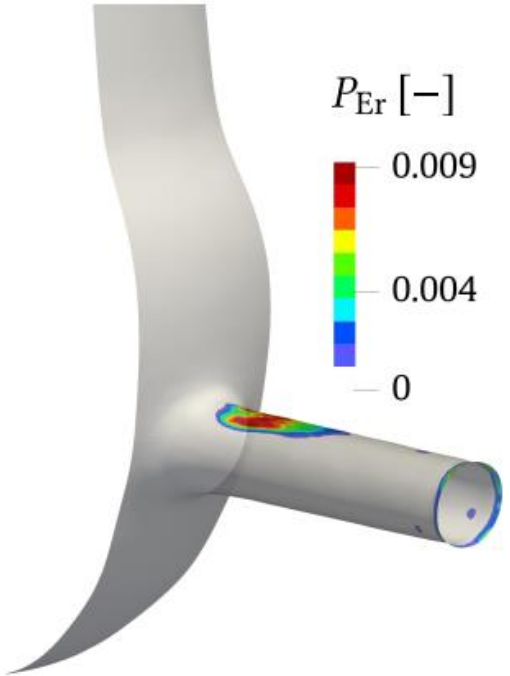


Grenoble case[3)]



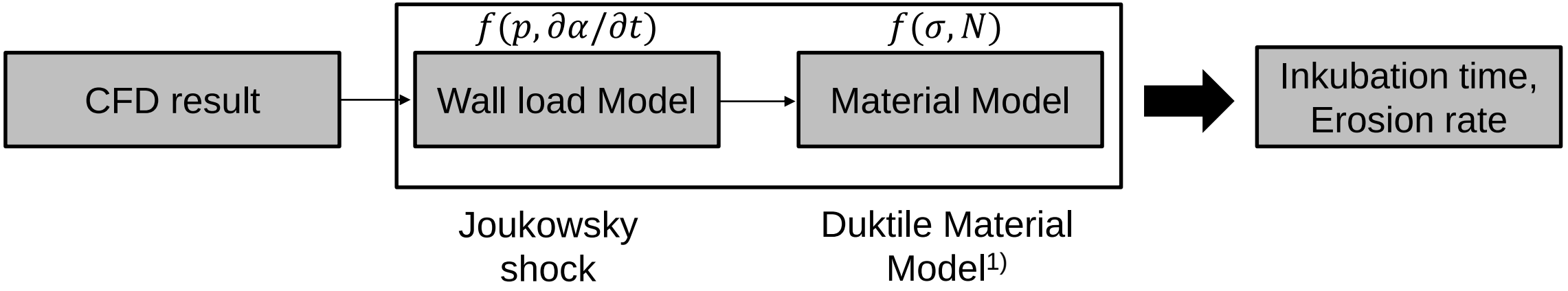


Fuel injector[4)]



1) Mottyll & Skoda (2016), Ultrasonics Sonochemistry 31, 570–589
2) Blume & Skoda (2019), Wear 428-429, 457-469
3) Mottyll (2018), PhD Thesis
4) Falsafi et al. (2021), Int. J. of Engine Research

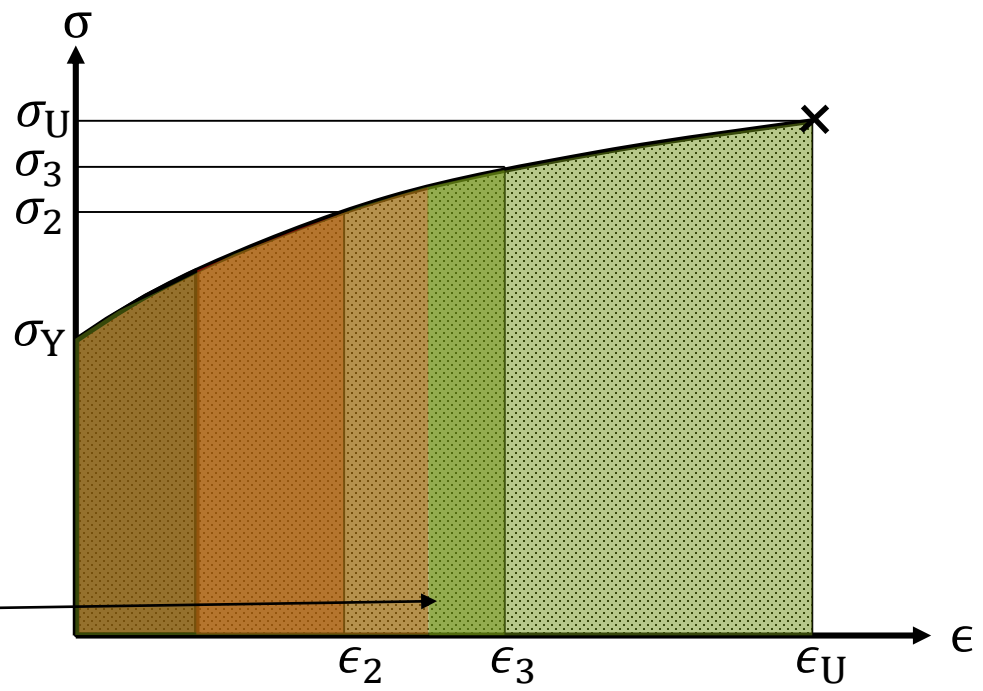
Coupling of CFD with material model



Material model[1)]

- Accumulation of plastic deformation energy
- Ludwig-type hardening $\sigma(\epsilon) = \sigma_Y + K\,\epsilon^n$
- Incubation time is reached:

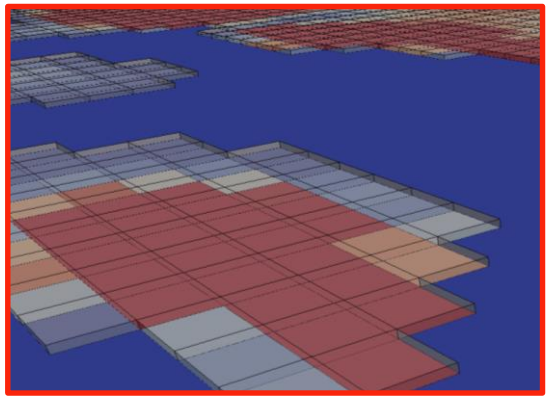
$$W(\sigma_U) \leq \sum W(\sigma_i) = W(\sigma_1) + W(\sigma_2) + W(\sigma_3)$$



[1)] J.-P. Franc (2009), J. Fluids Eng., Vol. 131, 21303.

