Monday, May 25, 2026

C. Smith Award Presentation

Monday, 9:30-10:30

David Srolovitz: The University of Hong Kong

Symmetry, Structure and Stress Effects on Gain Boundary Migration and Microstructure Evolution

The structure of grain boundaries can have profound effects on how grain boundaries (GBs) move and how microstructures evolve that can be traced back to symmetry and bicrystallography. I will review some simple symmetry/bicrstyallography concepts that lead to the idea that GBs move by the motion of GB-constrained line defects, disconnections. Then, I will demonstrate that GB migration necessarily leads to stress generation, so-called shear coupling, and that these stresses fundamentally change of how microstructure evolves. While the suggestion by CS Smith that GB curvature (and interface energy) drives GB migration remains valid, stress provides an additional driving force for GB migration and disconnection dynamics modifies the classical curvature flow picture. Next, I will present multiple types of simulations that all demonstrate that inclusion of these effects are needed to understand the higher resolution experimental microstructure evolution data that have become available in the past 15 years. Finally, I will demonstrate that symmetry considerations demonstrate that GB mobility depends on the direction of GB migration and its implications for microstructure evolution.

Experimental Techniques I (MDCL 1110)

Monday, 10:50-11:20

Mikael Malmstrom: Swerim

Laser ultrasonics for microstructure monitoring ex situ and in situ in the metal industry

Hans Magnusson, Johan Wikmark Lönnqvist, Hampus Kreuger, Bevis Hutchinson

Laser ultrasonics (LUS) provides non-contact, real-time measurements of microstructure in hot and moving steel, enabling integration into thermal and thermomechanical processes. At Swerim, LUS research has evolved over 25 years from feasibility studies to industrial deployment, including an online grain-size gauge at SSAB Borlänge hot strip mill. This gauge converts ultrasonic attenuation into austenite grain size and now also aim to leverage the shear-wave echo splitting to estimate accumulated strain and infer recrystallized fraction (RX), offering robust feedback for process control without reducing measurement frequency. To complement mill measurements, the GLUS® testbed, combining GLEEBLE and

LUS, captures microstructure evolution during hot compression in most steels. LUS resolves dynamic, static, and metadynamic recrystallization sequences and subsequent grain growth, while longitudinal wave velocity trends indicate texture changes. Simulations of multi-stand finishing schedules demonstrate GLUS as a powerful tool for validating alloy concepts and deformation strategies. Recent developments include improved optical working distance for easier gauge placement and feasibility studies (LUMHEAT project) exploring benefits across Nordic plate, bar, and strip mills. Together, these advances establish LUS as a versatile platform for real-time microstructure monitoring, both in situ for process control and ex situ for mechanistic understanding of recrystallization and grain growth.

Keywords: Laser ultrasonics, microstructure monitoring, process control, in-situ measurements.

Monday, 11:20-11:40

Grünsteidl Clemens: Research Center for Non Destructive Testing GmbH

Determining the stiffness tensor of FCC-iron at elevated temperatures by observing abnormal grain growth

Christian Kerschbaummayr, Edgar Scherleitner, Christian Hoflehner, Markus Sonnleitner.

Despite the practical relevance of FCC-iron, surprisingly sparse experimental results on its crystalline elastic stiffness tensor at elevated temperatures are available. We ascribe this mainly to the difficult handling at high temperatures (912-1394°C) and the problem of obtaining a crystalline sample. Laser-ultrasound (LUS) measurements of longitudinal sound velocity on polycrystalline samples in the required temperature range previously helped to partly validate ab-initio calculations of the stiffness tensor. However, to fully determine the 3 independent entries of the cubic stiffness tensor, additional information is required. Using a LUS-technique based ultrasonic plate resonances, we aimed to extend these measurements by the transverse sound velocity. Below 900°C, our measurements show good agreement to velocities calculated from reference BCC-iron stiffness tensor values (Dever 1972) – we thus consider the method as well as the sample suitable. Above the phase transition temperature to FCC-iron, a significant mismatch to transverse velocities calculated from ab initio models is observed and suggests a correction of the tensor values. Interestingly, a strong and repeatable change in sound velocities is observed at around 1100°C, where grain growth is expected. Our hypothesis to explain this behavior is that abnormal grain growth with a sharp texture formation is occurring. Assumptions on the occurring texture and its reconstruction form EBSD data allow us to use the measurements after grain growth as additional information. Based on it, we attempt to fully determine the elastic stiffness tensor for FCC-iron.

Keywords: Laser Ultrasound, Elasticity, FCC iron, abnormal grain growth.

Monday, 11:40-12:00

Roonak Khamooshian: KTH

In-Situ Laser Ultrasonic Monitoring and Computational Modeling of Grain Growth in Case hardening steel

Sven Haglund, Jerome Senaneuch, Johan Fahlkrans, Greta Lindwall, Annika Borgenstam.

Low-pressure carburizing (LPC) is an alternative to traditional gas carburizing. Unlike traditional methods, LPC uses short pulses of carbon-rich gas to transfer carbon, offering significantly lower CO_2 emissions, potential energy savings, and productivity gains. Although LPC requires higher initial investment, improved efficiency could accelerate its adoption. LPC furnaces allow high-temperature carburizing, but most commercial case-hardening steels suffer grain growth at elevated temperatures, reducing fatigue strength. This study focuses on understanding grain growth mechanisms in 20NiCrMoS2-2 and developing approaches for alloy design to maintain fine-grained structures during high-temperature carburizing. Experiments were conducted to study grain growth using laser ultrasonic measurements, for in situ grain size measurement.

Samples were heated across varied temperatures and times and then rapidly cooled without any subsequent heat treatment. Microstructural characterization using Electron Backscatter Diffraction (EBSD) was preformed to validate ultrasonic measurements and provide detailed grain size distribution. EBSD analysis was further used for parent grain reconstruction to enhance interpretation of prior austenite grain structure. Transmission Electron Microscopy was employed to analyze precipitates and their role in grain boundary pinning. Thermodynamic and kinetic simulations were conducted using a Thermo-Calc module employing a mean-field approach to predict precipitate nucleation, growth, and evolution during heat treatment. These simulations facilitated model parameter calibration and supported the development of predictive alloy design strategies aimed at mitigating grain growth at elevated temperatures. The combined experimental and computational approach establishes a framework for designing alloys that resist grain growth at high temperatures, thereby improving fatigue performance while reducing heat treatment cycle time.

Keywords: Grain Growth, Laser Ultrasonics, EBSD, Thermodynamic and Kinetic Modeling.

Monday, 12:00-12:20

Minghui Lin: The University of British Columbia

Quantification of austenite recrystallization kinetics from laser ultrasonics measurements

Matthias Militzer

Quantitative knowledge of austenite recrystallization and its dependence on steel chemistries and hot deformation conditions is critical for thermo-mechanical controlled processing (TMCP) of high-strength low-alloy steels, which involves controlled rolling below the non-recrystallization temperature to form pancaked austenite and refined ferrite. Conventional experimental tools such as optical or electron microscopy and flow-stress based softening methods can quantify recrystallization but are time-consuming when full kinetics are required. In contrast, laser ultrasonics allows rapid, in-situ monitoring of recrystallization based on the sensitivity of ultrasonic attenuation to changes in austenite grain size. While the start and finish of recrystallization can be readily identified from such measurements, the technique has not yet been used to quantify recrystallized fractions during partial recrystallization. Here, a methodology is presented to determine austenite recrystallization kinetics from grain size measurements by laser ultrasonics. The approach is applied to selected low-carbon C–Mn and Nb-microalloyed steels over a range of initial grain sizes, deformation temperatures, and strains, and further validated with interrupted double-compression tests. The resulting kinetics are interpreted using physically based models to elucidate the retarding effect of Nb on static recrystallization. This work extends the capability of laser ultrasonics to include both grain size evolution and recrystallization kinetics, providing a unique opportunity to accelerate the evaluation of alloy and processing parameters for TMCP.

Keywords: Recrystallization; laser ultrasonics; microalloying; hot deformation; HSLA steels.

Grain Growth I (MDCL 1105)

Monday, 10:50-11:20

Greg Rohrer: Carnegie Mellon University

The influence of grain boundary energy anisotropy on grain boundary migration

Zipeng Xu.

Recent studies of grain growth in polycrystals by three-dimensional high energy X-ray diffraction microscopy have been able to quantify grain boundary migration rates in a variety of materials. One of the principal findings has been that grain boundary curvature is not a good predictor of the direction or speed of grain boundary migration. This presentation will

focus on the influence of grain boundary energy anisotropy on the driving force and, more specifically, the anisotropy associated with the grain boundary plane inclination. Measurements of grain boundary migration in the solid state will be compared to migration in the presence of a liquid phase, where grain boundary energy anisotropy is minimized. Grain boundary migration will be compared to the curvature driving force, the grain boundary stiffness driving force, and possible driving forces associated with stored energy. Another potential driving force arises from local grain boundary area changes are that are correlated to the differences in the energies of the grain boundaries that meet at a triple line. This driving force, and its potential to cause grain boundaries to migrate in a direction opposite to their mean curvature, will be discussed and compared to experimental observations.

Keywords: Grain boundary migration, grain boundary energy.

Monday, 11:20-11:40

Andrej Ostapovec: Institute of Physics of Materials AS CR, v. v. i.

Shear-Coupled Migration of Grain Boundaries: Analysis of Approaches to Coupling Factor Prediction.

Ritu Verma, Dmitri Molodov.

Shear-coupled migration of grain boundaries under applied mechanical stress is one of the possible mechanisms of metal plasticity. Different approaches to describing shear-coupled grain-boundary migration and to predicting the coupling factor exist in the literature. One approach is based on consideration of the grain-boundary dislocation content, which can be obtained, for example, by solving the Frank–Bilby equation. Another approach is based on consideration of disconnection glide along the grain boundary. The first approach describes the boundary as an array of dislocations, whereas the second considers the glide of disconnections along a dislocation-free boundary. Despite considerable efforts, there is currently no general framework that harmonizes the existence of grain-boundary disconnections with the dislocation content derived from the Frank–Bilby equation and enables prediction of the coupling factor for shear-coupled grain-boundary migration. In the present work, we demonstrate the internal interrelation between these approaches by considering shear-coupled migration of several grain boundaries in FCC and HCP crystals. It is shown that there is no contradiction between the two approaches and that their combination can help elucidate the physical mechanisms of shear-coupled grain-boundary migration.

Keywords: Grain boundaries, plasticity, shear.

Monday, 11:40-12:00

Jing Tang: Montanuniversität Leoben

Shear-coupled grain boundary migration induces gradients in grain growth kinetics

Yan Runlun; Lorenz Romaner, Kapp Marlene, Marco Salvalaglio, Oliver Renk.

Emerging evidence from 4D (3D plus time) X-ray diffraction–based experiments and atomic-to-mesoscale simulations has challenged the established, pure diffusive, curvature-driven grain growth theory. Large-scale 4D data sets on Ni revealed no correlation between grain boundary (GB) velocity and local curvature; GB segments moving away from their center of curvature ('anti-curvature migration') and measurable residual strains in well-recrystallized grains were observed, questioning applicability of established theory to 3D polycrystalline microstructures. GB migration realized by GB disconnections (line defects existing in the GB plane) could explain these unexpected observations. Besides translation, disconnection motion inherently produces shear along the boundary (shear-coupled migration) due to the Burgers vector of the disconnection. Under constraints imposed by the surrounding GB network, shear-coupled migration leads to stress

buildup, which will influence subsequent disconnection motion. The relaxation of such stress fields may therefore strongly affect grain growth kinetics. Differences between the growth of near-surface and interior grains can thus be expected. Grain growth experiments on pure nickel show that grains in the specimen interior—where constraints and stress buildup are expected to be larger—grow faster than near-surface grains. Notably, this trend is not limited to the very surface (grooving effects may occur), but persists for 5th to 10th grain layer. We will show that this gradient growth kinetics is expected for disconnection-mediated grain boundary migration. As for lattice dislocations, disconnection stress fields differ near a surface compared to the bulk, while the orientation of the Burgers vector relative to the free surface plays a predominant role.

Keywords: Grain growth; Grain boundary disconnection; Electron backscatter diffraction (EBSD); Phase field simulation.

Monday, 12:00-12:20

Oliver Renk: Montanuniversität Leoben

Grain growth is shear-coupled grain boundary migration

Jing Tang, Markus Kratzer, Christian Teichert, Jules Dake, Carl Krill, Lorenz Romaner, Marlene Kapp

Grain boundary (GB) migration is typically assumed to proceed by diffusive atomic events following curvature-driven flow. However, recent 4D (3D plus time) experiments and atomic-to-mesoscale simulations have shown that thermally induced grain growth in polycrystals deviates from this assumption. GB migration mediated by disconnections—producing both boundary translation and shear—may resolve this discrepancy, although such shear is usually restricted by surrounding grains. However, it might be measurable at the specimen surface, where constraint is partially relaxed. Applying in-situ electron microscopy and atomic force microscopy to 10 µm-sized pure nickel we directly demonstrate that thermally induced grain growth occurs by shear-coupled boundary motion. Migrated GBs induced significant surface topography changes, clearly differing from grooves observed for stationary GBs. Calculated apparent shear-coupling factors are significantly lower than theoretical predictions, but in line with those observed for stress driven boundary motion in polycrystals. Consequences for this paradigm change will be the center of discussion.

Keywords: Grain growth; Shear-coupled migration; Disconnections; Atomic force microscopy.

Recrystallization I (MDCL 1102)

Monday, 10:50-11:20

Knut Marthinsen: Norwegian University of Science and Technology (NTNU)

Recrystallization behaviour during extrusion of aluminium alloys

Ali Elashery, Marie Lycke Kjøllmoen.

The extrusion process is a hot-deformation process characterized by rapid temporal and spatial variations in strain, strain rate and temperature. Depending on the alloy composition and processing conditions (billet temperature; extrusion speed and cooling conditions), the as-extruded grain structure can be (i) predominantly non-recrystallized (fibrous), possibly still often with a thin recrystallized layer at the surface, (ii) partly recrystallized, often with a few, very large, recrystallized grains, or (iii) fully recrystallized. In the latter case strong through thickness variations are still often observed both in grain size and texture. The as-extruded grain structure (and texture) is a result of the local (through thickness) stored energy and a subtle interaction between the presence and intensity of different recrystallization nucleation mechanisms and dragging forces from alloying elements in solid solution (solute drag), and a Zener-Smith pressure from possible dispersoids. Although the recrystallization behaviour of different Al-alloys during extrusion, in view of the different factors mentioned

above, has been extensively studied over several tens of years, the different behaviours and phenomena involved are still not well understood, and fully adequate models to predict and control the behaviour are still largely lacking. In this presentation, we will review some of the previous work on this topic as well as present more recent work, including extrusion of scrap-based aluminium alloys with potentially even more complex microstructures. Detailed microstructure characterizations that link the microstructures (inter-metallics, dispersoids, solid-solution level) across processing steps to the final as-extruded grain structure and texture will be presented and discussed.

Keywords: Aluminium, extrusion, recrystallization, recycling.

Monday, 11:20-11:40

Thomas Mineau: CNRS

EBSD in-situ experiments to unravel feedbacks between microstructure, dynamic recrystallization, and mechanical behaviour in AZ31 Mg alloy

Andrea Tommasi, Maurine Montagnat, Fabrice Barou

Tensile tests on AZ31 samples with in-situ SEM-EBSD acquisition at 250°C and 10^{-3} s^{-1} were conducted to study the evolution of dynamic recrystallization (DRX) and its effect on the material's mechanical behaviour. Three sets of samples with distinct initial microstructures and crystallographic textures were investigated: a fine-grained homogeneous microstructure with a point maximum of [0001] normal to the tensile axis and a coarser and more heterogeneous microstructure with a fibre distribution of [0001] oriented either normal or at 55-60° to the tensile axis. Five specimens per set underwent stepwise tensile tests with in-situ EBSD acquisition at 4% strain increments until out of plane movement deteriorated the EBSD measurement (16% bulk strain). Each test was initiated at set deformation values in order to cover the entire deformation range usp to failure at around 65-70% strain (i.e. 0 to 16%, 12 to 28%, 24 to 40%, 36 to 52%, and 48 to 64%). EBSD maps covering a large area of the gauge section were acquired before and after deformation to assess the representativity of the in-situ measurements. The EBSD and mechanical data analysis shows that both the initial microstructure and texture have major roles on the kinetics and spatial distribution of dynamic recrystallization and thereby on the mechanical behaviour. Both hard orientations and finer grain sizes accelerate DRX, which involves polygonization and grain boundary migration and can onset softening as early as at 15% strain. The spatial distribution of the DRX grains controls strain localization, conducing to either failure or enhanced ductility.

Keywords: Dynamic recrystallization, strain localization, in-situ EBSD

Monday, 11:40-12:00

Moritz Theissing: Graz University of Technology

Investigating Recrystallization Phenomena in Wrought Aluminum Alloys

Vitesh Shah, Georg Falkinger, Stefan Mitsche, Sebastian Samberger, Matheus Tunes, Stefan Pogatscher, Gerald Kothleitner.

Recrystallization, together with recovery and grain growth, plays a central role in defining the microstructure and therefore properties of wrought aluminum alloys. Because these processes occur rapidly and depend on numerous internal and external parameters, they are difficult to study. The aim of this work was to evaluate different characterization techniques for investigating recrystallization in aluminum alloys. A cold-rolled AA8079 foil stock material was examined using two approaches: ex situ annealing combined with EBSD and hardness measurements, and in situ annealing combined with EBSD. A major finding is that ex situ and in situ annealing lead to similar recrystallization behavior and comparable final

microstructures. In situ experiments enable recovery, recrystallization, and grain growth to be monitored in a single experiment but offer limited statistics. Ex situ methods compensate with large, high-resolution datasets but require multiple samples at different stages of heat treatment, which is a major drawback. These insights were then applied to investigations of recrystallization in other alloys. First, the effect of dispersoids on recrystallization and grain growth was investigated in two AlMgZnCu crossover alloys, with dispersoids present in only one alloy. Dispersoids strongly pin grain growth but do not significantly affect recrystallization or nucleation. In a second study, the recrystallization behavior of an ultrafine-grained AA6061 alloy was investigated using in situ EBSD and compared with in situ TEM. The onset of recrystallization was precisely identified, enabling better assessment of potential service conditions for the alloy.

Keywords: in situ EBSD, ex situ EBSD, Recrystallization, Aluminum Alloys.

Monday, 12:00-12:20

Mark Taylor: University of Manchester

The Origin of Dislocation Density During the Austenite Memory Effect Low-Alloy Steels Studied Using In-Situ EBSD and Synchrotron XRD

Rhys Thomas, Albert Smith, Grace Fidler, Yahya Hoque Mozumder, Tamas Ungar, Chris Hutchinson, Fabio Scenini, Phil Prangnell, Ed Pickering.

Many martensitic steels austenitise via an austenite memory effect, wherein the prior austenite grains are re-formed both in morphology and orientation. However, the newly formed memory austenite grains contain a high dislocation density. In some steels, this provides a sufficient driving force for recrystallisation in the newly formed austenite, thus enabling grain refinement through cyclic heat treatments without the application of external deformation. Here, the origin of the dislocation density in austenite is investigated: was it inherited from the martensite across the transformation interface, or generated in the austenite during the phase transformation? The progression of austenitisation and subsequent recrystallisation in two low alloy steels was recorded using a high temperature automated in-situ EBSD and analogous high temperature in-situ transmission SXRD experiments. GIFs produced by combining successive EBSD frames record microstructural evolution demonstrating that the memory orientation austenite has a growth advantage over other orientations. CMWP line profile analysis of the SXRD data reveals the development of dislocation density in both martensite and austenite throughout the transformation, indicating that dislocation density in the newly formed austenite was not dependent on the prior martensite. Factors that may influence whether a steel will undergo a memory effect only, or a memory effect and autogenous recrystallisation, are discussed, including austenitisation temperature, carbide formation and heating rate.

Keywords: Steels, Austenitisation, In-Situ EBSD, Martensite.

Industrial Applications I (MDCL 1105)

Monday, 13:30-14:00

Michael Fahrmann: Haynes International, Inc.

Abnormal grain growth in polycrystalline Ni-base superalloys – an industry perspective

Dave Metzler, Tom Mann, Austin Hernandez.

Abnormal grain growth (AGG) is a well-known phenomenon to occur, under certain conditions, in commercial cast & wrought and commercial powder metallurgy Ni-base superalloys as well. Several distinct processing paths have the potential to result in AGG: (a) the annealing of lightly worked structures exhibiting a plastic strain below the critical strain for recrystallization, (b) the annealing at temperatures above the solvus temperature of grain boundary-pinning phases, and

(c) the annealing below the solvus temperature of grain boundary-pinning phases. The latter is of particular concern to industry since sub-solvus annealing is designed to produce fine-grained, fatigue-resistant components, and was studied in several Haynes alloys. Two alloys will be reported on: HAYNES 244 alloy, a high strength low CTE alloy featuring grain-boundary pinning intermetallic precipitates, and HAYNES 233 alloy, a high-temperature creep- and oxidation-resistant alloy featuring grain-boundary pinning secondary carbides. Irrespective of the nature of the pinning phase, the common footprint of AGG in these and other polycrystalline alloys are initially isolated, very large (10x the matrix grain size) grains that exhibit a high density of annealing twins and a distinct intragranular precipitate distribution. Typically, these abnormally large grains are only observed after an annealing temperature- and prior-processing-dependent incubation period. Examples of abnormally large grains will be shown and discussed in terms of their nucleation and growth conditions. Potential mitigation of this type of AGG will be addressed as well.

Keywords: Superalloys, sub-solvus annealing, abnormal grain growth.

Monday, 14:00-14:20

Mahesh Somani: University of Oulu

Static recrystallization characteristics and kinetics of austenitic stainless steels amenable for TMCP for high strength LH2 storage applications

Ahmed Abdelghany, Sumit Ghosh, Ali Smith, Frank Hoffman, Marta Muratori.

To develop strong and tough alloys for liquid hydrogen (LH2) storage applications, three austenitic stainless steels amenable for thermomechnical processing (TMCP) were designed based on the chemistries of type 304 and 204 steels by varying nitrogen and alloying contents in order to impart improved yield and tensile strengths at room and sub-zero temperatures, together with adequate toughness and austenite stability. However, to be able to design optimized thermomechanical rolling processes, it is mandatory to characterize the static recrystallization (SRX) behaviour of the austenitic stainless steels. The SRX characteristics and kinetics of the steels were determined using the double-hit compression technique on a Gleeble 3800 thermomechanical simulator and modelled in terms of the effects of temperature, strain, strain rate and initial grain size using a fractional softening approach. Detailed recrystallization data analyses enabled estimation of material parameters, including the powers of strain (ε -3.1), and strain rate (ε -0.3), and estimation of apparent activation energies of recrystallization that clearly depicted the effects of alloying with 0.1 wt.% Nb (273 kJ/mol) in one steel and 7.0 wt.% Mn (298 kJ/mol) in another steel compared to the reference 304L steel (251 kJ/mol). The presence of Nb and Mn in the two austenitic stainless steels retarded their static recrystallization rates, but the influence of nitrogen could not be clearly established. Together with detailed metallography, confirmation experiments suggested reasonability of the developed fractional softening equations. New empirical equations were developed that could predict the SRX grain size over the TMCP range with reasonable accuracy.

Keywords: Static recrystallization, austenitic stainless steel, thermomechanical processing, activation energy of recrystallization

Monday, 14:20-14:40

Cécile Rampelberg: McMaster University

Impact of Boron and Titanium on the Mechanical Properties and Recrystallization Behaviour of Low Carbon Hot Rolled and Cold Rolled Batch Annealed HSLA Steels

DiGiovanni Christopher, Tihe Tom Zhou, Chad Cathcart, Babak Shalchi Amirkhiz, Hatem Zurob, Colin Scott.

High Strength Low Alloy (HSLA) steels are crucial in industries like automotive, construction, and transportation for their strong mechanical properties and cost-efficiency. In automotive applications, these steels improve vehicle safety, fuel efficiency, and reduce CO_2 emissions. Titanium addition (Ti) enhances strength through precipitation strengthening and controlled recrystallization, making Ti a cost-effective option for improving HSLA steels mechanical properties. Moreover, boron (B) added at ppm levels also significantly affects steel microstructures and properties [1]. This study investigates the impact of B on the recrystallization behavior and the performance of low-carbon Ti microalloyed steels during batch annealing. By analyzing the tensile stress-strain behavior and microstructural changes, the study reveals that Ti+B microalloying improves strength in hot-rolled steel by increasing hardenability, which promotes finer ferrite grains and higher dislocation densities. However, the beneficial effect of B disappears after cold rolling and annealing. This effect is related to the solute drag effect of Ti being more influential than TiC particle pinning. Precipitation during the annealing of the cold-rolled material therefore results in coarser grains and reduced tensile strength in the annealed product compared to the hot-rolled strip. These findings indicate that although B can improve hot-rolled properties, it poses challenges for cold-rolled and batch-annealed processes [2]. Optimizing microalloying elements and processing conditions, informed by insights into how B affects Ti microalloyed HSLA steels, is key to developing advanced materials with tailored properties for critical industrial applications. [1] J. Takahashi, et al. Ultramicroscopy 159(2015)299–307. [2] C. DiGiovanni, et al. Mat.Sc.&Eng. (2024) A, 147424.

Keywords: Ferrous alloys; Thermomechanical treatment; recrystallization; Microstructure and property experimental characterization.

Monday, 14:40-15:00

Toshio Ogawa: Aichi Institute of Technology

Evaluation of microstructural evolution and tensile properties in tempered martensite and cold-rolled and annealed martensite steels

Yuta Kitagawa, Yu Kinoshita, Hiroyuki Dannoshita.

We evaluated the microstructural evolution and tensile properties of tempered martensite (TM) and cold-rolled and annealed martensite (AM) steels. After quenching, a low-carbon steel was either tempered or cold-rolled and subsequently annealed. TM and AM steels with Vickers hardness levels of approximately 350, 300, 250, 200, and 170 Hv were prepared. Microstructural evolution and tensile properties were examined by optical microscopy and tensile testing, respectively. In addition, quantitative analysis of the dislocation substructure was conducted using X-ray line profile analysis. No recrystallization occurred in the TM steel even after long-term tempering, whereas recrystallization occurred in AM steel even after short-term annealing. The ferrite grains in the TM steel exhibited a lath-like morphology, whereas those in the AM steel were fine and equiaxed. For all specimens, the tensile strength of the TM steel was higher than that of the AM steel, while the total elongation of the AM steel was higher than that of the TM steel. For the specimens with Vickers hardness above 250 Hv, the AM steel exhibited higher uniform elongation than the TM steel, whereas the TM steel showed higher local elongation than the AM steel. In contrast, for the specimens with Vickers hardness below 200 Hv, the TM steel exhibited higher uniform elongation than the AM steel, while the AM steel showed higher local elongation than the TM steel. The differences in tensile properties between the TM and AM steels with the same hardness are attributed to differences in dislocation density and ferrite grain morphology.

