Technical University
of **Leoben**

Science 4 Technology – Poster Exhibition 2026

Department: Physics, Mechanics and Electrical Engineering

Chair: Mechanics

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Poster Exhibition 2026

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On the influence of combined hardening on the acoustoelastic effect

Problem formulation

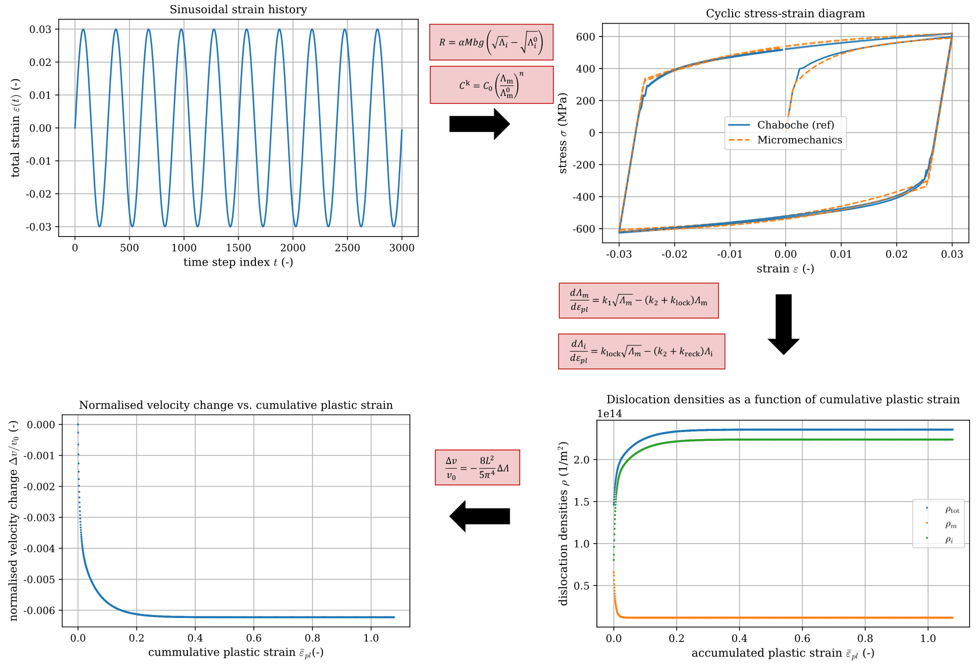
The propagation velocity of ultrasonic waves in solids depends on the present stress state, a phenomenon known as the acoustoelastic effect. However, the influence of plastic deformation on wave propagation velocity has not yet been fully characterized.

Methodology

The macroscopic material behavior is described using a micromechanical dislocation density–based model. Isotropic hardening is controlled by the immobile dislocation density, while kinematic hardening is controlled by the mobile dislocation density. The evolution of both dislocation densities is described by two coupled differential equations. Subsequently, numerical methods are used to simulate the cyclic stress–strain behavior, from which the evolution of the dislocation densities is determined. The resulting dislocation density evolution is then used to evaluate the change in wave velocity as a function of cumulative plastic strain.

Results

The results demonstrate that the micromechanical model accurately reproduces the cyclic stress–strain behavior. In addition, the dislocation densities exhibit saturation beyond a certain cumulative plastic strain. The propagation velocity of the ultrasonic wave initially decreases significantly and subsequently approaches a saturation regime.



$$R = \alpha M b g \left(\sqrt{\Lambda_i} - \sqrt{\Lambda_i^0} \right)$$

$$C^{\mathrm{k}} = C_0 \left(\frac{\Lambda_{\mathrm{m}}}{\Lambda_{\mathrm{m}}^0} \right)^n$$

$$\frac{d\Lambda_m}{d\varepsilon_{pl}} = k_1 \sqrt{\Lambda_m} - (k_2 + k_{\mathrm{lock}})\Lambda_{\mathrm{m}}$$

$$\frac{d\Lambda_i}{d\varepsilon_{pl}} = k_{\mathrm{lock}} \sqrt{\Lambda_m} - (k_2 + k_{\mathrm{reck}})\Lambda_{\mathrm{i}}$$

$$\frac{\Delta v}{v_0} = -\frac{8L^2}{5\pi^4}\Delta\Lambda$$

Fig. 1 Results of the numerical results

Conclusion and Outlook

The model successfully captures the cyclic stress–strain behavior and the evolution of dislocation densities under plastic deformation. The results show that ultrasonic wave velocity decreases significantly at early stages of plastic deformation and then approaches a saturation regime as dislocation densities stabilize.