Wall load model

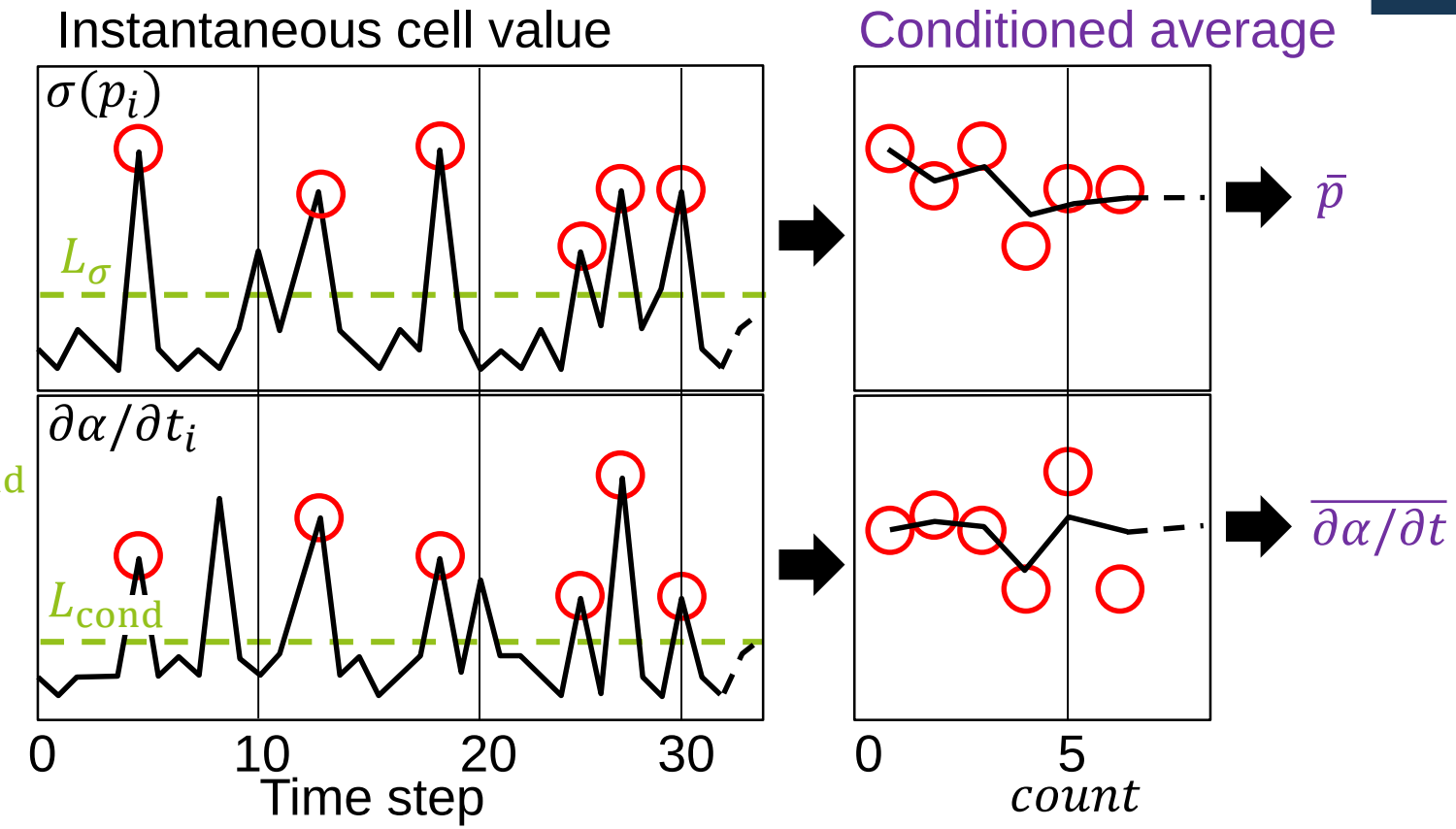
For each wall cell face i



$\sigma(p_i) > L_\sigma$

&

$\partial\alpha/\partial t_i > L_{\mathrm{cond}}$



➢ Wall load

$$c_{\mathrm{jet,Plesset}} = 8.97 \cdot \gamma^2 \sqrt{|\bar{p} - p_{\mathrm{sat}}|/\rho_l}$$

$$\bar{\sigma} = f(\bar{p}) = \rho_{\mathrm{l}} c_{\mathrm{s}} c_{\mathrm{jet}}$$

➢ Load rate

$$N = -n_0 \cdot V \cdot \overline{\partial\alpha/\partial t}/A \cdot P_{\mathrm{Er}} \cdot F_{\mathrm{cond}} \qquad P_{\mathrm{Er}} = \frac{count * \Delta t}{t_{\mathrm{Sim}}}$$

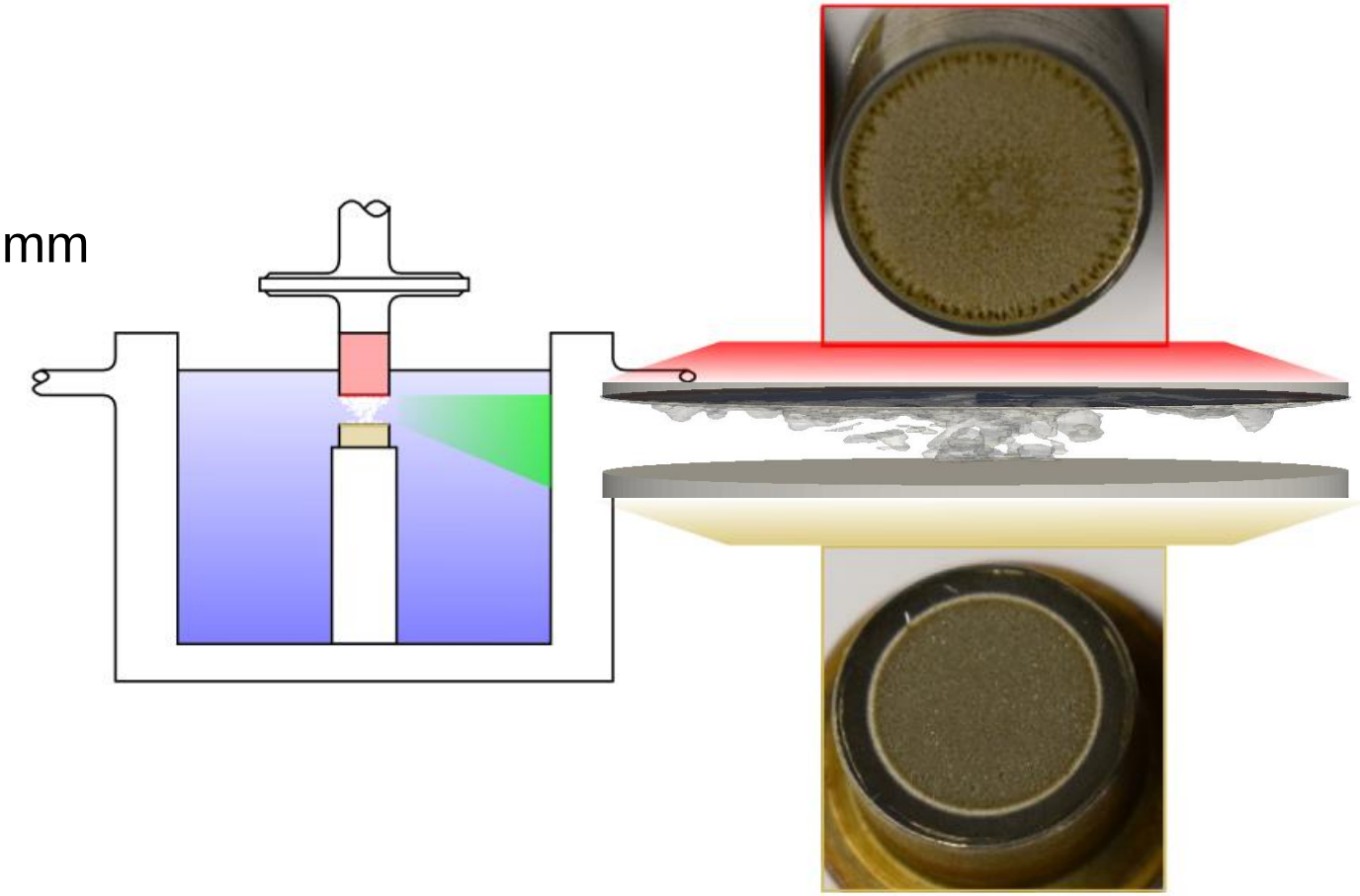
➢ Material model[1]: $\mathbf{t_{inc}}$ & **MDPR** = $f(\bar{\sigma}, N)$

[1] J.-P. Franc (2009), J. Fluids Eng., Vol. 131, 21303.