Keywords: Martensite steel, Recrystallization, Tempering, Annealing.

Monday, 15:00-15:20

Tihe Tom Zhou: Stelco Inc.

Study of Microstructure Evolution and Mechanical Properties of High Strength Low Alloy Steels during Batch Annealing Process.

Jonathan Juneau, Haden Lee, Cecile Rampelberg, Mubarak Ahmad, Chris Martin-Root, Chad Cathcart.

This study investigated the effects of cold rolling reduction ratio, batch annealing temperature, and soaking time on the microstructural evolution and mechanical properties of titanium-added high-strength low-alloy (HSLA) steels. During batch annealing, the deformed ferritic microstructure experienced recovery, recrystallization, and grain growth, accompanied by Ti(C,N) precipitation at different stages depending on annealing temperature and soaking duration. Processing parameters significantly influenced grain refinement, precipitation behavior, and overall mechanical performance. The batch-annealed Ti-added HSLA steels demonstrated yield strengths of 340–550 MPa and ultimate tensile strengths of 440–650 MPa, while maintaining excellent ductility and formability. These properties satisfy the requirements of cold-rolled fully processed HSLA steel grades Gr50 (340), 55 (380), 60 (420), 70 (490), 75 (520), and higher. The results indicate that optimized cold rolling and batch annealing setups facilitates the production of Ti-added HSLA steels suitable for demanding automotive, structural, and industrial applications.

Keywords: Batch anneal, Ti-microalloyed steels, microstructure, mechanical properties.

Modelling & Simulations I (MDCL 1110)

Monday, 13:30-14:00

Chuang Deng: University of Manitoba

Grain boundary segregation prediction in nanocrystalline metals with solute-solute interactions

Zuoyong Zhang

Solute segregation at grain boundaries (GBs) plays a critical role in determining the properties of nanocrystalline metals. In recent years, the spectral approach has emerged as a powerful tool for predicting GB segregation. However, existing models based on this approach rely primarily on per-site segregation energy spectra and therefore neglect solute–solute interactions. In this talk, we introduce a segregation framework in which the segregation energy spectra intrinsically account for solute–solute interactions. The refined model accurately predicts GB segregation behavior obtained from hybrid molecular dynamics/Monte Carlo simulations over a broad temperature range and across varying solute concentrations prior to secondary-phase formation, as demonstrated in a series of binary systems. The framework is further extended to ternary alloys, where it successfully predicts co-segregation of different solute species. The results reveal that solute–solute interactions can outweigh site competition between certain solute types during co-segregation. Overall, this model provides an effective and accurate approach for predicting GB segregation in nanocrystalline metals and offers guidance for the design of advanced nanocrystalline alloys.

Keywords: Grain boundary segregation; solute-solute interactions.

Monday, 14:00-14:20

Tianchi Li: Centre for Material Forming (CEMEF)- Mines Paris

High-Fidelity Modeling of Polycrystalline Grain Growth

Marc Bernacki.

In the context of hot metal forming, capillarity-driven grain growth during the final stage of annealing plays a decisive role in determining the microstructure and, consequently, the performance of metallic components. In the state-of-the-art, level-

set method is widely used in academia and industry for modeling grain growth, owing to its ability to naturally incorporate topological changes and large deformations with relatively low computational cost. However, existing numerical models based on mean curvature flow often fail to capture the kinetics of individual grain boundaries, especially at multiple junctions that dominate the evolution of polycrystals. When applied in recent reverse-engineering studies, these models are unable to interpret the grain growth behavior observed in 3D in-situ experiments. To address these limitations, we developed a novel level-set formulation for grain growth, which, to the best of our knowledge, represents the highest-fidelity front-capturing framework based on Mullins' mean curvature flow theory. The proposed model accurately describes triple junction kinetics, even under traditionally unconsidered extreme grain boundary energy ratios. Ongoing work extends this approach to the polycrystalline scale, by including an additional source term field that encodes grain boundary energy distributions. The model's polycrystalline generalization is validated through statistical analysis of large-scale grain growth simulations.

Keywords: Multiple Junction Kinetics; Polycrystalline Grain Growth; Heterogeneity; Anisotropy.

Monday, 14:20-14:40

Fotios Tsiolis: Max Planck Institute for Sustainable Materials, 40237 Düsseldorf

Modelling Recrystallization Textures in Particle-Containing Aluminium Alloys: A Subgrain-Resolved CPFFT–CA Framework for PSN-Induced Texture Components

Spyros Papaefthymiou, Franz Roters.

Recrystallization texture formation in aluminium alloys containing coarse, non-deformable particles is dictated by the process parameter-sensitive complex interactions between strain heterogeneity around particle-deformation zones (PDZs) and microchemistry-controlled phenomena that occur during annealing. Recovery, solute drag, concurrent precipitation timing and the associated Smith-Zener pinning exerted by both pre-existing and newly formed dispersoids act at the subgrain-boundary length scale and can decisively influence texture formation. Owing to this intrinsic multiscale complexity, most recrystallization modelling frameworks remain grain-resolved for computational reasons. This scale gap is typically closed by treating recrystallization as a nucleation-and-growth process, imposing deterministic or probabilistic nucleation laws. Here, we establish a subgrain-resolved, physics-based framework by coupling high-resolution FFT-based crystal plasticity (CPFFT) simulations with an abnormal subgrain growth cellular automaton recrystallization model (AsGG-CA) based on the capillary competitive (sub)grain growth concept. CPFFT is performed at a spatial resolution sufficient to resolve both intragranular orientation gradients in the matrix and around PDZs, resolving their substructure. The simulated orientation field is regridded and mapped onto the CA regular grid, where local orientation gradients determine spatially heterogeneous driving forces for curvature-driven boundary migration. The coupled CPFFT–CA framework predicts recrystallization microtexture evolution of a coarse-particle-containing commercial Al–Mn–Fe–Si alloy and captures the selective formation of PSN-induced P ({011}<566>) and Cube-ND ({001}<310>) texture components, which stem from strain heterogeneities located at PDZs around coarse intermetallic particles. By linking deformation-induced strain heterogeneity to emergent recrystallization texture selection, the approach provides a robust basis for integrating microchemistry-dependent effects into predictive thermo-chemo-mechanical through-process simulations.

Keywords: Recrystallization Texture, Particle-Stimulated-Nucleation (PSN), Crystal Plasticity, Cellular Automata.

Monday, 14:40-15:00

Pungponhavoan Tep: Université PSL

High-Fidelity Grain Growth Modeling: Leveraging Deep Learning for Fast Computations

Bernacki Marc

Grain growth simulation is a fundamental process in materials science, crucial for predicting and enhancing the mechanical properties of materials, including corrosion resistance and strength. Traditional simulation methods rely on conventional rule-based approaches such as partial differential equations (PDEs) to model the evolution of grain structures. While accurate, these methods are computationally intensive and time-consuming, often requiring minutes to hours, or even weeks, for a single simulation. This computational burden creates bottlenecks in materials design and manufacturing. Our research introduced a novel machine learning framework for efficiently predicting grain growth evolution. The approach combines two key neural networks: a Convolutional Long Short-Term Memory (ConvLSTM) and Autoencoder that tailored for the task of grain growth. The ConvLSTM captures both spatial and temporal aspects of grain evolution, while the Autoencoder compresses high-dimensional data into features for learning. Our trained models demonstrate that the proposed deep learning model can predict grain growth evolution with acceptable error rates while significantly reducing prediction time. For a 2D grain growth simulation on a 2×2 mm domain, traditional PDE-FE methods required approximately 10 minutes on high-performance computing machines. In contrast, our trained model completed predictions in under 10 seconds while maintaining error rates below 5%. Additionally, the models can predict long-term evolution from minimal input window of data. These results make it particularly valuable for industrial applications where time constraints limit conventional simulation feasibility, offering practical solutions for real-time process optimization and rapid material design iterations in manufacturing environments.

Keywords: Microstructure; Grain growth; Grain boundary; Deep learning

Monday, 15:00-15:20

Jun Song: McGill University

A unified non-planar dislocation mediated micro-twining nucleation and growth mechanism in Ni-based superalloys

Cheng Chen.

In Ni-based superalloys, micro-twinning has been demonstrated to plays a vital role in deformation, critically affecting their creep and fatigue characteristics. Notable mechanisms proposed to explain micro-twinning in Ni-based superalloys include Kear, Knowles and Chen (K-C), and Kolbe models. However, clear contention and discrepancies exist, with respect to the responsible twinning partials and need of thermal activation. Employing comprehensive molecular dynamics simulations in the representative γ-Ni /γ'-Ni3Al system, we have explicitly elucidated possible micro-twinning nucleation and growth routes through non-planar dislocation reactions and associated transformation. Three distinct dislocation shearing mechanisms, each generating intrinsic stacking fault (SISF) with specific Burgers vector combinations, which contribute to the formation of micro-twins. The results addressed the discrepancies in the responsible twinning partials, and indicated the need of necessary modification in the dislocation reactions involved and propagation paths of extended planar faults for the Kear and K-C mechanisms. Meanwhile, the results demonstrated that the dislocation mediated micro-twining nucleation and growth mechanism does not mandate thermally activated diffusion or atomic reordering process as postulated by the Kolbe mechanism. The validity of our simulations and mechanism proposed was further confirmed by successfully replicating experimentally observed micro-twin morphologies. A continuum model of dislocation mechanics was then developed to predict the threshold conditions required in the proposed micro-twining mechanism, with good agreement achieved between our model predictions and simulation results. The present study provides new mechanistic insights to understand the micro-twining in ordered superalloys and interpret the experimental observations.

Keywords: Micro-twinning, Dislocation, Complex stacking fault, Molecular Dynamics.

Recrystallization II (MDCL 1102)

Monday, 13:30-14:00

Erik Offerman: Delft University of Technology

Nucleation during static recrystallization of austenite: an alternative nucleation criterion

Pablo Garcia-Chao, Winfried Kranendonk, Kees Bos, Jilt Sietsma.

Nucleation during static recrystallization (SRX) governs the grain size and texture after recrystallization and thereby influences the performance of the material. Nucleation during recrystallization is considered to be the initiation of growth of (nearly) dislocation-free grains into the deformed microstructure. Strain-induced boundary migration (SIBM) or bulging is generally accepted as the nucleation mechanism when nucleation occurs at deformed grain boundaries. However, the present study challenges that view. In a study about nucleation during SRX of austenite after hot deformation in a Ni-30 pct Fe model alloy we show that only a small fraction of the potential nucleation sites around deformed boundaries effectively develops into SRX grains: while dozens of sub-grains exist at each deformed boundary, the boundary nucleation potency (defined as the number of SRX grains formed per boundary) ranges between two and four. Moreover, the results indicate that the number of bulges developed in the deformed microstructure is over four times larger than the number of SRX nuclei. We show that SRX nucleation occurs only when the low-angle boundary (LAB) between a pre-existing bulge and its parent grain transforms into a high-angle boundary (HAB). Based on these observations, an alternative nucleation criterion is proposed, which can apply to SRX irrespective of the nucleation site (and to dynamic or meta-dynamic recrystallization): nucleation occurs whenever the misorientation of the LAB surrounding a bulge reaches the minimum misorientation of high-angle boundaries (e.g. 15 degrees).

Keywords: Nucleation, recrystallization, austenite, steel.

Monday, 14:00-14:20

Hugo Latuner: Framatome and MINES St-Etienne

Recrystallization mechanisms activated during single and multi-pass forging of austenitic stainless steels

Julien Favre, Aurélien Helstroffer, Gregory Inacio Da Rosa; Pierre Joly, Emeric Plancher; Marion Roth, Christophe Desrayaud, Guillaume Kermouche.

Multi-pass forging is used to produce large components in austenitic stainless steels for Generation III and III+ nuclear reactors. Gaining a deeper comprehension of multi-pass forging is crucial for optimizing the end-process microstructure and mechanical properties of the materials. The primary objective of this study is to characterize and model the microstructural evolution occurring in multi-pass thermomechanical processing, with a particular emphasis on the dynamic and post-dynamic recrystallization mechanisms. To this end, an experimental simulation of single and multi-pass hot forging by uniaxial hot compression was performed under different thermomechanical conditions, with a specific focus on small strain increments. SEM-EBSD was employed to characterize the resulting microstructures. The processed EBSD data are used to develop a mean-field model combining dynamic and post-dynamic recrystallization. Further investigation into the microstructural effects of successive deformations helps to understand the contribution of the elastic stored energy to the recrystallization mechanisms and the resulting grain size distribution.

Keywords: Mean-field modeling; Dynamic recrystallization; Austenitic stainless steels; Forging.

Monday, 14:20-14:40

Evgueni Poliak: ArcelorMittal Global R&D USA

Revisiting Mechanical Manifestations of Discontinuous Dynamic Recrystallization Occurring in Hot Deformation of Austenite

Discontinuous Dynamic Recrystallization (DDRX) is a long-known phenomenon that plays an important role in thermomechanical processing of steels. In case of steels that undergo phase transformations in cooling the mechanical tests are the key tools to detect and evaluate DDRX under various deformation conditions. The review of characteristic manifestations of DDRX is presented that are typically observed in high temperature constant strain rate and stress relaxation mechanical tests of conventional steels. Specific mechanical features pertinent to onset and progress of DDRX, as well as to stationary DDRX, with emphasis on their sensitivities to deformation conditions, are analyzed within the framework of thermodynamics and viscoplasticity. The considerations of heterogeneity and related flow gradients and their impact on mechanical characteristics associated with DDRX are also outlined. Applicability of traditional Arrhenius-type mechanics to assessing the effects of deformation conditions on DDRX mechanical behavior, its limitations and potential modifications are also addressed.

Keywords: Dynamic recrystallization, mechanical behavior, steels.

Monday, 14:40-15:00

Satoshi Motozuka: Kyushu Institute of Technology

Formation Process of Recrystallization Texture on Flake Powder of Iron-based Soft Magnetic Materials using Ball Milling Treatment

Hisashi Sato.

During ball milling treatment, BCC metal powder plastically deforms into flake powder. Milling aids such as graphite or oil act as lubricants, promote uniform deformation, and form a deformation texture. The texture is a (001) and (111) double fiber texture typically observed in rolled BCC metal sheets. The (001) plane contains the easy axis of magnetization, whereas the (111) plane does not and exhibits small magnetic anisotropy. Because the (001) and (111) orientations exhibit excellent magnetic properties at low and high frequencies, respectively, controlling texture of ball-milled flake powder is practically important. This study investigates the effects of raw powder composition and milling aids on the recrystallization texture of iron-based soft magnetic flake powder obtained by ball milling. Pure iron and Fe–6.5Si steel powder were used as raw materials, while boron nitride and lubricating oil served as milling aids. Although differences in lubricants did not notably affect the deformation texture, they had significant influence on the recrystallization texture. When Fe–6.5Si was combined with boron nitride, the flake face preferentially oriented to the (001) plane, whereas lubricating oil produced a (111)-oriented texture. Furthermore, in pure iron flake powder, the recrystallized grain size readily exceeded the flake thickness, whereas in Fe–6.5Si it remained comparable to the thickness. This suggests that surface energy strongly influenced the recrystallization process, even though heat treatment was performed at the relatively low temperature of 600°C. Based on these findings, the recrystallization process of ball-milled iron-based soft magnetic powder is discussed.

Keywords: Magnetization axis, soft magnetic material, iron core, powder.

Monday, 15:00-15:20

Kyeongjae Jeong: Sungkyunkwan University

Athermal Recrystallization and Phase Transformation under Electric Current in Metals

Howook Choi, Junyoung Chae, Heung Nam Han.

Electric current has emerged as an effective processing variable capable of modifying microstructural evolution in metals beyond conventional thermal treatments. This presentation examines two representative consequences of electric current application in metallic systems: athermally enhanced recrystallization and altered phase transformation behavior. We show

that electric current markedly accelerates recrystallization, enabling extensive microstructural renewal at lower temperatures and shorter times than those required for conventional annealing. Quantitative kinetic analysis suggests that this acceleration cannot be explained solely by Joule heating, but rather reflects a reduction in effective activation barriers. Beyond recrystallization kinetics, the influence of electric current on phase transformations during annealing is also discussed. In situ diffraction and microstructural characterization demonstrate a systematic decrease in transformation temperatures under electric current, with pronounced dependencies on grain size and applied current density. Finite element simulations reveal preferential current localization at grain boundaries, while atomistic calculations indicate that defect-induced charge imbalance modifies lattice vibrations and vibrational entropy, thereby altering the thermodynamic driving force governing phase stability. Taken together, these findings show that electric current interacts strongly with grain boundaries, affecting both kinetic processes and phase stability during annealing. This perspective provides new insight into current-assisted recrystallization, grain growth, and phase evolution, offering new opportunities for energy-efficient and pathway-selective microstructure control in metallic materials.

Keywords: Electric current; Athermal effect; Recrystallization kinetics; Phase transformation

Plenary Presentation (MDCL 1305)

Monday, 15:40-16:40

Roland Loge: EPFL

3D Microstructure Design in Additive Manufacturing

Jamasp Jhabvala, Reza Esmaeilzadeh, Claire Navarre, Lucas Schlenger, Nikola Kalentics, Amir Jamili, Milad Hamidi, Eric Boillat, Charlotte de Formanoir, Cyril Cayron, Giulio Masinelli, Vigneashwara Pandiyan, Killian Wasmer, Patrik Hoffmann, Nicola Casati, Daniel Grolimund, Federica Marone, Steven Van Petegem.

Processes from past centuries have shown multiple ways of designing properties of metallic products based on partial control of thermo-mechanical processes. However, the spatial resolution at which microstructures could be designed, and the available degrees of freedom, were limited. In the Additive Manufacturing (AM) context, the developments of monitoring approaches and numerical modelling at the relevant space and time scales provide the opportunity of a bottom-up manufacture, which may even include multiple materials. Recent work shows increasing trends in controlling microstructures, typically from tuned heat source (laser, electron beam) parameters, or beam profile (i.e. beam shaping). Considering the partly stochastic nature of AM, the vision consists in optimizing the processing conditions, while keeping the option of corrective actions whenever undesired events are detected. In this presentation, I will discuss our recent advances in the 3D control of defects and microstructures with the Laser Powder Bed Fusion (LPBF) process. A first part will focus on operando experiments, to follow defect formation and microstructure changes during LPBF or upon local laser heat treatment. The experiments are monitored with high energy X-Rays as well as with acoustic emission. Combined with multiscale LPBF thermal models, they help defining optimal time-dependent laser parameters. A second part will describe two new hybrid processes, combining traditional LPBF with either Laser Shock Peening, or Sheet Lamination. The former approach proved effective in the 3D control of residual stresses and dislocation density. The latter demonstrated a clear advantage in the multi-material printing of non-weldable alloys.

Keywords: Laser Powder Bed Fusion, residual stresses, dislocation density, acoustic emission.

Electrical Steels (MDCL 1102)

Monday, 16:40-17:00

Taner Ozdal: Max Planck Institute for Sustainable Materials

Quantitative Assessment of Texture, Microstructure, and Magnetic Properties of Grain Oriented Electrical Steels

Sohrab Masteri Farahani, Stefan Zaefferer

Grain-Oriented Electrical Steels (GOES) are soft magnetic materials with nominal composition Fe-Si 3wt.%, and they are an indispensable material of choice for the electrical transformers. GOES are distinguished by their large grain sizes in the range from millimeters to several centimeters, and pronounced Goss texture, i.e. {011}<001>, both of which formed by abnormal grain growth from a primary recrystallized matrix. This unique microstructure is advanced from abnormal growth of Goss grains during the high-temperature secondary annealing. The sharpness of Goss texture, specifically <001>//RD alignment, is vital for the efficient performance of the transformers, as <001> direction is the easiest to magnetize for α-iron. Additionally, the microstructural design of the final GOES sheets must allow unobstructed movement of the magnetic domain walls under alternative current to minimize core losses. Herein, texture sharpness and the occurrence of abnormal grain growth are influenced by the process parameters. Therefore, the objective of the present study is to reveal process sensitivity in GOES production by cumulative assessment of Goss texture sharpness, microstructure, and magnetic properties. We have investigated industrially produced GOES sheets processed by two distinct cold rolling routes modifying the working roll diameters, followed by primary recrystallization at different temperatures as model systems. To this end, large area orientation maps were recorded using the electron backscatter diffraction (EBSD) technique. From these intrinsic "fingerprint" graphs, displaying grain size vs. grain orientation were produced and correlated with the magnetic behavior of different GOES sheets.

Keywords: Electrical Steels, Texture, Abnormal Grain Growth, Soft Magnets.

Monday, 17:00-17:20

Ning Zhang: Central Iron and Steel Research Institute Co.

Study on the recrystallization and grain growth behaviors of ultrathin non-oriented silicon steel prepared by planar flow casting

Meng Li, Tu Yang, Fu Chao

The planar flow casting (PFC) technique tends to generate a strong {100} texture in columnar-grained solidified structure, which can be used to prepare ultrathin non-oriented silicon steel with superior magnetic properties through a short-process treatment. Using PFC ribbons as the starting material, this paper investigates the recrystallization and grain growth behaviors during the rolling and annealing processes, aiming to enhance the heritage of {100} texture and achieve a coarsened microstructure. When the PFC ribbon is annealed directly, grain growth is primarily governed by temperature and is also influenced by the initial grain size distribution. The driving force is dominated by temperature-dependent grain boundary energy, grain growth is limited and no significant difference is observed among grains with different orientations. When rolling is applied prior to annealing, the overall grain size can be markedly increased due to the contribution of strain energy. At rolling reduction below 10%, grains with lower Taylor factor, including those with {100} orientations, exhibit stronger growth ability during annealing, driven by strain energy differences. However, when the rolling reduction is increased to 15%, grain growth ability loses its orientation dependence. As a result, the advantage of {100} grains disappears and {100} texture is weakened. In summary, applying temper rolling with a reduction below 10% followed by annealing to planar flow cast ribbons is beneficial for optimizing the {100} texture and the corresponding microstructure.

Keywords: Ultrathin non-oriented silicon steel, planar flow casting, texture, grain growth.

Industrial Applications II (MDCL 1105)

Monday, 16:40-17:00

Hamza Sofiane Meddas: École de Technologie Supérieure

Effect of prior cold deformation on grain growth and on the kinetics of austenite formation during heating

Mousa Jahazi, Mohammad Jahazi

The effect of pre-deformation on austenite formation and subsequent microstructural evolution was investigated in a modified A8 cold-work tool steel. Bars in the annealed condition were deformed by 10%,20% and 30% at 500 °C, followed by austenitizing and quenching. High-resolution dilatometry was employed to quantify the kinetics of austenite formation during continuous heating, while X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to characterize the quenched microstructures and quantify the dislocation density. The results indicate that increasing the deformation level initially shifts the critical austenite transformation temperatures to higher values, reaching a maximum at 10% deformation before decreasing at higher strains. The 10% deformed condition exhibited the highest post-quench dislocation density and hardness, suggesting the strong influence of stored energy and residual strain on martensitic hardening. In contrast, larger deformation levels promoted refinement of the prior-austenite grain size (PAGS), from about 12 µm in the non-deformed state to approximately 7 µm after 30% deformation, despite a concurrent decrease in dislocation density and hardness. These results highlight the interplay between deformation-induced stored energy, grain growth, and transformation behavior, and provide guidance for optimizing thermomechanical processing of cold-work tool steels.

Keywords: Pre-deformation, Grain growth, Austenite formation, Dislocation density.

Monday, 17:00-17:20

Feiyu Zhao: Central Iron and Steel Research Institute

Influence of prior austenite grain size on crystallographic variant selection and mechanical properties of Al-containing carbide-free bainitic steel

Qian Yu, Jue Lei, Weiwei Wang, Yong Yang, Jun Hu

This study aims to elucidate the effect of prior austenite grain size (PAGS) on crystallographic variant selection, retained austenite (RA) stability, and mechanical properties of carbide-free bainitic steels. Austenitization was conducted at different temperatures (850 °C, 900 °C, and 950 °C), followed by austempering at 400 °C for 1 h. The microstructural evolution was characterized using scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), transmission electron microscopy (TEM), and X-ray diffraction (XRD). The results indicate that increasing the austenitization temperature leads to a pronounced coarsening of PAGS, bainitic ferrite, and retained austenite. Austenitization temperature plays a critical role in crystallographic variant selection, with a higher temperature promoting the preferential formation of specific variant pairs, particularly the V1/V2 pairs associated with high-angle grain boundaries (HAGBs). Consequently, both the fraction and density of HAGBs increase with increasing austenitization temperature. This phenomenon is primarily attributed to the reduced stability of retained austenite at higher austenitization temperatures, which facilitates martensitic transformation during cooling to room temperature after isothermal bainitic transformation, thereby enhancing yield strength. At austenitization temperatures of 900 °C and 950 °C, a significant fraction of martensite and coarse, low-stability retained austenite is formed, resulting in a degradation of mechanical performance. In contrast, a lower austenitization temperature of 850 °C promotes the formation of refined bainitic ferrite and significantly enhances both the volume fraction and stability of retained austenite. Tensile testing demonstrates that the steel austenitized at 850 °C exhibits the optimal strength–ductility balance, achieving a value exceeding 40 GPa·%, with an ultimate tensile strength of 1030 MPa and a total elongation of 40.1%.

Keywords: Crystallographic variant; Carbide-free bainitic steel; Austempering; Retained austenite.

Role of Residual Elements I (MDCL 1110)

Monday, 16:40-17:00

Jiaqi Duan: University of Warwick

Assessing the solute drag of scrap residual elements of Sn and Cu in austenite

Yulin Ju, Pedram Dastur, Carl Slater, Martin Strangwood, Claire Davis

Different levels of the scrap residual elements Sn (0.05-0.20 wt %) and Cu (0.15-0.90 wt %) were added individually to a plain C-Mn steel, and their effects on austenite grain growth were investigated in the temperature range of 900°C to 1150°C. Grain sizes under each condition were measured using optical microscopy (OM). The results show both Sn and Cu suppress grain growth compared with the base alloy; with Sn being more effective. A comparison of the grain size distributions in samples with similar average grain sizes but different Sn and Cu levels indicates that solutes do not significantly alter the statistical characteristics of the grain population during grain growth. Sn segregation along austenite grain boundaries was clearly observed using Scanning Transmission Electron Microscopy (STEM)/ energy dispersive X-ray spectroscopy (EDS), while Cu segregation was not evident, after heat treatment at 950°C for 40 min. The solute drag model was applied to derive the segregation energy of Sn and Cu. The fitted values varied with temperatures, for Sn, from -0.31 eV to -0.52 eV and for Cu from -0.014 eV to -0.060 eV. The obtained segregation energies of Sn and Cu, along with the reported ones of Mo and Nb, were used to assess their solute drag effects. Predictions of grain boundary migration retardation at a given boundary migration rate indicate the following order: Nb > Mo > Sn > Cu.