These findings improve the physical understanding of how plastic deformation influences the acoustoelastic effect and support the development of more reliable ultrasonic-based material diagnostics.

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On the thermo-acoustoelastic effect of ultrasonic waves in solid materials

Problem formulation

The acoustoelastic effect describes the dependence of ultrasonic wave propagation velocity on the existing stress and strain state. However, the temperature-induced velocity change is approximately 10–20 times larger than the stress-induced change. Therefore, accurate residual stress measurements require accounting for the temperature dependence of the acoustoelastic effect.

Methodology

Temperature-dependent acoustoelastic parameters L_{ij} are derived within the framework of nonlinear elasticity theory using a small-on-large formulation. Furthermore, strain-dependent temperature parameters β_{ij} are also derived.

$$L_{ij}(T)=\frac{1}{2}\left(\frac{1}{B^0_{ij}(T)}\frac{\partial B_{ij}}{\partial E_{11}}-\frac{1}{\rho^0(T)}\frac{\partial \rho}{\partial E_{11}}\right)$$

$$\beta_{ij}(E_{11})=\frac{1}{2}\left(\frac{1}{B_{ij}(E_{ij})}\frac{\partial B_{ij}}{\partial T}\Big|_{E_{11}}-\frac{1}{\rho(E_{ij})}\frac{\partial \rho}{\partial T}\Big|_{E_{11}}\right)$$

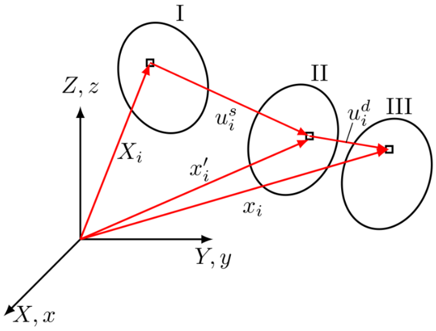

Fig. 1 Kinematics of a material point for small-on-large formulation

Results

The results in **Fig. 2** and **Fig. 3** show that the temperature dependence of the acoustoelastic effect varies among different wave modes. Furthermore, the temperature coefficient exhibits negligible dependence on stress. Experimental results (KFU Graz) confirm the analytical predictions.

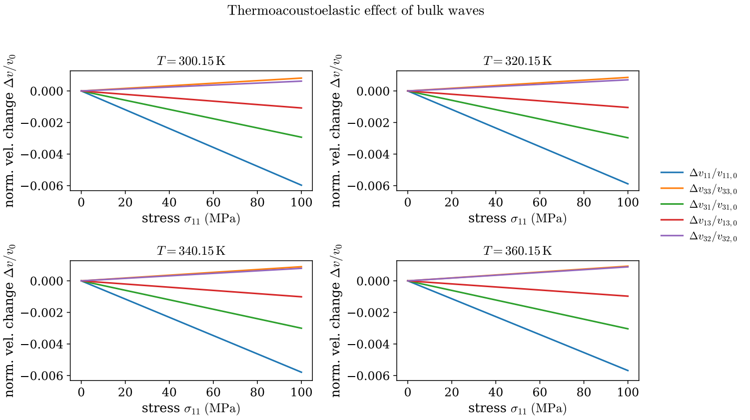

Fig. 2 Temperature-dependent acoustoelastic effect

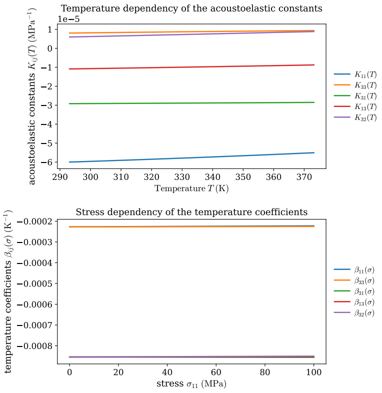

Fig. 3 Visualisation of the results in eq (1) and eq (2)

The temperature dependence of the acoustoelastic effect is small but not negligible.

