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Near surface nanoscale structures produced by plastic deformation

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Ultrafine Grained Materials VII: Plenary Session

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Program Organizers: Suveen Mathaudhu, U.S. Army Research Office; Xiaoxu Huang, Risø National Laboratory for Sustainable Energy, Technical University of Denmark; Hyoung Seop Kim, POSTECH; Terence Langdon, University of Southern California; Terry Lowe, Manhattan Scientifics, Inc. ; Ruslan Valiev, Ufa State Aviation Technical University; Xiaolei Wu, Institute of Mechanics, Chinese Academy of Sciences; Michael Zehetbauer, University of Vienna

Monday AM — Room: Swan 5
March 12, 2012 — Location: Swan Resort

Session Chairs: Xiaoxu Huang, Risoe National Laboratory for Sustainable Energy, Technical University of Denmark; Suveen Mathaudhu, U.S. Army Research Office; Terry Lowe, Manhattan Scientifics, Inc.; Michael Zehetbauer, University of Vienna

8:30 AM Introductory Comments

8:35 AM Keynote
Physics of Grain-Size Effect on Twinning in Nanostructured fcc Metals: *Yuntian Zhu*[1]; Xiaolei Wu[2]; Xiaozhou Liao[3]; [1]North Carolina State University; [2]Institute of Mechanics; [3]The University of Sydney

Deformation twinning is an effective approach for enhancing the ductility while at the same time also improves the strength. In this talk, I will present the physics and modeling on the effect of grain size on deformation twinning in nanocrystalline fcc metals. An analytical model based on observed deformation physics, i.e. grain boundary emission of dislocations, will be first presented. The result will be then compared with experimental observation of an optimum grain size range for the formation of deformation twins and the inverse grain-size effect. The physical origin of the observed grain size effect will be delineated.

8:55 AM Invited
Deformation Mechanisms in Nano and Ultrafine Crystalline Nickel: *Marisol Koslowski*[1]; [1]Purdue University

Deformation of polycrystalline materials includes mechanisms in the grain interior as well as in the grain boundaries. The competing grain-boundary and dislocation-mediated deformation mechanisms in crystalline Nickel with grain sizes in the range 4 nm to 128 nm are investigated with numerical simulations. We present a three dimensional phase field model that tracks the evolution of grain boundaries and individual dislocations, including the elastic interaction, the core and the stacking fault energies. Our model shows that the transition from Hall-Petch to inverse Hall-Petch as the grain size is reduced cannot be characterized only by the average grain size, but it is also affected by the grain boundary energetics, the grain size distribution and the initial defect concentration. We find that the grain size corresponding to the maximum yield stress (the transition from Hall Petch strengthening with decreasing grain size to inverse Hall Petch) decreases with increasing grain boundary energy.

9:15 AM Invited
Near Surface Nanoscale Structures Produced by Plastic Deformation: *Niels Hansen*[1]; Xiaodan Zhang[1]; Yukui Gao[2]; Xiaoxu Huang[1]; [1]Risø DTU; [2]Beijing Institute of Aeronautical Materials

Hard surface microstructures produced by plastic deformation can improve the fatigue and wear resistance of industrial structures. Such structures have been produced in iron by shot peening and by surface mechanical attrition and characterized by transmission electron microscopy, electron backscattering diffraction and microhardness testing. The structure is subdivided by boundaries forming a lamellar structure. Such a structure also characterizes samples cold rolled to medium and high strains where the structure is graded with respect to the lamellar spacing with decreases with increasing strain. This dependency can be represented by a power law relationship which allows the strain to be estimated at different depths in the near surface layer and the stress strain relationship to be derived based on the microhardness data. A discussion will focus on the structural evolution in the nanoscale regime and on strengthening mechanisms.

