

**The 3rd International Symposium on
Advanced Structural Materials
- Deformation and Strengthening Mechanisms**

November 1-4, 2019; Chongqing, China

PROGRAM

Agenda

Friday, November 1 st 2019		
08:00-22:00	Registration and check in the Holiday Inn	
18:30-20:30	Welcome Reception: Meet on the First Floor of Holiday Inn	
Saturday, November 2 nd 2019		
Lecture Hall 101 of Science Building at Huxi Campus, Chongqing University (Meet on the first floor of Holiday Inn at 8:00 AM and take bus to conference hall)		
Time	Proceedings	Chair
8:30-8:45	Opening Speech	Qing Liu
Microstructural Design		
8:45-9:15	Effects of Deformation Microstructures on Recrystallization Dorte Juul Jensen <i>1 Technical University of Denmark, Denmark</i> <i>2 Chongqing University, China</i>	Xiaoxu Huang
9:15-9:45	Hetero-deformation Induced (HDI) Hardening in Heterostructured Materials Yuntian Zhu <i>1 Nanjing University of Science and Technology, China</i> <i>2 North Carolina State University, Raleigh, USA</i>	
9:45-10:15	Computational Design of Defect Engineering for Hierarchical Microstructures Yunzhi Wang Ohio State University, USA	
10:15-10:40	Photo and Coffee Break	
10:40-11:10	Strengthening and Work Hardening in Gradient Nanotwinned Metals Lei Lu <i>Institute of Metal Research, Chinese Academy of Sciences, China</i>	Dorte Juul Jensen

11:10-11:40	Rapidly-heating Induced Ultrahigh Stability of Nanograined Copper Xiuyan Li <i>Institute of Metal Research, Chinese Academy of Sciences, China</i>	
11:40-12.10	Dislocation Engineering: a New Alloy Design Strategy Mingxin Huang <i>University of Hong Kong, China</i>	
12:10-13:30	Lunch: The 3 rd Canteen of Huxi Campus, Chongqing University	
Advanced Characterization		
13:30-14:00	Synchrotron-based X-ray Characterization Techniques for Exploring the Deformation and Damage Mechanisms Yandong Wang <i>University of Science and Technology Beijing, China</i>	Lei Lu
14:00-14:30	Novel Neutron Imaging Modalities Søren Schmidt <i>Technical University of Denmark, Denmark</i>	
14:30-15:00	Local Stress Tailoring Effects of Layered Structure: a Coupled Synchrotron and Neutron Study Guohua Fan <i>Nanjing Tech University, China</i>	
15:00-15:30	Coffee Break	
15:30-16:00	Development of 3D Electron Microscopy Methods for Crystalline Materials Satoshi Hata <i>Kyushu University, Japan</i>	Yandong Wang
16:00-16:30	In-situ Investigations of Plastic Yielding in Aluminum Prepared by Spark-Plasma Sintering with Near-Micrometre Grain Size Andrew Godfrey <i>Tsinghua University, China</i>	

16:30-17:00	Multiscale Perspective of Deformation Twinning in Hexagonal Metals Jian Wang <i>University of Nebraska-Lincoln, USA</i>	
17:10	Take the bus to Holiday Inn	
18:30-21:00	Banquet: Meet on the first floor of Holiday Inn	
Sunday, November 3rd 2019		
Lecture Hall 101 of Science Building at Huxi Campus, Chongqing University (Meet on the first floor of Holiday Inn at 8:00 AM and take bus to conference hall)		
Plastic Deformation Behavior		
8:30-9:00	Quantitative Analysis of Serration Behavior in Al-Mg Alloys by Means of Digital Image Correlation (DIC) Nobuhiro Tsuji <i>Kyoto University, Japan</i>	Satoshi Hata
9:00-9:30	Special Twinning Behaviors in Al and Ti Alloys Induced by Dynamic Plastic Deformation Yanjun Li <i>Norwegian University of Science and Technology, Norway</i>	
9:30-10:00	In-situ Neutron Diffraction Analysis for Phase Transformation and Deformation Behaviors During Thermomechanical Processing Akinobu Shibata <i>Kyoto University, Japan</i>	
10:00-10:30	Coffee Break	
10:30-11:00	Constitutive Modelling of Large Strain Behaviour of Metals: with Emphasizing on HCP Polycrystals Peidong Wu <i>McMaster University, Canada</i>	Nobuhiro Tsuji
11:00-11:30	Quantitative Prediction of Texture Effect on Hall-Petch Slope for Magnesium Alloys Yunchang Xin <i>Chongqing University, China</i>	

11:30-12:00	Progress in Development of 3D Dislocation Crystallography Zongqiang Feng <i>Chongqing University, China</i>	
12:00-13:30	Lunch: The 3 rd Canteen at Huxi Campus, Chongqing University	
Advanced Light Alloys		
13:30-14:00	The Relationship Between Strain Localization at Grain Boundaries and Fracture in Al-Mg-Si-Mn Alloys Warren Poole <i>University of British Columbia, Canada</i>	Peidong Wu
14:00-14:30	Natural Age-Hardening in 6xxx Series Alloys Malcolm James Couper <i>Monash University, Australia</i>	
14:30-15:00	Development of Aluminum Auto Body Sheet Alloys Robert Sanders <i>Chongqing University, China</i>	
15:00-15:30	Coffee Break	
15:30-16:00	Quantitative Election Tomography with Applications to Studying Aluminum Alloys Jianghua Chen <i>Hunan University, China</i>	Warren Poole
16:00-16:30	Atomic-scale segregation of solutes in Mg and Al Alloys Jianfeng Nie <i>1 Monash University, Australia</i> <i>2 Chongqing University, China</i>	
16:30-17:00	Experimental Characterization and Modelling of the PLC Effect in an Al-Mg-alloy Knut Marthinsen <i>Norwegian University of Science and Technology, Norway</i>	

