Technical University of Denmark

Structural Parameters and Strengthening Mechanisms in Cold-Drawn Pearlitic Steel Wires

Zhang, Xiaodan; Godfrey, Andy; Huang, Xiaoxu; Hansen, Niels

Published in:
Abstract Book

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Ultrafine Grained Materials VII: Young Scientist
Sponsored by: The Minerals, Metals and Materials Society, TMS Structural Materials Division, TMS/ASM: Mechanical Behavior of Materials Committee, TMS: Nanomechanical Materials Behavior Committee, TMS: Shaping and Forming Committee
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

Wednesday 2:00 PM
March 14, 2012
Room: Swan 5
Location: Swan Resort

Funding support provided by: Army Research Office: Synthesis and Processing Program

Session Chair: Justin Scott, Institute for Defense Analysis; Matthias Hockauf, Chemnitz University of Technology; Suveen Mathaudhu, U.S. Army Research Office; Yuntian Zhu, North Carolina State University

2:00 PM
3D-Architecturing Aluminium Sheets by ARB Processing with Graded Copper Particle Reinforcement: *Christian W. Schmidt*[1]; Mathis Ruppert[1]; Patrick Knödler[1]; Heinz Werner Höppel[1]; Mathias Göken[1]; [1]Friedrich-Alexander-Universität Erlangen-Nürnberg
In this work copper particles (d ~ 1 µm) are introduced in a highly controlled manner by airgun spraying from aqueous suspension into aluminium AA1050A during ARB. A 3D-architecture by controlling spatial distribution of particles is demonstrated. In sheet plane, spraying distance and feed rate of the air spray gun are used to control the particle content. In sheet height certain distributions including homogeneous and stepwise graded distributions are generated by a smart stacking sequence during ARB processing. In the system Al-Cu continuous and stepwise gradation of particle distribution are proven by solutionizing and subsequent mechanical testing as well as through visualisation by micro-computer-tomography. With this freedom of design concerning particle distribution, the material properties of ultrafine-grained sheets can be adjusted within one tailored sheet in a certain range with a desired 3D-profile. In the case of Al-Cu a combination of high strength with high electrical conductivity is exemplarily demonstrated.

2:15 PM Student
Advantageous Anisotropy: Designed Performance in Mg Alloy: *David Foley*[1]; Sonia Modarres-Razavi[1]; Suveen Mathaudhu[2]; Laszlo Kecskes[3]; Ibrahim Karaman[1]; K. Hartwig[1]; Vince Hammond[3]; [1]Texas A&M University; [2]US Army Research Office; [3]US Army Research Laboratory
One general characteristic of wrought Mg alloys is a strong texture developed during forming. These strong textures, combined with high critical resolved shear stress ratios between deformation mechanisms, result in large mechanical anisotropy. While some alloying elements and processing conditions can weaken this texture and encourage more isotropic deformation, this is not always desirable. For example, if component failure is only expected under only one loading direction, enhanced performance in that deformation condition may be advantageous even at the expense of others. This talk will cover SPD and post-SPD thermomechanical processing methods to engineer mechanical response in AZ31B. Strain path and temperature control result in high strength UFG materials with twice the strength of the starting wrought material.

2:30 PM Student

Analysis of Microstructure and Microhardness of Zr-2,5%Nb Processed by High Pressure Torsion (HPT): *Mychelle Companhoni*[1]; Jose Matheus[1]; Andre Pinto[2]; [1]Military Institute of Engineering (IME); [2]Brazilian Center for Physics Research (CBPF)

Nanostructured materials have been widely studied due the improvement of their mechanical properties comparing to coarse grain materials. The present work intended to analyze the microstructure and microhardness of Zr-2,5%Nb processed by high-pressure torsion (HPT), one of the severe plastic deformation (SPD) techniques. The deformations were carried out atroom temperature using a pressure of 5 GPa and five anvil turns. Vickers indentation was used to evaluate the microhardness of the samples. Transmission electron microscope (TEM) and X-ray diffraction were used to analyze the microstructure. The results showed a significant refinement from the initial microstructure achieving nanometric grain size lower than 50 nm and phase transformation $\alpha \rightarrow \omega$ induced by shear. The Vickers microhardness values of material submitted to HPT technique were significantly higher than non-deformed material. Also, HPT procedure resulted in a huge grain refinement of the material and phase transformation.