Keywords: Solute drag; Grain growth; Austenite; Scrap element.

Monday, 17:00-17:20

Carl Slater: University of Warwick

Microstructural Forsite – Removing fitting parameters to make a fast 3D recrystallisation model with a focus on residuals in steels.

Jiaqi Duan, Yulin Ju, Pedram Dastur, Martin Strangwood, Claire Davis

Classical recrystallisation models for steels are typically empirical and rely on fitting parameters that capture the effects of composition, grain size and strain. Increasing use of recycled feedstocks introduces variable residual elements, which can alter recrystallisation kinetics and reduce the reliability of conventional approaches. There is consequently a need for a framework capable of predicting recrystallisation behaviour in near real time once the steel composition is known. Microstructural Forsite is an empirical–synthetic hybrid model designed to meet this requirement. It employs statistically representative 3D synthetic microstructures and explicitly incorporates the spatial distribution of triple-junction nucleation sites together with grain growth behaviour. This allows the model to predict the number of successful nucleation events and the subsequent evolution of recrystallised volume. The approach reproduces the grain size sensitivity of recrystallisation and yields accurate Avrami kinetics without requiring these dependencies to be prescribed explicitly. By combining empirical fitting with synthetic microstructural physics, the model provides rapid and composition-responsive recrystallisation predictions. A single rolling pass can be evaluated in approximately 20 s, making the method suitable for process optimisation during hot rolling once the composition has been established.

Keywords: steel, residuals, fast empirical model, inline.

Tuesday, May 26, 2026

Plenary Presentation (MDCL 1305)

Tuesday, 9:00-10:00

Leo Kestens: Ghent University

In memory of John J Jonas: a lifetime dedicated to microstructurally based metal science

Hossein Beladi, Minh Nguyen, Castro Tuan, Roumen Petrov.

During his academic career, which spanned nearly 60 years of active research, John J. Jonas made various seminal contributions to core metal science research at the intersection of properties, structure, and processing. He was one of the early pioneers to study the mechanisms of dynamic recrystallisation during high-temperature austenite deformation of low-carbon steel. This work subsequently gave rise to TMCP (Thermo-Mechanical Controlled Processing), for which he made foundational contributions to the measurement, interpretation and modelling of microstructural evolution during hot deformation of steels. He has provided the metal manufacturing industry with a clear framework for interpreting laboratory hot-working flow curves, determining the non-Recrystallisation Temperature (Tnr), reliably detecting the onset of dynamic recrystallisation and predicting the extent of post-deformation softening (static versus meta-dynamic recrystallisation). Building on his TMCP work, he developed a keen interest in crystallographic texture development during hot and cold rolling and subsequent annealing of steel sheets. He published two seminal review papers on (i) phase transformation textures of hot-rolled sheet and on (ii) cold rolling and annealing textures. His work on texture was not confined to low carbon steel only but also covered the crystallographic aspects of processing hexagonal materials, such as magnesium, titanium and zirconium alloys. In his most recent work, he has explored the austenite-to-ferrite transformation during hot deformation above the Ae_3 temperature — the so-called dynamic transformation. His group explicitly defined dynamic transformation as an additional softening mechanism alongside recovery and recrystallisation and demonstrated its ability to reduce rolling load.

Keywords: Steel, Thermo-Mechanically Controlled Processing, Dynamic Recrystallisation, Texture.

Experimental Techniques II (MDCL 1110)

Tuesday, 10:20-10:50

Fred Gaidies: Carleton University

Size-dependent crystal growth in geological materials

M.T.A.G Yogi, Z.M.G. Li, F.R. George

There is a long-standing hypothesis in the Earth Sciences that a positive correlation can only exist between the size of a crystal and its radial growth rate, if that crystal is nm-sized. For larger crystals it has been assumed that there is no correlation between their sizes and radial growth rates, or that this correlation is negative, as commonly observed during diffusion-controlled growth. However, based on the size and spatial distribution, as well as the compositional zoning, of garnet crystals in metamorphic rocks, we provide evidence for size-dependent growth, such that smaller crystals grew slower than larger ones, up to sizes of 1.5 mm in diameter, causing growth rate divergences as large as 45%. We infer that the size dependence of the growth rates was caused by the interfacial energy penalty to growth, which becomes energetically significant if growth takes place close to equilibrium. For the same reason, an increase in the surface to volume ratio of crystals decreased their growth rates – an inference seemingly at odds with the general view that growth speeds up as the surface to volume ratio of a crystal increases. Our results indicate that this view is only valid for growth far from equilibrium, as is common during laboratory experiments, where driving forces for growth are orders of magnitude

larger than interfacial energies. However, interfacial energies play a more important role for crystal growth in geological materials that develop close to equilibrium, challenging existing models of grain growth and microstructure formation in our planet's lithosphere.

Keywords: crystal growth, interfacial energy, equilibrium, geological materials.

Tuesday, 10:50-11:10

Nicholas Lucas: University of British Columbia

Grain growth and recrystallization in geological materials

Grain growth, recovery and recrystallization are fundamental processes governing the evolution of microstructures in crystalline materials, from structural alloys to rocks, minerals and ice. These varied materials are linked by a common thermodynamic framework in which microstructure evolution is driven by the reduction of interfacial energy, stored lattice strain energy, chemical potential gradients and an applied stress. Geological materials provide natural examples of these processes operating in chemically complex, multiphase systems under a wide range of pressures, temperatures, stress regimes, timescales as well as redox and fluid environments. Rocks and minerals exhibit a diverse range of microstructures analogous to those in alloys, produced via processes of bulging, subgrain rotation, grain boundary migration, Zener pinning, oriented growth and phase decomposition. While these phenomena are typically described using concepts developed in metallurgy, geological systems extend them into regimes where multiple processes operate simultaneously and evolve on timescales of up to hundreds of millions of years. This provides a useful perspective for understanding microstructural evolution in advanced engineered materials, such as multicomponent steels. In this contribution, I highlight parallels between silicate rocks and alloys in terms of microstructural development under a range of conditions. I discuss routine analytical and modelling approaches used in geology and how they compare to those in metallurgy. Finally, I outline concepts from metamorphic geology that may find potential use in advancing my current research on steel.

Keywords: Geological materials, microstructure evolution, Earth Sciences, steel.

Tuesday, 11:10-11:30

Evgueni Poliak: ArcelorMittal Global R&D USA

Application of Confocal Microscopy to Evaluate Austenite Grain Growth and Recrystallization in Advanced High Strength Steels

Girina Olga, Poliak Evgueni, Lin Brian

Mechanisms and kinetics of grain growth and recrystallization in austenite, as well as their effects on phase transformation in cooling were studied in situ using confocal microscopy of several Advanced High Strength Steels. Evolution of austenite grain structure was monitored during reheating, soaking at 900 – 1200oC (with and without tensile deformation) and during subsequent cooling including that under load. Depending on steel chemistry and on austenite grain size attained after transformation to austenite various grain growth mechanisms were revealed, including conventional grain boundary (GB) migration, GB bulging, dissociation of lower energy GBs, especially under deformation, evolution of triple junctions, the combinations of the above, etc. Dynamic recrystallization in austenite under different deformation conditions was detected with mechanisms naturally depending on grain size prior to deformation, GB energy and steel chemistry. The condition of austenite and application of load during cooling have pronounced impacts on types and kinetics of phase transformations and on the variability of resultant microstructure. Limitations of confocal microscopy technique to investigations of high temperature grain microstructure evolution are also discussed.

Keywords: Grain growth, recrystallization, confocal microscopy.

Tuesday, 11:30-11:50

Eric Taleff: The University of Texas at Austin

Differentiating between recovery and recrystallization using combined backscatter electron imaging

Thomas J. Bennett, Sucharita Banerjee.

Acquiring microstructural data sufficient to confidently distinguish between recovery (RV) and recrystallization (RX) is a problem as old as metallography itself. Electron backscatter diffraction (EBSD) techniques are currently considered the benchmarks for distinguishing between RV and RX. The application of high (angular) resolution techniques to EBSD data (HR-EBSD) significantly improves upon standard EBSD for this purpose. However, EBSD techniques are still expensive in terms of both time and the need for specialized instrumentation. As an alternative, we demonstrate a new method based on backscattered electron (BSE) imaging at multiple specimen tilts; we call this combined BSE (CBSE) imaging. The CBSE technique provides data superior to standard BSE for distinguishing grain boundaries. Moreover, its high sensitivity to lattice curvature provides clear visual patterns that can make it easy to distinguish between regions containing high and low (geometrically necessary) dislocation densities. Because of these features, CBSE data can be used to readily distinguish RV from RX in useful situations while being relatively easy and inexpensive to acquire. We demonstrate the use of CBSE data to distinguish regions of microstructure that underwent RX from those that underwent only RV in unalloyed Nb materials. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Keywords: Recovery, recrystallization, backscattered electron imaging (BSE), electron backscatter diffraction (EBSD).

Tuesday, 11:50-12:10

Minyu Tseng: University of British Columbia

Austenite Formation and Grain Growth in As-Cast Line Pipe Steels

Sabyasachi Roy, Ruth Birch, Matthias Militzer, Warren J. Poole, Michael J. Gaudet

The desired microstructures and properties of line pipe steels can be achieved by tailoring the thermo-mechanical process. In a hot mill, as-cast slabs undergo reheating, followed by rolling and run-out table cooling. This study focuses on austenite formation and grain growth during reheating which provides the initial microstructure for subsequent processing steps and may affect the final product significantly. Austenite formation and grain growth tests were conducted for a Ti-Nb microalloyed line pipe steel using both as-cast and as-rolled materials. As-rolled material with a more uniform microstructures is typically employed for these studies, but the present work mainly focuses on as-cast material to better reflect the actual manufacturing conditions. The grain structure during grain growth was revealed by prior austenite grain reconstruction from Electron Backscatter Diffraction (EBSD) data. Heterogeneous grain structures with a mixture of small and very large grains were observed in the as-cast material and can be attributed to local variations in the distribution of Ti-rich carbo-nitrides. In contrast, as-rolled material showed homogeneous grain structures. To clarify the underlying mechanisms, austenite formation tests were conducted on both materials. The as-cast material exhibited delayed austenite formation, with most of the delay occurring at the initial stage, which is associated with microstructure heterogeneity and segregation. Microstructure characterization was performed for a number of stages during austenite formation using intercritical quenching. Further, the effect of heating rate on austenite formation was investigated as well. This study enhances knowledge on microstructural evolution during reheating and its implication for optimizing steel processing routes.

Keywords: Austenite formation, microalloyed low carbon steel, as-cast line pipe steel, reheating.

Grain Growth II (MDCL 1105)

Tuesday, 10:20-10:50

Carl E. Krill III: Ulm University

Vacancy-mediated extreme abnormal grain growth in inert gas-condensed nanocrystalline Pd–Au: When what's missing turns out to run the show!

Fabian Andorfer, Johannes Wild, Jürgen Markmann; Markus Ziehmer, Jules M. Dake, Torben Boll, Dorothée Vinga Szabó; Stefan Wagner, Astrid Pundt.

Inert gas-condensed Pd–Au exhibits extreme abnormal grain growth (AGG), characterized by a small fraction of grains growing dendritically through a nanocrystalline matrix and ultimately reaching sizes of 100 μm or more. As in many AGG systems, both the trigger for rapid growth (emergence) and the mechanism sustaining the growth advantage (persistence) remain poorly understood. We show that annealing under hydrogen accelerates the emergence of abnormal grains without altering their morphology. This finding points to a central role played by the ∼5 vol% porosity intrinsic to inert gas condensation. Not only does this porosity pin matrix/matrix grain boundaries, but it also appears to govern where and when abnormal grains emerge within the bulk. In polycrystals, pores can coarsen by vacancy diffusion along grain boundaries, with larger pores growing at the expense of smaller ones. Small-angle x-ray scattering measurements on our Pd–Au samples support a corresponding evolution of the pore-size distribution during annealing. Our results are most consistent with vacancy transport establishing the spatiotemporal conditions for the emergence of AGG in this system, rather than variations in grain boundary mobility. We further propose that the same vacancy-mediated mechanism may be responsible for the persistence of AGG, as well.

Keywords: Abnormal grain growth, nanocrystalline material, Pd-Au, porosity.

Tuesday, 10:50-11:10

Marcel Chlupsa: University of Michigan

Origins and evolution of stored strain energy during abnormal grain growth of CuAlMn

Zachary Croft, Katsuyo Thornton, Ashwin J. Shahan

Abnormal grain growth (AGG) offers a potential route to fabricate single- or coarse-grained Cu-17at%-Al-11.4at%-Mn shape memory alloys. AGG is induced by so-called cyclic heat treatment (CHT), which subjects the material to oscillations about the solvus temperature, yielding repeated precipitation and dissolution of FCC-α within a BCC-β matrix. Prior work commonly attributes AGG to stored strain energy generated in the matrix during CHT. However, the relations between the particulate FCC-α phase, matrix strain field, and grain boundary dynamics and morphology remain elusive. Here, we present fresh insights on the dynamics of stored-strain-driven AGG via 4-D high energy x-ray diffraction microscopy (HEDM) acquired during two CHTs designed to reach different maximum FCC-α volume fractions. Enabled by the upgraded brightness of the 4th generation Advanced Photon Source at Argonne National Laboratory, we achieve finer temporal sampling than previous HEDM studies. Phase-field-based smoothing facilitates accurate grain boundary curvatures, while local crystallographic orientation gradients provide lower-bound geometrically necessary dislocation densities that are used to estimate stored strain energy. We discuss several proposed mechanisms of strain generation throughout precipitation and dissolution. Using these measurements, we quantify how the FCC-α state, the matrix strain

field, and boundary curvatures co-evolve across the CHTs. Furthermore, we evaluate how each CHT affects the timing and extent of strain generation and grain growth. Overall, this work provides a time-resolved, 3-D experimental basis for evaluating the dynamics of AGG and disentangling the roles of stored strain energy and curvature in driving grain boundary evolution in multiphase systems

Keywords: Abnormal grain growth, x-ray microscopy, dislocation dynamics, grain boundary curvature

Tuesday, 11:10-11:30

André Schulz-Harder: Ulm University

Tracking the Emergence and Persistence of Abnormal Grain Growth in an Aluminum Alloy using 3D X-Ray Microscopy

Jules M. Dake, Karolína Gutbrod, Madlen Atzen, Markus Ziehmer, Thomas Wilhelm, Orkun Furat, Haixing Fang, Pierre-Olivier Autran, Charles Romain, Wolfgang Ludwig, Marc Bernacki, Volker Schmidt, Carl E. Krill III

Abnormal grain growth (AGG) plays a critical role in the microstructure evolution and properties of many engineering materials, yet its governing mechanisms remain unclear. A major challenge is the limited availability of three-dimensional, time-resolved data capturing grain evolution during thermal processing. In this work, we investigate AGG in a commercial aluminum alloy (AA5252) using synchrotron-based diffraction-contrast tomography (DCT) to obtain sequential three-dimensional grain maps following repeated annealing steps. These datasets enable the identification of grains exhibiting extreme growth behavior and allow their evolution to be tracked over time, nearly from the moment of their emergence. To examine the influence of second-phase particles on AGG, complementary phase-contrast tomography (PCT) measurements are performed. The combined analysis of DCT and PCT data sheds new light on the locations at which abnormal grains emerge and on how they are able to maintain a persistent growth advantage with further annealing. Additional measurements at shorter annealing intervals offer the potential to further refine our understanding of the factors governing abnormal grain growth.

Keywords: Abnormal Grain Growth; Microstructural Evolution; Aluminum Alloy; Diffraction-Contrast Tomography; Phase-Contrast Tomography.

Tuesday, 11:30-11:50

Kerui Song: Tohoku University

Texture evolution through oriented growth and abnormal grain growth in a FeMnAlNi shape memory alloy

Xu Sheng, Kainuma Ryosuke, Omori Toshihiro.

FeMnAlNi shape memory alloys (SMAs) exhibiting large recoverable strains (>8%) have attracted substantial interest as cost-effective alternatives to conventional NiTi-based SMAs, which are limited by insufficient workability. In FeMnAlNi SMAs, crystallographic orientation plays a decisive role in optimizing mechanical properties, particularly superelasticity. This study controls the crystallographic orientation of FeMnAlNi SMAs through tailored thermomechanical treatments. Both oriented growth during primary recrystallization and abnormal grain growth during secondary recrystallization are found to be critical for the formation of strong texture. The 94.1% cold-rolled sample initially exhibits a dominant FCC phase with a minor volume fraction of the BCC phase. During primary recrystallization, the FCC phase gradually transforms into the BCC phase. At this stage, the Zener pinning pressure from the FCC phase exceeds the driving pressure for grain growth of the BCC phase, effectively suppressing grain-boundary migration. To minimize total boundary energy, BCC grains tend to form coherent interface boundaries with surrounding FCC grains and low-angle grain boundaries with

adjacent BCC grains. As a result, this oriented growth promotes the development of strong transformation textures of {433}⟨337⟩ and {100}⟨011⟩. At elevated temperatures, the FCC phase almost completely transforms into the BCC phase. The driving pressure on BCC grain boundaries eventually surpasses the pinning pressure generated by the residual FCC phase, leading to abnormal grain growth. During this process, the presence of colonial structures and Σ9 grain boundaries in the BCC phase likely contributes to the preferential abnormal grain growth of {211}⟨011⟩-oriented grains. Ultimately, a pronounced {211}⟨011⟩ texture is established in the BCC single-phase microstructure, resulting in excellent and stable superelasticity.

Keywords: Oriented growth; Abnormal grain growth; Fe-based alloy; Shape memory alloy.

Tuesday, 11:50-12:10

Caihao Qiu: The University of Hong Kong

Revisiting Grain Growth: The Impact of Internal Stress on Grain Boundary Migration

David Srolovitz, Gregory Rohrer, Jian Han, Marco Salvalaglio.

Grain growth describes the increase in mean grain size during the annealing of polycrystals, traditionally attributed to capillarity, where grain boundaries (GBs) migrate toward centers of mean curvature (i.e., mean curvature flow, including its anisotropic extensions for GB energy and mobility). However, this mean curvature flow model has proven overly simplistic and inconsistent with recent experimental and atomistic simulation data. We demonstrate that internal stress generated by GB shear coupling during GB migration is a primary factor causing deviations from the conventional curvature-based model. We employ a bicrystallography-respecting continuum model for GB migration that utilizes a diffuse-interface approach. Our findings, validated through atomistic simulations, show that the scatter in the GB curvature-velocity relationship closely aligns with experimental results for grain growth in 3D polycrystals, a phenomenon inadequately explained by previous models. This work highlights the critical role of mechanical effects in understanding grain growth in crystalline solids.

John J. Jonas Symposium I (MDCL 1102)

Tuesday, 10:20-10:50

You Liang He: CanmetMATERIALAS

Orientation Relationships: From Meteorite, Steel to Titanium

It has long been recognized that precisely defined crystallographic orientation relationships may exist between the parent/matrix phase and the daughter/precipitate phase during phase transformation or precipitation, which plays an important role in determining the microstructure, texture, and properties of the final material. The first such orientation relationship was accredited to J. Young who discovered the crystallographic relation between the taenite and kamacite in iron meteorite in 1926, which was later more widely known as the Kurdjumov-Sachs (K-S) relationship. With a century of research, many more orientation relationships have been discovered in different materials and new characterization techniques have also emerged, which have enabled the advancement of the theory on orientation relationships. However, the mechanisms governing the transformation/precipitation processes are still not completely understood and there are still controversies regarding the transformation/precipitation processes, e.g., the theory on variant selection during martensite transformation. This paper summarizes the journey the author has taken with Professor John J. Jonas on the research of orientation relationships in iron meteorites and steel. The work with Professor Jonas has inspired the author to develop a computer software package that generalizes and unifies the formulations of all orientation relationships in any crystals. The software calculates all the variants of any theoretical orientation relationship and displays the variants in pole figure and Rodrigues-Frank space. It can also display orientation data in inverse pole figure maps. Examples are given to illustrate the

direct comparison between individual variants of theoretical orientation relationships and experimental results using this software.

Keywords: Orientation relationships, phase transformation, meteorite, steel.

Tuesday, 10:50-11:20

Laszlo Toth: Lorraine University

Modeling of textures due to dynamic recrystallization in torsion of copper – revisiting the approach of Toth-Jonas 1992

A modeling approach was presented in two papers in 1992 by Toth and Jonas [1] and Jonas Toth [2] for textures developing under discontinuous dynamic recrystallization (DDRX) of copper during large strain torsion. These works were actually the first polycrystal modeling of deformation textures under DDRX. The model was based on oriented nucleation and selective growth and lead to nearly perfect reproduction of the textures observed at shear strains of 4 and 11 at 300°C. The main result was a constant proportion of the two processes with a contribution of 1:2 between oriented nucleation and selective growth. This modeling is revisited in this presentation by updating it with today's much better computational means, with application to other cases. The quality of the texture reproduction is precisely quantified using a correlation calculation between the experimental and simulated textures. References [1] Tóth, L.S., Jonas, J.J., 1992. Modelling the texture changes produced by dynamic recrystallization. Scripta Metallurgica et Materialia 27, 359–363. DOI: 10.1016/0956-716X(92)90526-K [2] Jonas, J.J., Tóth, L.S., 1992. Modelling oriented nucleation and selective growth during dynamic recrystallization. Scripta Metallurgica et Materialia 27, 1575–1580. DOI: 10.1016/0956-716X(92)90147-7

Keywords: Discontinuous dynamic recrystallization, crystallographic texture, modeling, torsion of copper.

Tuesday, 11:30-12:00

Brigitte Bacroix: CNRS

Mechanical and microstructural characteristics of the main texture components obtained in rolling in Grain-Oriented Electrical Steels before primary and secondary recrystallization.

Laura Herard, Yann Charles, Sohrab Masteri Farahani.

Grain-oriented Electrical Steels are characterized by a strong Goss texture obtained by a complex thermomechanical treatment, which includes primary recrystallization after cold rolling and abnormal grain growth during the final annealing stage. The factors resulting from rolling that may influence the recrystallization and grain growth mechanisms are still poorly understood. The present work aims at improving our understanding of the intricate interplay between cold deformation and the final texture. Some mechanical tests have been performed at various cold rolling steps in order to identify and validate both a macroscopic constitutive law and a microscopic (dislocation-based) hardening law. The evolution of the microstructure and the texture during rolling has been quantified from EBSD maps. A methodology has then been developed to simulate deformation at both the surface and core of the material. Macroscopic finite element simulations of the rolling process were used to extract the velocity gradient tensor associated with the deformation, which was then used as input data for a self-consistent polycrystalline simulation (VPSC) integrating the identified hardening law. Different simulations have been performed depending on whether the centre, surface or full thickness of the sheet is modelled. For each case, some important characteristics, such as number and type of active slip systems or dislocation density have been extracted for all texture components, including the Goss component. The differences observed between the Goss and the other orientations are small but not negligible. They are analyzed in relation to the most recent abnormal growth theories.

Keywords: Electrical Steels, Goss texture, cold rolling, VPSC.

Electrical Steels II (MDCL 1105)

Tuesday, 13:30-14:00

Pello Uranga: CEIT and University of Navarra

Softening Kinetics and Recrystallization Behavior in Hot-Deformed Fe-Si Electrical Steels with High Silicon Content

Xabier Martínez, Nerea Isasti.

Understanding softening and recrystallization mechanisms in Fe-Si electrical steels is essential for optimizing their thermomechanical processing. This work investigates the hot deformation and post-deformation softening behavior of laboratory-melted Fe-Si alloys containing 3 to 6.5% Si using hot torsion tests. Through a combination of double-hit testing and post-mortem metallographic analysis using optical microscopy and EBSD, the contributions of recovery and dynamic and static recrystallizations were systematically evaluated. The results reveal a strong dependence of recrystallization kinetics on Si content, with higher levels of silicon leading to delayed nucleation and reduced grain boundary mobility. The evolution of mean flow stress (MFS) during deformation further correlates with observed microstructural transitions. These insights provide a deeper understanding of high-Si steel recrystallization behavior and offer guidance for designing processing windows to control grain refinement and texture development in electrical steels.

Keywords: Electrical steels, Fe-Si alloys, recrystallization kinetics, EBSD

Tuesday, 14:00-14:20

Shohta Morimoto: Nippon Steel

Effect of Primary Recrystallized Grain Size and Texture on Secondary Recrystallization Orientations in Lightly Cold-rolled Fe-Si Alloys

Wada Naoki, Yasuda Masato, Morishige Nobusato, Ushigami Yoshiyuki

Secondary recrystallization is a phenomenon in which grains with specific orientations grow selectively. In Fe-Si alloys, the phenomenon in grain-oriented electrical steel (GO) grains with a specific orientation, Goss orientation {110}<001>, is well known. For improving properties of GO, the mechanisms, such as the relationship between grain size, texture in primary recrystallization, and secondary recrystallization orientations, have been studied, particularly for the high cold-rolling range(>85%). On the other hand, for lightly cold-rolled(50-70%) Fe-3%Si, it has been reported that Goss-orientation and deviated Goss-orientations rotated approximately 20-30° around the normal direction(ND)({110}<227>-{110}<225>) develop, and that coincidence site lattice(CSL) boundaries such as ∑5 and ∑9 grain boundaries can affect the evolution of these orientations. This study investigated the relationship between grain size, texture in primary recrystallization, and grain secondary recrystallization orientations in lightly cold-rolled(~60%) Fe-3%Si. The details of these findings will be reported.

Keywords: {110}<001>, Secondary Recrystallization, Fe-3%Si, Coincidence site lattice(CSL) boundaries.

Tuesday, 14:20-14:40

Tuan Nguyen-Minh: Ghent University

Orientation dependence of the energy stored in BCC structured materials after conventional cold rolling

Estefanía Hernandez Sepúlveda, Felipe M. Castro Cerda, Leo A. I. Kestens.

