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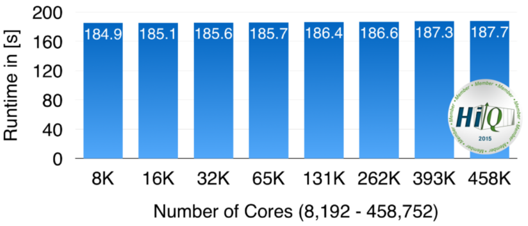
FE2TI: Computational Scale Bridging for Dual-Phase Steels

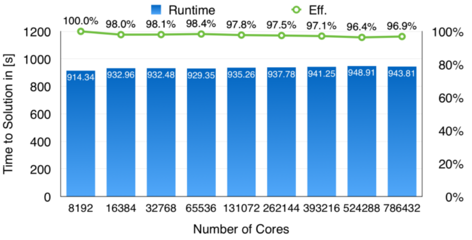
Motivation

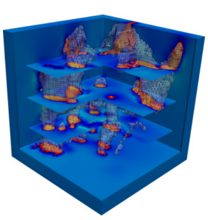
Advanced High Strength Steels (AHSS) provide a good combination of both strength and formability and are therefore applied extensively in the automotive industry, especially in the crash relevant parts of the vehicle. Dual-phase (DP) steel is an example for such AHSS which is widely employed. The excellent macroscopic behavior of this steel is a result of the inherent micro-heterogeneity and complex interactions between the ferritic and martensitic phases in the microstructure. Thus, considering the microscale is indispensable for realistic simulations.

Radical Scale Bridging by FE^2-Framework (FE2TI)

The FE^2-method as illustrated for the Nakajima test below on the right, cf. [1, 2], is a direct multiscale method and provides a suitable numerical tool for radical scale bridging. We present our successfull FE^2 implementation FE2TI developed in the EXASTEEL project (SPPEXA), which we have scaled to 458 752 cores and 1.8×10^6 MPI ranks of JUQUEEN [3] and to the complete Mira (786K cores) at Argonne National Laboratory [4] for hyperelasticity problems already in 2015. Inexact or exact FETI-DP methods are used to solve the 3D microscopic boundary value problems.

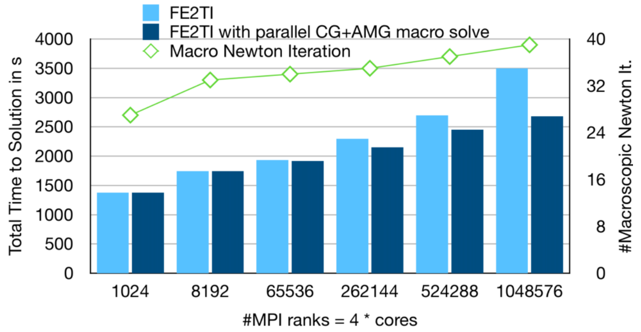






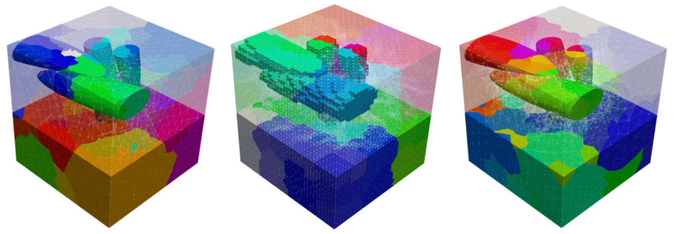
Scalability for a Realistic Setup Using a Parallel Macro Solver

If the macroscopic problem is large, a parallelization is necessary. We recently included the option to use CG with a BoomerAMG preconditioner [5] on the macroscale instead of using sparse direct solvers. 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), the time to solution can be reduced by a factor of 1.3. We also include a scaling graph for a similar realistic setup.



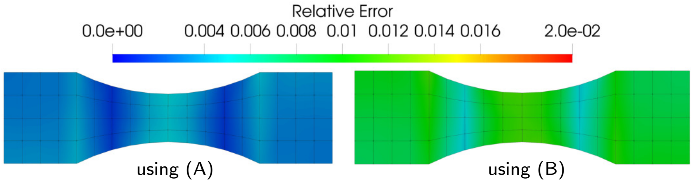
Unstructured Grids in FE2TI

Recently, we investigated the influence of the resolution of the microstructure on the macroscopic solution; see [6]. Therefore, we compared the macroscopic stresses for unstructured and structured meshes on the RVEs and used a J2-elasto-plasticity material model with realistic parameters fitted to dual-phase steels; see [7].



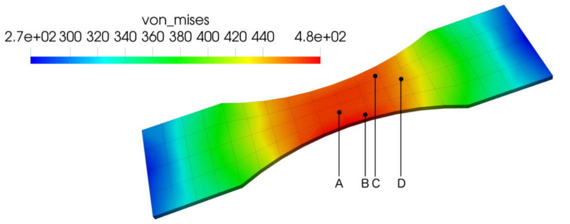
(A) unstructured; 103K dofs (B) structured; 945K dofs (C) unstructured; 921K dofs

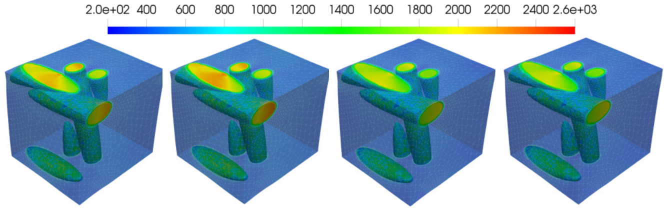
Using (C) as reference RVE, (A) approximates the stresses on the macroscale much better than (B), despite (A) 10 times smaller.



Production Run with Elasto-Plasticity on JUQUEEN

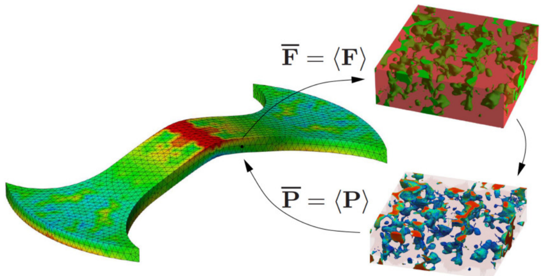
Based on the results from [6], we performed a long FE2TI production run using an unstructured mesh for the RVEs and a macroscopic geometry which is similar to the Nakajima geometry.





Nakajima Test

An illustration of the FE^2 scale bridging method for the Nakajima test; averaging of Kirchhoff stresses $\mathbf{P}$ on the microscale.



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