2:45 PM Student

Combining Extrusion and ECAP – an Efficient Processing Route for Large Scale UFG Materials: *Philipp Frint*[1]; Matthias Hockauf[1]; Thorsten Halle[1]; Gernot Strehl[2]; Martin F.-X. Wagner[1]; Thomas Lampke[1]; [1]Chemnitz University of Technology; [2]S+C Extrusion Tooling GmbH

The use of ultrafine-grained materials processed by equal-channel angular pressing (ECAP) in industrial applications is limited because of the small volumes of the billets and difficulties in integrating them into conventional extrusion processes. Here, we propose a combination of extrusion and large scale ECAP (cross section: 50mm x 50mm) performed at room temperature as an efficient two-step process followed by a suitable heat treatment. We demonstrate that, for the aluminum alloy 6060, an improvement of yield and tensile strengths by up to 20% can be achieved – without a further reduction of ductility – compared to “conventionally” ECAPed material. Microstructural analysis shows that this excellent combination of strength and ductility can be related to the beneficial effects of fine precipitates, ultrafine grains and a recovered microstructure. These results highlight the potential of our combined ECAP/extrusion process for the production of homogenous, high performance aluminum materials on an industrial scale.

3:00 PM Student

Consolidation of Nanostructured Copper and Copper Based Alloys via High Pressure Torsion: Hamed Bahmanpour[1]; Daria Setman[2]; *Jelena Horky*[2]; Michael Kerber[2]; Susi Kahofer[2]; Suhrit Mula[1]; Michael Zehetbauer[2]; Ronald Scattergood[1]; Carl Koch[1]; [1]North Carolina State University; [2]Faculty of Physics, University of Vienna

Samples of pure Cu, and Cu alloyed with Zn and Nb were processed by high energy ball milling. Small flakes with homogeneous nanostructures revealing grain sizes below 40nm were produced after milling at 77K. The milled flakes were used as a precursor for consolidation with high pressure torsion (HPT). The resulting samples were analyzed by means of XRD, TEM and mechanical tests not only comprising microhardness but also tensile tests. HPT processing yielded entirely flaw-free samples with only slightly increased grain sizes provided more than 50 revolutions and hydrostatic pressures of about 8 GPa were carried out. For example, those samples exhibited values of UTS up to 892 MPa (Cu) and 1240 MPa (Cu-10%Zn), and values of tensile strain up to 5.8% (Cu) and 10% (Cu-10%Zn), which all seem to be outstanding compared to data published so far in literature on SPD consolidated powder materials.

3:15 PM Student

Effects of Post Process Treatments on the Mechanical Stability of Rolled Nanostructured Aluminum: *Jacob Kidmose*[1]; Lei Lu[2]; Grethe Winther[1]; Niels Hansen[1]; Xiaoxu Huang[1]; [1]Risoe DTU; [2]Institute of Metal Research

Nanostructured aluminum produced by cold rolling to high strains shows an early onset of localized necking causing a low ductility during straining in tension. In order to improve the properties, post-process treatments such as annealing and cold deformation have been applied to aluminum sheets produced by accumulative roll bonding. The treatments have been followed by tensile testing where in-situ high resolution maps of the strain distribution over the tensile sample gauge length and thickness have been obtained by using a commercial ARAMIS system. These maps allow localized and diffuse necking to be characterized and to obtain correlation between the mechanical behavior and the structural changes being a result of the post-process treatments.