The energy stored in plastically deformed crystals is known to drive the recrystallization of metallic materials during a thermal annealing. Specifically, the inhomogeneous distribution of the plastically stored energy among the grains of a polycrystal aggregate affects the crystallographic orientation preference after annealing. Although various characterization methods have been used to quantify the stored-energy in deformed crystals, the relationship between orientation and the stored-energy remains unclear. In this study, the energy stored in grains of an 85% cold-rolled Fe-2.8 wt.% Si alloy is quantified by EBSD characterization. Orientation statistic quality and the accuracy of orientation determination by the EBSD technique have been improved with the wide-field, high resolution scanning strategies. Advanced indexing methods (i.e. dictionary and spherical indexing) help determine the orientation of severely deformed crystal regions (e.g. near grain boundaries and in micro shear bands …) and provide insight into the energy distribution among variously oriented crystals. The results of this study also contribute to the current understanding of texture evolution in BCC-structured materials after conventional cold rolling and annealing.

Keywords: Deformation sub-structure; crystallographic texture; EBSD; electrical steels.

Tuesday, 14:40-15:00

Kyung-Jun Ko: POSCO

Effect of Pre-strain and High-Temperature Annealing on the Microstructure and Texture control of Grain-Oriented Si Steel

Byung-Kab Lee, Hyung-Don Joo

During the final high-temperature batch annealing of grain-oriented electrical steel, abnormal grain growth (AGG) of {110}<001> Goss-oriented grains occurs. In this process, a few Goss grains grow selectively at the expense of primary recrystallized grains, which directly determines the magnetic properties of the final product. This study explores the possibility of reducing manufacturing costs by achieving AGG within a significantly shortened annealing time of approximately 10 minutes. To reduce the incubation period for the AGG of the Goss texture during high-temperature annealing, tensile pre-straining and temper rolling were applied to the specimens prior to the annealing process. Depending on the annealing conditions and the degree of pre-strain, AGG of either Goss or non-Goss oriented grains evolved within 10 minutes. This paper investigates and discusses the resulting microstructures, textures, and magnetic properties observed under these various pre-strain and high-temperature annealing conditions.

Keywords: Grain-oriented Si steel, Abnormal Grain Growth, Goss texture, Pre-strain and high temperature annealing.

Tuesday, 15:00-15:20

Huiping Ren: Inner Mongolia University of Science and Technology

Exploration of grain oriented electrical steel using copper precipitation particles as the sole inhibitor to induce abnormal grain growth

Weimin Mao, Yiming Li

As is known, significant difference in molar volumes between inhibitors, e. g. MnS/AlN etc., and ferrite matrix is the key factor inducing abnormal growth of Goss grains in oriented electrical steels. However, in order for inhibitors to exert inhibition effects, several high-temperature processes in the production of grain oriented electrical steels are inevitable, resulting in significant energy consumption. It has been indicated that there is also certain molar volume difference between copper precipitation particles and ferrite, and the occurrence of the inhibition effect does not require any process with very

high temperatures. A Fe-3%Si-1%Cu system without any other alloying elements was proposed as a new type of oriented electrical steels. Experimental investigations have shown that the maximum temperature of each corresponding processing step does not need to significantly exceed 1000℃, ultimately achieving over 70% Goss grains with dimensions up to centimeter level, as well as encouraging magnetic properties. Additionally, the strength level of the steel can also be significantly improved. The process significantly reduces energy consumption, and therefore the corresponding new grain oriented electrical steel presents positive development prospects.

Keywords: Oriented electrical steel, copper inhibitor particles, secondary recrystallization, energy conservation.

John J. Jonas Symposium II (MDCL 1102)

Tuesday, 13:30-14:00

Dengqi Bai: SSAB Americas

Importance of Three Critical Temperatures during Plate Steel Production

In modern microalloyed steels, Ti and Nb are often added to control the as-reheated prior austenite grain size and the temperature window for controlled rolling. There are three critical temperatures, namely, no-recrystallization temperature (Tnr), recrystallization temperature (TR), and austenite-to-ferrite transformation start temperature (Ar3), during hot rolling of microalloyed steels. During plate steel production, it is very important to understand how these temperatures affect the rolling process and microstructure evolution in order to produce a desirable fine grain structure in the final products. In this paper, the methods used to determine these critical temperatures will be discussed. Several examples will also be used to illustrate the importance of these temperatures during plate steel production.

Keywords: Microalloyed steel, controlled rolling.

Tuesday, 14:00-14:30

Matthew Barnett: Deakin University

High Strength Cold Rolled Microalloyed Steels

I thoroughly enjoyed the entirety of my 3 years as a PhD student with John Jonas. As these years drew to a close, we proposed a mechanism for recrystallization texture control that relied on manipulation of the deformation structure. At the time, John was an ardent proponent of selective growth. To my relief, he displayed no reticence in accepting a “very” nucleation-based proposal. Our proposal led – as it should - to a number of expectations. The present talk presents some (slightly) more recent findings by ourselves and others and critically examines the extent to which these expectations have been born out in the annealing of warm rolled steel.

Tuesday, 14:40-15:10

Weiping Sun: Nucor Corporation

Recrystallization-Controlled Process for Galvanizing

Sanjeev Sharma.

It has been well-recognized that recrystallization is an important phenomenon related to thermomechanical processing or disciplined hot rolling/deformation of steels. The relevant knowledge has been extended and successfully applied to galvanizing operation on high strength micro-alloyed steel strips during this R&D study. By understanding the relationship between microstructure, particularly recrystallization fraction and grain size, and mechanical properties, such as yield strength, tensile strength and elongation, a recrystallization-controlled process was designed and optimized for galvanizing high strength cold rolled microalloyed steel strips. Such cost-effective design concept has been validated during the industry mill trials and following productions. The high strength steels produced in this way can readily meet customers' specifications. These high-quality high strength microalloyed steels have thus been successfully applied to the automotive industry to reduce vehicle weight, lower production cost, boost fuel efficiency, cut greenhouse emissions, and enhance safety performance.

Keywords: Recrystallization, Galvanizing process, Microalloyed Steels, Process-Microstructure-Property Relationship.

Modelling & Simulations II (MDCL 1110)

Tuesday, 13:30-14:00

Vsevolod Razumovskiy: Materials Center Leoben Forschung GmbH

Multiscale Modelling of Interface Segregation in Steel

Interfaces critically influence the microstructure–property relationships in steels. Among the key factors governing interface behavior is solute segregation, which can substantially modify interface characteristics and, consequently, the properties of the entire material. Segregation-driven phenomena are well documented in steels, including interface embrittlement caused by elements such as hydrogen, tramp elements, or elements associated with liquid metal embrittlement. Additionally, solute segregation impacts microstructural evolution processes such as recrystallization and grain growth. This work presents a multiscale modelling framework that integrates density functional theory (DFT) calculations with atomistic simulations and phenomenological approaches to predict segregation behavior at interfaces and its implications for mechanical performance. The methodology enables a quantitative understanding of segregation energetics at the atomic scale and their translation into mesoscale models including microstructure evolution. By bridging scales, it aims to provide predictive insights into how solute-interface interactions govern steel properties, offering pathways for alloy design and improved performance in demanding applications.

Keywords: Grain boundary segregation, density functional theory, continuum modeling, steel.

Tuesday, 14:00-14:20

Aiden Ha: University of Manchester

A phase-field model of the development of abnormally coarse-grained structures during β-annealing of Ti-64

Samuel Engel, Adam Plowman, Thomas Flint, Pratheek Shanthraj, Joao Quinta da Fonseca.

After thermomechanical processing and β-annealing, abnormally coarse grains (ACGs) have occasionally been observed in Ti-6Al-4V products. The ACGs appear in the mid-plane of forgings and rolled products, within a matrix of fine cube grains (or rotated-cube grains in rolled material). Previous work found that grains within a "Goldilocks" misorientation range ~20°–30° from the matrix, as well as γ-fibre grains (~40°–60°) initially grow rapidly during annealing. However, only the Goldilocks grains develop into the ACGs, whereas the γ-fibre grains are eventually consumed by the surrounding matrix. We model this behaviour employing a 2D phase-field approach, describing GB energy with a Read–Shockley profile saturating at 50° misorientation. The mobility of grain boundaries was represented by a sigmoidal function of misorientation, transitioning from low to high mobility between 10°–25°. The model reproduces the initial growth and shrinkage of γ-fibre grains and the sustained abnormal growth of Goldilocks grains within a rotated-cube matrix. However, this required an unrealistically large nucleus with a 4:1 size ratio over the surrounding subgrains. As the β-phase orientations are determined during deformation, they are likely spatially correlated. To investigate this microtexture effect, we employed a Markov chain Monte Carlo method to generate a microstructure with clusters of grain orientations. We found that there is an optimal level of clustering that reproduces the observed texture changes and abnormal grain growth, without requiring an initial grain-size difference. These findings have implications for understanding the origin of ACGs and how they might be prevented.

Keywords: Ti64, Abnormally coarse grains, phase-field modelling, grain growth.

Tuesday, 14:20-14:40

Shuma Ohga: Tokyo University of Agriculture and Technology

Parameter Estimation for Multi-phase-field models of Grain Growth in a Metallic Thin Film using Non-sequential Bayesian Data Assimilation

Akinori Yamanaka.

In metallic materials, prediction and control of grain growth which is a key phenomenon governing microstructure evolution are essential for achieving desired properties. Multi-phase-field (MPF) models, which can simulate the microstructure evolution using phase-field variables describing individual grains, have been widely used to predict the grain growth behavior. The predictive accuracy of MPF models strongly depends on the model parameters, and the identification from experimental observations is difficult. This study focuses on data assimilation (DA) based on the Bayes' theorem, which integrates experimental observations with numerical simulations to estimate model parameters. Meanwhile, in situ observation of the grain growth has recently become possible using scanning transmission electron microscopy (STEM) with a heating holder. However, the thickness of specimen observable by STEM should be an order of 100 nm. In a metallic thin film, a thermal grooving at the specimen surface by surface diffusion can suppress grain growth. Therefore, the effect of thermal grooving must be incorporated to the MPF model of grain growth in a metallic thin film. In this presentation, we conduct numerical experiments by applying Data assimilation method Minimizing the Cost function using Tree-structured Parzen Estimator (DMC-TPE) to MPF model that can model thermal grooving, assimilating only the distributon of crystal grains on the specimen surface. We present the estimation results for the phase-field mobility, grain boundary mobility, and surface mobility in the MPF model, and demonstrate the feasibility of integrating in situ STEM observations of the grain growth in a metallic thin film with MPF simulations.

Keywords: Grain growth, Thermal grooving, Multi-phase-field models, Bayesian data assimilation.

Tuesday, 14:40-15:00

Akinori Yamanaka: Tokyo University of Agriculture and Technology

Data-driven Multi-phase-field Simulation of Static Recrystallization in Aluminum Alloy using in-situ EBSD observation and Bayesian Data Assimilation

Umezawa Motoki, Ito Masato, Akiba Kishu, Yaguchi Kenichi

Static recrystallization in aluminum alloys is a key metallurgical process that governs their mechanical performance. In-situ observation using scanning electron microscopy and electron backscatter diffraction (SEM-EBSD) with a heating stage provides valuable insights into the evolution of microstructures. However, experimental observation alone is insufficient for a comprehensive understanding, which requires integration with predictive modeling. In this study, we developed a

framework to assimilate in-situ SEM-EBSD data with results from multi-phase-field simulations using Bayesian data assimilation (DA). The proposed DA method was applied to static recrystallization in A1100 aluminum alloy. The results demonstrate that the stored energy distribution which is the driving force for recrystallization can be inversely estimated from the experimentally obtained inverse pole figure (IPF) maps of crystallographic orientation. Furthermore, the reconstructed stored energy field exhibits strong correlation with the spatial distribution of Taylor factors. These findings highlight the potential of the proposed DA-based framework as a predictive tool for microstructure evolution in metallic materials

Keywords: Static recrystallization, In-situ observation, Bayesian data assimilation, Phase-field model.

Tuesday, 15:00-15:20

Amine Kli: Université Bourgogne Europe & Mines-ParisTech

Atomistic and mesoscale investigations of grain boundary migration in the presence of nanoscale precipitates

Olivier Politano, Marc Bernacki.

Solid-state joining techniques include uniaxial pressing and hot isostatic pressing (HIP), with the latter offering significant advantages for the consolidation of large components with complex geometries. The control of microstructural evolution during these processes, along with a thorough understanding of the associated phenomena, is essential to obtain a homogeneous and continuous material exhibiting the required mechanical properties. In particular, the mechanisms governing grain boundary (GB) dynamics remain insufficiently understood, particularly at interfaces where migration is obstructed by second-phase particles or other microstructural barriers. In this work, molecular dynamics (MD) simulations were conducted to investigate grain boundary (GB) migration in a nanocrystalline system, both in the presence and absence of obstacles. Several configurations were simulated using LAMMPS with an Embedded Atom Method potential for Cu-Ag systems. First, a half-loop GB in a Cu matrix, into which Ag particles of different geometries were introduced, was used to derive mobility laws in the presence of nanoprecipitates. Secondly, stability and mobilities of triple junctions were investigated. The same configurations were investigated using a Level-Set (LS) approach to benchmark the obtained results on identical systems with a front capturing description of the different interfaces. Later, quantities extracted from MD, such as mobility laws, might be used to refine intrinsic models, used by the Level-Set model, to study long-term microstructural evolution on large-scale samples

Keywords: Hot isostatic pressing, diffusion bonding, level-set method, molecular dynamics.

Plenary Presentation (MDCL 1305)

Tuesday, 15:40-16:40

Eugen Rabkin: Technion – Israel Institute of Technology

Plasticity, Recovery, and Recrystallization in Supported Metal Nanoparticles

Jonathan Zimmerman, Feitao Li

Plastic deformation of submicrometer-scale objects (such as thin films and nanoparticles) differs fundamentally from bulk behavior. At these dimensions, the accumulation and storage of lattice defects are strongly constrained by the proximity of free surfaces and interfaces, which promote efficient defect annihilation. As a result, the classical conditions required for recrystallization during post-deformation annealing may not be satisfied, raising fundamental questions about the lower size limits of recrystallization and its governing mechanisms.

In this work, we examine these limits using model single-crystalline metallic nanoparticles subjected to controlled plastic deformation and subsequent thermal annealing. Faceted Pt and Mo nanoparticles with well-defined crystallographic orientations were fabricated on sapphire and plastically deformed under uniaxial compression, followed by annealing at elevated temperatures. Plastic deformation produced systematic crystallographic reorientation, reflecting the rotation-dominated plasticity characteristic of single-crystals.

Thermal annealing revealed markedly different relaxation pathways depending on material, deformation level, and temperature. In some cases, the original crystallographic orientation was restored through the nucleation and growth of recrystallized grains, while in others the deformed orientation was largely retained, indicating dominant recovery rather than recrystallization. Recrystallization of Pt nanoparticles, when it occurred, was accompanied by pronounced interfacial phenomena, including localized material transport and the formation of holes to the substrate.

These observations are interpreted within a unified framework that emphasizes the non-equilibrium nature of grain boundaries and interfaces generated during nanoscale plastic deformation, and a size-dominated competition between recovery and recrystallization. More broadly, this work underscores the need to rethink classical recrystallization concepts when extending them to nanoscale systems, where surfaces and interfaces play a dominant role.

Poster Session (MDCL Lobby)

Tuesday, 19:00-21:00

Timo Brederode: TU Delft

The Effect of Impurities on Static Recrystallization of Austenite in Steel

Erik Offerman, Leo Kestens, Hossein Beladi.

More scrap is being used in steel production to decrease the CO_2 emissions. With scrap comes an increased amount of impurity elements, like Cu and Sn. This changes the chemical composition of the steel and affects different steel processes, like austenite recrystallization after hot rolling. In previous research, it has been shown that Cu and Sn additions will retard the austenite recrystallization. In this work, the effect of Cu, Sn in combination with temperature on the microstructural evolution and kinetics of austenite recrystallization are quantified using a Fe-C-Mn model alloy and a 100Cr6 bearing steel. Early results on the kinetics, from the double hit test, and the microstructural evolution, from SEM-EBSD scans in combination with austenite reconstruction, are presented. These results can be used by industry to alter their process conditions to account for the effect of impurities, which allows them to produce steel with lower emissions while maintaining a high quality.

Keywords: Austenite, Static Recrystallization, Steel scrap, Impurities.

Tuesday, 19:00-21:00

Sanggu Choi: Pukyong National University

Texture Evolution and Recrystallization Behavior of Mg–Ag Alloys during Plane Strain Compression

Jimin Yun, Jeongbin Park, Kwonhoo Kim.

Magnesium and its alloys have long attracted considerable interest as lightweight structural materials due to their excellent specific strength, vibration damping capacity, and biocompatibility. However, the limited number of active slip systems at room temperature increases the likelihood of defect formation during deformation, resulting in poor formability. Although

high-temperature processing can activate additional slip systems, the low crystallographic symmetry promotes the development of strong basal textures, causing pronounced plastic anisotropy. Understanding and controlling microstructure and textural evolution during processing is therefore essential. Rare-earth additions have been widely explored to modify microstructures in Mg alloys, but their high cost and supply instability hinder applications. Consequently, alternative alloying elements such as Ag have gained increasing attention. Previous research on Mg–Ag alloys examined microstructure and texture behavior during plane strain compression at a strain rate of 0.05 s^{-1} and suggested that Ag content and strain rate may alter the deformation mechanisms. In this study, texture evolution during plane strain compression was investigated under a lower strain rate of 0.0005 s^{-1}. Mg–(3, 6, 9 wt%)Ag alloys were hot-rolled at 673 K to establish the initial texture and homogenized at 773 K. Plane strain compression tests were conducted at 723 K to true strains of 0.4, 0.7, and 1.0, and microstructural and textural changes were characterized using FE-SEM and EBSD. The results indicate that Ag content significantly affects recrystallization kinetics and that the mechanisms of texture development differ from previous studies.

Keywords: Magnesium, Mg-Ag, Texture, Recrystallization.

Tuesday, 19:00-21:00

Daniel Dickes: Max Planck Institute for Plasma Physics

Abnormal surface grain growth in tungsten during fusion-relevant heat flux exposure

Daniel Dickes, Bernd Boswirth, Katja Hunger, Francesco Crea, Riccardo De Luca, Andrei Galatanu, Yiran Mao, Jan W. Coenen, Selanna Rocella, Jeong-Ha You, and Johann Riesch.

In future fusion devices like ITER and DEMO, W will be used in plasma-facing components like the divertor, which is exposed to steady state and transient thermal loads. Repetitive heat fluxes of up to 20 MW/m² are expected to occur, leading to surface temperatures of more than 2000 °C on the W components. This triggers microstructure changes like recovery, recrystallization, and grain growth in W, the extent of which has been intensively studied for commercially available rolled W. These studies cover furnace-based annealings and fusion-relevant cyclic thermal loading in high heat flux test facilities. Only during the latter, a phenomenon referred to as “abnormal surface grain growth” occurs, together with undesired plastic deformation and surface roughening. In this contribution, we assess whether such an abnormal surface grain growth also exists for newly developed W-fibre reinforced W composite (Wf/W) and Potassium-doped W-laminate plasma-facing components, which, due to their manufacturing route, possess thermomechanical histories and initial microstructures significantly different from commercially rolled or forged W. For this purpose, Wf/W and W-laminate components are heat flux exposed in the high heat flux test facility GLADIS, followed by a metallographic cross-section preparation and an SEM/EBSD analysis of the resulting microstructure. Furthermore, an experimental strategy to investigate a potential link between the occurrence of abnormal surface grain growth during cyclic high heat flux exposure and the initial microstructure, as well as the surface preparation method, is outlined.

Keywords: Tungsten, high heat flux testing, surface grain growth.

Tuesday, 19:00-21:00

Clemens Grünsteidl: Research Center for Non Destructive Testing GmbH

Laser-Ultrasound for In-Situ Monitoring of Microstructural Changes in Metals

Christian Kerschbaummayr, Edgar Scherleitner, Matthias Militzer, Christian Hoflehner, Markus Sonnleitner.

Typically, the microstructure of metals is analyzed ex-situ, by standard metallography or more advanced methods such as electron backscatter diffraction. While the information gained is most comprehensive, drawbacks are low throughput and practical limitations of these ex-situ investigations. Other common methods, such as in-situ dilatometry and ex-situ hardness testing can provide useful information on selected material parameters with faster and cheaper experiments, but are still restricted as techniques that require direct contact with the material probed. With laser-ultrasound (LUS) techniques, elastic waves can be generated and detected in metallic samples. Their main advantage is the contactless operation, which allows for remote in-situ measurements on hot and moving samples. Industrial setups enable the detection on unprepared surfaces first in-line setups are emerging. Both, the velocity, and attenuation of ultrasonic waves are affected by changes in the microstructure. Thus, they can potentially be used in evaluations to retrieve information about microstructure parameters. We show in-situ LUS measurements performed on steel samples in a thermal simulator, monitoring the processes of austenitic grain growth, austenite decomposition, and ferrite recrystallisation after cold rolling. During grain growth the ultrasonic attenuation due to grain scattering is changing and a calibrated model is used to infer the mean grain size evolution. During austenite decomposition, the phase transformation manifests as a change in elastic properties affecting the measured sound velocity. Further, the change in texture accompanying recrystallisation influences the macroscopic elastic anisotropy and leads to a change in sound velocity. For quantitative information on the recrystallized volume fraction, we compare measured values to models which we obtained from EBSD data. This in-situ use of LUS in the laboratory provides high throughput, which we consider especially valuable when adapting processes to changing raw materials, as is the case with the transition to greener steel production routes. Besides the demonstrations listed above, we will introduce the experimental and theoretical basics and aim to inspire new studies and applications, also for other materials.

Keywords: Laser-Ultrasound, In-Situ.

Tuesday, 19:00-21:00

Seongmo Jang: Pukyong National University

Influence of Pb addition on the microstructure and texture development of magnesium alloys

Yeom Jinseok, Kim Kwonhoo.

Magnesium alloys are promising lightweight structural materials owing to their low density and high specific strength; however, their application is limited by poor formability resulting from restricted slip activity at room temperature and by strong texture development during high-temperature processing. To address these issues, texture control using rare-earth alloying has been extensively studied, but its practical application is restricted by high cost. Therefore, alternative alloying elements such as Ca and Pb have recently attracted attention. Although Pb is known to influence microstructural evolution by reducing grain boundary energy and suppressing solute diffusion, the texture evolution behavior of Mg–Pb alloys has not been fully clarified. In this study, the effects of Pb addition on microstructure and texture evolution in an Mg–11 wt% Pb alloy were investigated under high-temperature plane strain compression. The alloy was hot-rolled at 673 K and subsequently heat-treated at 773 K to obtain a homogeneous initial microstructure. Plane strain compression tests were conducted at 723 K with a strain rate of 5×10^{-2} s^{-1}. Microstructural evolution and texture development were analyzed using FE-SEM/EBSD and XRD, respectively. Under all deformation conditions, work softening behavior was observed after the peak stress, indicating the occurrence of dynamic recrystallization during high-temperature deformation. In the recrystallized regions, fine equiaxed grains with dispersed crystallographic orientations were formed, leading to an overall weakening of texture intensity. These results suggest that Pb addition promotes recrystallization-assisted orientation randomization and contributes to texture weakening in magnesium alloys.

Keywords: Microstructure, texture, Mg-Pb, magnesium.

Tuesday, 19:00-21:00

Anish Karmakar: Indian Institute of Technology Roorkee

Role of Cerium in Controlling Deformation and Softening Behavior of Low-Carbon Steels

Chetan Kadgaye, Md. Sameer Ansari, Sudipta Patra.

The present work investigates the softening behavior of cerium (Ce)-modified steels subjected to 60% cold rolling and isothermal annealing at 600 °C for 2–16 h. Two alloys with varying Ce levels were examined: low Ce (LCe, 0.03 wt%) and high Ce (HCe, 0.6 wt%). Cold deformation introduced greater strain localization in the ferritic matrix of LCe steel compared to HCe steel, where homogenous strain distribution was facilitated by soft Ce_2O_3 particles. During annealing, both steels exhibited partial recovery and recrystallization after 16 h, though HCe achieved a higher softening fraction (≈34 vol%) relative to LCe (≈28 vol%). In LCe steel, strain-free grain nucleation occurred at grain and interphase boundaries during early annealing; however, recrystallization was subsequently impeded by fine CeO_2 and Fe_3C dispersions exerting strong pinning effects. In contrast, HCe steel initially experienced delayed nucleation due to Ce segregation at grain boundaries, but at later stages recrystallization accelerated as coarse Ce_2Fe_{17} and Ce_2C_3 particles provided weak resistance to dislocation recovery and boundary migration. The findings demonstrate that Ce addition significantly influences strain distribution, particle pinning, and recrystallization kinetics. While fine Ce-based dispersions in LCe steel enhance resistance to recrystallization, coarse Ce-rich phases in HCe steel promote faster softening upon extended annealing. This study underscores the potential of controlled Ce alloying to tailor recovery and stability in ferritic steels for structural applications

Keywords: Cerium modified steel, Subcritical annealing, Cerium precipitates, Recrystallization kinetics.

Tuesday, 19:00-21:00

Yiming Li: Inner Mongolia University of Science and Technology

Texture simulation of cold rolled industrial pure zirconium by RS model

Huiping Ren, Weimin Mao

Texture is an important factor affecting the plastic deformation and service performance of metals, which is usually tailored by deformation and recrystallization in industry. Texture evolution of the industrial pure zirconium during recrystallization and cold rolling process was studied by both experiment and simulation in this work. Dynamic recrystallization of the industrial pure zirconium was introduced by three way forging and annealing to obtain the recrystallization state without texture, and then cold rolled by increased strain rate. Texture evolution was characterized by XRD and EBSD. The intergranular interaction and its influence on the starting of sliding system during deformation were studied. The reaction stress (RS) model based on the interaction between grains was also used to simulate and calculate the evolution of the starting slip system and texture during grain deformation, by which the plastic deformation mechanism of hexagonal zirconium were explored. The experimental results showed that texture of the zirconium alloy gradually concentrated on the {0001} basal plane orientation by cold rolling, and the most sharp texture component was $\{0001\}\langle 10\bar{1}0\rangle$. The simulated results were consistent with the experimental results. The main deformation mechanisms of zirconium alloy were $\{0001\}\langle 10\bar{2}0\rangle$" basal plane slip, $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$" and $\{11\bar{2}1\}\langle 1\bar{1}\bar{2}6\rangle$ tensile twinning.