17:00-17:30	Grain Refinement in an Additively Manufactured Aluminum Alloy Mingxing Zhang <i>University of Queensland, Australia</i>	
17:40	Take the bus to Holiday Inn	
18:30-21:00	Banquet: Meet on the first floor of Holiday Inn	
Monday, November 4th 2019		
Lecture Hall 101 of Science Building at Huxi Campus, Chongqing University (Meet on the first floor of Holiday Inn at 8:00 AM and take bus to conference hall)		
Advanced Light Alloys		
8:30-9:00	Mechanical Properties of Sandwich-structured Aluminum Oleg Mishin <i>Technical University of Denmark, Denmark</i>	Jianfeng Nie
9:00-9:30	Prediction of strain rate effects on high temperature deformation of Mg alloy Adrien Chapuis <i>Chongqing University, China</i>	
9:30-9:45	Variant Selection Rules for Grain Boundary Alpha in a Metastable Beta-Ti Yu Zhang (PhD) <i>Chongqing University, China</i>	
9:45-10:00	Directly Measure of Grain Rotations in Nanocrystalline Nickel Qiongyao He (PhD) <i>Chongqing University, China</i>	
10:00-10:30	Coffee Break	
10:30-9:45	Precipitation in the Stretched AA7085 alloy Lu Wang (PhD) <i>Chongqing University, China</i>	Oleg Mishin
10:45-11:00	Precipitation in Mg-Sn(-Zn) Alloy Chaoqiang Liu (PhD) <i>Chongqing University, China</i>	

11:00-11:15	Simultaneous Increments of Strength and Tensile Elongation in Fine-grained Mg-3Gd Xuan Luo (PhD) <i>Chongqing University, China</i>	
11:15-11:30	Closing Speech	Xiaoxu Huang
11:30-13:30	Lunch: The 3 rd Canteen of Huxi Campus, Chongqing University	
13:30-16:00	Annual Meeting of International Joint Laboratory for Light Alloys and the "111" Project (Only the members of the International Joint Laboratory members and the "111" Project are invited)	Xiaoxu Huang

**The 3rd International Symposium on
Advanced Structural Materials
- Light Alloys: Microstructural Design and
Characterization**

Chongqing, China November 1-4, 2019

ABSTRACTS

Effects of deformation microstructures on recrystallization

D. Juul Jensen

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The deformation microstructures in metallic materials are generally inhomogeneous on several length scales. These variations are of utmost importance for the subsequent recrystallization of the deformed metals.

In the present talk, the effects on recrystallization of variations on three length scales within deformation microstructures will be discussed based on recent experimental observations. The three length scales cover variations within individual grains, between grains of different crystallographic orientations and on the sample scale. It will be shown that nucleation of recrystallization is enhanced in local regions with high stored energies, which is in accord with existing theories. It will however also be shown that the high local stored energy is not the only requirement for successful nucleation; the topology of the deformation microstructure is also essential. Likewise, for boundary migration during recrystallization it is not only the stored energy, which is determining the migration rate. Also for this process the details of the deformation microstructure needs to be considered. Here key parameters include misorientation between deformed matrix and recrystallizing grain, the type of deformation induced dislocation boundaries within the matrix as well as their geometrical alignment relative to the migrating boundary.

The experiments to be presented as case stories include measurements by SEM/EBSP, TEM and synchrotron X-ray diffraction to visualize the microstructures in 2D, 3D and 4D.

Hetero-deformation induced (HDI) hardening in heterostructured materials

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² *Department of Materials Science and Engineering, North Carolina State University,
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Heterostructured materials have been reported as a new class of materials with superior mechanical properties, which is attributed to the mechanical incompatibility. During tensile testing of a heterostructured sample, the soft domains will start plastic deformation with geometrically necessary dislocations piled up against the boundary with the hard domains. This produces back stress in the soft domains to make them appear stronger, while the stress concentration at the domain boundary exerts forward stress to the hard domain, making hard domain appear weaker. The combination of the back stress and forward stress represents hetero-deformation induced (HDI) stress to enhance the yield stress of the heterostructured material. The HDI stress also produces extra strain hardening to improve ductility. The “back stress” reported in the literature should be more accurately redefined as the HDI stress. In this presentation, I’ll analyze the evolution of back stress and forward stress and raise issues for future study.

