EXASTEEL: Multiscale Simulation of Steel using FE2TI

Project Phase 1 (2013-2015), Project Phase 2 (2016-2018)

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 FE^2-Framework (FE2TI)

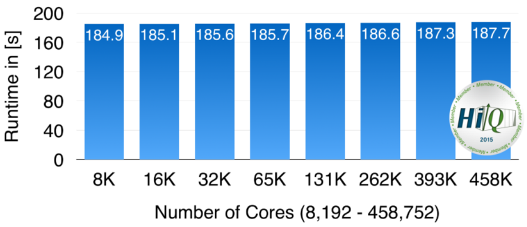
The FE^2-method

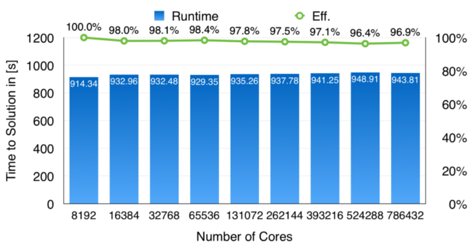
- is a direct multiscale method,
- provides a suitable framework for radical scale bridging,
- is illustrated for the Nakajima test below (right), cf. [1, 2].

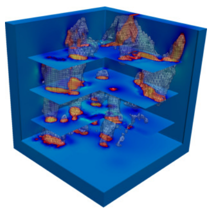
We present our successfull FE^2 implementation FE2TI

- 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.

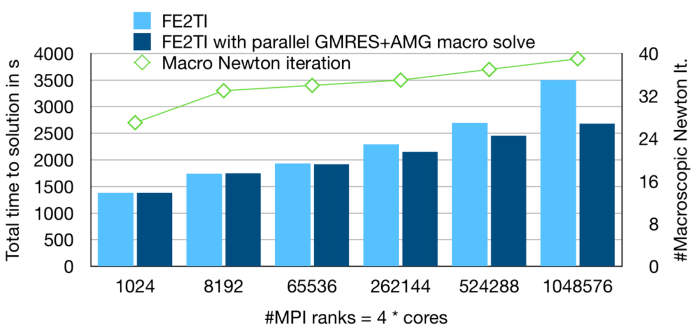






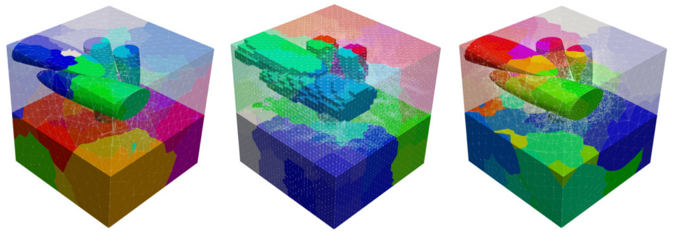
Scalability for a Realistic Setup Using a Parallel Macro Solver

- 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).



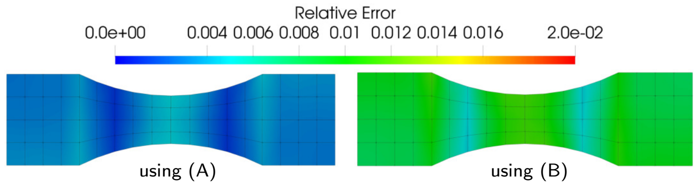
Unstructured Grids in FE2TI

- 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].



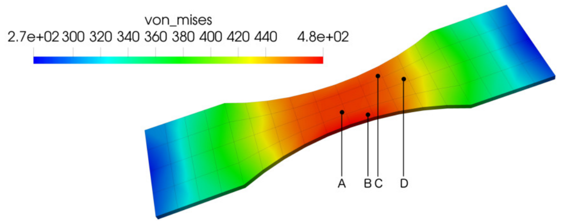
(A) unstructured; 103K dofs (B) structured; 945K dofs (C) unstructured; 921K dofs

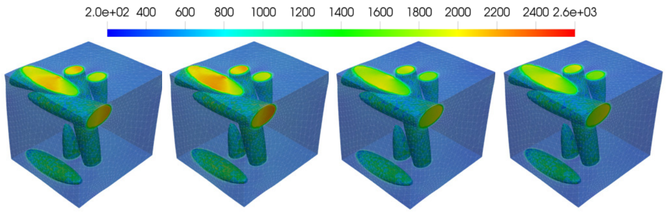
Using (C) as reference RVE, (A) approximates the stresses on the macroscale much better than (B), despite (A) 10 times smaller.



Production Run with Elasto-Plasticity on JUQUEEN

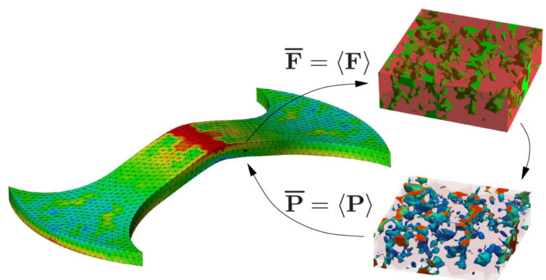
Based on the results from [6], we performed a long FE2TI production run using an unstructured mesh for the RVEs and a macroscopic geometry which is similar to the Nakajima geometry.





Project Outlook: Nakajima Test

The next project steps are: contact algorithm for the Najakima test, crystal plasticity model, FE^2 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]

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