Keywords: Texture; pure zirconium; reaction stress model; basal plane slip; tensile twinning

Tuesday, 19:00-21:00

Zi-Lin Li: University of Science and Technology Beijing

Novel Mg-Ga-Li alloys

Zhang-Zhi Shi

Mg-Ga-Li alloys exhibit excellent corrosion resistance and mechanical properties. This study systematically investigates the microstructure evolution and mechanical properties of solution-treated and as-extruded Mg-5Ga-1Li (GL51) alloy. A core-shell structure second phase is detected in the as-cast sample, while solution treatment (3 h at 450 °C, termed the SS sample) induces the dissolution of this phase. Notably, a novel spherical precipitation phase (average diameter Davg = 0.10 μm) emerges in the SS sample matrix. Prolonged solution treatments lead to precipitate coarsening, with Davg increasing from 0.45 μm (10 h) to 0.61 μm (24 h). The yield strength (YS), ultimate tensile strength (UTS), and elongation to failure (EL) of the SS sample are 64.7 MPa, 202.5 MPa, and 14.0%, respectively. Constitutive equation and hot processing map are established based on isothermal compression data. Guided by the hot processing map, two extruded samples with extrusion ratios of 7.1 (EX1) and 16.0 (EX2) are prepared. With increasing extrusion ratio, the average grain size decreases from 14.4 μm (EX1) to 6.5 μm (EX2). The mechanical properties of EX1 and EX2 are: YS (171.7 vs. 137.0 MPa), UTS (272.7 vs. 261.1 MPa), and EL (19.2% vs. 27.0%). This work provides guidance for the future development of novel Mg-Ga-Li alloys.

Keywords: Mg-Ga-Li alloy, Microstructure, Mechanical properties, Recrystallization.

Tuesday, 19:00-21:00

Kensuke Morimiya: Tokyo Denki University

Improvement of Bending Formability of AZX612 Mg Alloy by Shot Peening and Heat Treatment

Kensuke Morimiya, Takuzo Niwa, Ren Imada, Yusuke Onuki.

Magnesium alloys exhibit high specific strength among engineering metals; however, their ductility is inherently limited. Rolled magnesium alloy sheets are known to possess a strong basal texture, in which the (0001) planes are preferentially aligned parallel to the sheet surface, leading to poor ductility. Although various approaches have been proposed to weaken the basal texture in order to improve ductility, such methods often result in a simultaneous reduction in strength. To achieve a balance between ductility and strength in the Ca-added magnesium alloy AZX612, the authors aimed to locally weaken the basal texture by applying shot peening followed by heat treatment. Experimental results revealed that the basal texture near the surface of the magnesium alloy was weakened during recrystallization induced by the suggested process. As a result, bending deformation with a punch radius of 2.5 mm was successfully achieved for the sheet having thickness of 1 mm, demonstrating a localized improvement in ductility. In order to clarify how the locally modified texture and microstructure achieve the better bending formability, the deformation behavior during bending was investigated using digital image correlation (DIC). It was found that the application of shot peening and subsequent heat treatment caused the shift of the bending neutral surface toward the outer surface, which was identified as a key factor enabling successful bending deformation.

Keywords: Magnesium, Shot Peening, Texture Control, Digital Image Correlation.

Tuesday, 19:00-21:00

Jeongbin Park: Pukyong National University

Effect of Ag Addition on Microstructure and Texture Evolution during High-Temperature Plane-Strain Compression

Jimin Yun, SangGu Choi, KwonHoo Kim.

Magnesium alloys with the addition of aluminum and zinc are receiving attention as lightweight materials due to their high specific strength and excellent vibration damping properties. However, due to the HCP crystal structure of Mg, the number of activated slip systems at room temperature is limited, resulting in poor formability and restricting commercial applications. Therefore, research on improving room-temperature formability by controlling microstructure and texture has been ongoing. Magnesium alloys containing Ag are attracting attention as biomaterials due to their excellent biocompatibility and corrosion resistance, making them suitable for implants. However, there is still a lack of research on the deformation mechanisms of Mg-Ag alloys. Previous studies have investigated microstructure and texture evolution behaviors during high-temperature deformation of AZ-series alloys, finding that Mg-Ag alloys exhibit similar texture evolution behaviors. This study aims to investigate the effects of Ag addition on microstructure and texture evolution during high-temperature plane-strain compression. A Mg alloy with 3wt% Ag was used. After rolling, the samples were heat-treated, and high-temperature plane-strain compression was performed at 723 K with a strain rate of 5.0×10^{-2} s^{-1}. To investigate microstructural evolution, three different samples with distinct initial crystallographic orientations were prepared, and the effects on microstructure and texture changes were analyzed. Stress-strain curves of the Mg-Ag alloy during high-temperature deformation showed an increase to peak stress, followed by a decrease, then a subsequent increase in stress. EBSD and XRD analyses revealed that microstructure and texture distributions varied depending on the initial texture.

Keywords: Texture, Microstructure, Mg-Ag, Magnesium.

Tuesday, 19:00-21:00

Oliver Petry: TU Darmstadt

Grain boundary hardening vs softening in Nanocrystalline CuZn30

Bruder Enrico, Sos Marcel, Mathias Julian, Dai Yuting, Kübel Christian, Durst Karsten.

Nanocrystalline (NC) and ultrafine-grained (UFG) materials are known for increased mechanical strength compared to their coarse grained (CG) counterparts. However, at elevated temperatures softening as well as enhanced strain rate sensitivity can be observed in NC and UFG materials. In this study the different effects of temperature, strain rate and strain on the microstructure and mechanical strength of NC and CG CuZn30 are investigated. High pressure torsion (HPT) is used to produce bulk samples of nanocrystalline CuZn30. Tensile, compression and nanoindentation tests are employed to investigate the mechanical properties at temperatures up to 300°C. This study shows the strengthening effect of GBs at RT and the softening effect at elevated temperatures. It is shown that the microstructure is thermomechanically stable at temperatures up to 150°C and that the softening at these temperatures is fully reversible. At higher temperatures, a transient phase can be observed where the NC material softens further, but deformation driven grain growth leads to coarsening. The Coble creep, Blum-Zeng and Figueiredo-Langdon models are compared to experimental data for the strain rate sensitivity exponent m. The best agreement was found for the Figueiredo-Langdon model, which fits well for the stable temperature regime from RT up to 200°C.

Keywords: Ultrafine-grained; nanocrystalline, strain rate jump; brass; high pressure torsion; thermomechanical.

Tuesday, 19:00-21:00

Andreas Rechberger: voestalpine Stahl GmbH

Monitoring the recrystallization of a 3rd Gen Advanced High-Strength Steels (AHSS) with Laser-Ultrasonics

Hoflehner Christian, Neundlinger Lukas, Daniel Krizan, Hebesberger Thomas, Schnitzer Ronald.

Advanced High-Strength Steels (AHSS) are widely used in automotive applications due to their favorable strength-to-weight ratio. Microstructural control is essential for achieving the desired properties, with recrystallization playing a notable

role. However, conventional characterization methods are often destructive and time-consuming. Laser-Ultrasonics (LUS) offers a non-contact, real-time method for monitoring recrystallization by detecting changes in ultrasonic velocity. In this work, LUS was employed to investigate the isothermal recrystallization kinetics of cold-rolled AHSS, with complementary microhardness measurements and microstructural analysis used to validate the results. The experimental results were evaluated using the Johnson-Mehl-Avrami-Kolmogorov (JMAK) model to characterize recrystallization kinetics. Our results demonstrate that LUS is a reliable approach that complements standard techniques such as hardness testing.

Keywords: Advanced High-Strength Steels (AHSS), Laser-Ultrasonics (LUS), Microhardness, JMAK model.

Tuesday, 19:00-21:00

Benedek Sziklai: University of Miskolc

Thermal stability of ultrafine graine FALEP processed Al1050 alloy

Mate Sepsi, Tamas Ungar, Valeria Mertinger.

With severe plastic deformation (SPD), an ultrafine-grained microstructure can be achieved. As a result of the deformation, the stored energy and the driving force for continuous dynamic recrystallization (CDRX) and post-dynamic recrystallization (pDRX) increase immensely. In this case, however, the advantageous properties (increased strength, texture) of the metals can be lost. Therefore, to control the recrystallization and the heat stability of this material is important. The present study focuses on the recrystallization after the friction assisted lateral extrusion (FALEP) process under different heating conditions on Al1050 alloy up to 350°C. Continuous heating processes were performed in an in-situ synchrotron experiment (at DESY) with the heating rate of 10K/min and with DSC using different heating rates. From the synchrotron-tested samples using CMWP methode the average crystallite size and dislocation density were determined. Isothermal heating processes were carried out for one hour with different heating temperatures ranging from 100°C to 340°C with 20°C increments. Hardness data and EBSD images were collected to characterize the grain structure. The results of the investigation provide evidence of the unique recrystallization of the FALEP-processed materials.

Keywords: SPD, recrystalization, synchrotron.

Tuesday, 19:00-21:00

Varun Srinivas Venkatesh: University of Michigan

A graph-based approach for tracking grains in time-resolved 2D/3D microstructural datasets

Zachary Croft, Katsuyo Thornton, Ashwin J. Shahani.

The microstructure of polycrystalline materials consists of an interconnected network of grains and grain boundaries whose evolution during processes such as annealing or deformation directly influences properties including strength, ductility, and fatigue resistance. Tracking the temporal evolution of individual grains is therefore essential for testing new theories and linking processing conditions to microstructural evolution. Even so, grain tracking in time-resolved datasets is challenging due to topological changes, grain translation, sample deformation, and registration errors.To address these challenges, we present two registration-independent grain tracking algorithms. The first is a coordinate-transformation approach based on local misorientations. The second is a graph-based method that represents the microstructure as a network of grains (nodes) and grain boundaries (edges) and uses graph matching to resolve grain correspondences while preserving topological consistency. We benchmark both approaches against conventional volume overlap and centroid-proximity methods using three-dimensional phase-field simulations and an experimental laboratory x-ray diffraction contrast tomography dataset of pure aluminum containing over 2,200 grains. Across all datasets, the graph-based approach consistently achieves the highest

accuracy and efficiency, particularly in cases involving substantial microstructural evolution or sample deformation. The robustness of the graph-based approach lends itself to other problems of microstructure evolution wherein the microstructure can be encoded as a graph. Finally, by analyzing how tracking accuracy degrades as grains disappear over time, we estimate the maximum time interval between scans required for reliable grain tracking. Together, these results establish a new, scalable framework for grain tracking and provide practical guidance for the design of time-resolved microstructural experiments.

Keywords: Three-dimensional microstructure; Temporal evolution; x-ray tomography; phase-field simulation; quantitative microanalysis.

Tuesday, 19:00-21:00

Jinseok Yeom: Pukyong National University

Effect of Zener-Hollomon parameter on Microstructure and Texture Development Behavior during High Temperature Plane Strain Compression in Mg-Pb magnesium alloys

Kwonhoo Kim.

Magnesium alloys have attracted many attention as a lightweight structural material due to its high specific strength and low density. Recently, damping capacity is also one of the well-known properties of magnesium alloys. However, they have low formability at room temperature due to the lack of active slip systems associated with HCP structure. Even during high temperature processing, a basal texture would be formed inducing plastic anisotropy and mechanical defects, such as fractures or cracks. This results in many restrictions of magnesium alloys on commercial applications. In this study, Mg-8 wt.% Pb, Mg-11 wt.% Pb and Mg-15 wt.% Pb magnesium alloys were used as starting material. Hot rolling was carried out at 673K until rolling reduction of 25% to make three different specimen type depending on ND, TD and RD. Heat treatment was carried out at 723K for 1H to form uniform microstructure and stress relief. High temperature plane strain compression was performed at 693K and 723K with a strain of -0.4, -0.7 and -1.0. SEM and EBSD analysis were performed after cutting middle area to observe microstructure and texture, respectively. Continuous Dynamic Recrystallization were confirmed after observing all the specimens after compression. Flow stress is affected by deformation temperature, strain rate and Z parameter. Pb content in Mg alloys contributed to a decrease in stacking fault energy, inhibited cross slip and lead strengthening of basal texture. As high as alloying element content is, peak stress of S-S curves and intensity of basal texture after compression were even increased.

Keywords: Stacking Fault Energy, Dynamic Recrystallization, Zener-Hollomon parameter, Mg-Pb magnesium alloys.

Tuesday, 19:00-21:00

Jimin Yun: Pukyong National University

Solute Ag Effects on Microstructure and Texture Development in Mg Alloys

Sanggu Choi, Jeongbin Park, Kibeom Kim, Kwonhoo Kim.

Magnesium (Mg) and its alloys have attracted significant interest as lightweight structural materials due to their high specific strength and excellent vibration damping capacity. However, the limited number of operative slip systems arising from the hexagonal close-packed (HCP) crystal structure results in poor room-temperature formability and deformation-induced defects. Although high-temperature processing can activate non-basal slip systems, the formation of strong (0001) basal textures often leads to pronounced plastic anisotropy, making texture control a critical challenge. Alloying strategies using rare-earth (RE) elements have been widely investigated to weaken basal textures; among them, silver (Ag) has been

suggested to promote local atomic clustering that enhances mechanical performance. Nevertheless, the influence of Ag on microstructure and deformation behavior in single-phase Mg–Ag alloys remains insufficiently understood. In this study, the effects of Ag concentration on microstructural evolution and texture development in Mg–Ag alloys were systematically investigated under high-temperature plane-strain compression. Mg–(3, 6, 9) wt%Ag alloys were prepared and characterized using XRF and SEM-EDS to confirm chemical composition and phase constitution. Differential scanning calorimetry and phase diagram analysis were employed to determine appropriate solution treatment conditions. After hot rolling at 673 K with a 25% thickness reduction, specimens were solution-treated at 773 K for 1 h in Ar-sealed quartz tubes to suppress oxidation. Plane-strain compression tests were conducted to evaluate deformation behavior. Microstructural evolution and dynamic recrystallization were analyzed using FE-SEM and EBSD, while deformation textures were examined by XRD. All alloys exhibited a single-phase microstructure after homogenization. The peak flow stress increased with increasing Ag content. Following plane-strain compression, extensive dynamic recrystallization occurred; however, locally retained coarse grains were observed, which are attributed to variations in dislocation density and initial crystallographic orientation. These results indicate that Ag addition modifies the microstructure and texture evolution mechanisms during high-temperature deformation in Mg–Ag alloys.

Keywords: Magnesium, Texture, Microstructure, Mg-Ag.

Wednesday, May 27, 2026

Plenary Presentation (MDCL 1305)

Wednesday, 9:00-10:00

Liz Holm: University of Michigan

Can we predict grain growth?

Theoretical models for polycrystalline grain growth are deterministic. However, computer simulations based on these models do not reliably predict experimental growth trajectories for individual grains. Disagreement between experiment and simulation has generally been attributed to shortcomings in the computer models, but even after several decades of improving our models, discrepancies remain. This leads us to consider the sources of uncertainty in grain growth simulations and experiments. We build ensembles of nominally identical molecular dynamics simulations to characterize the uncertainty in grain growth trajectories. Surprisingly, we find that microstructural events are extraordinarily sensitive to atomic-scale processes. The implication is that grain growth has a fundamental, innate uncertainty that limits our ability to predict its outcomes. Simulation and experiment can never agree perfectly; however, simulations can predict the range of possible experimental outcomes.

Experimental Techniques III (MDCL 1110)

Wednesday, 10:20-10:50

Amanda Krause: Carnegie Mellon University

Capturing Abnormal Grain Growth with 3D X-ray Diffraction Microscopy

Models and simulations derived from curvature-based motion cannot predict irregular, albeit commonly observed, grain growth behavior. In particular, the cause of abnormal grain growth, in which a few grains have a growth advantage compared to their neighbors, is still debated. Laboratory x-ray diffraction contrast tomography (LabDCT), a non-destructive

3D microstructural characterization method, provides an opportunity to observe the microstructure prior to abnormal grain growth. This talk will highlight how LabDCT and similar x-ray methods provide new insights on grain growth to create or train predictive models. Experimental observations of abnormal grain growth in nickel and alumina will be used to explore potential descriptors (curvature, number of neighbors, grain boundary character, etc.). The outstanding challenges and opportunities for using 3D x-ray diffraction microscopy to elucidate microstructural evolution will be discussed.

Keywords: Abnormal grain growth; Laboratory X-ray Diffraction Contrast Tomography; Ni.

Wednesday, 10:50-11:10

Ruth Birch: University of British Columbia

3D analysis of variants at a prior austenite grain (PAG) twin boundary in steel

Warren Poole, Ben Britton.

Thermomechanical processing is widely used to control the microstructure and properties of high strength low alloy steels, and these steel alloys are used in demanding environments. In these materials, optimization of the thermomechanical processing can be performed through better understanding of microstructural evolution during processing. A key step is the solid-state phase transformation during cooling from the high-temperature austenite to the room-temperature microstructure (e.g., bainite) during cooling, which significantly influences the final microstructure and properties. Specifically, the population of different variants and grain shapes that form affect the types and morphology of the grains, and grain boundary network which may influence strength and toughness of the final component. In this presentation, we will apply 3D microscopy using a Xe-plasma focussed ion beam scanning electron microscope (pFIB-SEM) which is equipped with electron backscatter diffraction (EBSD) in a static configuration to characterize the room temperature microstructure of a steel sample, and then use a '2.5D' prior austenite grain (PAG) reconstruction code to explore the relationship between the austenite phase and the room temperature microstructure. A remarkable result for the present work is the collection, and analysis, of data from a large volume (150 x 150 x 100 µm3, with a 150 nm3 voxel size) which enables analysis of a complete prior austenite grain. Analysis of variants within this grain demonstrates that high-temperature twin boundaries likely govern variant selection and grain growth in the child microstructure. This suggests opportunities to engineer novel microstructures by controlling the high-temperature grain boundary character.

Keywords: steel; 3D EBSD; twin; prior austenite grain reconstruction.

Wednesday, 11:10-11:30

Lucia Puertas Pelaez: ESRF

Multimodal 3D X-Ray Imaging of Grain Boundary Migration at Triple Junctions

A. Shukla, L. Lesage, V. Sanna, M. Sarkis, Y. Zhang, W. Ludwig, C. Yildirim.

Classical models of grain growth fail to reproduce the complexity observed experimentally, while more recent theories remain weakly constrained by experiments due to the lack of in situ measurements combining high strain sensitivity, nanometric spatial resolution and three-dimensional microstructural context. In this work, we present a high-resolution, multimodal X-ray diffraction imaging study of grain growth in fully recrystallized aluminum 1050 alloy enabling direct and non-destructive quantification of triple junction morphology, grain boundary curvature, intragranular orientation, strain fields and dislocation structures within the same microstructure. By combining Dark-Field X-ray Microscopy (DFXM), 3D X-ray Diffraction (3DXRD), Diffraction Contrast Tomography (DCT), and phase-contrast tomography, we map the 3D evolution of three neighboring recrystallized grains and their surroundings during interrupted in situ annealing at temperatures up to approximately 0.96 T_m. DFXM provides strain sensitivity on the order of 5×10^{-5} with ~100 nm spatial resolution, while DCT and 3DXRD provide the surrounding grain topology, boundary curvature and energetic context. This approach allows us to track triple junction evolution in real space, identify grain boundary segments migrating against curvature-driven predictions, and correlate boundary motion with local elastic strain, strain gradients and intragranular misorientation. We directly assess experimental signatures of shear-coupled grain boundary motion, including stress concentration and effective drag at triple junctions, and examine their persistence at high homologous temperature. These results provide a stringent experimental test of grain growth mechanisms beyond curvature flow.

Keywords: Grain Growth, Polycrystalline Microstructures, X-Ray Diffraction Imaging, Shear Coupled Dynamics.

Wednesday, 11:30-11:50

Mario Heinig: Xnovo Technology

Time-Resolved 4D Study of Grain Growth in Armco Iron using LabDCT: Tracking Microstructural Evolution in 3D

Erik Lauridsen, Håkon Ånes, Jette Oddershede, Jette Pengxiang Wang, Yubin Zhang, Dorte, Juul Jensen.

Understanding grain growth in metallic systems is important to control the microstructure and tailor mechanical properties. We present a four-dimensional (3D + time) lab-based diffraction contrast tomography (LabDCT) study of grain growth in Armco iron over a series of interrupted heat treatments. The experiment captures orientations of individual grains at multiple time steps, enabling tracking of grain boundary migration over time. By reconstructing and indexing thousands of grains in 3D during growth, we provide a statistically relevant dataset that offers detailed insight into the growth behaviour of individual grains. This allows visualization of the evolution of grain size, shape, and orientation, revealing heterogeneous growth behavior influenced by local neighbourhood interactions. Furthermore, the complete 4D dataset will be published as an open-access resource, providing the broader community with opportunities for advanced statistical and computational analyses, including orientation-dependent growth modeling, boundary mobility quantification, and correlation with the thermal history. The study demonstrates the potential of lab-based 4D diffraction imaging as a versatile tool for characterization of microstructural evolution in iron and other polycrystalline materials, bridging the gap between laboratory-scale experiments and synchrotron studies.

Keywords: LabDCT, 4D microstructure, grain growth, iron.

Wednesday, 11:50-12:10

Mehdi Mosayebi: McMaster University

Benchmarking Non-Destructive 3D Grain Mapping for Recrystallized and Cast Microstructures: Quantitative Comparison of Lab-DCT and Serial-Section 3D-EBSD

Pardis Mohammadpour, Pierre-Antony Deschênes, Laurent Tôn-Thât, Daniel Paquet, Andre B Phillion, Nabil Bassim.

Recrystallization and grain growth are governed by the three-dimensional morphology of grains and the topology and crystallographic character of grain boundary networks. Reliable experimental access to these descriptors in 3D is therefore essential for validating mesoscale models, tracking microstructural evolution, and quantifying boundary populations that control boundary mobility. In this work, we present a direct, quantitative comparison between laboratory-based diffraction contrast tomography (Lab-DCT) and serial-section three-dimensional electron backscatter diffraction (3D-EBSD) for two representative microstructures: fully recrystallized pure Fe (BCC) and a chill-cast modified E309L austenitic stainless steel (FCC). Using 3D-EBSD as a reference, we assess the capability of Lab-DCT to reconstruct grain morphology, grain size

distributions, network topology (grain faces, triple junctions, and quadruple points), and five-degree-of-freedom grain boundary character, including grain boundary plane distributions (GBPDs). Lab-DCT reproduces dominant grain orientations and global network statistics with high fidelity, with accuracy improving for larger grains and minor discrepancies primarily arising from small or partially illuminated grains. In the cast FCC alloy, modest deviations are linked to residual strain and intragranular orientation gradients, which locally reduce diffraction completeness and introduce mild orientation smoothing. Despite local differences in boundary geometry, Lab-DCT captures key trends in misorientation distributions and CSL boundary networks, including dominant Σ3 and Σ5 boundary families. Overall, the results demonstrate that Lab-DCT provides a rapid, non-destructive route for quantitatively mapping 3D grain structures and boundary networks relevant to recrystallization and grain growth, while 3D-EBSD remains essential for resolving fine-scale boundary faceting and local orientation gradients.

Keywords: 3D microstructure; Diffraction contrast tomography (Lab-DCT); 3D electron backscatter diffraction (3D-EBSD).

Grain Growth III (MDCL 1105)

Wednesday, 10:20-10:50

Dikai Guan: The University of Southampton

4D grain growth evolution and statistical tracking in a magnesium alloy using lab-based diffraction contrast tomography

Haoran Yi, Gareth Douglas, Jette Oddershede, Jack Donoghue, Bo Chena, Dikai Guan

Grain growth governs the strength, ductility and creep performance of metals, yet spatial heterogeneity and mechanisms of abnormal grain growth (AGG) remain debated. We coupled 4D LabDCT with our newly developed grain-tracking toolbox (Track-4DGG) to investigate grain growth in a WE43 Mg alloy during interrupted annealing. The evolution of grain properties (e.g., orientation, volume, curvature) can be extracted from the tracking results, at both individual grain and grain cluster scales. We observe pronounced spatial differences in growth kinetics, with the surface section suppressing normal coarsening but promoting AGG rates. Contrarily, the inner section contains more AGG occurrences but with lower growth rates. More than 50% of the grains within two grain diameters of the initial surface are consumed, and the surviving grains are larger than their interior counterparts. This divergence in growth kinetics is attributed to a ring-like second-phase free band (SPFB) forming towards the surface during annealing.

Keywords: Magnesium Alloys; Grain Growth; EBSD; LabDCT.

Wednesday, 10:50-11:10

Hailey Hall: Carnegie Mellon University

Grain Growth in Textured and Untextured Alumina

Miles Haraldsson, Daniel DeLellis, Michael Kesler, Amanda Krause.

Classical grain growth models use topological cues such as curvature to predict microstructural evolution in polycrystalline systems. However, recent experimental studies in 3D suggest that these features are ineffective metrics for predicting growth behavior at the local scale. Here, microstructures of undoped, polycrystalline alumina are studied as a function of heat treatment time using laboratory diffraction contrast tomography. Both textured and untextured alumina are assessed to determine how grain boundary energy and mobility anisotropy influence growth. Textured alumina samples are prepared by slip casting under a strong magnetic field, causing preferential alignment of grains within the microstructure while

maintaining particle morphology. As sintered microstructures of the untextured and textured alumina share similar grain size and shape, allowing for direct comparison between the two systems. Observations in these microstructures reveal that the textured sample grows at a much slower rate than the untextured case with random grain orientation. Supported by award number DE-EE0009131.

Keywords: Microstructure evolution, grain growth, alumina.

Wednesday, 11:10-11:30

Eisuke Miyoshi: Osaka Metropolitan University

Triple-junction drag effects on two- and three-dimensional grain growth kinetics: A phase-field investigation

The kinetics of grain growth in polycrystalline materials are governed by the interplay between grain boundary and triple-junction mobilities. While boundary-controlled growth typically exhibits parabolic kinetics, pronounced triple-junction drag can drive the system toward a linear growth regime. Although identifying this transition is essential for tailoring the microstructures of fine-grained materials， the criteria defining the shift remain insufficiently understood, particularly for practically relevant three-dimensional systems. In this study, large-scale phase-field simulations are employed to systematically investigate the transition between these kinetic regimes. By explicitly incorporating finite triple-junction mobility into a multi-phase-field framework, we simulate the evolution of approximately half a million grains under junction drag in both two- and three-dimensional systems. The primary objective is to examine how the grain growth exponent varies as a function of a dimensionless drag parameter that characterizes the relative strength of triple-junction effects, thereby clarifying the conditions that govern changes in growth behavior. Furthermore, similarities and differences in junction-drag effects across spatial dimensions are explored to assess the potential for dimensionally invariant transition criteria. The non-steady-state evolution of grain size distributions under varying drag intensities is also examined, providing a foundation for improved prediction of grain growth behavior in fine-grained materials.