The temperature coefficient exhibits negligible dependence on stress.

Conclusion and Outlook

The results show that the temperature coefficient is nearly independent of the existing strain, while the acoustoelastic parameters exhibit a slight temperature dependence. This results are highly relevant for temperature-compensated residual stress measurements.

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Mechanism based modeling of copper degradation

Microstructural thermomechanical fatigue under high strain rates bridging time and length scales

Introduction

Copper metallization in power electronic exposed to extreme thermomechanical fatigue caused by rapid heating cycles under high heating rates are observed. These conditions lead to a viscoplastic material response, including grain boundary sliding, localized plasticity and diffusion-driven pore formation. These mechanisms are not yet fully understood, however they are essential for predicting device reliability.

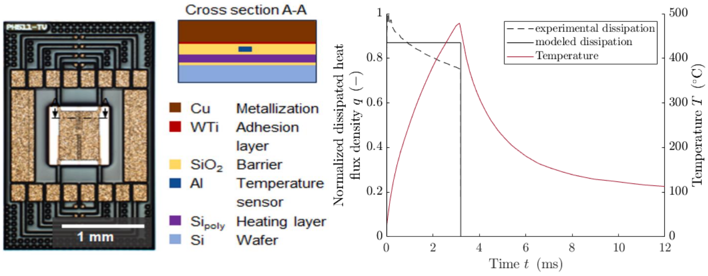

Fig. 1: Schematic diagram of the device under test (left) [1], thermal short pulse conditioning (right)

Methodology

- Multiscale finite-element framework bridging device-level loading with microstructural degradation.
- Coupled transient thermomechanical analysis at device level applied to the microstructural model
- Microstructural model derivation from experiments including local mechanisms.
- Normal stresses of grain boundaries drive a physics-based diffusion model for pore formation.

Results

- Simulations reproduce the observed stress–temperature relation of the copper metallization.
- Pronounced viscoplastic material response occurs during fast thermal cycling.
- Local tensile stress concentrations are observed at triple junctions initiating pore formation.

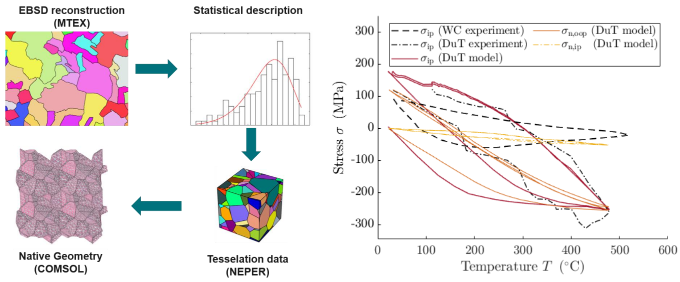

Fig. 2: Workflow of microstructural model representation (left), mechanical stresses acting on the metallization (right),

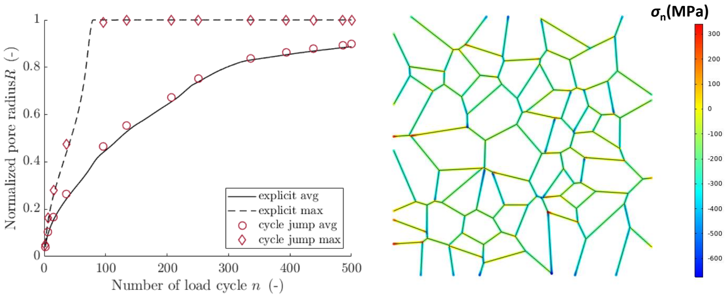

Fig. 3: Exemplary normalized pore growth and degradation extrapolation (left), local tensile hotspots at triple junctions (right)

Conclusion

- Copper degradation during ultra-fast thermomechanical cycling is governed by local mechanisms.
- A purely macroscopic model cannot capture the observed damage behavior.
- The multiscale framework links device loading, grain-scale deformation and damage evolution.
- The approach enables improved reliability prediction of microelectronic metallization.