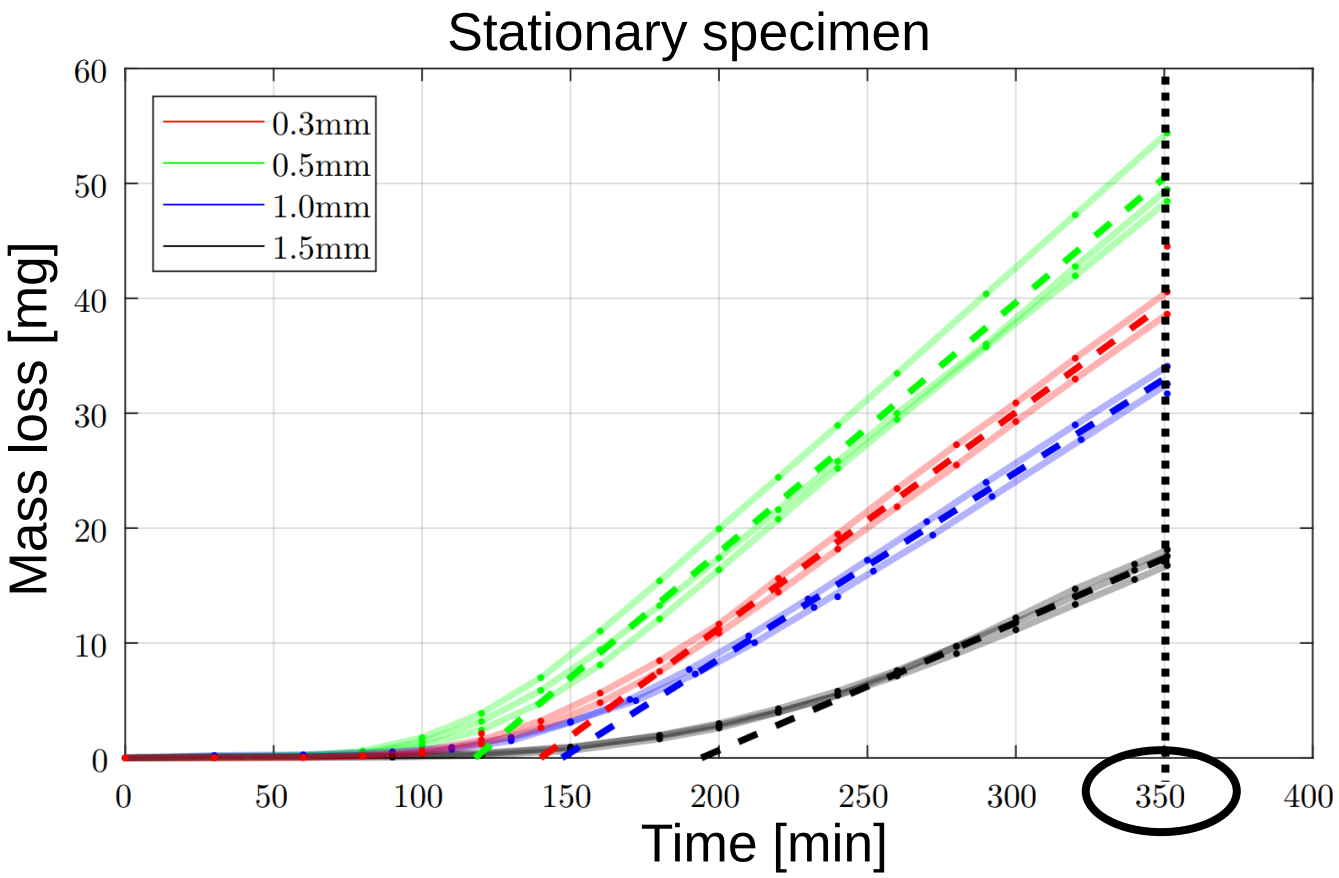
Test case – Sonotrode

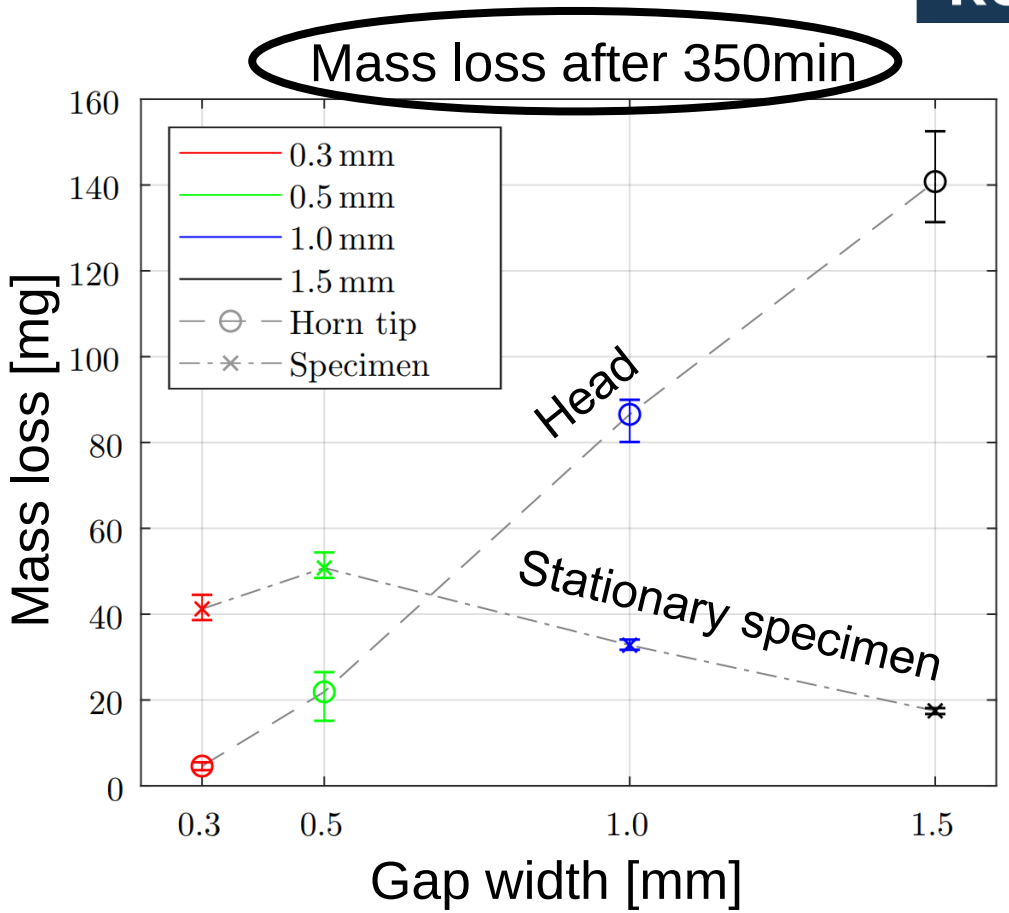
ASTM G32

- f ~ 20kHz, A_{pp} ~ 40µm
- Gap width variation 0.3; 0.5; 1.0; 1.5mm



Material test [1)]