Computational Design of Defect Engineering for Hierarchical Microstructures

Yunzhi Wang

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Highly heterogeneous or hierarchical microstructures (e.g., mixture of micron sized grains with nano-grains) or gradient microstructures have been shown to have a synergistic combination of (rather than trade-off between) strength and ductility, e.g., ultrafine-grain strength with coarse-grain ductility. In this study, we design computationally such hierarchical precipitate microstructures with well-controlled length scale of spatial heterogeneities, with an expectation of similar synergistic effect on strength and ductility. This is important because most structural materials are strengthened by second-phase particles. Using phase field simulation as the primary tool, we explore the possibilities to create various heterogeneous and hierarchical microstructures through defect engineering, including both structural and compositional defects. The former includes dislocations, stacking faults, incoherent or semicoherent interphase interfaces and grain boundaries, while the latter includes precursory spinodal decomposition, congruent dissolution of precipitates in pre-prepared two-phase mixtures upon up-quench, and concentration modulated in the parent phase produced either naturally by solute segregation during solidification (as in 3D printing) or engineered by interdiffusion. In addition to the conventional nucleation and growth, these defects could activate simultaneously various non-conventional transformation pathways, including congruent precipitation, pseudo-spinodal decomposition, segregation transition and localized phase transformation, leading to heterogeneous and hierarchical microstructures of well-controlled spatial distributions. These simulation results may motivate and guide further experimental efforts on developing the next generation of advanced structural materials (including orthopedic implants) of unprecedented properties.

Strengthening and work hardening in gradient nanotwinned metals

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Understanding structural gradient related deformation and mechanical behavior is crucial as gradient structures ubiquitously exist in a wide range of engineering materials as well as in nature lives. Inspired by excellent strength-ductility synergy and superior fatigue resistance of highly oriented nanotwins, we explored the mechanical performance of a gradient nanotwinned structure with highly tunable structural gradients. A large structural gradient leads to superior work hardening and a high strength, beyond even its strongest component. Systematic experiments and atomistic simulations reveal that the concurrent strengthening and work hardening of gradient nanotwinned structures are controlled by a unique patterning of ultrahigh densities of geometrically necessary dislocations in grain interiors. This work sheds light on the design strategy of structural gradient materials and introduces a superior strength-hardening synergy approach in metals.

Rapidly-heating induced ultrahigh stability of nanograined copper

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Chinese Academy of Sciences, Shenyang, China

Abstract: Inherent thermal and mechanical instability of nanograined materials bottlenecks their processing and technological applications. We discovered that rapidly heating may trigger intensive grain boundary relaxation of pure Cu nanograins with sizes up to submicrometers, a length-scale with notable instability in metals. The rapidly-heated Cu nanograins remain stable at as high as $0.6 T_m$, even higher than the recrystallization temperature of deformed coarse-grained Cu. The thermally-induced grain boundary relaxation originated from generation of high-density nanotwins offers a novel approach to stabilizing nanostructured materials.

Key Words: Grain boundary relaxation, Stability, Nanograined Metals

Dislocation engineering: a new alloy design strategy

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Improving the strength of alloys frequently results in a reduction in ductility, which is known as the strength-ductility trade-off in metallic materials. Current alloy design strategies for improving the ductility of ultrahigh-strength alloys mainly focus on the selection of alloy composition (atomic length scale) or manipulating ultrafine and nano-grained microstructure (grain length scale). The intermediate length scale between atomic and grain scales is the dislocation length scale. A new alloy design concept based on such dislocation length scale, namely *alloy design by dislocation engineering*, is illustrated in the present work. This dislocation engineering concept has been successfully substantiated by the design and fabrication of a deformed and partitioned (D&P) steel with a yield strength of 2.2 GPa and a uniform elongation of 16%. In the D&P steel, high dislocation density can not only increase strength but also improve ductility.

Synchrotron-based X-ray characterization techniques for exploring the deformation and damage mechanisms

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The synchrotron-based high-energy X-ray diffraction and X-ray micro-diffraction techniques provide effective *in-situ* tools for studying the multi-scale distribution of stress field and grain rotation. The spatial-temporal complexities of submicrostructure evolution buried in bulk materials during plastic deformation related to various fundamental mechanisms, such as dislocation motions and deformation twinning, can be thus revealed. The in-situ measurements can also be bridged to various numerical simulations for elucidating the stress/strain accommodations. Here we will present recent important progresses in our group on the experimental findings and simulations on microscopic mechanisms of deformation and damage in some typical metals with a stress/microstructure gradient. A new perspective on the role of both GND dislocations and dislocation pile-ups in stress accommodations that cause the appearance of both high strength and toughening in some advanced structured materials will be given.

Novel neutron imaging modalities

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Abstract: The talk will give an overview of recent advancements in neutron imaging regarding (1) 3D characterization of crystalline and magnetic structures in the bulk of materials [including: 1,2,3] and in (2) neutron phase contrast tomography [4]. A discussion of the availability of these methodologies using white neutron beams and time resolved neutron beams is made.

References:

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Local stress tailoring effects of layered structure: a coupled synchrotron and neutron study

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Ductility is of critical importance for structural materials for both manufacturability and performance. Strengthening materials while sustaining the ductility stands as one of the most challenging issues for materials design. Structural architecture has been proved to be a novel method to evade the strength-ductility dilemma. Many theories, i.e. back stress strength and interface affected zone, have revealed that local deformation with structural architecture is highly constrained and local stress state has a strong impact on the performance of material which might lead to the variation of deformation mechanism or catastrophic failure. However, the limitations of conventional characterization methods lead to scarce observation on evolution of microstructure as well as local stress state at the same time, which is essential to the understanding of superior properties of heterogenous materials.