[1] T. Ziegelwanger et al., Materials & Design, 2025

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Phase transformations in martensitic steels

Materials design by gradients in composition

Starting from earlier work [1], the influence of various heat treatments on the microstructure of a martensitic, mainly Fe-Cr-Ni steel is further investigated. It turns out that the most promising microstructures are those where strong gradients in austenite remain present in the microstructure during cooling.

The evolution of reverted austenite is analyzed using in-situ X-ray diffraction data. The heating, holding and cooling curves for tempering at 600°C for 2h and 10h, respectively are shown in Fig 1. While the mass fraction of austenite remains comparatively low after a holding time of 2h, it is much higher (closer to equilibration) after holding at 10h. Simulating the formation of reverted austenite during tempering by means of a sharp interface, finite interface mobility model can provide details of the underlying coupled interface migration and bulk diffusion processes. It is shown in Fig. 2 that pronounced mole fraction gradients (here Cr-profiles) can occur in austenite during tempering at 600°C which will remain present in case that the system‘s time for equilibration is not sufficient. As demonstrated in [2], the effect of chemical boundaries (strong composition gradients in austenite) might even be better exploited by employing high heating and cooling rates. This could open up new possibilities also for the design of these martensitic steels.

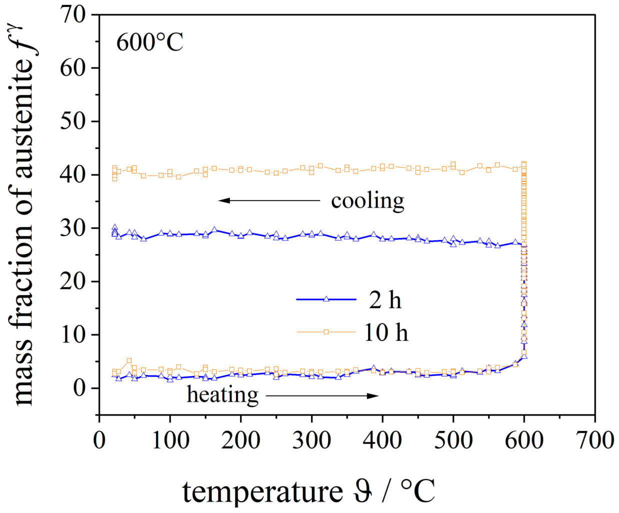

Fig. 1: Mass fraction of austenite during tempering for 2h or 10h.

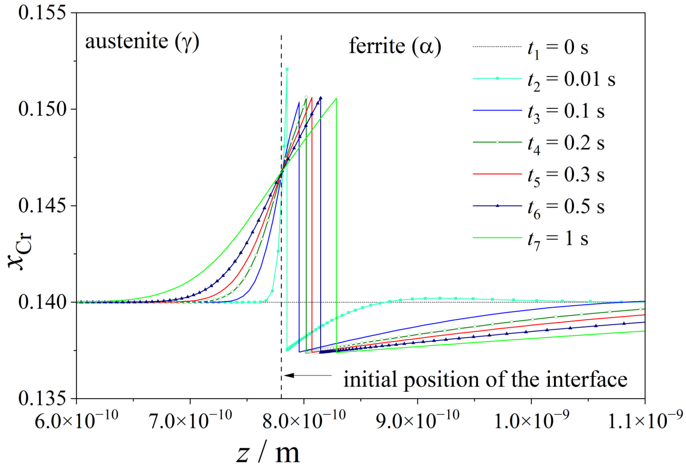

Fig. 2: Formation of reverted austenite shown by Ni-profiles at certain times.

References

[1] M. Wiessner, et al.: Effect of reverted austenite on tensile and impact strength in a martensitic stainless steel − An in-situ X-ray diffraction study, Materials Science & Engineering A 682 (2017) 117–125.