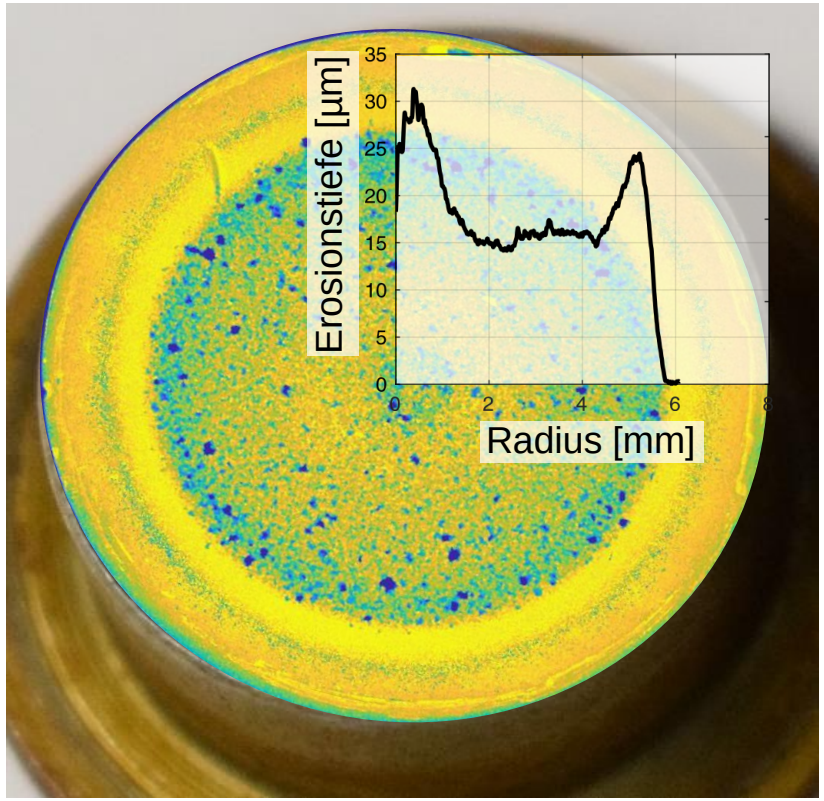


Gap width [mm]	**0.3**	**0.5**	**1.0**	**1.5**
Incubation time [min]	140	118	147	194
Erosion rate [mg/h]	11.3	13.0	9.8	6.7

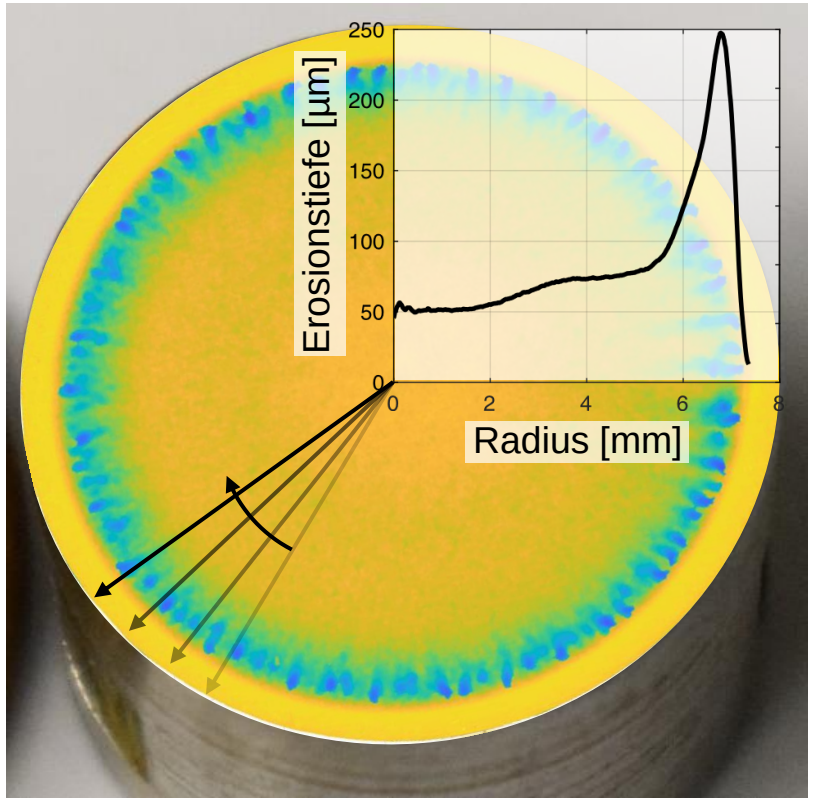
[1)] Schreiner, Hanke, Skoda (2021), Wear 484-485, 203989

Measurement of surface topography[1)]