Herein, we choose Ti-Al layered structure as an ideal model to investigate the origin of superior properties of heterogenous materials. Neutron diffraction, high energy X-ray diffraction and Laue diffraction are utilized and then the data is coupled. Despite the complex Laue pattern shape, which is induced by plastic deformation, is hard to analyze with general software (XMAS), we made our way to extract the distribution of dislocation density and the slip system could also be indexed by simulation. The results suggest the existence of local stress transferring during elastic-plastic deformation stage in Ti-Al layered structure. Then, the new stress state would control subsequent deformation and exert the deformation potential of composite. We suppose the local stress transferring is attributed to the inconsistent yield strength of Ti and Al which lead to the sequential yielding of different layers. Thus, the local stress could be tailored by controlling the properties of components. This hypothesis has been utilized into Ti-Ti layered composites. The yield strength of each layer is manipulated by controlled grain size and the better strength-ductility combination has been achieved. The combination of neutron diffraction, high energy X-ray diffraction and Laue diffraction makes the in-

situ, high-throughput and non-destructive observation available. On the light of these characterization methods, the local stress tailoring effect in heterogenous materials is revealed. The properties improvement in heterogenous material with local stress tailoring is expectable with further research.

Development of 3D electron microscopy methods for crystalline materials

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Abstract: There have been researches on the development of 3D electron microscopy observation methods towards a more in-depth understanding of deformation behaviors in crystalline materials. Here, the word, “crystalline”, usually contains the following issues: (i) how to avoid diffraction contrast in acquiring the material contrast in SEM or the mass-thickness contrast in TEM/STEM for 3D visualization of objects such as a secondary phase in a matrix phase; and (ii) how to acquire appropriate diffraction contrast images of an object that can be reconstructed into a 3D volume of the object such as dislocations.

In the case of TEM/STEM, diffraction contrast is often higher than mass-thickness contrast and violates the projection requirement [1]. Therefore, the issue (i) described above is essential for electron tomography (ET) in which acquisition of a tilt-series data set is mandatory, and use of high-angle annular dark-field (HAADF) STEM is a standard solution [2, 3]. As far as the present author knows, SEM-FIB serial sectioning and 3D X-ray microscopy [4] can be free from the issue (i) and also demonstrate promising resolution powers and functionalities, which are sometimes in competition with those of ET.

On the other hand, the issue (ii) is common among ET, SEM-FIB serial sectioning and 3D X-ray microscopy. Various 3D diffraction contrast imaging methods at the nm scale have been reported [5–12]. In these 3D imaging methods, the issue (ii) during 2D image data set acquisition has been solved by different ways, such as maintaining a diffraction condition [5–9]; acquiring many images under different diffraction conditions [10]; and optimizing 3D reconstruction procedure [11, 12].

The author has been contributing to researches on the methodology of ET for crystalline materials [13, 14] where the issues (i) and (ii) are still essential for the establishment of those methods. The current status and future directions of these ET methods will be discussed.

Reference:

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In-situ investigations of plastic yielding in aluminum prepared by spark-plasma sintering with near-micrometre grain size

Andrew Godfrey

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A detailed microstructural characterization of as-synthesized samples of spark plasma sintered aluminium has been carried out using electron backscatter diffraction, transmission electron microscopy and high-brightness X-ray diffraction. As part of ongoing work to understand the onset of plastic flow in these samples in-situ tensile loading experiments have been carried out using high energy synchrotron radiation, supplemented by investigations in the scanning electron microscope using digital image correlation (DIC). For the synchrotron studies a white-beam Laue 3D micro-diffraction technique has been used allowing the collection of diffraction signal from a volume with a resolution of 1 μm in all three dimensions. The orientation data obtained from the micro-diffraction are used to estimate the local variation, and changes during loading, of geometrically necessary dislocation density, and correction factors are suggested for voxels where neighbors are missing in either one or two dimensions. The results demonstrate a considerable heterogeneity in deformation in the early stages of plastic deformation, also seen in the DIC data obtained on samples deformed to larger tensile strains.

Quantitative election tomography with applications to studying aluminum alloys

Jianghua Chen

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Developments of high-strength aluminum alloys have always faced a difficult problem: owing to their small size, the early-stage strengthening precipitates are difficult to characterize in terms of composition, structure and evolution. Here we employ atomic-resolution transmission electron microscopy (TEM) imaging and first-principles energy calculations to address these problems. Recent years, we have investigated tens of typical high strength aluminum alloys, such as 2xxx (AlCu, AlCuMg and AlCuLiMg), 6xxx (AlMgSi and AlMgSiCu) and 7xxx (AlZnMg and AlZnMgCu) alloys, with different compositions and with varying thermal processes for understanding their property-structure-process correlations. Using aberration-corrected high-resolution TEM (HRTEM) and aberration-corrected scanning TEM (STEM), much of our attention has been paid to revisit the strengthening precipitates in these important alloys and to clarify the controversies left in the past about their precipitation behaviors. Our study demonstrates the followings:

(1) Atomic-resolution imaging in STEM can provide straightforward structure models at the atomic-scale, whereas atomic-resolution imaging in HRTEM with rapid quantitative image simulation analysis can provide the refined structures with high precision beyond the resolution limitation of the microscope. The combination of the two techniques can be more powerful in solving difficult structure problems in materials science.

