

Motivation

Advanced High Strength Steels (AHSS)

- provide a good combination of both strength and formability,
- are applied extensively in the automotive industry, especially in the crash relevant parts of the vehicle.

Dual-phase (DP) steel is a widely employed AHSS with

- excellent macroscopic behavior,
- inherent micro-heterogeneity,
- complex interactions of the ferritic and martensitic phases.

Incorporating the microscale is indispensable for realistic simulations!

Radical Scale Bridging by FE²-Framework (FE2TI)

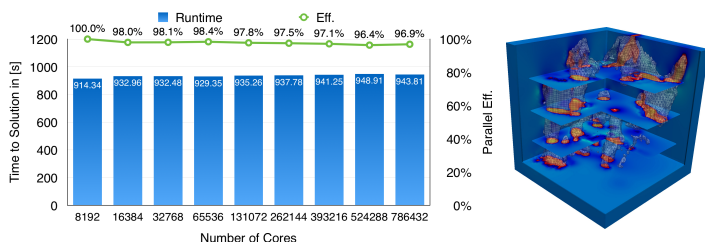
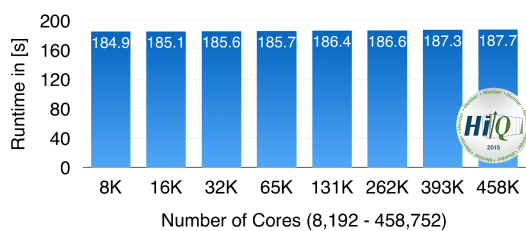
The FE²-method

- is a direct multiscale method,
- provides a suitable framework for radical scale bridging,
- is illustrated for the Nakajima test below (right), cf. [1, 2].

We present our successful FE² implementation FE2TI

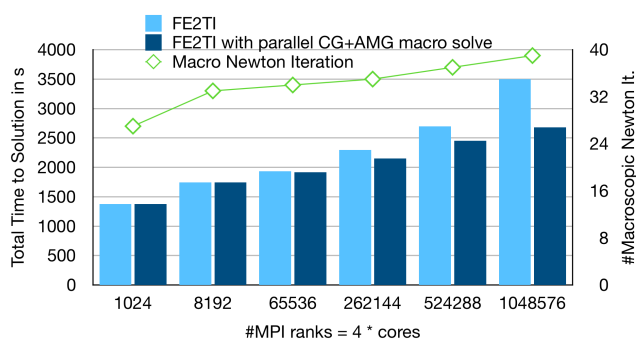
- developed in the EXASTEEL project (DFG SPPEXA),
- scales to 458 752 cores (1.8×10^6 MPI ranks) on JUQUEEN [3],
- scales to 786 432 cores, i.e., the complete Mira supercomputer at Argonne National Laboratory [4].

Inexact or exact FETI-DP methods are used to solve the 3D microscopic boundary value problems.



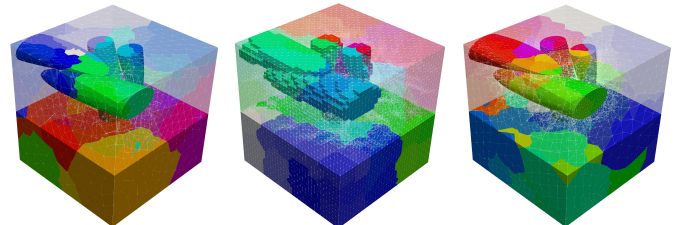
Scalability for a Realistic Setup Using a Parallel Macro Solver

- Parallel macroscopic problem improves scalability.
- Production run using **917,504 MPI ranks on the complete JUQUEEN** for a FE2TI production simulation (unstructured RVEs, an J2-elasto-plasticity material model, several load steps, a large macroscopic deformation problem with 14K degrees of freedom).



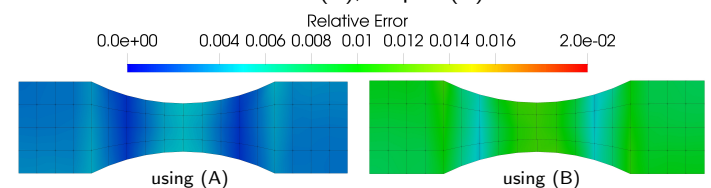
Unstructured Grids in FE2TI

- Mesh convergence study for the microstructures; see [6]
- Comparison of the macroscopic stresses for unstructured and structured meshes on the RVEs (J2-elasto-plasticity) [7].



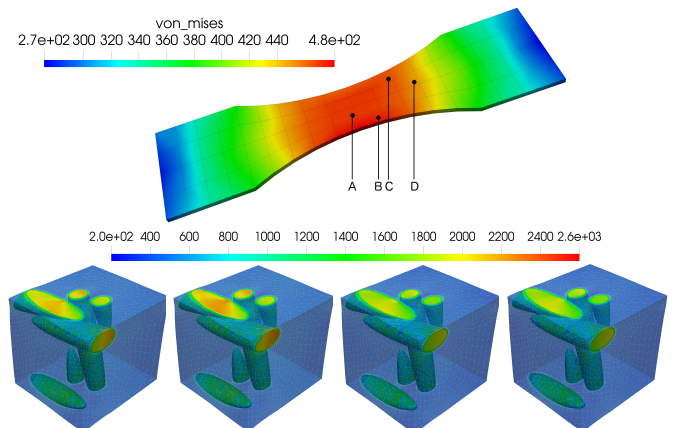
(A) unstructured; 103K dofs (B) structured; 945K dofs (C) unstructured; 921K dofs

Using (C) as reference RVE, (A) approximates the stresses on the macroscale much better than (B), despite (A) 10 times smaller.



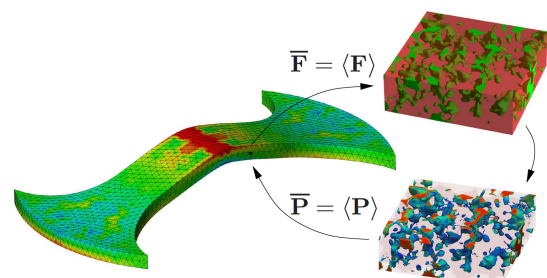
Production Run with Elasto-Plasticity on JUQUEEN

Based on the results from [6], we performed a long FE2TI production run using an unstructured mesh for the RVEs and a macroscopic geometry which is similar to the Nakajima geometry.



Project Outlook: Nakajima Test

The next project steps are: contact algorithm for the Nakajima test, crystal plasticity model, FE² simulation with contact for the Nakajima geometry.



- [1] SCHRÖDER, J.; HACKL K. [2014], Plasticity and Beyond, CISM.
- [2] BALZANI, D.; GANDHI, A.; TANAKA, M.; SCHRÖDER, J. [2015]
- [3] KLAWONN, A.; LANSER, M.; RHEINBACH, O. [2015a]
- [4] KLAWONN, A.; LANSER, M.; RHEINBACH, O. [2015b]
- [5] BAKER, A.; KLAWONN, A.; KOLEV, T.; LANSER, M.; RHEINBACH, O.; MEIER YANG, U. [2016]
- [6] KLAWONN, A.; KÖHLER, S.; LANSER, M.; RHEINBACH, O. [2018]
- [7] BRANDS, D.; BALZANI, D.; SCHEUNEMANN, L.; SCHRÖDER, J.; RICHTER, H.; RAABE, D. [2016]