Stationary specimen

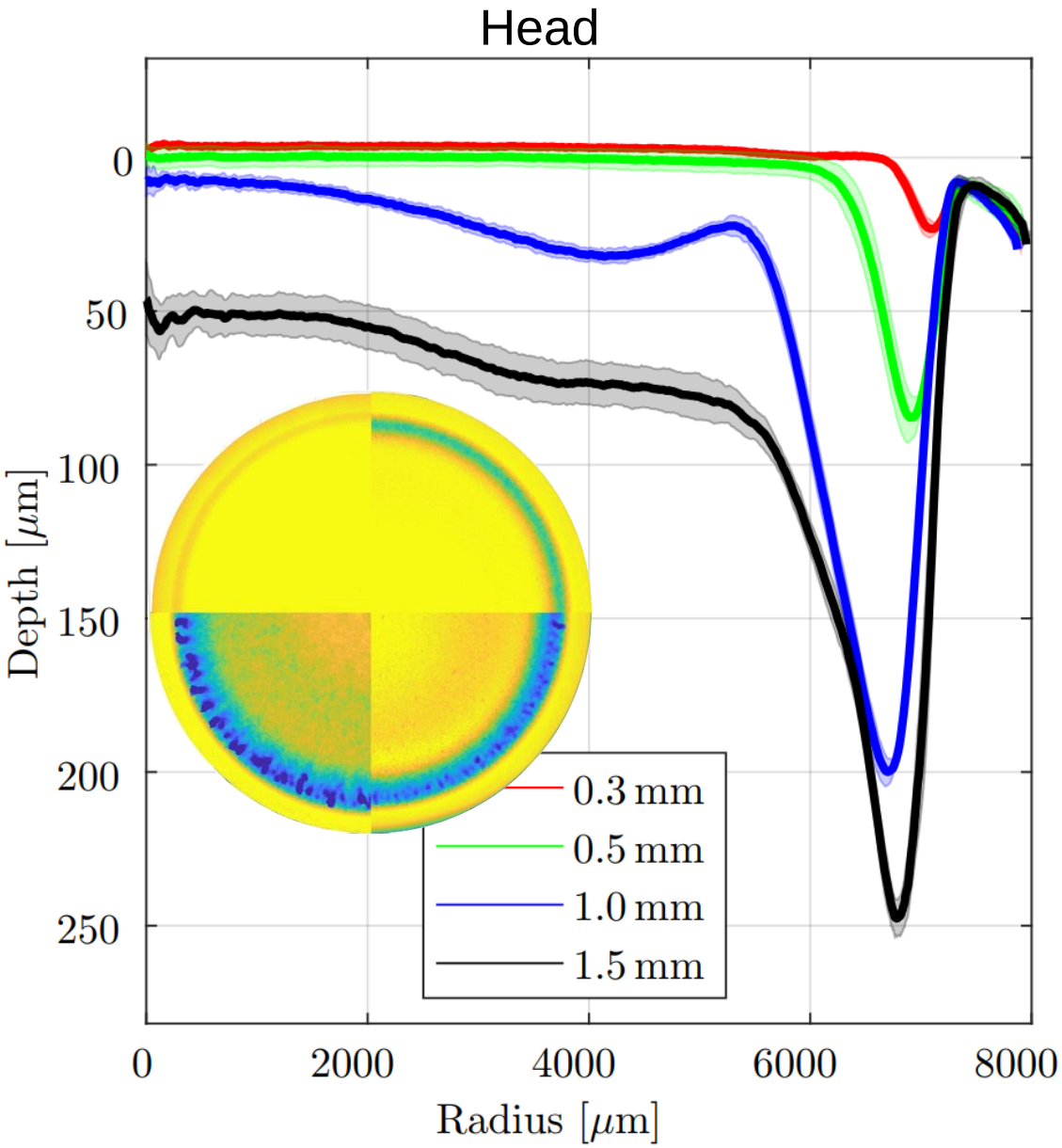


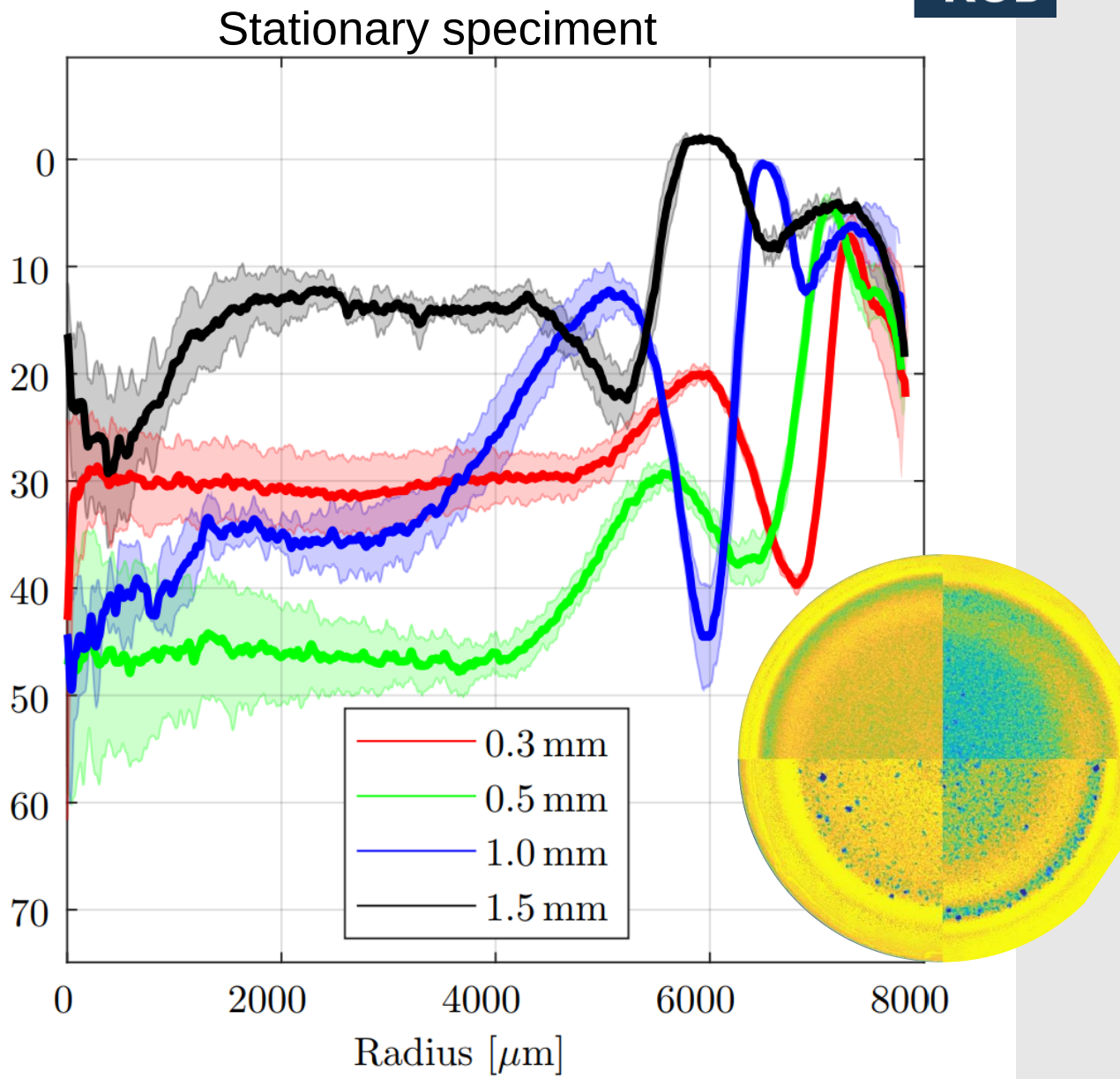
Head



[1)] Schreiner, Hanke, Skoda (2021), Wear 484-485, 203989

Measurement of surface topography[1)]