(2) Most of the early-stage precipitates in aluminum alloys are highly dynamic in both composition and structure. Typically, having their characteristic genetic skeletons to guide their evolution, these dynamic precipitates initiate, mature and grow with thermal aging following characteristic evolution paths. The fine precipitation scenarios revealed in our studies are rather different from previous understandings in the textbooks and literatures published thus far.

Progress in development of 3D dislocation crystallography

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Quantitative characterization of dislocation structures in three dimensions (3D) is of vital importance to fully understand many dislocation-related dynamic processes in materials science. Our recent years' effort has well promoted the establishment of a novel method named 3D dislocation crystallography which can simultaneously characterize the geometric, crystallographic and energetic features of dislocations. In this presentation, the recent progress in the improvement of the method will be introduced, and its applications in revealing complicated dislocation structures in a quenched aluminum alloy and a deformed pure aluminum will be presented. The obtained results with good coupling well unveil various characteristics of the dislocation structures, further enlightening us for a better knowledge of dislocation generation and evolution under thermal and mechanical loadings.

Multiscale Perspective of Deformation Twinning in Hexagonal Metals

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68588

Twinning and de-twinning, which are the dominant deformation mechanisms in hexagonal-close-packed (HCP) metals, exhibit more complex nucleation and propagation mechanisms than those associated with dislocation slip and those in cubic structures (FCC and BCC). Specifically, twinning and de-twinning are directional, involve atomistic shuffling, and they induce a strong crystallographic reorientation. Twin nucleation, a necessary first stage of twinning, seems to invariably take place at grain boundaries in hcp materials, and to involve complex dislocation reactions. After twin nucleation, twin propagation and growth seem more complicated than that in cubic crystals because of the formation of serrated coherent twin boundaries. In this talk, I will focus on the fundamental understanding of nucleation, propagation, and interactions of deformation twins and their effects on mechanical behavior according to atomistic simulations and in situ microscopic observations. These findings provide theoretical base for researchers to revisit experimental data, rebuild the frame of twinning mechanisms including nucleation and propagation of twins, and advance the development of materials modeling tools at meso- and macro- scales as well as alloy design.

Constitutive Modelling of Large Strain Behaviour of Metals: with Emphasizing on HCP Polycrystals

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We first introduce various polycrystal plasticity models including the Visco-Plastic Self-Consistent (VPSC) model, the Elastic-Plastic Self-Consistent (EPSC) model, and the Elastic Visco-Plastic Self-Consistent (EVPSC) model, as well as twinning models including the Predominant Twin Reorientation (PTR) model and the Twinning and De-Twinning (TDT) model, with emphasizing on characteristic differences between these models. Then, we demonstrate that the EVPSC-TDT model is able to capture key features of large strain behaviour of HCP materials (such as Mg, Ti and Zr alloys) under various deformation processes including uniaxial tension and compression, plane strain compression, simple shear, and torsion. Some of recent improvements to the EVPSC-TDT model are also introduced.

Special twinning behaviors in Al and Ti alloys induced by dynamic plastic deformation

Yanjun Li

Department of Materials Science and Engineering, Norwegian University of Science and Technology (NTNU). 7491 Trondheim Norway

With the nature of high strain rate impact loading, dynamic plastic deformation (DPD) has been proved an efficient method to produce nano-twin structures in FCC metals and alloys low stacking fault energies (SFE). Our research work shows that DPD can also change the deformation behavior of hcp metals and high stacking fault energy Al alloys. In a coarse-grained Al-7Mg alloy, a significant fraction of incoherent $\Sigma 3\{112\}$ twin boundaries (ITBs) could be generated by DPD. A systematic study shows that these ITBs have formed by gradual lattice rotation from copious low-angle deformation bands through $\langle 111 \rangle$ -twist Σ boundaries like $\Sigma 43$, $\Sigma 31$, $\Sigma 21$, $\Sigma 13$ and $\Sigma 7$. During DPD process of commercial purity (CP) Ti at low deformation strain, it is found that a large fraction of kink bands could form at low deformation strains. With increasing deformation strain, the kink bands gradually evolved into $\{11-21\}$ twins. This is a new mechanism to form twin boundaries in Ti, which is completely different from the conventional deformation twinning. The mechanism for the special twinning behaviors in the two alloys induced by DPD has been discussed.

Quantitative Analysis of Serration Behavior in Al-Mg Alloys by Means of Digital Image Correlation (DIC)

Myeong-heom Park ¹, Xiaodong Lan ², Akinobu Shibata ^{1,2}, Nobuhiro Tsuji ^{1,2*}

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In Al-Mg alloy systems, it is known that a drastic fluctuation in flow stress, so-called “serration”, occurs during deformation. Although many studies on the serration behavior of Al-Mg alloys have been reported, grain size effect on serration has not yet been clarified. In order to explore serration behavior of Al-Mg alloys having different grain sizes, we quantitatively characterized macroscopic deformation behavior by digital image correlation (DIC) method. We found that an Al-2.5Mg alloy with the mean grain size of 12 micro-meter showed much more remarkable serration behavior than that with the average grain size of 110 micro-meter. It was also found from the DIC analysis that the fine-grained Al-Mg alloy showed more obvious strain-localized band than coarse-grained one.