Keywords: Phase-field model; grain growth; grain boundary; triple junction.

Wednesday, 11:30-11:50

Eric Taleff: The University of Texas at Austin

The effect of subgrains on dynamic grain growth in BCC metals during high-temperature deformation

Thomas J. Bennett.

Dynamic grain growth (DGG) occurs during the plastic deformation of metals and alloys at elevated temperatures. It is typically much faster than static grain growth (SGG) at equivalent temperatures and has been observed to produce both normal and abnormal grain growth. Dynamic abnormal grain growth can produce large single crystals. Single crystals several centimeters in size were so produced in unalloyed Mo. Normal DGG was studied in an interstitial-free steel to characterize growth rates with respect to both time and strain. DGG is approximately 30 times faster than SGG when only time is considered. DGG also produces grain size distributions distinguished by long left tails and negative skewness. Subgrain boundaries, which naturally arise and evolve during high-temperature (creep) deformation of BCC metals, are intimately involved in driving DGG. The driving force from subgrain boundaries was estimated through measurements of boundary geometry to demonstrate that their effect is greater than that from general dislocation density reduction. The importance of subgrains to explaining DGG during deformation at elevated temperatures will be described in the context of both theoretical predictions and experimental data. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Keywords: Dynamic grain growth, subgrains, BCC metals, creep.

Wednesday, 11:50-12:10

Varun Srinivas Venkatesh: University of Michigan

Learning grain growth from experimental datasets using topology-aware graph neural networks

Yubin Zhang, Ashwin J. Shahani.

Understanding grain growth is essential for microstructural design because material properties depend strongly on microstructure. However, experiments and simulations are expensive and time-consuming, motivating the need for efficient data-driven models. While many data-driven approaches to quantify grain growth rely on large synthetic datasets, three-dimensional experimental measurements remain comparatively underexplored. To address this, we present a graph neural network (GNN) framework that learns grain growth directly from time-resolved three-dimensional (3D) experimental data obtained using synchrotron based diffraction contrast tomography (DCT) in pure polycrystalline Fe. The evolving microstructure is represented as a graph, with grains as nodes and grain boundaries as edges. The model is trained to predict changes in microstructural connectivity, corresponding to grain boundary appearance, disappearance, and persistence, using boundary-level features extracted from the data. We introduce a topology-aware loss function that penalizes invalid connectivity updates during training, improving physical consistency and achieving approximately 85% top-1 accuracy in predicting topological changes. The learned representations are extended to other datasets (collected at different anneal temperatures and time intervals) using transfer learning, requiring minimal retraining while preserving prediction performance. In addition to prediction, the framework enables direct comparison between experiments and simulations. Analysis of learned feature weights reveals which microstructural descriptors causes discrepancies between 3D experiments and phase field simulations, providing quantitative insight into missing physics. These results show that machine learning can extract meaningful grain growth mechanisms directly from experimental microstructure data, offering a pathway to improve physics-based models and microstructural design. Preliminary results to this end will be presented and discussed.

Keywords: Grain growth; Graph neural networks; Diffraction contrast tomography (DCT); Microstructural topology.

Recrystallization III (MDCL 1102)

Wednesday, 10:20-10:50

Dorte Juul Jensen: Technical University of Denmark (DTU)

Effects of Deformation Microstructure Morphology on Recrystallization

Hongjiang Pan, Roy Vandermeer, Yuwei Guo, Anderw Godfrey, Xiaodan Zhang.

This work investigates effects of deformation microstructure morphologies on nucleation and growth of recrystallization. It is shown that deformation of commercially pure aluminum by different processes, namely cold rolling and uniaxial compression to a strain of 1.9, leads to different recrystallization characteristics. The deformation microstructures, and the microstructural evolution during isothermal annealing at 280°C are characterized by electron back scattering diffraction (EBSD); and microstructural path modelling (MPM) is used to analyze the microstructural data. Even though the two types of samples are deformed to the same strain and have similar stored energies, clear recrystallization differences are observed. These are related mainly to the nucleation attributes, but also the growth of grains during recrystallization are different in the two samples. It is discussed how the two deformed microstructure morphologies and distributions of crystallographic orientations lead to different spatial distributions of nucleation sites, as well as different nucleation and growth rates, and thus to different recrystallization kinetics and recrystallized microstructures. The work highlights how important local

microstructural variations in the deformed state are for recrystallization. Additionally, this paper illustrates how the MPM methodology may be used to deduce key information about nucleation and growth.

Keywords: Recrystallization, deformation microstructure, microstructural path modelling, aluminum.

Wednesday, 10:50-11:10

Yusuke Onuki: Tokyo Denki University

Pseudo-Superplastic Deformation Assisted by Dynamic Recrystallization in AZX612 Magnesium Alloy

Kensuke Morimiya, Shunya Aomori, Haruki Hosokawa.

Magnesium alloys exhibit good strength but poor ductility at room temperature. Although its flammability is another disadvantage, it can be overcome by addition of calcium. Consequently, high temperature deformation becomes a promising forming process. The authors found that a calcium-added magnesium alloy, AZX612, shows a large elongation in uniaxial tensile test at elevated temperatures, despite its limited ductility at room temperature. Experimental results suggest that this behavior is attributable to the grain boundary sliding occurring in the dynamically recrystallized regions. In this study, grain boundary sliding is directly observed using the digital image correlation (DIC) technique. The strain concentration in the vicinity of grain boundaries supports the authors' hypothesis. In addition, the blow forming by using argon gas pressure is attempted as an application of the above mechanism. Although a thickness reduction of 50% is achieved, the deformed microstructure consists of equiaxed grains. This suggests that dynamic recrystallization takes please during the rate-sensitive deformation process.

Keywords: Magnesium alloy, dynamic recrystallization, superplasticity.

Wednesday, 11:10-11:30

Javier Miranda: McMaster University

Hot Deformation of a Ti–Al–V–Fe Alloy in the β-Phase Field

Hatem Zurob, Andre Phillion.

Fe-containing metastable β-titanium alloys offer a cost-effective alternative to conventional commercial β-Ti alloys. Their hot workability is determined by the rates of dynamic recovery (DRV) and dynamic recrystallization (DRX). Available studies on the hot deformation of these alloys often involve the formation of the α phase, leading to ambiguous interpretations of the interplay between DRV and DRX. Moreover, the origin of jerky flow observed at high strain rates is still unclear. In the present study, microstructural observations were used to interpret the flow-stress behavior of a sintered Ti-1Al-6V-5Fe during hot compression. Isothermal compression tests were performed on a Gleeble 3800 simulator at 871 °C and 955 °C, within the β-phase region, and at strain rates from 0.001 to 1 s^{-1} up to a true strain of 0.6. And the microstructural analysis was conducted by using SEM/EBSD. The observations show that deformation was dominated by DRV with a minor contribution from discontinuous DRX at high strain rates, following a power-law creep response ($n \approx 3$, $Q \approx 155$ kJ·mol^{-1}). Jerky flow is attributed to dynamic strain aging that occurs when $D/\dot{\varepsilon} \approx 10^{-13}$ m^2 and is induced by Fe at high strain rates near 950 °C, while V acts over a wider range and both solutes stabilize sub grains at low strain rates. These findings highlight the dominant role of dynamic recovery and solute–dislocation interactions in controlling the hot workability of V and Fe-rich β-Ti alloys.

Keywords: Softening mechanisms, Strain rate sensitivity, hot compression.

Wednesday, 11:30-11:50

Daisuke Adachi: Institute of Science Tokyo

Continuous and Discontinuous Recrystallization in Pearlite: Effects of Initial Microstructure and Cementite as a Second Phase

Ryota Nagashima, Nobuo Nakada, Koji Yamashita, Nanba Shigenobu.

To optimize the plastic deformation processes in medium- and high-carbon steels, the effect of the initial microstructure on the recovery and recrystallization behavior of pearlite was investigated. A fully pearlitic microstructure and ferrite-pearlite duplex microstructure were prepared using a near-eutectoid steel (Fe-0.73mass%C) and a hypoeutectoid steel (Fe-0.29mass%C), respectively. These steels were annealed at 973 K for various times after 40% cold rolling. The microstructural, crystallographic, and mechanical characteristics were examined using scanning electron microscopy with electron backscatter diffraction (SEM-EBSD) and nanoindentation. In the fully pearlitic microstructure, lamellar cementite was fragmented and spheroidized, accompanied by the formation of a ferrite subgrain structure. The ferrite subgrains grew while being pinned by spheroidized cementite particles. During this process, the average grain boundary misorientation of the subgrains increased continuously with subgrain growth, eventually resulting in a very fine-grained ferrite microstructure with high-angle grain boundaries. In contrast, in the ferrite-pearlite duplex microstructure, clearly recrystallized ferrite grains formed at the interface between proeutectoid ferrite and pearlite, and preferentially consumed the deformed proeutectoid ferrite. Subsequently, they advanced across the spheroidized cementite particles and also consumed the deformed pearlite with a subgrain structure, eventually leading to the formation of a coarse-grained ferrite microstructure. Nanoindentation measurements revealed that grain boundary migration of the consuming recrystallized ferrite caused discontinuous changes not only in crystallographic orientation but also in local hardness. From these results, it is concluded that the recrystallization mechanism of pearlite changes for continuous to discontinuous recrystallization with the presence of proeutectoid ferrite.

Keywords: Steels, pearlite, continuous recrystallization, cementite particle.

Wednesday, 11:50-12:10

Ali Amininejad: University of Miskolc

Dual role of texture evolution in grain refinement during severe plastic deformation: fragmentation vs coalescence

Laszlo Toth, Valeria Mertinger.

Severe plastic deformation (SPD) produces ultrafine-grained microstructures with enhanced properties. During deformation, continuous dynamic recrystallization (CDRX) occurs as geometrically necessary dislocations rearrange into dislocation walls, low-angle boundaries, and eventually high-angle grain boundaries. A limiting grain size exists where further reduction is not possible, the steady-state regime, where fragmentation is balanced by grain growth. However, at intermediate strain levels prior to the steady-state, the possibility of increasing grain size has often been neglected. To date, only two studies have examined this phenomenon: one experimental investigation reported a significant grain size increase with further straining [1], and a 3D simulation showed that up to 40% of grains can coalesce at a shear strain of 4 in fcc materials [2]. The present study demonstrates that grain refinement during plastic deformation involves two competing mechanisms: grain fragmentation and grain coalescence, both dependent on texture evolution. A severely deformed copper sample exhibited bimodal grain size distributions, with larger grains located near ideal texture components and small grains spread across a wider range of orientations. Simulations indicated that divergence rotation fields promote fragmentation by increasing misorientation between subgrains, while convergence rotation fields reduce mutual disorientation. Near ideal orientations, where lattice rotation rate is minimized, orientation differences can fall below the grain boundary detection angle, resulting in the disappearance of boundaries and the formation of larger grains through coalescence. These findings reveal that grain coalescence plays a significant role in microstructural evolution, a factor typically neglected in SPD

studies. [1] Gu, C. F., Toth, L. S., Rusz, S., Bova, M. Texture Induced Grain Coarsening in Severe Plastic Deformed Low Carbon Steel. Scripta Materialia 86 (2014) 36–39. [2] Zhang, C., Toth, L. S. Polycrystal Simulation of Texture-Induced Grain Coarsening during Severe Plastic Deformation. Materials, 13 (2020), 5834.

Keywords: Severe Plastic Deformation, Grain Fragmentation, Grain Coalescence, Texture Evolution.

Thursday, May 28, 2026

Plenary Presentation (MDCL 1305)

Thursday, 9:00-10:00

Hardy Mohrbacher: NiobelCon BV

Application of Microalloying for Controlling Recrystallization and Grain Growth During Downstream Steel Processing

Downstream processing of steel products involves a large variety of heat treatments in the ferrite as well as in austenite phase. Different from austenite conditioning in the upstream processing stage, deformation and temperature schedules are usually decoupled in downstream processing. Fundamental characteristics of microalloying elements regarding their effects on recovery, recrystallization, phase transformation and grain growth during downstream processing will be reviewed. Relevant characteristics of microalloying elements are the atom size, the solubility and temperature stability of related carbides or nitrides, the tendency of segregating at grain boundaries, dislocations and point defects, as well as the diffusivity. The various interactions and resulting microstructural effects will be demonstrated on a variety of industrial steel developments. The selected examples cover microalloy effects in ferrite and austenite phases, under slow and fast thermal cycles, as well as during short and long treatment times. Based on the observations and the related interpretation, a qualitative understanding of the microalloy interactions will be developed that is generally applicable despite the considerable variation of processes and products. It will also be highlighted how appropriate process and microalloy adaptations resulted in remarkable product optimization under industrial conditions.

Experimental Techniques IV (MDCL 1110)

Thursday, 10:20-10:50

Anthony Rollett: Carnegie Mellon University

Novel Quantification of Non-convex Grain Morphology in Printed Ti–6Al–4V

Ioannis Dalezios, Gregory D. Wong, Tuan Nguyen-Minh, Leo A.I. Kestens.

Complete and accurate quantification of additively manufactured microstructures, along with all their relevant features, is essential for reliable model development, calibration and qualification. This study analyzed trends in grain size and shape in a set of orientation maps acquired from samples of LPBF Ti–6Al–4V printed with varying power and scan speed, all within the process window. The EBSD maps of the alpha phase were used to reconstruct the parent beta grain structure. Fitting a convex hull around each beta grain and computing solidity was found to be effective in capturing the non-traditional morphology of the AM microstructures and their asymmetry with respect to the build direction. An equivalent synthetically generated microstructure with similar grain size and aspect ratio was used for comparison of the developed metrics between it and the AM-fabricated samples. The comparison shows that the aspect ratio fails to capture the morphological complexity of AM microstructures, whereas the new metrics effectively differentiate the two types of microstructures. Other than a slight variation in grain size, the grain shape exhibits negligible variation across the range of processing conditions explored.

Thursday, 10:50-11:10

Can Yildirim: European Synchrotron Radiation Facility

From Deformation to Grain Growth: Time-Resolved Multiscale Diffraction Imaging with Pink-Beam DFXM

Shukla Aditya, Zhang Yubin, Mavrikakis Nikolas, Lesage Louis, Sanna Virginia, Sarkis Marilyn, Li Yaozhu, Detlefs Carsten, Poulsen Henning Friis, Ludwig Wolfgang, Staeck Steffen, Henningsson Nils Axel, Kabukcuoglu Merve Pinar, La Bella Michela

Linking deformation microstructures to subsequent recrystallization and grain growth remains a central challenge in annealing studies. While grain-boundary motion is routinely quantified, direct experimental access to inherited intragranular orientation gradients and defect structures that influence annealing behavior is still limited, particularly in bulk materials and under in-situ conditions. Highly deformed structures are weakly diffracting, and techniques with sufficient spatial resolution are often too photon hungry for time-resolved grain-growth experiments. Pink-beam Dark Field X-ray Microscopy (pDFXM) provides a unique solution by enabling access to both deformed microstructures and time-resolved grain growth within the same non-destructive framework. pDFXM delivers a 27-fold increase in diffracted intensity while preserving ~100 nm spatial resolution, enabling rapid intragranular orientation mapping in heavily deformed materials and real-time tracking of grain growth during annealing. In this talk, we present recent examples on Al1050, where grain growth is tracked in situ with sub-second temporal resolution, and on cold-rolled Fe–3%Si, where highly deformed intragranular structures are resolved that are inaccessible in monochromatic mode. The results reveal pronounced spatial heterogeneity in grain-boundary velocity, including intermittent stop-and-go motion, and show that recrystallized grains can retain and develop local orientation gradients due to interactions with neighboring grains during late-stage annealing. We discuss the advantages and limitations of pink-beam operation and show how combining pDFXM with three-dimensional X-ray diffraction (3DXRD), diffraction contrast tomography (DCT), and phase contrast tomography (PCT) yields a genuinely multiscale microscope for studying annealing phenomena in bulk materials.

Keywords: Grain boundary dynamics, Deformation substructure, In-situ diffraction imaging, Dark Field X-ray Microscopy.

Thursday, 11:10-11:30

Vuk Manojlović: European Synchrotron Radiation Facility- ESRF/SIMAP

High-Throughput Mapping of Dislocation Recovery in Low-Carbon Graded Alloys via In Situ HEXRD

Hugo Paul Van Landeghem, Veijo Honkimäki, Guillaume Geandier, Benoît Denand, Frédéric Bonnet, Océane Buggenhoudt, Alexis Deschamps.

Alloy design requires exploring a wide parameter space where both composition and processing routes dictate the resulting microstructure and material properties. To streamline this process, the SIMaP laboratory of Grenoble INP developed a high-throughput methodology termed COMPASS. This approach integrates space- and time-resolved High-Energy X-ray Diffraction (HEXRD) with in situ thermal processing in a continuously translating sample environment, enabling rapid mapping of microstructure evolution kinetics. The aim of the present work is to determine the influence of substitutional solutes on dislocation recovery in low carbon steels. We investigate steels with graded molybdenum, manganese, and silicon compositions to understand their recovery behavior following cold rolling. A dedicated furnace, designed by the

Institut Jean Lamour (IJL) and operated at ID31, enables real-time tracking of dislocation density through modified Williamson–Hall and Warren–Averbach methods. By synchronizing continuous sample translation with fast data acquisition (10 Hz), this methodology efficiently quantifies dislocation density evolution as a function of local composition and temperature. Preliminary results confirm that in situ measurements successfully capture how solute additions slow down recovery kinetics across compositional gradients. Real-time monitoring reveals how subtle variations in alloying element content influence recovery, preserving critical transient states often missed by post-mortem analyses. This integrated approach links compositional variations to microstructural evolution, offering significant advances over traditional ex situ techniques. The insights gained will serve as valuable input for refining computational models and guiding the design of next-generation alloys with optimized properties.

Keywords: Dislocation recovery, High-throughput methodology, In situ HEXRD.

Thursday, 11:30-11:50

Erik Lauridsen: Xnovo Technology

3D Grain Mapping of Annealing Microstructures Using Laboratory Diffraction Contrast Tomograph

Mario Heinig, Jette Oddershede, Florian Bachmann.

Crystallographic orientation strongly influences annealing behavior in polycrystalline materials, controlling microstructural evolution during nucleation, recrystallization, and grain growth. Three-dimensional mapping of grain orientations therefore provides essential experimental input for understanding and predicting these processes in technologically relevant materials. Originally developed at synchrotron facilities in the early 2000s, non-destructive techniques such as diffraction contrast tomography (DCT) and 3D X-ray diffraction microscopy (3DXRD/HEDM) enabled direct observation of microstructure evolution in bulk samples during thermal treatments. Over the past decade, substantial progress has been made in transferring DCT to laboratory-based X-ray systems, significantly improving accessibility for applied research and materials development. Today, lab-based DCT supports routine, non-destructive, time-resolved 3D grain mapping over representative sample volumes. This presentation focuses on recent methodological developments in laboratory DCT, including advances in data acquisition strategies, reconstruction algorithms, and indexing robustness, aimed at increasing spatial resolution, acquisition efficiency, and accessible sample volume. Applications to quantitative grain-scale analysis and coupling with mesoscale microstructure evolution simulations for model validation and improved predictive capability will be discussed.

Keywords: Grain Growth, LabDCT, Characterization.

Thursday, 11:50-12:10

Johannes Neumüller: Materials Center Leoben Forschung GmbH

In-Situ Investigation of Precipitation and Grain Growth in Alloy 718 by High-Temperature Synchrotron Experiments

Thomas Hönigmann, Gerald Ressel, Thomas Leitner, Manfred Stadler, Volker Wieser, Martin Stockinger.

During thermo-mechanical processing of nickel-base superalloys, precipitation kinetics and grain growth strongly influence microstructure evolution and are therefore critical for achieving a targeted microstructure. For process design and optimization, a detailed understanding of these phenomena under relevant thermal conditions is required. Conventionally, the latter is investigated by ex-situ heat treatments and subsequent microstructural investigations, and then used to approximate the former. In the present work, high-temperature synchrotron experiments are employed to obtain in-situ insight into both of these processes directly. The investigated material is Alloy 718. Its high precipitate content makes it well suited for studying precipitation-related effects during thermal processing. After characterization of the initial microstructure, high-temperature synchrotron experiments with varying holding temperatures have been conducted, enabling a qualitative evaluation of precipitation kinetics and the determination of grain-growth kinetics. Consistent with literature reports, grain growth is strongly influenced by the delta phase: It remains limited below the delta-solvus temperature and increases markedly above it. The presented approach enables process-relevant in-situ characterization of precipitation behavior and grain-growth kinetics during thermal exposure of Alloy 718. It provides a direct basis for assessing the interaction between precipitate evolution and grain growth and support for the development of forming and heat-treatment strategies.

Keywords: Alloy 718, Precipitation Kinetics, Grain Growth, Synchrotron.

Thursday, 10:20-10:50

Wanquan Zhu: Chongqing University

Comparative five-parameter grain boundary character analysis of as-deposited and annealed nanocrystalline nickel

Wei Cai, Xiaobing Huang, Tianlin Huang, Guilin Wu, Xiaoxu Huang.

Nanocrystalline materials possess a substantially higher grain-boundary area fraction than their coarse-grained counterparts, giving rise to unique mechanical responses as well as thermodynamic instability. Upon annealing, grain growth and concurrent evolution in grain-boundary character commonly occur, altering the material's macroscopic properties. However, only a limited number of studies have been able to fully quantify the evolution of the five macroscopic grain-boundary parameters in nanocrystalline materials between their as-prepared and annealed states. In the present study, we successfully reconstructed the three-dimensional microstructures of electrodeposited nanocrystalline nickel and an annealed counterpart using three-dimensional orientation mapping in the transmission electron microscope (3D-OMiTEM). Both samples exhibit a preference for misorientations with <110> rotation axes, including Σ9, Σ11, and Σ3 boundaries. In the as-deposited state, Σ9 boundaries show a diffuse preference around the (–449) || (9–94) asymmetric-tilt character, while Σ11 boundaries correspond to diffused tilt characters. After annealing, Σ9 and Σ11 boundaries display preferences for (–115) || (1–1–1) asymmetric-tilt and (1–13) symmetric-tilt configurations, respectively. The fraction of coherent twin boundaries also increases after annealing. Comparison with theoretical grain-boundary energy model reveals that the annealed sample adopts a grain-boundary plane distribution corresponding to a lower overall grain-boundary energy state relative to the as-deposited microstructure. These results demonstrate the capability of 3D-OMiTEM to resolve five-parameter grain-boundary character distributions in nanocrystalline materials and provide insight into grain-boundary energy minimization during annealing.

Keywords: Nanocrystalline; Grain boundary; Microstructure; Three-dimensional transmission electron microscopy.

Thursday, 10:50-11:10

Dmitri Molodov: Kumamoto University

Gradual changing grain boundary character and forming lattice curvature near the boundary during deformation of magnesium bicrystals

Kevin Bissa, Marcel Schreiber, Konstantin Molodov, Talal Al-Samman.

Grain boundaries play a significant role in the deformation of polycrystals. Their response to deformation is however not completely understood, particularly with respect to how they accommodate lattice rotation of adjoining crystallites. The current study thus investigates the deformation behaviour of Mg bicrystals with 90°⟨10-10⟩ and ⟨11-20⟩ tilt boundary

strained in plane-strain compression up to different final strains. Due to the initial soft orientation of the two crystals, activation of basal slip in each crystal gave rise to lattice rotation around the transverse direction towards the compression direction of the channel-die. Orientation measurements showed that the initial character of the grain boundary changed significantly during plastic straining. This was interpreted in terms of the interaction between grain boundary and incoming lattice dislocations gliding on the basal planes, which caused a gradual annihilation of the grain boundary structural units. When deformation in the two grains became markedly non-uniform at larger strains of – 0.3 and – 0.4 due to the presence of the boundary, the adjacent regions of the latter underwent a pronounced lattice curvature of about 0.005 deg/µm persisting over a distance of 4 mm from the boundary. The reported observations demonstrated the excellent capability of the investigated grain boundary to accommodate strain-induced lattice rotation by substantially changing its structure, thereby preventing intercrystalline fracture of the material up to a certain level of deformation.

Keywords: Grain boundary; Lattice rotation; Dislocation gliding; Magnesium.

Thursday, 11:10-11:30

Giuseppe Abbruzzese: RINA CSM

The Influence of Grain Boundary Energies and Mobility on Texture Selection in GOES: A Comparative Analysis of Fundamental Mechanisms Governing Secondary Recrystallization Kinetics

The fundamental roles of grain boundary energy and grain boundary mobility in texture selection for grain-oriented electrical steel (GOES) are critical to understanding the mechanisms behind secondary recrystallization. This paper provides a comparison of the basic mechanisms influencing the kinetics of secondary recrystallization. For many years, the underlying mechanism of secondary recrystallization in GOES has been widely discussed. The debate has primarily centered on whether the selection of Goss grains is driven by high boundary mobility—which favors Goss grains, since in such strongly textured materials, a few Goss grains are more likely to have high-angle grain boundaries—or by low boundary energy, such as boundaries with high coincidence site lattice (CSL). Reduced boundary energy decreases the effective drag force exerted by second-phase particles (grain growth inhibitors) on the grain boundaries, thereby enhancing the kinetics of Goss orientation during secondary recrystallization. Historically, these mechanisms have been analyzed using the Statistical Theory of Grain Growth (Abbruzzese-Lücke Theory), which allows for the consideration of grain growth in the presence of texture and various types of boundaries drag, including Zener and atomic drag. This theory demonstrates that both mechanisms can facilitate effective secondary recrystallization, though each operates with distinct characteristics. More recently, attention has also been given to the kinetics of the reduction in grain growth inhibition—a factor critical to texture selectivity—as well as, the impact of chemical composition, processing parameters, and surface conditions on the "inhibition drop kinetics" (MOGOCA Software). In this paper, we attempt to analyze the influence of these fundamental mechanisms on the selectivity of Goss grains. This includes introducing realistic kinetics of inhibition drop during the final batch annealing and simulating a typical thermal cycle of the industrial process. The simulations will consider four texture components: two major components {111}<112> and {411}<148> , a deviating Goss component (Goss grains deviating from the [100] direction by 4° to 10°), and a precise Goss component (grains deviating from the exact Goss orientation by only a few degrees, typically less than 3°), in order to describe the most relevant patterns of microstructural evolution. The fundamental influence of grain boundary energies and grain boundary mobility in the selection of texture in GOES is significant. A comparative analysis of the principal mechanisms governing the kinetics of secondary recrystallization highlights significant differences in factors such as the evolution of texture component volume fractions, mean radius kinetics, secondary grain size, grain size distribution profiles, and other pertinent parameters.