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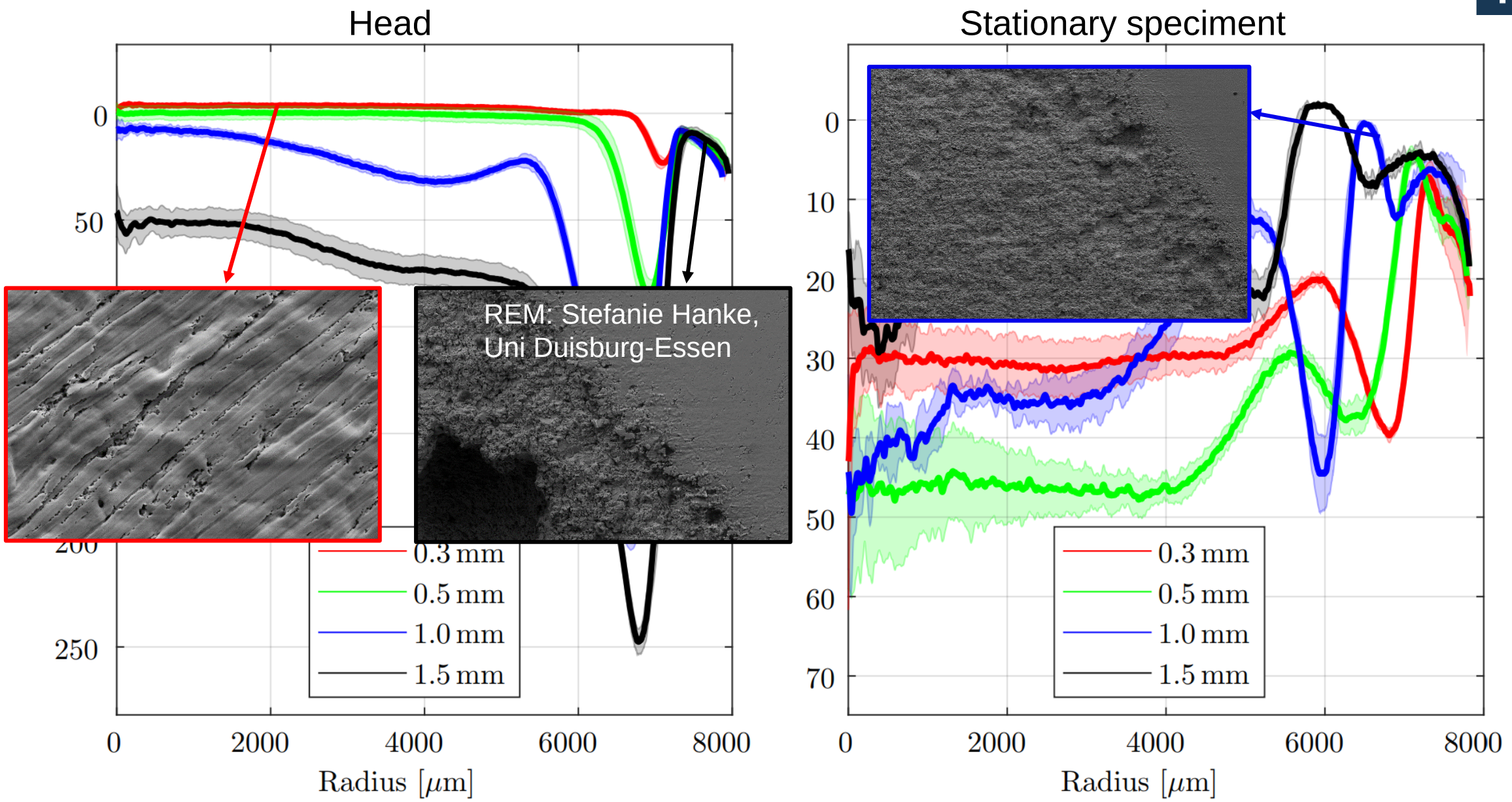
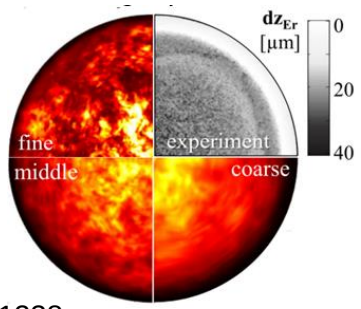


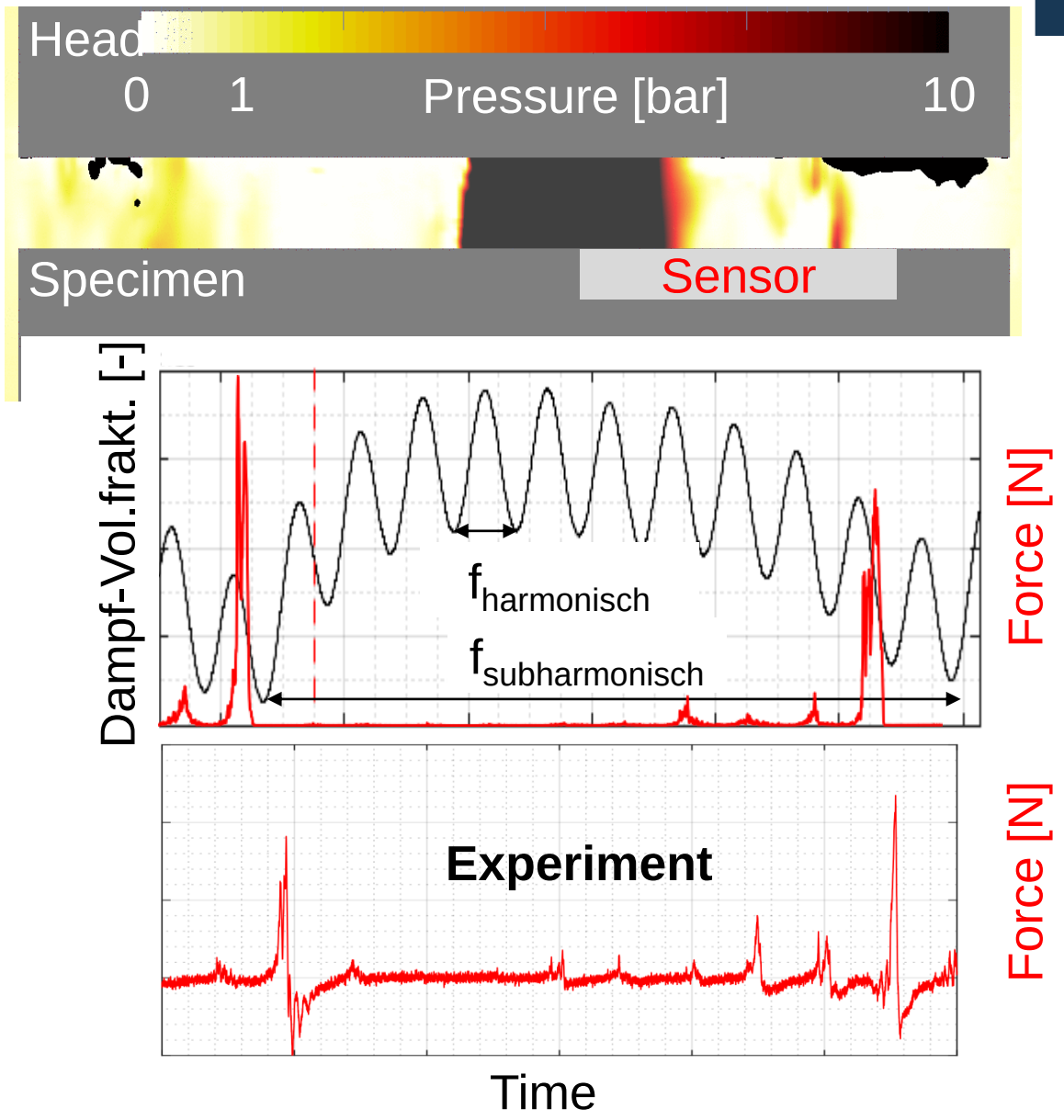
[1)] Schreiner, Hanke, Skoda (2021), Wear 484-485, 203989