Quantitative prediction of texture effect on Hall–Petch slope for magnesium alloys

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The high texture dependence of a Hall–Petch slope (k) for Mg alloys has been frequently reported. Several important equations used to calculate k have been previously developed, and although they seem to work well for fcc and bcc materials, they often fail to predict the highly texture-dependent k in Mg alloys. A new equation based on the dislocation pile-up model was developed in this study. The validity of this new equation was tested through a comparison of the predicted k values with the experimental values as well as the calculations from older equations. The results indicate that the new equation can achieve an accurate prediction for several previously reported texture effects on k , whereas the k values predicted by the older equations often exhibit a clear deviation. The reasons for this were analyzed and discussed. The strong deformation anisotropy for Mg alloys leads to a complex texture effect on k , including the effects from both external and internal stresses. Both effects are well expressed in the new equation. In contrast, the old equations consider the external stress effect, but do not express well the internal stress effect. In addition, the old equations consider only the predominant deformation mode. However, our results indicate that the activation of a portion of another deformation mode other than the predominant one plays an important role in the k value. Using the important parameters of the new equation, the mechanisms for several texture effects on k as previously reported were discussed and new understandings were obtained.

In-situ neutron diffraction analysis for phase transformation and deformation behaviors during thermomechanical processing

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Thermomechanical processing, i.e., precisely controlled rolling and heat treatment at elevated temperature, has been practically used to make commercial large steel products. Nowadays, the process utilizing dynamic ferrite transformation, which is a ferrite transformation occurring during deformation of parent austenite phase, has been received much attention as a new thermomechanical processing, because ultrafine-grained ferrite structures with grain sizes less than 1 μm can be achieved through dynamic ferrite transformation. To date, however, nature of dynamic ferrite transformation and formation mechanism of ultrafine-grained structure are still unclear. Recently, we have developed a physical thermomechanical processing simulator for in-situ neutron diffraction analysis which is applicable to BL19 “TAKUMI” in the MLF at J-PARC. In this presentation, we report the nature of dynamic ferrite transformation (transformation mode and formation mechanism of ultrafine-grained structure) analyzed by in-situ neutron diffraction analysis. We found that the lattice constant of dynamically-transformed ferrite increased and then decreased significantly during the deformation. Assuming that the partitioning behavior changed from para- to ortho-equilibrium during transformation, the change in lattice constant of ferrite can be well explained. As a result, we concluded that dynamic ferrite transformation occurred in a diffusional manner, whose partitioning behavior changed from para- to ortho-equilibrium with the progress of transformation. Moreover, based on the fact that the dislocation density in the austenite phase tended to decrease with increasing strain, we proposed that dynamic recrystallization of dynamically-transformed ferrite was the main mechanism for the formation of ultrafine-grained structure.

**The relationship between strain localization at grain boundaries and fracture in
Al-Mg-Si-Mn alloys**

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The ductility of Al-Mg-Si-Mn-Fe extrusion alloys is an important property which affects the forming of automotive parts and the in-service behaviour, e.g. crash performance. The precipitation of Mg-Si particles on the grain boundaries during quenching and artificial aging can reduce the fracture strain of the material due to i) strain localization at the grain boundary due to the formation of a precipitate free zone adjacent to the grain boundary, and ii) reduction of the cohesive strength of the grain boundary. In this study the effect of quench rate and aging treatment on strain distribution within the grains and across the grain boundaries has been quantified using high resolution digital image correlation. The results show the degree of strain localization at the grain boundary is dependent on the cooling rate after the solution treatment. The localization correlates with the width of the precipitate free zone and the cohesive strength relates to the density of precipitates on grain boundaries.

Natural Age-Hardening in 6xxx Series Alloys

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The room temperature equilibrium solid solubility of many elements, or combinations of elements, in aluminium is very low. For Al-Mg-Si ternary alloys, the solubility is reduced by the formation of the equilibrium phase (Mg_2Si) and further reduced by an excess of Mg. Super-saturation of solute can be realised by quenching a solid solution from within the alpha phase region, whilst avoiding incipient melting. The subsequent precipitation age-hardening (sequence, compositions and structures) continues to be studied as techniques improve, but the evolution during natural ageing is not as easily quantified despite significant hardness increases.

The size, number density and fraction of solute in non-random clusters formed during natural ageing, as typically measured by 3DAP, does not seem to provide an adequate explanation for the hardness increases observed. A model for the hardness as a function of Mg and Si alloy content suggests the presence of equal amounts of Mg-Si has a higher hardening effect than excess of either solute separately.

Development of Aluminum Auto Body Sheet Alloys

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The use of aluminum sheet on automobiles dates to the early 1900's but current issues with automotive emissions and CO₂ emissions are driving automakers worldwide to adopt aluminum sheet in larger volumes. The increased demand has forced significant changes in the aluminum rolling industry to supply the quality and quantities of sheet needed by automotive customers. Currently 5xxx and 6xxx alloys make up the largest portion of aluminum sheet production, but 2xxx alloys were critical in early applications and 7xxx alloys have entered the picture where strength is most critical. This paper will review the key developments and inflection points in alloy development and manufacturing capabilities over the past 100 years. Key contributions from aluminum companies in Europe, North America, and Japan have brought aluminum sheet to its current position as an economically viable solution for high volume auto production.

