Engineering Mechanics based on Size-dependent Materials Properties – SizeDepEn

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When confined to sub-micrometer dimensions, many materials exhibit unexpected and potentially useful properties different from their bulk behavior. This unusual behavior can be exploited in small-scale mechanical devices in high-tech industries. Since conventional continuum theory cannot account for size-dependencies there is a need for new material models complying with both the description of physical effects and the applicability to engineering design. The development of size-dependent continuum theories for both small scale plasticity and fracture mechanics was the central aim of the EU-funded Marie Curie Research Training Network (MC-RTN) SizeDepEn, which was co-ordinated by izbs. SizeDepEn consisted of six partners in five European countries and ran from June 1st 2004 to November 30th 2007.

SizeDepEn achieved major breakthroughs in several areas. With respect to a physically- based size-dependent continuum theory of plasticity, the basis for a three dimensional continuum theory of dislocations was laid in collaboration with the University of Edinburgh and IZBS (T. Hochrainer, et. al., Phil. Mag, 2007). This theory was compared to discrete dislocation dynamics simulations as well as to experiments and turned out to predict various size effects occurring in small scale plasticity.

Furthermore, detailed statistical analyses have revealed the intermittent nature of plastic flow on the micrometric scale which gives rise to intrinsic limitations of forming procedures in small dimensions (F.F. Csikor, Science, 2007). The statistical modeling of dislocation based plasticity was also extended to the treatment of multiple slip processes. New theoretical approaches have been developed which will allow for further generalizations in the future.

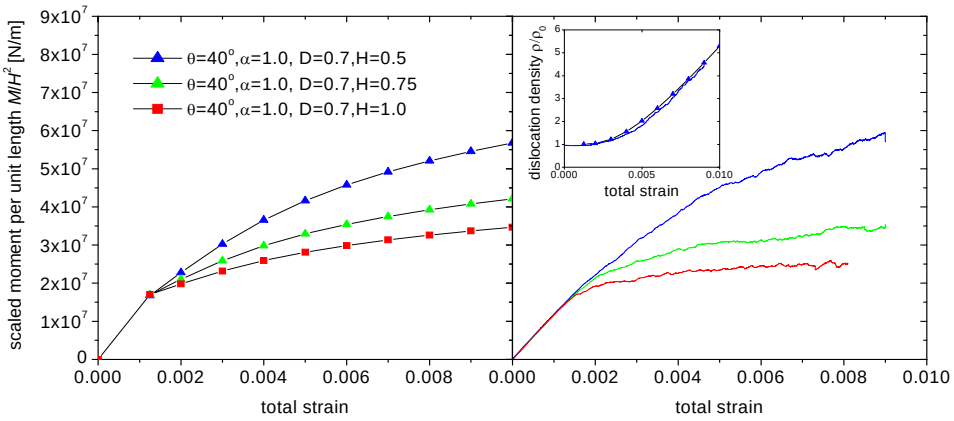

Fig. 1: Bending moment vs. bending strain for different beam thicknesses in simulations of a bending test; left: continuous dislocation dynamics (CDD) results; right: discrete dislocation dynamics (DDD) results; small diagram in right figure: comparison of evolution of total dislocation density in CDD and DDD (courtesy of M. Zaiser)

The discrete dislocation modeling tool at IZBS was improved in various respects through the implementation of mobility laws for motion obtained from atomistic simulations and the treatment of complex boundary conditions. Several columnar grains undergoing plastic

deformation were simulated by the discrete dislocation method and the results were compared to finite element simulations. Continuum simulations of the fatigue behavior of a thin film made up of 250 grains during 1000 cycles of tensile deformation have been performed and the development of surface roughness induced by plasticity has been predicted in detail.

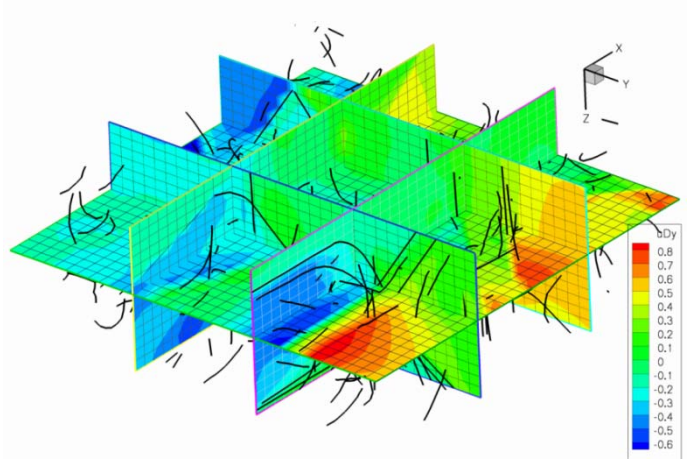

Fig. 2: Multigrain structure in a DDD simulation consisting of a regular 3x3 grain arrangement. The grain boundaries and a horizontal cut through the grain structure are plotted. The colors indicate the accumulated plastic slip. Pile-ups of dislocations against grain boundaries can be observed

SizeDepEn organized five major events. First, a scientific workshop on 'Size-dependent Mechanical Properties' in Leiden (NL) in March 2005 and second, a summer school session on 'Multiscale Modeling of Plasticity and Fracture by means of Dislocation Mechanics' at the CISM in Udine (I) in July 2005. A smaller workshop was on 'Experimental Characterization of Materials' organized in Budapest in May 2006. The next training event was an industrial workshop organized in Freiburg in March 2007, which attracted all appointed researchers and 12 industrial participants. Finally, in August 2007 SizeDepEn co-organized the IWCMM 17 as the final conference in Paris. This conference attracted 102 participants from all over Europe and abroad and was the ideal platform to inform the research community about the results achieved in the projects. An intensive exchange program for the appointed researchers confronted them with different scientific methods and schools of thoughts. The project promoted the buildup of new collaborations between the involved partners which will surely exceed the project's duration.