3:30 PM Student
Nanoindentation Analysis for Local Properties of Ultrafine Grained Copper Processed by High Pressure Torsion: *Hyeok Jae Jeong*[1]; Eun Yoo Yoon[1]; Nack Joon Kim[2]; Hyeong Seop Kim[1]; [1]Department of Materials Science and Engineering, POSTECH, Korea; [2]Graduate Institute of Ferrous Technology, POSTECH, Korea
Recently, severe plastic deformation (SPD) techniques have been available for producing bulk UFG metallic materials. High pressure torsion (HPT) leads to smaller microstructures than those achieved using the other SPD processes because of its higher strain. It is known that HPT processed metals show highly heterogeneous not only along radius due to the nature of torsional deformation but also through the thickness. Since the sample size for the HPT is small, the local properties of the HPT processed samples have not been investigated yet. Recently we propose a method converting the nanoindenting curve to stress-strain curve combining the finite element method and the recursion method. In this presentation, we employe the nanoindentation technique in order to elucidate the local mechanical properties especially stress-strain curves. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2010-0026981).

3:45 PM Break

4:00 PM Student
Strengthening of Al through Addition of Fe and by Processing with High-Pressure Torsion: *Jorge Cubero-Sesin*[1]; Zenji Horita[1]; [1]Kyushu University
Iron (Fe) is a common impurity element in aluminum (Al) and is expected to be used in a controlled manner. In this work, High-Pressure Torsion (HPT) was applied to 10 mm in diameter bulk disk-type samples of Al-Fe alloys with different Fe weight fractions: 0.5%, 1%, 2% and 4%, and initial states: as-cast, extruded, and annealed at 500ºC for 1 hour. Powder samples were also consolidated in the HPT facility with similar Fe contents including an additional 10% Fe. HPT was carried out at room temperature under a pressure of 6 GPa for several numbers of revolutions: 1, 10, 20, 50 and 75. Vickers microhardness and tensile tests were performed on specimens extracted from the disks. Microstructural analyses by transmission electron microscopy and x-ray diffraction revealed significant potential to improve mechanical properties via microstructure refinement, supersaturation of Fe and dispersion of intermetallic phases throughout the Al matrix.

4:15 PM
Structural Parameters and Strengthening Mechanisms in Cold-Drawn Pearlitic Steel Wires: *Xiaodan Zhang*[1]; Andy Godfrey[2]; Xiaoxu Huang[3]; Niels Hansen[3]; [1]Tsinghua University, Risø DTU; [2]Tsinghua University; [3]Risø DTU
Pearlitic steel wires have a nanoscale structure and a strength which can reach 5 GPa. In order to investigate strengthening mechanisms, structural parameters including interlamellar spacing, dislocation density and cementite decomposition, have been analyzed by transmission electron microscopy and high resolution electron microscopy in wires cold drawn up to a strain of 3.7. Three strengthening mechanisms, namely boundary strengthening, dislocation strengthening and solid solution hardening have been analyzed and good agreement has been found between the measured flow stress and the value estimated based on an assumption of linear additivity of the three contributions.

4:30 PM Student

Study of Grain Boundary Weakening using In-Situ Synchrotron X-Ray Diffraction of Ultrafine Grained Materials: *Jennifer Girard*[1]; Jiuhua Chen[1]; Helen Couvy[2]; Xiaoyang Liu[3]; [1]Florida International University; [2]University of Michigan; [3]Jilin University

When size of crystal grain decreases down to nanometers, volume fraction of near surface atoms becomes significant. Comparative in situ synchrotron x-ray diffraction at high pressures on micron and nano crystalline powder samples has been conducted to determine the effective bulk modulus of grain boundary. The volume vs. pressure data of the micron and nano specimens obtain from the x-ray diffraction are used to determine their bulk moduli through equation of state. Using a shell/core grain model, the bulk modulus of grain boundary is derived from the moduli of micron-size sample and nano-size sample (representing significant contribution from the shell). The result indicates that the bulk modulus of grain boundary is remarkably smaller than that of the core, by 37% in magnesium silicate, Mg2SiO4, and by near 50% in metal(Ni). While strengthening by smaller grain size is expected by Hall–Petch law, these results reveal an inverse Hall–Petch relation.