Atomic-scale segregation of solutes in Mg and Al alloys

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Homo-phase and hetero-phase interfaces play a critical role in plastic deformation and ultimately in controlling mechanical properties of many structural materials. A major technical barrier to the achievement of unprecedented properties, and thus wider application, of these materials is the control of boundaries during thermomechanical processes and applications. Defects in such boundaries, especially segregated solute atoms, are often small in scale and their detection and characterization are beyond the capability of conventional electron microscopy techniques. Consequently, gaining fundamental insights into such defects has proved elusive. Advances in aberration-corrected scanning transmission electron microscopy (STEM), especially the techniques of high-angle annular dark-field STEM and energy-dispersive X-ray spectroscopy STEM, provide an opportunity to reveal the distribution and identity of solutes at the atomic scale. This presentation will review recent progress on the characterization of segregated solute atoms in boundaries of some Mg and Al alloys. Implications of such observations on intelligent design for achieving better properties will be discussed.

Experimental characterization and modelling of the PLC effect in an AlMg-alloy

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Abstract: Atoms in solid solution may move during deformation, by atomic jumps or short-range diffusion, causing dynamic strain aging (DSA) phenomena. DSA can make the stress-strain curve become dis-continuous and serrated at certain temperatures and strain rates, which is known as the Portevin–Le Chatelier (PLC) effect (Le Chatelier, 1909). Uniaxial tension tests have been utilized to study the thermo-mechanical response of an AA5182 sheet. The measurements range from the strain rate of 10^{-4} to 10^{-1} s^{-1} at temperatures of 298K, 325K, 378K, and 418K. The digital image correlation (DIC) technique was used to characterize the temporal-spatial behavior of localization bands. A local virtual extensometer was used to accurately measure the stress-strain curves, and the critical strain of the PLC effect are detected by plotting the strain rate field maps. A constitutive model is proposed to predict the stress–strain response over the studied temperature and strain rate ranges. This calibrated model is also used to evaluate the onset of plastic instabilities and solutes' influence on the work hardening behavior. It is found that the competition between work hardening and strain rate softening plays a key role in the PLC instabilities.

Keywords: Thermo-mechanical behavior, Portevin–Le Chatelier effect, Digital image correlation

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Grain refinement in an additively manufactured aluminum alloy

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A new grain refiner has been successfully identified for additively manufactured (AMed) aluminum alloys through crystallographic calculation based on the edge-to-edge matching model. Small addition of the grain refiner can not only completely eliminated the columnar structure resulted from epitaxial growth, but also significantly refined the grains in the melt pools. As a result, the isotropic mechanical properties were obtained in the AMed aluminum alloy. The grain refinement mechanism was also discussed.

Mechanical properties of sandwich-structured aluminum

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A heavily rolled AA1050 sample with a microstructurally continuous sandwich structure, characterized by distinct microstructural evolution in the center and subsurface layers, has been annealed at different temperatures for 2 h with the objective of establishing optimized combinations of strength and ductility. It is observed that a large reduction in the fraction of high angle boundaries taking place during recovery in the subsurface layers results in delayed onset of recrystallization compared to that in the center layer, where the change in the fraction of high angle boundaries during recovery is small. The different recrystallization rates in this sandwich structure facilitate control of the overall recrystallized fraction, and can therefore be advantageous in obtaining a desired combination of both strength and ductility. A good combination of moderate strength and intermediate ductility is obtained in the material annealed at 250 °C and 270 °C, where the area fractions of recrystallized microstructure in the center are 7% and 36%, respectively. By analyzing the dependence of mechanical properties on the microstructure it is found that the mechanical strength can be described by a simple composite model using a rule of mixtures.

Prediction of strain rate effects on high temperature deformation of Mg alloy

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The plastic deformation behavior of metals can be predicted using crystal plasticity models. The visco-plastic self-consistent model (VPSC) is often used to reproduce the complex behavior of HCP metals such as Mg at room temperature. The VPSC uses a rate sensitive equation that allows convergence of a single solution. Simulations can be done with arbitrary strain rate sensitivity (SRS) parameter, as it is done at low temperature, or with the real SRS exponent, that can be measured by tests at different strain rates at high temperature. In this study, for Mg alloy AZ31, the strain rate sensitivities of all the deformation modes are estimated at 250°C: basal slip and twinning have low strain rate sensitivity, whereas prismatic and pyramidal $\langle c+a \rangle$ slips have a SRS $m=0.08$ and $m=0.1$, respectively. This result in a transition from slip dominated deformation at low strain rate, to twin dominated deformation at high strain rate. The study also shows the effect of strain rate and SRS on predicted deformed textures and plastic anisotropy.