9:35 AM Invited
Strain-Induced Phase Transformations under Compression and Shear in Rotational Diamond Anvil Cell: *Valery Levitas*[1]; [1]Iowa State University

Experimental results on phase transformations obtained under compression and large plastic shear of materials in rotational diamond anvil cell (RDAC) are presented. Multiscale (nano-, micro- and macroscales) continuum thermodynamic theory and simulations for strain-induced transformations were developed, which explain a number of mechanochemical phenomena. Specifically, the theory explains why the superposition of plastic shear and high pressure in RDAC leads to: (a) significant reduction (by a factor of 3-5) of transformation pressure and pressure hysteresis, (b) appearance of new phases (in particular, nanostructured), which were not obtained without shear, (c) substitution of reversible transformation by an irreversible one, and (d) strain-controlled kinetics. New phenomenon of phase transformation induced by rotational plastic instability is revealed. It allowed us to reduce the pressure for irreversible phase transformation from rhombohedral to cubic BN from 55 GPa under hydrostatic pressure to 5.6 GPa. Transformation-induced plasticity under pressure and shear is revealed, quantified and modeled.

9:55 AM Invited
Tailoring or Grading Sheet Materials by Using New Concepts in ARB-Processing: *Heinz Werner Höppel*[1]; [1]University Erlangen-Nürnberg

The ARB-process is well know to produce UFG sheet materials in larger quantities. Besides, this technique also allows to produce multiphase, tailored or graded sheet materials with promising properties. By an intelligent ARB-processing 3D-architectured multiphase materials can be achieved aiming for locally tailored materials properties. It is shown, that the materials properties can be tailored locally by an adopted powder spraying process via the ARB process. Moreover, by using an appropiate post ARB-heat treatment, this technique can aslo be used to strengthen the sheet material by the formation of intermatallic phases in the sheet. In the talk, microstructural and mechanical properties with respect to the processing parameters will be discussed in detail.

10:15 AM Invited
Analysis of Plastic Flow during High-Pressure Torsion: *Roberto Figueiredo*[1]; Maria Teresa Aguilar[1]; Paulo Cetlin[1]; Terence Langdon[2]; [1]Federal University of Minas Gerais; [2]University of Southern California

It is now established that high-pressure torsion is able to produce bulk nanostructured metallic materials through severe plastic deformation-SPD. This technique produces material with the finest grain structures among all SPD processes. Despite the recent rise in interest, there are many process parameters whose influence on the sample is not clear. For example, some researchers consider the distribution of deformation homogeneous while others report heterogeneity, the hydrostatic stress and the temperature rise due to plastic strain are also not clear. It is thus important to clarify these aspects in order to analyze structure and properties evolution. The present paper reviews the experimental and theoretical results on processing parameters during HPT.

10:35 AM Break

10:50 AM Invited
Microstructure and Microtexture Evolution in Pure Metals after Ultra-High Straining: *Alexander Zhilyaev*[1]; Terence Langdon[2]; [1]School of Engineering Sciences, University of Southampton, Southampton SO17 1BJ, U.K. and Institute for Metals Superplasticity Problems, Russian Academy of Science, 39 Khalturina, Ufa, 450001 Russia) ; [2]School of

Near surface nanoscale structures produced by plastic deformation

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Abstract

Hard surface microstructures produced by plastic deformation can improve the fatigue and wear resistance of industrial structures. Such structures have been produced in iron by shot peening and by surface mechanical attrition and characterized by transmission electron microscopy, electron backscattering diffraction and microhardness testing. The structure is subdivided by boundaries forming a lamellar structure. Such a structure also characterizes samples cold rolled to medium and high strains where the structure is graded with respect to the lamellar spacing with decreases with increasing strain. This dependency can be represented by a power law relationship which allows the strain to be estimated at different depths in the near surface layer and the stress strain relationship to be derived based on the microhardness data. A discussion will focus on the structural evolution in the nanoscale regime and on strengthening mechanisms.

Reference:

[1] Hall–Petch and dislocation strengthening in graded nanostructured steel. Xiaodan Zhang, Niels Hansen, Yukui Gao, Xiaoxu Huang. Acta Materialia 2012; 60: 5933-5943.