4:45 PM Student

Understanding the Ultrafine Grain Formation and Recrystallization Mechanisms in Magnesium through Extrusion-Machining: *Mert Efe*[1]; Dinakar Sagapuram[1]; Wilfredo Moscoso[2]; Srinivasan Chandrasekar[1]; Kevin Trumble[1]; [1]Purdue University; [2]Pontificia Universidad Catolica Madre y Maestra

Large Strain Extrusion Machining (LSEM), a constrained chip formation SPD process, is demonstrated as a method for producing ultrafine grained sheet/foil of magnesium AZ31. Temperature is varied locally in the deformation zone through adiabatic heating due to the high strain rate nature of the process. Ultrafine grain formation and recrystallization mechanisms responsible for various microstructures are explained as a function of temperature and strain rate. Continuous dynamic recrystallization (CDRX) is shown to operate at low temperatures (below 170°C) and results in ultrafine grain sizes (100-200 nm), high hardness values (120 HV) and non-basal textures. At high temperatures (above 170°C), the recrystallization mechanism switches to discontinuous dynamic recrystallization (DDRX), which results in fine grain sizes (2-3 µm), low hardness (50 HV) and basal-type textures. Implications for formability and mechanical properties will be discussed.

5:00 PM Student

Reinforcement Phase Size Effects on a Cryomilled Al – B_4C Nanocomposite: *Hanry Yang*[1]; Troy Topping[1]; Zhihui Zhang[1]; Enrique Lavernia[1]; Julie Schoenung[1]; [1]University of California Davis

Cryomilled Al 5083 - boron carbide (Al-B_4C) metal matrix composites (MMCs) are of interest due to their light weight and high strength. Cryomilling is a mechanical milling process during which the powder is ball milled in a liquid nitrogen slurry at cryogenic temperatures. In addition to generating nanocrystalline powder, cryomilling breaks up the nascent oxide layer on the as-received Al powder and introduces nitrides into the microstructure. The dispersed nano-metric inclusions enhance the thermal stability of the powder for subsequent consolidation and thermomechanical processing, ensuring the MMC retains an ultra-fine grained (UFG) microstructure. In this study, the effect of milling time, B_4C particle size, and consolidation variables on the microstructure and mechanical properties of consolidated bulk nanocomposites was investigated. Specific attention was placed on the differences resulting from the incorporation of 0.5 µm and 6 µm B_4C particulates. The relationship between microstructure and mechanical properties of the nanocomposites are discussed.

5:15 PM Student

Homogenizing Process and Strain Hardening Behavior of a Two-Phase Cu-Ag Alloy Processed by High-Pressure Torsion (HPT): *Y.Z. Tian*[1]; Z.F. Zhang[1]; R.B. Figueiredo[2]; N. Gao[3]; T.G. Langdon[4]; [1]Institute of Metal Research, Chinese Academy of Sciences; [2]Federal University of Minas Gerais; [3]University of Southampton; [4]University of Southern California

Disks of a two-phase Cu-28 wt.% Ag alloy were processed by high-pressure torsion (HPT) from 1 to 20 revolutions to reveal the microstructural evolution and the mechanical properties. It is shown that the deformation starts at the outer region of the disks in the form of local vortices and then spreads inwards with increasing the number of revolutions. Deformation patterns were also observed near the center of the disk after HPT for 20 revolutions. It is found that the Cu-Ag alloy displays a much stronger strain hardening capability than Cu due to a continuous refinement of the microstructure. A two-stage Hall-Petch relationship was obtained for the Cu-Ag alloy which is attributed to the development of multiple strengthening mechanisms.