CFD of Sonotrode

hydRUBFoam

- Compressible, time-explicit density-based non-viscous (Euler) solver
- Shock wave resolution by Riemann solver[1)]
- Barotropic EOS
- Homogeneous mixture approach
- Harmonic and subharmonic dynamics of Sonotrode are well captured [2)] (see rhs)
- Erosion sensitive wall zone capturing [3)]





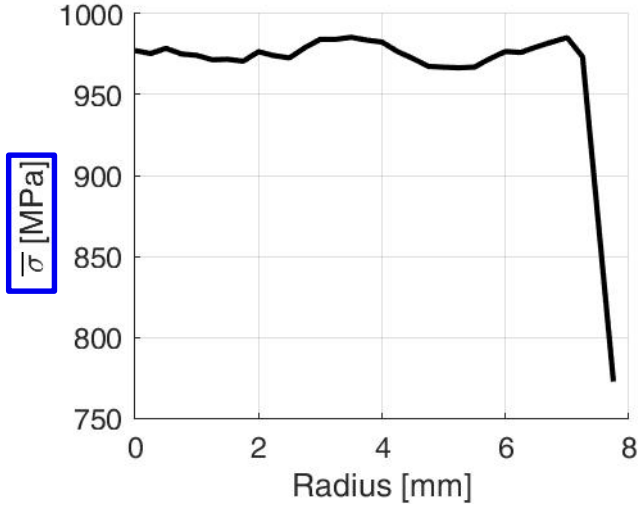
[1)] Schmidt et al. (2008), 46th AIAA, paper 2008-1238

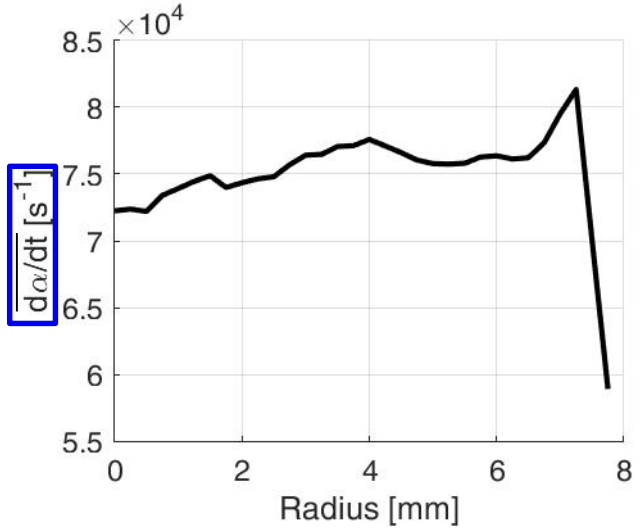
[2)] Schreiner et al. (2019), Ultrasonics Sonochemistry 67, 105091

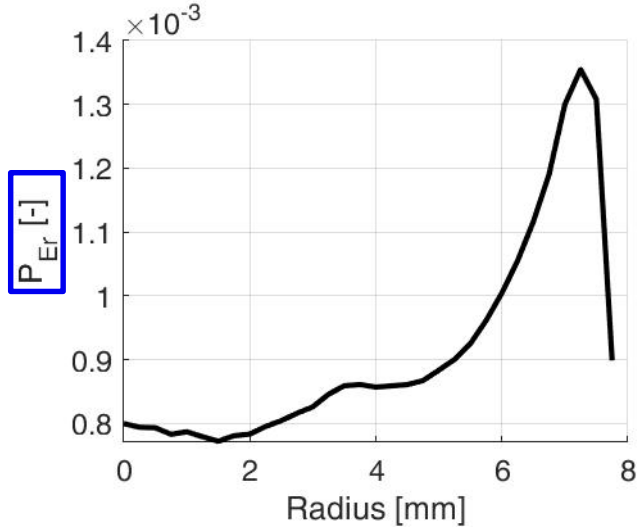
[3)] Mottyll & Skoda (2016), Ultrasonics Sonochemistry 31, 570–589

Radial wall load profile on head for s = 1.5 mm

Wall load model







➢ Wall load

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$$\boldsymbol{\overline{\sigma}} = f(\bar{p}) = \rho_l c_s c_{\text{jet}}$$

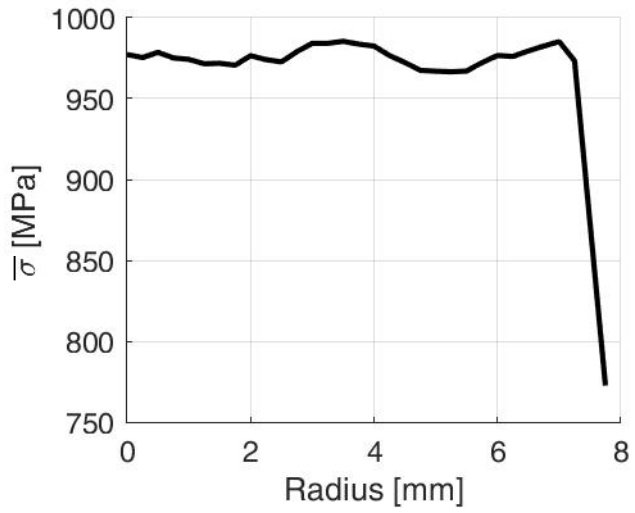
➢ Load rate

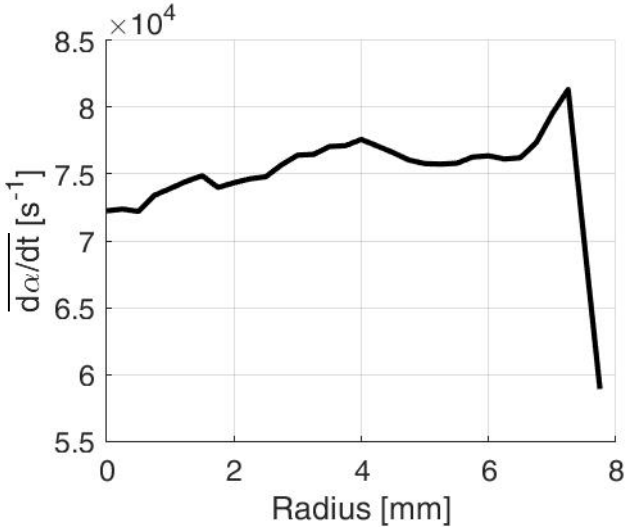
$$N = -n_0 \cdot V \cdot \boldsymbol{\overline{\partial\alpha/\partial t}}/A \cdot P_{\text{Er}} \cdot F_{\text{cond}} \qquad \boldsymbol{P_{\text{Er}}} = \frac{count * \Delta t}{t_{\text{Sim}}}$$