Variant Selection Rules for Grain Boundary Alpha in a Metastable Beta-Ti

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The final mechanical properties of titanium alloys are strongly influenced by β -transformed microstructures, especially the morphology and crystallographic orientation of α phase. During cooling from the β field, the α phase first precipitates at the prior β grain boundaries (GBs) and maintains the Burgers orientation relationship (BOR) with one of two adjacent β grains. This GB α layer is considered as the origin of low ductility, leading to intergranular fracture. Therefore, it is crucial to figure out the crystallography of GB α and its variant selection rules. In this talk, five parameters of GBs in a TB8 alloy were determined by combined use of electron backscatter diffraction (EBSD) and focused ion beam (FIB) techniques. Then, a systematic investigation regarding the use of multiple variant selection rules including the effect of both misorientation and grain boundary plane (GBP) inclination was carried out. The results suggested that rule 1 based on the double BOR could shortlist candidates among 24 possible variants when disorientation angle $\theta_m < 10^\circ$. To further refine data predicted by rule 1, five additional rules dealing with arrangement of GBP were also analyzed. Overall, the combined use of empirical rules looks promising for predicting which variant to select at prior β GBs.

Directly Measure of Grain Rotations in Nanocrystalline Nickel

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Abstract: Grain rotation is a well-known phenomenon during high temperature deformation and recrystallization of polycrystalline materials. In recent years, grain rotation has also been proposed as a plasticity mechanism for nanocrystalline grains with grain size less than 100 nm. Here, we present a non-destructive *in-situ* measurement of microstructural evolution in nanocrystalline Ni metals for the first time by correlation of *in-situ* nanomechanical testing and three dimensional orientation mapping in transmission electron microscope. The microsturctral evolution as it undergoes plasitic deformation was *in-situ* followed. And the rotation of individual nanograins was tracked to discuss the possible deformation mechanisms.

Keywords: Nanocrystalline Ni, Grain rotations, 3D-OMiTEM, and In-situ deforation

The Effect of Stretching on Precipitation in AA7085 alloy plate

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Aluminum alloy plates are normally stretched 1-4% after quenching to relieve residual stresses induced by rapid cooling. However, stretching is often observed to reduce the strength of T6 or T7 temper plate, AA7085 alloy plate was investigated in this paper. Dislocation density measurements of the quenched plate show that work hardening of the quenched plate occurs during stretching. SAXS data show that the size of GP zones in the stretched sample is smaller than that of the unstretched sample after heating to the artificial aging temperature. This is because the dislocations act as nucleation sites for GP zones. The dislocations also aid the diffusion of solute atoms, leading to the formation of η phases at dislocations from GP zones after soaking for 24 hours at 120°C.

Precipitation in Mg-Sn(-Zn) alloy

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Mg-Sn based alloys have received considerable attention in recent years due to their potential to develop high strength wrought magnesium alloys. These alloys are precipitation hardenable as the solid solubility of Sn decreases significantly with the decrease in temperature. The precipitation process has been traditionally accepted as involving the exclusive formation of the equilibrium β -Mg₂Sn phase; any metastable phases have not been reported so far in those alloys. Considering that the formation of metastable phases is very important in the whole precipitation process, it is necessary to systematically investigate whether there is any metastable phase forming during ageing, especially at the early stage of ageing. In addition, β precipitates, as the main strengthening phase, have a coarse distribution in binary alloys, which results in a poor age-hardening response of the binary alloys. Additions of Zn can remarkably improve the age-hardening response of binary alloys by refining the distribution of β precipitates, but its role remains unclear.

Therefore, in our studies, we used atomic resolution high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) imaging and energy dispersive X-ray spectrometry (EDS) spectroscopy techniques to systematically characterize the precipitates formed in aged samples of Mg-9.8Sn (wt.%) and Mg-9.8Sn-1.2Zn alloys. In the binary alloy, we found the formation of GP zone and a metastable phase designated β' (Fig. 1) prior to the equilibrium β phase. Both of them have a plate morphology with their habit planes parallel to the basal plane of magnesium matrix. β' precipitate has a L1₂ structure (space group $Pm\bar{3}m$, $a = 0.453$ nm) and a Mg₃Sn composition. It forms from either GP zones or magnesium matrix and can transform *in situ* to the β phase during the ageing process. In the ternary alloy, we found that Zn atoms invariably segregate to the interphase boundaries between β precipitates and α -Mg matrix (Fig. 2), irrespective of the interfacial structures and orientation relationships between the β precipitates and the α -Mg matrix and ageing conditions. These findings shed light on the precipitation sequence in Mg-Sn based alloys and provide insight to the understanding of the

enhanced nucleation and thermal stability of β precipitates in the Zn-containing Mg-Sn alloys.

Simultaneous increments of strength and tensile elongation in fine-grained Mg-3Gd

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Abstract: Fine-grained Mg-3Gd samples were prepared by accumulative roll-bonding processing and subsequent annealing. Based on observations of the mechanical behavior of Mg-3Gd samples characterized by tensile test at room temperature, a reversion of the trade-off, simultaneous increments of flow stress and tensile elongation, were observed in the alloy. Structural evolution is analyzed as a function of strain to identify dislocation-based mechanisms, underpinning changes in strength and ductility with increasing tensile strain. Based on quantification of structural parameters, strengthening mechanisms are discussed and a strength-structural relationship is proposed.

Keywords: Mechanical properties; Deformation mechanism; Yield point phenomenon; Dislocation dynamic recovery; Mg-3Gd