5:30 PM Student

Microhardness and Microstructural Evolution in Cu-Zr Alloy after High-Pressure Torsion Processing: *Jittraporn Wongsa-Ngam*[1]; Megumi Kawasaki[1]; Terence Langdon[1]; [1]University of Southern California

A copper alloy, Cu-0.1% Zr, was subjected to severe plastic deformation at room temperature using the procedure of high-pressure torsion. Disks were strained through different numbers of revolutions up to 10 turns with an applied pressure of 6.0 GPa in order to examine the evolution of hardness and microstructure. Microhardness results reveal lower values in the center regions in the early stages and there is a high degree of hardness homogeneity after 5 and 10 turns. For these conditions, the average grain sizes and the distributions of grain boundary misorientations are similar in the center and at the periphery of the samples. It is shown that there is a gradual evolution in both hardness and microstructure with increasing numbers of turns.

@inproceedings{Zhang2012StructuralPA, title={Structural Parameters and Strengthening Mechanisms in Cold-Drawn Pearlitic Steel Wires}, author={X. Zhang and A. Godfrey and Xiaoxu Huang and N. Hansen}, year={2012} }. X. Zhang, A. Godfrey, +1 author N. Hansen. Published 2012. Materials Science. Book. backend.orbit.dtu.dk. Save to Library. It has been established that, in the case of heavily cold drawn pearlitic steel wire, severe plastic strain leads to enhanced spheroidization of cementite due to relatively easy carbon dissolution from deformed cementite into pearlitic ferrite during bluing treatment.52â˜'55 Gridnev and Garririlyuk56 proposed that easy carbon dissolution during the bluing treatment of heavily cold drawn pearlitic steel wire could be. attributed to higher binding energy between dislocations in pearlitic ferrite and carbon atoms than that between the Fe atoms in cementite and the carbon atoms.Â Strengthening Mechanisms in Steels. G. Krauss, in Encyclopedia of Materials: Science and Technology, 2001. 3.1 Pearlite Strengthening. Chapter 7 dislocations and strengthening mechanisms. Issues to address â€¢ PLASTIC DEFORMATION and DISLOCATIONS * Dislocation motion * Slip in: -single crystals -polycrystalline materials * Dislocation motion and strength. â€¢ how to increase materials strength?Â â€¢ Strain hardening or cold working is the phenomenon of increasing hardness and strength of the a ductile material as a result of plastic deformation at temperatures far below its melting point. â€¢ Indeed, plastic deformation leads to the multiplication of dislocations, which strain fields start to interact more â€œcloselyâ€, hindering the dislocations motion.Â on the stress-strain behavior of low-carbon steel. 3nd drawn wire. 1st drawn wire. Initial wire. Cold Work Analysis. Microstructure and Strengthening mechanisms in cold drawn pearlitic steel wire. Submitted by Shubham Pandey , Anuvrat Singh Hada and Priyanshi Jain Undergraduates Dept. of Materials Science and Metallurgical Engineering MANIT, Bhopal. Physical Metallurgy of Steels Course Code: MSM 334. SUMMARY. This review paper deals with the strengthening mechanisms and strengthâ€"structure relationships which have been analyzed in a cold- drawn pearlitic steel with a structural scale in the nanometer range and a flow stress of about 3.5 GPa. The wires have been drawn up to a strain of 3.7 and the structures a Drawing process of pearlitic steel wire was investigated. Behavior of pearlite colonies on the surface and the central layer of the wire were researched, based on the multiscale computer simulation. Cementite lamellae orientation in relation to the drawing axis, interlamellar spacing and shape of cementite inclusions were key factors.Â [7] X. Zhang, N. Hansen, A. Godfrey, X. Huang, Microstructural evolution, strengthening mechanisms and strength structure relationship in cold-drawn pearlitic steel wire, Proceedings of the RisÃ¸ International Symposium on Materials Science, 33 (2012) 407-416. [8] M. Zelin, Microstructure evolution in pearlitic steels during wire drawing, Acta Materialia. 50 (2002) 4431-4447. DOI: 10.1016/s1359-6454(02)00281-1.