[2] Ran Ding, et al.: Chemical boundary engineering: A new route toward lean, ultrastrong yet ductile steels, Science advances 6 (13) (2020) DOI: 10.1126/sciadv.aay1430.

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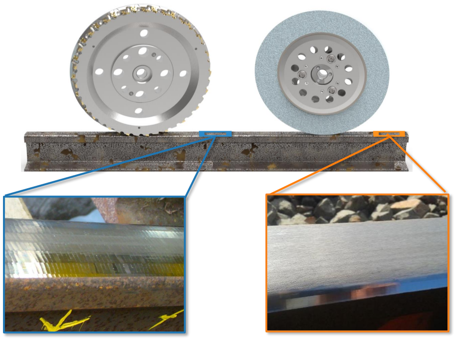
Finite Element Analysis of High-Speed Rail Milling

Numerical Simulation of Chip Formation and Temperature Evolution

1. Introduction

Rail milling is a non-abrasive cutting process that removes material from the rail surface as recyclable metal chips. It is used in rail maintenance to eliminate RCF defects and restore damaged rail profiles. Understanding chip formation, forces and temperature is essential for improving process efficiency. ALE-based FE modelling with adaptive remeshing enables simulation of continuous chip formation in rail milling.

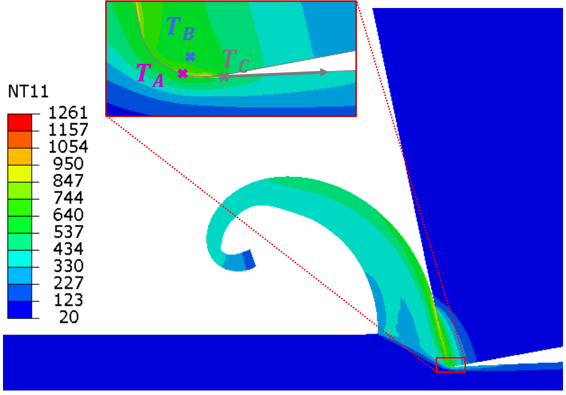


Stage 1: Milled *[visible facets]*

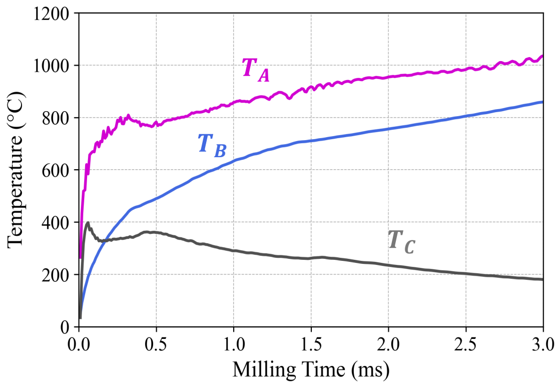
Stage 2: Polished *[facet tips removed]*

2. Numerical Model

- ALE formulation with adaptive remeshing
- Workpiece:
  R260 rail steel modelled using JC material model
- Cutting Tool:
  WC-10Co submicron grained substrate coated with TiAlN



Temperature distribution at 1 ms of milling



Temperature evolution during milling

3. Conclusion

- ALE-based FE model enables simulation of continuous chip formation in high-speed rail milling.
- Simulations predict temperature evolution in the cutting zone during high-speed milling.
- Results provide insight into thermo-mechanical behaviour of the cutting process.

4. References

- Kubin, W. et al. (2019) *Analysis of Rail Milling as a Rail Maintenance Process.* Wear, 438–439, 203029.
- Ambig, A. et al. (2025) *Modeling High-Speed Milling of Rails for Cost-Efficient Maintenance.* CM 2025, Tokyo.

RCF: Rolling Contact Fatigue; **FE:** Finite Element; **ALE:** Arbitrary Lagrangian–Eulerian; **JC:** Johnson–Cook; **WC–Co:** Tungsten Carbide–Cobalt; **TiAlN:** Titanium Aluminium Nitride

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