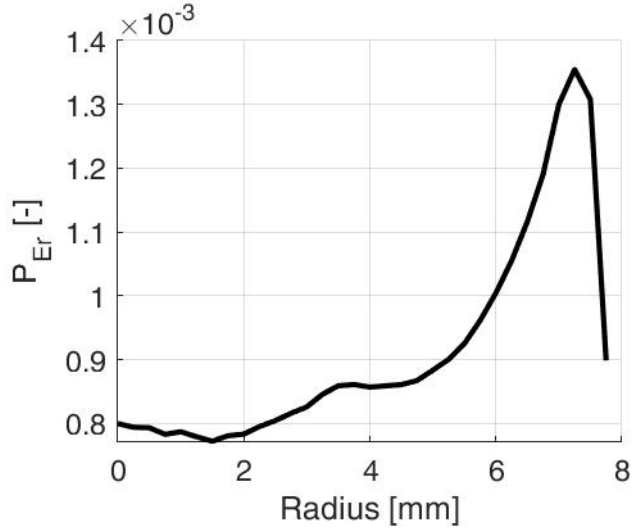
Radial wall load profile on head for *s* = 1.5 mm

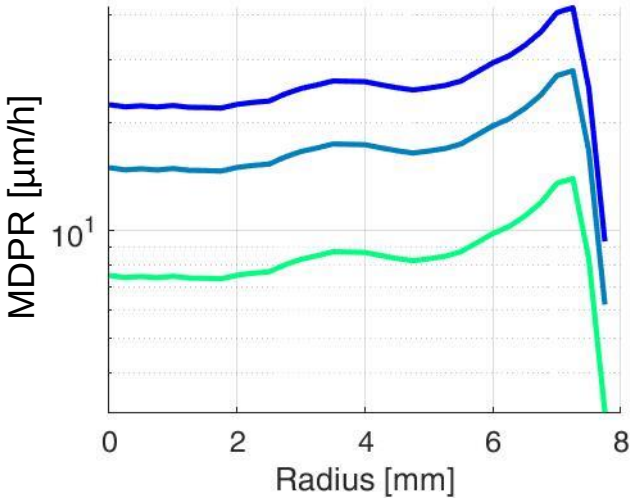
Wall load model

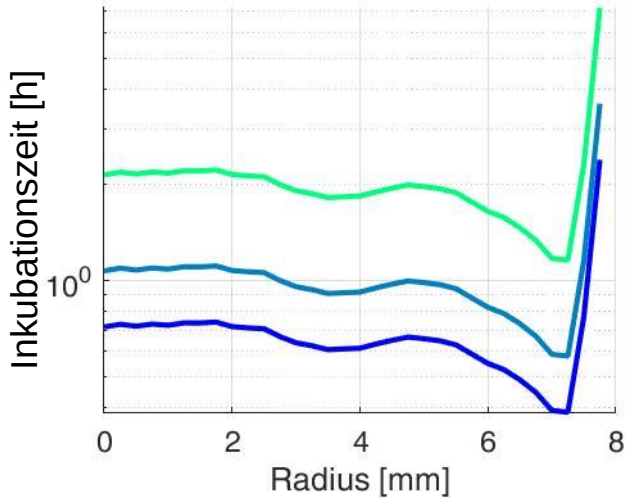
Material model

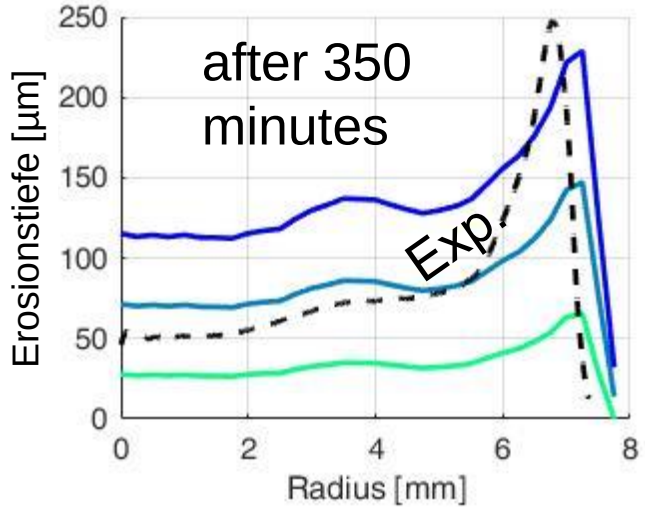










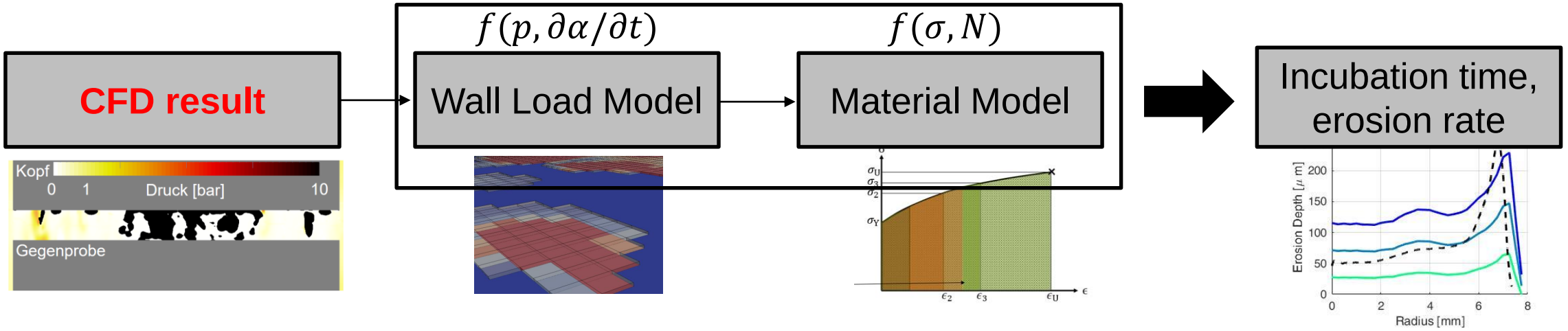


$F_{cond} = 1$

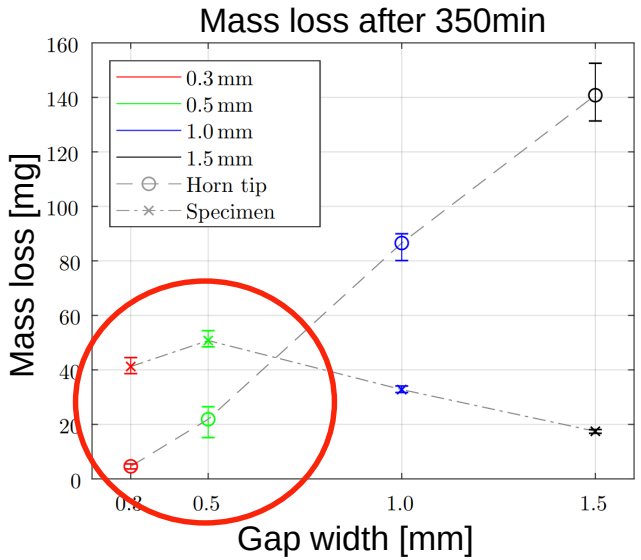
$F_{cond} = 2$

$F_{cond} = 3$

Conclusions



- Valuable tool in terms of an ***extended post-processing***
  - Publication in *Wear* is under preparation
- However: calibration necessary, case dependent
- Sonotrode simulation: CFD method has still limitations and is thus restricted to large gap width:
  - Thermal effects
  - Air content



Thank you for your attention!

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