Keywords: Secondary Recrystallization, Texture selection, Inhibition evolution, MOGOCA.

Thursday, 11:30-11:50

Bevis Hutchinson: Swerim AB

Grain boundary curvature and Zener pinning

Eigor Petry, Matthew Barnett.

The importance of boundary curvature as the driving force for grain growth has been strongly questioned in recent years as was especially evident at RexGG 2023. Experimental analysis and MD modelling have both shown that growth of individual grains does not happen as expected from a simple analysis of capillarity.
This raises the question of how Zener pinning occurs in the presence of second phase particles, a phenomenon of great importance in processing of many metals. Numerous publications since the Smith-Zener model was first presented in 1948 have all taken for granted that the pinning arises from restraining stresses from curved boundaries. Alternatively, it can be viewed that particles resist grain growth by removing net curvature and so eliminating the driving force for migration.
We start by reviewing some previous observations on silicon steel where abnormal growth seems to occur in spite of boundary curvature rather than because of it. We then consider the shape of grain boundaries when second phase particles are present. To do this we have utilized the effect of gallium in causing grain boundary separation in aluminium alloys. Whole grain surfaces perturbed by particles by can then be observed in detail using SEM and other techniques. Much behaviour expected from curvature is observed. Although this does not prove the importance of curvature in Zener pinning, it raises the question as to whether or how other processes can provide an explanation.

Keywords: Zener pinning, grain growth, curvature.

Thursday, 11:50-12:10

Anqi Qiu: University of Michigan

Mechanisms of shape evolution and rotation during crystal growth in cylindrical grains

Ian Caihao Chesser, Jian Han, David Srolovitz, Elizabeth Holm.

We perform molecular dynamics (MD) simulations of the growth of isolated cylindrical [001] tilt grains using a synthetic driving force that overcomes the curvature driving force. Unlike shrinking grains, growing grains with initial misorientations from 15° to 36.9° develop strong faceting, transitioning from octagonal to stable square shapes, accompanied by rotation to lower misorientation. In contrast, grains with misorientation greater than 36.9° exhibit predominantly cylindrical shapes and rotate to higher misorientations. Kinetic grain shape and facet type diverge from the equilibrium Wulff shape, being bounded by the slowest moving boundary planes. Grain boundary motion and grain shape evolution are governed by the nucleation and migration of grain boundary disconnections. A continuum disconnection model demonstrates that these processes require at least two active disconnection modes to replicate MD simulation results. These insights advance the understanding of grain growth mechanics, with implications for microstructural evolution under a variety of driving forces.

Keywords: Grain boundaries, grain growth, molecular dynamics, faceting.

Recrystallization IV (MDCL 1102)

Thursday, 10:20-10:50

Heung Nam Han: Seoul National University

An integrated numerical modeling framework for predicting anisotropy and formability of recrystallized metals

M-G. Lee, Min K.M. Park J. Bong H.J.

This study presents a numerical framework that integrates mechanical deformation with subsequent microstructural evolution during recrystallization. Grain-scale plastic deformation is described using a crystal plasticity formulation, while microstructural evolution is modeled using phase-field or cellular automata approaches. Local plasticity is captured through a dislocation density–based slip formulation implemented within a crystal plasticity finite element model, and the generalized strain energy release maximization scheme is employed to predict the formation of recrystallization textures during heat treatment. The predicted recrystallized microstructures are reconstructed as virtual representative volume elements (RVEs), which are subsequently used to evaluate mechanical properties such as plastic hardening, anisotropy, and formability under various loading conditions. As validation cases, the sheet anisotropy and localization-based formability of low-carbon steel subjected to cold rolling and annealing are first examined for different material orientations. In addition, the dynamic recrystallization behavior of stainless steel under hot compressive deformation is simulated to predict microstructural evolution and the associated mechanical response. The results demonstrate that the proposed integrated numerical framework, which explicitly accounts for heterogeneous grain-scale plastic deformation and subsequent microstructure evolution, provides a robust and predictive tool for linking processing, microstructure, and mechanical properties of metallic materials.

Keywords: Anisotropy, formability, Integrated numerical modeling, Crystal plasticity.

Thursday, 10:50-11:10

Katariina Lehtola: University of Oulu

The Effect of Niobium in Low-Carbon, Low-Alloyed Steel Recrystallization Kinetics

Oskari Seppälä, Jaakko Hannula, Juha Pyykkönen, Caio Pisano, Antti Kaijalainen.

In this study, the recrystallization behavior of three low-carbon, low-alloyed steels was studied with the stress relaxation method. The relaxation tests were conducted using the thermo-physical simulator Gleeble 3800 with various temperatures, strains, and strain rates. The studied alloying element was niobium, which affects recrystallization kinetics by solute drag and precipitation. A custom fitting tool was used to characterize the recrystallization behavior of the studied steels. The fitting tool uses well-known softening equations to fit recovery and recrystallization directly to the stress relaxation data. The precipitation behavior was also simulated by different commercial modeling tools. The results of this study showed clearly that niobium is affecting recrystallization by slowing or stopping it, which is evident from the relaxation curves of the experiments. With chosen parameters, the results show the differences between the studied steels. In the steel without niobium, recrystallization is completed at lower temperatures than in the steels that contain niobium. Additionally, the prior austenite grain size was studied with Electron Backscatter Diffraction (EBSD) to provide supplementary data for recrystallization kinetics characterization.

Keywords: Niobium, Precipitations, Recrystallization kinetics.

Thursday, 11:10-11:30

Gaeun Song: Seoul National University

Effects of Solute Atoms on Recrystallization Behavior of Platinum Alloys

Young-Kyun Kwon, So-Yeon Lee, In-Suk Choi.

Platinum (Pt) is a representative noble metal known for its excellent physical and chemical stability and high melting point, making it a good model system for investigating fundamental recrystallization behavior. This study examines the influence of solute atoms commercially used in the jewerly industry—copper (Cu) and tungsten (W)—on the recrystallization kinetics

of Pt alloys. The Pt alloys investigated here maintain a single solid-solution phase, allowing us to focus on how minor solute additions can drastically alter microstructures and mechanical properties. Three specimens (pure Pt, Pt–5 wt.% Cu, and Pt–5 wt.% W) were prepared, and changes in hardness and microstructure during annealing were analyzed. As a result, the recrystallization temperatures varied significantly depending on solute type and concentration: Pt (~600 °C) < Pt–Cu (~700 °C) < Pt–W (~1100 °C).
Through extensive microstructural characterization and computational analysis, we identified vacancy diffusivity and stacking fault energy (SFE) as the key factors controlling recrystallization kinetics. The effects of diffusivity and SFE on recrystallization were quantitatively evaluated. Furthermore, a modified JMAK-based model incorporating these two parameters successfully predicted the recrystallization behavior of other Pt alloys, such as Pt–Co and Pt–Mo.

Keywords: Platinum alloys, Recrystallization temperature, Vacancy diffusivity, Stacking fault energy.

Thursday, 11:30-11:50

Jack Mogus: University of Toronto

Cold Spray Deposition of Titanium and Thermal Stability of TiC-Reinforced Aluminum Powders: A Microstructural Study

Yu Zou, and Ali Dolatabadi.

Cold spray is a solid-state additive manufacturing process where metallic particles bond to a substrate through supersonic impact, severe plastic deformation, and adiabatic shear instability (ASI). This study examines the thermomechanical response and microstructural evolution of commercially pure Ti using SEM, TEM, and EBSD. Results show that bonding is governed by localized adiabaticity, jetting-induced energy dissipation, and transient viscous flow, rather than extensive particle flattening. TEM analysis reveals a heterogeneous microstructure of elongated, equiaxed, and nanocrystalline subgrains with high dislocation densities, indicating severe localized deformation and incomplete dynamic recrystallization (DRX). Owing to Ti's hexagonal close-packed structure, deformation is highly non-uniform, with dynamic recovery dominating. Localized thermal softening, enhanced by low thermal diffusivity, facilitates bonding. In parallel, gas-atomized TiC-reinforced aluminum alloys exhibit composition-dependent nanoparticle dispersion governed by rapid solidification and chemical segregation, with increased agglomeration in Al-7075. Thermal stability studies highlight solute redistribution, phase evolution, coarsening, and precipitation. These findings emphasize the critical role of cold sprayed coating microstructure in governing thermal stability relative to feedstock powders.

Keywords: Thermal Stability, Dynamic Recrystallization, Cold Spray, Metal Matrix Nanocomposite Materials.

Thursday, 11:50-12:10

Andras Borbely: MINES Saint-Etienne

In situ recrystallization study of two Zr-2.5wt.%Nb alloys with different initial strains

Victor Grand, Alexis Gaillac, Pierre Barberis, Peter Kenesei, Andrew Chuang, Andras Borbely.

High Energy X-ray Diffraction at the Advanced Photon Source was applied to study in situ the recrystallization of two Zr-2.5Nb alloys with different rolling reductions of 20% and 54%. The material consists of two-phases, the hexagonal α-Zr and a grain boundary network of metastable β-Zr. During annealing at 580°C the specimen with higher strain recrystallized, which was accompanied by the simultaneous β-Zr→ α-Zr + β-Nb phase transformation. This was not the case for the specimen with lower strain. Line profile analysis of high angular resolution diffraction peaks indicates that the different behavior originates from the difference in the stored energy. Using a new evaluation method considering the width of the

peaks, we could explore the heterogeneity of the stored energy not only in the two samples with different strains, but also in different texture components of the same specimen. The method is based on the optimization of the modified Williamson-Hall plot [1], and besides delivering the strain energy it also predicts the type and population of dislocations present in the material. It is shown that the grains corresponding to a texture component of the recrystallization fiber (Euler angles (0,0,30)) has a higher stored energy than the component of the deformation fiber (Euler angles (0,0,0). Recrystallization leads to the formation of new grains belonging to the recrystallization fiber. We also discuss the interplay between simultaneous recrystallization and phase transformation, taking place in the specimen with higher strain. [1] Borbély et al. J. Appl. Cryst. (2023) 56, 254–262

Keywords: Texture, dislocations, stored energy, recrystallization.

Industrial Applications III (MDCL 1105)

Thursday, 13:30-14:00

Marie Charpagne: University of Illinois

Three pathways to grain boundary engineering in Additive Manufactured alloys

Y.Nie, M.Gruber, J. Donoghue, A. Smith, YT. Chang.

Grain boundary engineering (GBE) aims to increase the fraction of low-energy boundaries in metallic microstructures, improving resistance to crack propagation and corrosion. In wrought alloys, GBE relies on repeated deformation–annealing cycles that induce critical recrystallization, a nucleation-limited regime that promotes large twin-related domains. However, these approaches are difficult to scale, time-intensive, and restricted to simple geometries. Laser-based additive manufacturing (AM) offers a pathway to overcome these limitations through near-net shaping in a single step. The rapid thermal cycles inherent to AM generate complex microstructures with high stored strain energy, primarily in the form of dense dislocation cell structures that should, in principle, favor recrystallization. Yet, recrystallization kinetics in AM alloys are often sluggish, requiring high homologous temperatures and long annealing times. First ,we investigate the origins of sluggish recrystallization in AM commercially pure Ni and 304L stainless steel. In-situ high-temperature EBSD at 950 °C is used to track microstructural evolution over statistically representative areas (mm² scale) with high spatial and temporal resolution. We show that dislocation cell structures strongly interact with migrating boundaries, leading to intermittent, avalanche-like boundary motion that hinders steady recrystallization. We then explore two alternative single-step pathways to introduce twin boundaries: (i) a BCC→FCC solid-state transformation, where twin boundaries form from the interaction of austenite variants sharing a Kurdjumov–Sachs relationship with a common BCC parent; and (ii) templated FCC nucleation on icosahedral motifs in undercooled liquids exhibiting topological short-range order. These mechanisms offer routes to bypass conventional GBE limitations in AM alloys.

Keywords: Grain boundaries, Additive manufacturing, In-situ.

Thursday, 14:00-14:20

Tianbo Yu: Technical University of Denmark

Recovery and recrystallization of stainless steel 316L produced by laser powder bed fusion

Stainless steel 316L fabricated via laser powder bed fusion (LPBF) exhibits a high density of dislocations and cell boundaries. These microstructural features constitute a significant stored energy that acts as the driving force for recovery and recrystallization when the metallic components are subjected to elevated temperatures. In this work, both the recovery mechanisms and kinetics of LPBF 316L are evaluated through hardness and microstructural characterization, and a significant difference is found compared to that of wrought counterparts, including a higher apparent activation energy.

Building-plate preheating can also provide a high temperature for the component during its building process. The effect of this in situ annealing on the dislocation recovery and solute homogenization is discussed, as well as the consequent microstructural gradient along the building direction. Furthermore, the recrystallization kinetics is analyzed using the Avrami equation, and the Cahn–Hagel growth rate is quantitatively evaluated. The sluggish recrystallization in LPBF 316L is found to be significantly affected by the microstructural heterogeneity.

Keywords: Recovery, Recrystallization, Stainless steel 316L, Laser powder bed fusion.

Thursday, 14:20-14:40

Alec Davis: University of Manchester

Recrystallisation Phenomena in High-Deposition-Rate Additively Manufactured Titanium Alloys

Jack Donoghue, Christopher Daniel, Jacob Kennedy, Joao Quinta da Fonseca, Albert Smith, Vivek Sahu, Bernadeta Karnasiewicz, Dongchen Hu, Martina Filomeno, Jialuo Ding, Jan Hönnige, Leonor Neto, Biswal Romali, Stewart Williams, Philip Prangnell.

High-deposition-rate directed-energy-deposition additive manufacturing (DED-AM) with titanium and its alloys is now being used regularly to produce near-net-shape parts, for industries such as aerospace, with significant sustainability benefits over conventional wrought manufacturing. Substantial technological advances have been made over recent years, including process additions and control measures that refine the heavily textured coarse and columnar β-grain structures that are often seen in these DED-AM alloys, leading to more isotropic and predictable mechanical behaviour overall. The thermal histories of DED-AM titanium parts differ radically from those of wrought production routes, exhibiting cyclical heating and cooling with rates higher by orders of magnitude. These accelerated thermal kinetics have been found to lead to novel recrystallisation phenomena, activated by microstructure deformation. This work investigated the recrystallisation mechanisms introduced when using inter-pass deformation (rolling and machine-hammer/ultrasonic peening) with Ti-6Al-4V wire-arc additively manufactured (WAAM) parts, where each solidified deposited layer is cold deformed and subsequently cyclically reheated during continued WAAM deposition. An 'autogenous recrystallisation' phenomena observed in commercially pure titanium WAAM was also investigated, which required no externally applied deformation to activate. The above recrystallisation mechanisms were investigated using novel WAAM 'stop-action' experimentation, lab-scale process replication, as well as direct in-situ electron microscopy observation and real-time synchrotron X-ray diffraction.

Keywords: Titanium, additive manufacturing, texture, in-situ testing.

Thursday, 14:40-15:00

Sabyasachi Roy: University of British Columbia

Recrystallization and Austenite Grain Evolution during Hot Rolling Simulation by Torsion Testing

Tseng Minyu, Patel Smit, Poole Warren, Militzer Matthias, Michael J. Gaudet.

Thermomechanical controlled processing (TMCP) is critical for modern steel production, enabling precise control of microstructure and mechanical properties through the interplay of deformation, recrystallization, grain growth and phase transformation. Quantifying recrystallization and austenite grain evolution under industrial conditions is essential for optimizing rolling schedules and product consistency.
This study uses high-temperature torsion testing to simulate reheating and rolling conditions representative of industrial steel processing. Two line pipe steel chemistries were investigated: one with only as-rolled material, and the other with both

as-cast and as-rolled material. A reheating schedule followed by multi-pass torsion deformation simulating roughing and finishing passes was applied, and stress-strain responses were recorded. Interrupted deformation with intermediate water quenching captured microstructural evolution during rolling simulation. Electron backscatter diffraction (EBSD) was used to characterize microstructures and reconstruct prior austenite grain (PAG) structures.
The study compares stress-strain behavior and grain size evolution between the two steels, and between as-cast and as-rolled conditions for the same steel. After reheating, the as-cast material shows a heterogeneous PAG distribution with some very large grains (>500µm) alongside many smaller grains (<100µm), while as-rolled material exhibits a more uniform grain size (<100µm). Recrystallization during roughing passes removes the large grains, resulting in comparable PAG distributions between as-cast and as-rolled conditions. Microstructural evolution between the two as-rolled chemistries is similar throughout. This study demonstrates that torsion testing, paired with EBSD-based austenite reconstruction, is a powerful approach to investigate recrystallization and grain growth during laboratory studies of TMCP, enhancing evaluation of microstructural evolution under industrially relevant conditions.

Keywords: TMCP, Prior Austenite Reconstruction, Torsion.

Thursday, 15:00-15:20

Charles Enloe: Steel Dynamics Southwest

Development of Cold-Rolled, Hot-Dip Galvanized HSLA Steel with 550 MPa Minimum Yield Strength

Felix Perez, Kazi Bhadhon, Richard Osei, Brandon Hance, Vinicius Giorgetti, Santi Gopal Samanta, John Speer.

The characteristic cost effectiveness, low alloy content and manufacturing efficiency of high-strength low-alloy steel offer opportunities toward alternatives to dual phase steels for automotive structural applications.. This analysis is focused on a hot-dip galvanized (GI) product with 550 MPa minimum yield strength—CR550LA per VDA 239-100; 550XF per SAE J2340. A low-carbon, Nb-Mo-Ti microalloying concept is utilized, in which the traditional interplay of Hall-Petch, solid solution and precipitation strengthening mechanisms is deployed. Additional dislocation and transformation strength contributions are imparted through partial recrystallization/ recovery during intercritical annealing. Notably, the subject steel exhibits a higher-than-anticipated level of process robustness despite the presence of a partially recrystallized microstructure, demonstrating stable mechanical performance across expected manufacturing variations. Trial material characterization results are described herein, including: microstructure, directional tensile properties, mechanical anisotropy (r-values) and local formability (fracture strain, hole expansion ratio). These aspects are considered alongside a competitive baseline AHSS material with 590 MPa minimum tensile strength (GI-CR590DP).

Keywords: HSLA, microalloying, niobium, recrystallization.

Modelling & Simulations III (MDCL 1110)

Thursday, 13:30-14:00

Daniel Scheiber: Materials Center Leoben Forschung GmbH

Multi-scale solute drag modelling and experimental validation of recrystallization and grain growth in steels

Maximilian Kern, Michael Bernhard, Christian Bernhard, Matthias Militzer.

The microstructure of steels forms during processing and is crucial to their mechanical and corrosive properties. Solutes affect the kinetics of microstructure evolution by the solute drag effect (SDE), where solutes interact with interfaces in the materials. Though recognized as a basis to control properties of steels, especially for the roles of impurities from high recycling rates, multi-scale modelling of SDE is challenging by limitations on how atomistic insights can be linked to

models at higher scales. This talk will outline how to connect atomistic data on solute interactions at grain boundaries with mean-field recrystallisation and grain growth models for SDE based on the Cahn-Lücke-Stüwe approach. The proposed modelling approach is validated with experimental data. As a prerequisite, solute segregation to grain boundaries was computed for most elements in the periodic table. Insights from modelling the kinetics of recrystallization for a large variety of solutes and impurities are compared to experimental observations from laser ultrasonics, electron-backscatter diffraction and classic metallography, showing the applicability of this approach. For austenite grain growth in steels, the interaction between C and P at grain boundaries was studied with ab initio calculations and with real-time observation of grain size using in-situ high-temperature laser scanning confocal microscopy on sample alloys. The combination of modelling and experiment showed that P significantly reduces GB migration rates, while carbon enhances grain growth rates due to suppression of P segregation. These examples serve as examples on modelling and predicting solute and impurity impacts on microstructure evolution in steels.

Keywords: Multiscale modelling; first principles; in-situ grain growth; EBSD.

Thursday, 14:00-14:20

Ronan Jacolot: Arcelormittal

Modelling of microstructural evolution during hot rolling and applications

Astrid Perlade.

Controlling the microstructural evolution of austenite during hot rolling is a key requirement for producing high performance steels. The final mechanical properties—strength, ductility, and toughness—are strongly governed by the austenite grain size, the state of recrystallization, and the precipitation behavior of microalloying elements throughout the thermomechanical process. For some years, Arcelormittal R&D has been developing models to describe the different phenomena occurring during hot rolling. This integrated model combines dynamic, static, and metadynamic recrystallization, grain growth, and precipitation kinetics to provide a realistic description of the thermomechanical behavior. This model is now used for industrial purposes such as optimization of rolling schedules, representativity at laboratory scale .vs. industrial scale

Keywords: Modelling, austenite, hot rolling.

Thursday, 14:20-14:40

Shabnam Fadaei Chatroudi: McMaster University

A Novel Mean-Field Model of Microstructure Evolution of Microalloyed Steels During Thermomechanical Processing

Robert Cicoria, Hatem Zurob.

The present study introduces a comprehensive mean-field model that couples precipitation kinetics with recovery, recrystallization, and grain growth, incorporating a physically based description of boundary migration. The objective is to couple these microstructural models in a unified mean-field approach that can subsequently be integrated into tools simulating the full hot rolling process. A novel nucleation criterion is introduced based on the derivation of the stress-dependent subgrain size as a function of temperature and chemical composition. This work introduces a novel approach for simulating recrystallization through a dynamic grain number adjustment algorithm, designed to enhance computational efficiency and enable accurate multi-pass simulations. The Downsampling procedure is implemented to prevent excessive growth in the grain ensemble size during simulation. This step becomes crucial under recrystallization conditions, where

nucleation of new grains can substantially increase the total grain count. By systematically reducing the number of representative grains while preserving the statistical characteristics of the microstructure, the Downsampling algorithm maintains numerical stability and ensures that the simulation remains computationally efficient without sacrificing physical accuracy. On the other hand, the Upsampling algorithm is employed to maintain a sufficient number of grains during grain growth in long-term simulations. In addition, a novel integration of the Zener pinning effect is introduced to ensure volume conservation of the system. The model is validated under a range of conditions for both single- and multi-pass cases. Ultimately, the following objective is to integrate this framework with an optimization algorithm to design hot rolling schedules that achieve optimized final properties.

Keywords: Mean-field Modeling, Zener Pinning, Microstructure Evolution, Multi-pass Deformation.

Thursday, 14:40-15:00

Pauline Hahn: Framatome

Characterization and Modelling of Zr-Nb Alloys Post-Dynamic Recrystallization: Influence of Initial Microstructure and Solute Drag Effect

Alexis Gaillac, Victor Grand, Baptiste Flipon, Madeleine Bignon, Marc Bernacki.

Zirconium alloys are mainly used in nuclear fuel assemblies due to their low neutron capture cross section, good mechanical properties and corrosion resistance. The material properties are determined by the microstructure, which evolves during the manufacturing process. To understand the microstructure evolution in Zr-Nb alloys during hot extrusion stage, it is necessary to study the physical mechanisms involved during recrystallization and grain growth. This work focuses on understanding physical phenomena governing the microstructural evolution during post-dynamic recrystallization (PDRX) occurring after hot forming in Zr-1Nb alloy. This alloy is composed of an α matrix and a β phase described as second phase particles (SPP). Four different initial microstructures are studied corresponding to an equiaxed microstructure, two Widmanstätten-type microstructures inherited from quenching from the β domain and an as-forged microstructure with slow cooling from the α + β domain. They have specific characteristics with different grain morphologies but also different β phases, leading to different PDRX kinetics. A coupled experimental and simulation study is carried out. After hot compression test, holding times are applied to study PDRX kinetics. First, experimental characterizations are performed using EBSD analysis, SEM and TEM to identify the impact of stored energy, crystallographic texture, niobium solute drag and SPP. Finally, full-field simulations with a level-set description of grain boundaries are used to confirm or exclude some of the assumptions exposed. The aim is to integrate all physical phenomena to get predictive simulations considering the impact of each phenomenon on the microstructural evolution during PDRX of Zr-1Nb alloy.

Keywords: Zr-Nb alloys, Recrystallization, Solute drag, Simulations.

Thursday, 15:00-15:20

Hao Zhang: University of Alberta

String-Like Cooperative Atomic Motion Governing the Martensitic α-β Transition in Titanium

Jiarui Zhang, Jack F. Dougla.

In a wide range of glass-forming (GF) liquids, dynamics slows down abruptly as the system approaches the glass transition temperature, where an enormous change in the rate of structural relaxation is found in association with the growth of string-like collective motion. More importantly, we have found that collective motion arises in systems that are not normally considered to be GF liquids. Our recent molecular dynamics (MD) simulations have indicated that string-like collective

motion is also prevalent in the interfacial dynamics of metal nanoparticles, the homogeneous melting of bulk crystalline Ni, the interfacial dynamics of bulk crystals, and the grain boundary (GB) migration of polycrystalline materials. In particular, highly cooperative string-like atom motion in the GB can greatly affect the mobility of different types of GBs. In the current study, we investigate the role of string-like cooperative atomic motion in mediating the α-to-β displacive phase transition in Ti using MD simulations. Our study reveals that migration is mediated by string-like collective atomic motion localized in temperature-dependent channels. We demonstrate that the scale of this motion decreases progressively as the transition temperature is approached and that the activation free energy of the moving interface correlates with the average string length. Moreover, our analysis reveals dynamic heterogeneity and non-Gaussian behavior during the migration, drawing meaningful parallels with the dynamics of GF liquids. These findings enhance our understanding of the microscopic mechanisms driving solid-to-solid phase transitions and provide a new perspective on how collective motion influences material dynamics.

Keywords: Boundary migration, Phase transformation, Titanium, Molecular dynamics.

Recrystallization V (MDCL 1102)

Thursday, 13:30-14:00

Victoria Miller: University of Florida

Controlling grain size extrema in a Ni base superalloy using heteroepitaxial recrystallization

Yonguk Lee.

Heteroepitaxial recrystallization (HeRX), the nucleation of coherent gamma grains at primary gamma prime particles, has many potential avenues for microstructure control in Ni-base superalloys. HeRX phenomena has been previously studied only under hot deformation near the solvus temperature, limiting our understanding of its impact on final microstructure under inhomogeneous strain and temperature conditions during processing and in-service. In this study, steep gradients of strain and temperature were induced to elucidate their effects on the frequency and growth of HeRX grains in a polycrystalline Ni-base superalloy, ATI 720. More frequent HeRX formation and reduced annealing twin density were observed at intermediate temperatures as compared to near-solvus temperatures. The findings suggest that the role of primary gamma prime particles can vary, either as a source of HeRX nucleation or annealing twin nucleation, depending on the annealing temperature. This suggests that more precise grain structure control for improved fatigue life can be achieved using the HeRX phenomena.

Keywords: Ni superalloy, heteroepitaxial recrystallizaiton.

Thursday, 14:00-14:20

Nobuo Nakada: institute of Science Tokyo

Static Austenite Recrystallization and Annealing Twin Formation Triggered by Martensitic Reversion in Super Invar Cast Alloy

Bao Rui, Naoki Sakaguchi.

A novel heat treatment consisting of subzero treatment followed by annealing has been reported to achieve significant grain refinement in super invar cast alloys with coarse austenitic structures. In this study, the mechanism of austenite recrystallization induced by martensitic reversion was investigated using detailed microstructural and crystallographic analyses based on electron backscatter diffraction (EBSD). Subzero treatment led to the formation of lenticular martensite along dendritic regions with locally reduced Ni concentration. During subsequent annealing, this martensite reversely transformed to austenite via a diffusionless martensitic reversion, resulting in a duplex austenitic microstructure consisting of untransformed and reversed austenite. Recrystallized austenite grains were found to nucleate by bulging of prior austenite grain boundaries at interfaces between untransformed and reversed austenite. Owing to the higher dislocation density in the reversed austenite, the recrystallized grains preferentially grew into this region. Furthermore, a high density of annealing twins was frequently formed during grain boundary migration, despite the high stacking fault energy of the alloy. The combined effects of bulging recrystallization and intensive annealing twin formation led to the development of a fine-grained austenitic structure with randomized crystallographic orientations. These findings clarify the essential role of martensitic reversion and heterogeneous dislocation distribution in promoting static austenite recrystallization and texture randomization in super invar cast alloys.

Keywords: Bulging recrystallization, martensitic reversion, austenite, super invar alloy.

Thursday, 14:20-14:40

Hanqing Che: Chongqing University

Competition between precipitation and recrystallization during heat treatment of gradient-structured Inconel 718 superalloy

Shaolong Li, Xiaoxu Huang.

Gradient structure has been proven effective in enhancing mechanical properties of metallic materials. Such a structure is challenging to achieve via plastic deformation with aged Inconel 718 superalloy due to the presence of gamma double prime precipitates, but is possible to fabricate through severe surface deformation using solutionized materials. This means an ageing treatment is needed after to further enhance its strength. During ageing, two processes can take place simultaneously, namely precipitation and recrystallization, and it is important to understand the competition between those two processes. In this work, gradient-structured Inconel 718 was obtained via ultrasonic surface rolling of the as-solutioned material, and the microstructural evolution during heat treatment was investigated. After severe surface deformation, a gradient structure with ultrafine-grains at the top surface was formed. During the subsequent aging process, it was found that those ultrafine grains remained stable, instead of gradually disappearing due to recrystallization and grain growth. Microstructural characterization showed that Nb segregated to the low-angle boundaries during aging, subsequently led to the formation of the delta phase at those boundaries. The precipitation of the delta phase stabilized the boundaries and prevailed in the competition with recrystallization and grain growth, preserving the ultrafine grains while enhancing the strength of the material.

Keywords: Inconel 718 superalloy; precipitation; recrystallization; gradient structure.

Thursday, 14:40-15:00

Natalia Rojas-Londono: Mines Paris, PSL University, CEMEF

Characterization of dynamic recrystallization occurring at high strain rates in Inconel 718

Marc Bernacki, Baptiste Flipon, Charbel Moussa.

Hot working is widely used to process metallic alloys. Thermo-mechanical conditions such as strain (ε), strain rate ($\dot{\varepsilon}$), and temperature (T) govern recrystallization (ReX) during deformation, leading to microstructural evolution and, therefore, to the final material properties. However, most studies focus on low to medium strain rates, while effects such as self-heating and friction are often not considered during laboratory experiments and can influence local ε, $\dot{\varepsilon}$, and T. The present study aims to provide, through an accurate estimation of local ε, $\dot{\varepsilon}$ and T, a better understanding of the microstructure evolution during hot compression (HC). The methodology is applied to high strain rates (1 and 10 s^{-1}) on Inconel 718, a nickel-based superalloy widely used in the aerospace industry for its excellent thermomechanical properties [1]. Tests were conducted under comparable conditions (ε, $\dot{\varepsilon}$ and initial mean grain size) at temperatures in the δ-supersolvus domain, where the alloy is monophasic, and in the δ-subsolvus domain, where the δ phase introduces Smith-Zener pinning effect [2]. A digital twin of the HC test in FE software is calibrated and validated with experimental measurements to estimate variations of ε, $\dot{\varepsilon}$ and T in the sample. The latter are expected to affect the local microstructural evolutions and should then be accounted for when characterizing the microstructure. An EBSD methodology is applied to discriminate dynamic and post-dynamic recrystallized grains. The resulting data should help to extend the domain of validity of an existing mean field model of ReX and grain growth to high strain rates conditions [3]. [1]. R.C. Reed and C.M.F. Rae, Physical Metallurgy of the Nickel-Based Superalloys, Elsevier, 2014. [2]. F.J. Humphreys and M. Hatherly, Recrystallization and Related Annealing Phenomena, Elsevier, Oxford, UK, 2004. [3]. L. Maire, J. Faure, M. Bernacki, N. Bozzolo, P. De Micheli, and C. Moussa, A new topological approach for the mean field modeling of dynamic recrystallization, Materials & Design, vol. 146, pp. 194–207, 2018.

Keywords: Hot compression, High strain rates, Self-heating, Recrystallization.

Thursday, 15:00-15:20

Haruka Katayama: Kumamoto University

Temperature-dependent phase separation behavior in equiatomic TiZrNbTaMo high-entropy alloy

Andrea Školáková, Pavel Lejček, Tsurekawa Sadahiro.

The equiatomic TiZrNbTaMo high-entropy alloy (HEA) has attracted attention for both biomedical and high-temperature structural applications due to the biocompatibility of its constituent elements and the inclusion of refractory elements such as Nb and Ta. This alloy is known to undergo two-phase separation upon heat treatment. However, little information is available regarding the temperature-dependent evolution of microstructures and the underlying phase-separation mechanisms. In this study, the microstructural evolution of equiatomic TiZrNbTaMo HEA as a function of annealing temperature and duration was systematically investigated. TiZrNbTaMo HEA ingots were prepared by arc melting and heat-treated under vacuum at temperatures between 800°C and 1200°C for durations ranging from 5 h to 168 h. XRD analysis demonstrated clear peak separation into two distinct bcc phases with different Zr concentrations under all annealing conditions. Combined EDS and EBSD analyses revealed a pronounced temperature dependence of the resulting microstructures. In the sample annealed at 1200°C for 168 h, both the Zr-rich and Zr-poor phases maintained the same crystallographic orientation, suggesting a spinodal-like phase separation mechanism. In contrast, samples annealed at 800°C and 1000°C exhibited Zr-rich and Zr-poor phases with different orientations. Detailed observations revealed that the Zr-rich phase maintained an orientation similar to that of the parent phase prior to phase separation, whereas the Zr-poor phase exhibited different crystallographic orientation and contained a high density of low-angle grain boundaries. These results suggest that the phase separation in TiZrNbTaMo HEA strongly depends on temperature, with microstructural evolution associated with nucleation or recrystallization processes at lower temperatures.

Keywords: TiZrTNbMo HEA, Microstructural evolution.

Plenary Presentation (MDCL 1305)

Thursday, 15:40-16:40

Stefan Zaefferer: Max Planck Institute for Sustainable Materials

Crystal defect observation in bulk samples via EBSD and ECCI, coupled with machine-learning data analysis

Rohit Batra, M. Sarma Gunashekar, P. V. Banavath.

The processes of deformation and subsequent recrystallization are controlled by the evolution and consumption of dislocations and related defects. The characteristics of dislocations, like local and global density, type, morphology, and mutual interactions are important measures to understand the details of deformation and recrystallization mechanisms. Electron diffraction techniques in scanning electron microscopy, namely electron backscatter diffraction (EBSD) and electron channelling contrast imaging (ECCI) are ideal tools to observe and characterize dislocations and the related elastic strain fields. EBSD, particularly with pattern analysis by spherical indexing and cross-correlation analysis, allows an accurate description of local elastic strains and plastic-elastic rotations. The latter are thought to be created by "geometrically necessary dislocations", GND. Other dislocations, subsumed under the term "statistically stored dislocations", SSD, are not detected by these techniques although their density is often significantly higher. ECCI is a technique that directly displays dislocations and strain fields, similar to diffraction images in transmission electron microscopy, but on bulk samples. The technique does not require the rather artificial distinction between SSDs and GNDs, but allows a comprehensive description of all dislocations, including their crystallographic and morphological characteristics. This enables, e.g., unique measurements of dislocation densities during in situ deformation or heating experiments. Correlative observations of ECCI and EBSD reveal interesting details about the deformation structure of materials and their influence on recovery and recrystallization structures. The large amount of dislocation images that are generated by ECCI require new tools to analyse the data. We develop machine-learning algorithms that detect, separate and characterize dislocations and other defects in ECC images.

Keywords: EBSD, ECCI, dislocation structures, machine learning.

Electrical Steels III (MDCL 1102)

Thursday, 16:40-17:00

Naoki Wada: Nippon Steel Corporation

Selective Growth Mechanism of {100}⟨001⟩ Grains in Secondary Recrystallization of Fe-3%Si steel

Morimoto Shota, Morishige Nobusato, Ushigami Yoshiyuki.

To clarify the development mechanism of the {100}⟨001⟩ texture during secondary recrystallization, the relationship between the primary and secondary recrystallization textures was investigated in cross-rolled Fe-3%Si steel sheets. The secondary recrystallization texture was dominated by the {100}⟨001⟩ orientation, with a small fraction of {100}⟨011⟩ orientations. In the primary recrystallization texture, a high frequency of grains exhibiting Σ7 and Σ9 coincidence site lattice (CSL) relationships with respect to the {100}⟨001⟩ orientation was observed. On the other hand, grains with Σ7 relationships were predominantly observed with respect to the {100}⟨011⟩ orientation. These results suggest that both Σ7 and Σ9 coincidence site lattice boundaries play important roles in the selective growth behavior during secondary recrystallization. Selective growth mechanism due to CSL grain boundaries will be presented and discussed.

Keywords: {100}<001>, Secondary Recrystallization, Fe-3%Si, Coincidence site lattice (CSL) boundaries.

Thursday, 17:00-17:20

Yoshiyuki Ushigami: Nippon Steel Technology Co. Ltd

Coincidence Site Lattice (CSL) Grain Boundaries and Selective Growth of Secondary Recrystallized Grains in Fe-Si alloys

Nobusato Morishige, Shohta Morimoto, Naoki Wada, Ryo Matsubara.

It has been reported that some specific orientations, Goss ({110}<001>), Cube ({100}<001>), and Deviated Goss ({110}<227>, {110}<112>) etc.) evolve by secondary recrystallization in Fe-Si alloys, suggesting that CSL grain boundaries such as Σ9, Σ7 and Σ5, may play an important role in their evolution. The role of CSL grain boundaries in secondary recrystallization has been investigated. The selective growth behavior of the specific secondary recrystallized grains was observed and was determined by measuring the interface between the primary recrystallized matrix and the secondary recrystallized grains. The deficit of some CSL grain boundaries at the interface can be explained as a preferential migration and consumption of these CSL grain boundaries. The selective growth behavior of secondary recrystallized grains due to these CSL grain boundaries will be presented and discussed.

Keywords: Coincidence site lattice (CSL) grain boundaries, secondary recrystallization, Fe-Si alloys, selective growth.

Thursday, 17:20-17:40

Weimin Mao: Inner Mongolia University of Science and Technology

Formation mechanism of strong Goss texture in grain oriented electrical steels

Despite long-term research, the formation mechanism of strong Goss texture in grain oriented electrical steels has not fully been clarified so far. The main challenge faced by this mechanism is that the size of Goss grains is often not larger than the surrounding grains before the start of secondary recrystallization. Therefore, the current theories concerning the abnormal growth of Goss grains, including the theory of coincident site lattice boundaries, high-energy boundary theory, the theory of solid-state grain boundary wetting, etc. which focus mainly on the migration characteristics of grain boundaries in the early stage of secondary recrystallization, could not really reveal the complete mechanism. It is indicated that the molar volume expansion effect of MnS and AlN in ferrite forces the precipitated particles to maintain dispersed distribution and hinders the grain growth. However, the particle density near free surface of steel sheet could be obviously reduced, which induces growth advantage of surface grains. The strong elastic anisotropy of high temperatures ferrite leads to further lower density of inhibitor particles in surface non-Goss grains than that in surface Goss grains. Therefore, the speed of grain boundary migration towards smaller surface Goss grains is significantly lower than that towards larger surface non-Goss grains. Hence, while the grain size inside the steel sheet remains basically unchanged, some surface Goss grains gradually become the largest among all surface grains. As the temperature of the secondary recrystallization increases and the inhibitor particles gradually dissolve into the ferrite, the surface Goss grains, which are already the largest in size, will engulf all other grains and complete the secondary recrystallization process.

Keywords: Grain oriented electrical steel; molar volume expansion effect; Goss grains; abnormal grain growth.

Industrial Applications IV (MDCL 1105)

Thursday, 16:40-17:00

Joao Quinta da Fonseca: University of Manchester

Abnormal Grain Growth during Beta Annealing of Hot Worked Ti64

Aiden Ha, Nicholas Byres.

Beta annealed Ti64 is widely used in airframe applications, often in the form of large forgings. Although beta annealed Ti64 has a lower strength than the as forged product, the transformation microstructure produced by annealing imbues it with enhanced toughness and retards crack propagation, characteristics which are desired in these applications. During beta annealing, heating rates and time above the beta-transus need to be controlled to avoid undesirable grain growth. However, even when these conditions are controlled, abnormal grain growth occasionally occurs, producing characteristic abnormal grain structures upon cooling. In this paper, we present a series of investigations into the origin of this phenomenon in both rolled plate and forged products. Electron back scatter diffraction (EBSD) was used to characterise the microstructure of the material before and after annealing. These studies were supplemented by in-situ heating EBSD studies. Our studies show that abnormal grain growth is primarily driven by beta texture development during hot-working (forging or rolling), which leads to a characteristic texture change during annealing, which can occasionally lead to abnormal grain growth. Simulations of grain growth in representative microstructures suggests that this behaviour can be explained using a specific body centered cubic grain boundary energy distribution, and by accounting for difference in microtexture in the as-deformed microstructure. These insights help explain why abnormal grain growth is only seen intermittently, and suggest ways in which it can be avoided during processing.

Thursday, 17:00-17:20

Lucas Cook: University of Sheffield

Comparing recrystallized microstructures and mechanical properties of titanium wire produced from various recycled feedstocks via continuous extrusion

Will Pulfrey, Eric Goodall, Martin Jackson.

In recent years, investigations have been made into the possibility of producing viable feed materials via the use of secondary material sources such as machining swarf. The opportunity exists due to the high percentage of waste materials that can be seen produced within sectors such as aerospace. The traditional supply of materials is inefficient, both economically and environmentally, with the production of materials such as titanium from primary sources being heavily affected by inefficient extraction and a large supply chain. The CONFORM TM process is one such viable avenue for the production of low-cost titanium from secondary sources. The CONFORM TM process utilises severe plastic deformation which creates extrusion pressure from friction and heat from the die. This processing route allows dynamic recrystallization of the feed materials to produce fine and ultra fine grain microstructures to increase the overall strength of the material. Research into the use of machining swarf/chips as feedstock shows that the CONFORM TM process can accommodate this change and produce viable, fully consolidated wire from swarf. This investigation aims to demonstrate the use of recycled aerospace waste as tooling within CONFORM TM to provide a direct comparison between the effects of the CONFORM TM process on wire produced from three different CP-titanium feedstocks: bar, powder, and swarf. The study assesses the severe plastic deformation on each feed material and analyses the effects of the recrystallization on produced microstructure to characterise the quality of the produced wire.

Keywords: Continuous Extrusion, Severe Plastic deformation, Titanium, Recycling.

Thursday, 17:20-17:40

Caio de Paula Camargo Pisano: CBMM

Recrystallization and Texture Evolution of a Hot Rolled Nb-Bearing Ferritic Stainless Steel

Rafael Tarcisio, Helio Wilian.

The control of recrystallization in ferritic stainless steels is critical for tailoring grain size and optimizing toughness, specially for high thickness grades. While the role of niobium (Nb) in delaying recrystallization is well established in austenitic systems, primarily for carbon steels which are usually hot rolled in austenite, its effect in ferritic stainless steels, which can be rolled in high temperature ferrite, is less discussed. In this work, we investigated the influence of Nb additions on the microstructural evolution of two Nb-alloyed high-chromium ferritic stainless steels, rolled in a laboratory-scale mill at temperatures between 800 °C and 1000 °C. Electron Backscatter Diffraction (EBSD) was used to quantify recrystallization, texture development and other microstructure characteristics. Our results confirms the strong effect of the

Nb in solid solution (solute drag) on delaying recrystallization for the high Nb-grade. We believe that the strong segregation of Nb atoms to dislocations at elevated temperatures creates a substantial drag force, inhibiting boundary migration, ultimately affecting recrystallization. The project team managed to use these effects to improve the quality of such hot bands, as when subjected to subsequent heat treatment, these deformed microstructures produced finer grain sizes than fully recrystallized hot bands.
These findings underscore the critical role of solute drag in ferritic systems and provide insights for designing thermomechanical processing routes to achieve superior toughness in high thicknesses Nb-bearing ferritic stainless steels

Keywords: Ferritic Stainless Steels, Niobium – Nb, Recrystallization Behaviour, Texture Development.

Role of Residual Elements II (MDCL 1110)

Thursday, 16:40-17:00

Paul Gawes: University of Applied Sciences Upper Austria

Effect of tramp elements on the austenite recrystallization in a Nb-micro-alloyed steel

Christian Hoflehner, Reinhold Schneider, Christof Sommitsch, Cecilia Poletti.

The use of an electric arc furnace (EAF) can significantly lower CO_2 emissions during the steelmaking process compared to the conventional blast furnace route. Depending on the accuracy of the sorting processes for scrap metal, elements such as chromium and tin can end up in the steel production process. These tramp elements are difficult or impossible to remove through metallurgical processing. Furthermore, these elements impact the thermomechanical processing and the associated recrystallization behavior of the austenite during hot working. This work investigates the influence of the tramp elements Cr, and Sn on the recrystallization behavior of the austenitic phase. The investigated steel was a niobium containing micro-alloyed steel with 0.08 wt.-% C, 0.9 wt.-% Mn and 0.04 wt.-% Nb. This base material is compared to two tramp element containing materials, which have 0.5 wt.-% Cr and 0.05 wt.-% Sn respectively. For the experiments, the pocket jaw unit of the Gleeble 3800-GTC was used to obtain the stress-strain curves for different temperatures and interpass times using double hit compression tests. With this data, we calculated the recrystallized fraction during the interpass time using the 5 % true strain and the 2 % offset method. Thermokinetic simulations via MatCalc© were performed to correlate the precipitation kinetics with the recrystallization behavior of the austenitic phase. The experiments reveal a big effect of niobium on the recrystallisation behavior compared to the rather small effect of the tramp elements.

Keywords: Static recrystallization, tramp elements, micro-alloyed steel.

Thursday, 17:00-17:20

Jieon Park: POSCO R&D

Effect of Si and Cu addition on the texture of ferritic stainless steels

Ferritic stainless steels are extensively used in home appliances, kitchenware, and automotive components. With the trend toward larger household appliances, such as washing machines and dryers, ensuring mechanical safety often requires increasing sheet thickness. However, this approach leads to higher product weight and increased CO2 emissions. Enhancing yield strength without increasing thickness is therefore a key objective. In this study, the effects of Si and Cu additions on the yield strength, recrystallization behavior, and texture evolution of ferritic stainless steels were examined. Si atoms substitute into the ferritic matrix, and due to differences in elastic modulus and atomic size between Fe and Si, they suppress dislocation cross-slip and act as pinning points, resulting in solid solution strengthening. Experimental results showed that Si addition increased yield strength by approximately 96.7 MPa per wt%, with negligible influence on recrystallization kinetics, grain size, or gamma-fiber texture formation. Cu addition provided significant precipitation strengthening through the formation of nanoscale Cu precipitates, increasing yield strength by about 89.3 MPa per wt% Cu. When Cu content exceeded 1 wt%, recrystallization was markedly suppressed, and gamma-fiber texture intensity was significantly reduced. This suppression is attributed to the pinning effect of fine Cu precipitates, which hinder both recrystallized grain growth and preferred orientation development. These findings highlight the distinct strengthening mechanisms of Si and Cu and their differing impacts on texture evolution, providing valuable insights for the design of high-strength ferritic stainless steels with controlled microstructural characteristics.

Keywords: Ferritic stainless steel, yield strength, recrystallization, gamma-fiber texture.

Thursday, 17:20-17:40

Pedram Dastur: University of Warwick

Austenite recrystallisation in steels - the effects of residual elements Cu / Sn and prior partial recrystallisation

Carl Slater, Jiaqi Duan, Yulin Ju, Martin Strangwood and Claire Davis.

Austenite recrystallisation in steels is governed by the interplay between stored deformation energy, austenite grain size, and grain boundary mobility. During electric arc furnace (EAF) production with high scrap steel content there is an increase in residual element content, such as Sn and Cu, which can influence microstructural evolution during thermomechanical processing. As a result, modelling recrystallisation kinetics using current empirical equations is less accurate as the effect of residual elements (such as via solute drag) is not well reported or quantified. Multiple fitting parameters are often required based on experimental data for specific grades of interest. The development of more fundamental recrystallisation models that explicitly relate the characteristics of residual elements and microstructural features (such as grain size distributions and spatially varying stored energy, for example arising from partial recrystallisation) to the driving force and grain boundary mobility offers a more robust and physically meaningful basis for predicting recrystallisation behaviour. In this study, the effects of Sn and Cu residual elements on the static recrystallisation behaviour of low-alloy C–Mn steels were investigated using a series of double-hit compression tests across a range of residual concentrations, strains, and temperatures. To further elucidate the interplay between stored energy and austenite grain size, a complementary set of experiments was performed on a separate alloy system. These tests focused on deformation and recrystallisation of partially recrystallised microstructures after a second deformation stage, highlighting strain partitioning and competitive recrystallisation kinetics between the nucleated strain-free grains and the remaining deformed austenite. The insights gained from these investigations formed the basis for developing a physically based model for austenite recrystallisation with limited fitting coefficients.

Keywords: Austenite recrystallisation, Residual elements, Solute drag, Stored energy.

Friday, May 29, 2026

Plenary Presentation (MDCL 1305)

Friday, 9:00-10:00

Xiuyan Li: Liaoning Academy of Material & Chinese Academy of Sciences

Strengthening NiMo alloy with high density of interfaces of negative-excess-energy

The strength of nanograined and nano-twinned metals is bottle-necked by the inherent instability of grain or twin boundaries below a length scale of typically ~10 nm. Further strengthening of metals requires more stable interfaces (hardeners) at even higher densities. Recently, we found the coherent interfaces between face-centered-cubic and hexagonal-close-packing lattices in supersaturated Ni(Mo) solution have a negative excess energy. The intrinsic stability of negative-excess-energy interfaces enables them an extremely-high density with average spacing as small as ~1 nm, that inhibits plastic deformation and elevates the strength close to the theoretical value of the alloys. The Young's modulus of the Ni(Mo) alloys increases obviously with the interface density, reaching 254.5 GPa, well above that of the same-compositional metallic glass and intermetallic compound (Ni3Mo), indicating an increase of the atomic bonding.

Experimental Techniques V (MDCL 1110)

Friday, 10:30-11:00

Takehito Seki: The University of Tokyo

Entropy-Stabilized Dynamic Grain-Boundary Structure Revealed by Magnetic-Field-Free STEM

Toshihiro Futazuka, Masaki Arai, Aowen Li, Ryo Matsubara, Nobusato Morishige, Naoya Shibata.

Grain boundaries (GBs) critically govern the magnetic properties of silicon steel through microstructural control. A key missing piece has been the direct identification of their atomic structures, because conventional transmission electron microscopy uses a magnetic objective lens that generates a strong field (typically a few tesla) at the specimen position, making atomic-resolution imaging of magnetic materials extremely difficult. Recently, a magnetic-field-free atomic-resolution system (MARS) has enabled atomic-resolution STEM observations under a near-zero field at the sample. Here we report direct atomic-structure analyses of iron-based GBs using MARS-STEM, combined with theoretical modeling. For the Σ9{221} GB, we observe an atomic configuration that contradicts conventional short-period predictions [1]. When we extend the theoretical model to allow a longer structural period, the calculated structure agrees with the experiment and reveals a lower-energy configuration. Detailed analysis suggests that the stable GB core is not simply periodic but becomes incommensurate, and that finite-temperature structural fluctuations can emerge from an internal degree of freedom of the incommensurate structure (a phason-like mode). Although such behavior has not been assumed in traditional GB models, it may appear generically when the crystal periodicity and the preferred interatomic spacing at the GB do not form an integer ratio. We further identify multiple GBs in silicon steel that show similar incommensurate features and fluctuations [2]. These results indicate that incommensurability and dynamic degrees of freedom should be explicitly considered to understand and control GB behavior in steels and potentially in many other materials. [1] T. Seki et al., Nature Commun. 14, 7806 (2023). [2] T. Seki et al., Submitted.

Keywords: Steel, STEM, Incommensurate.

Friday, 11:00-11:20

Aditya Shukla: European Synchrotron Radiation Facility,

Investigation the onset of recrystallization in cold-rolled α-iron using Scanning three-dimensional X-ray diffraction and texture tomography (TT)

Mads Carlsen, Loic Jegou, Louis Lesage, Nils Axel Henningsson, Can Yildirim.

Despite extensive research, fundamental aspects of onset of recrystallization and survival of successful nuclei during subsequent growth process remain unresolved because the process is governed by highly heterogeneous deformation microstructures that could not be mapped non-destructively in three dimensions at industrial deformation levels. As a result, it has not been possible to directly link the deformed state to the nucleation. Key questions therefore remain: how do local

deformation structures control recrystallization in 3D, and can nucleation sites and grain orientation be predicted from the deformed microstructure?
Here, we address these questions by using scanning three-dimensional X-ray diffraction (S3DXRD) in combination with texture tomography (TT) to track the microstructural evolution of 65% cold-rolled α-iron (Fe-3%Si) during isothermal annealing at 610 °C. The experiment comprises nine interrupted annealing steps, producing a comprehensive four-dimensional (3D + time) dataset that captures the full sequence of recovery, recrystallization onset, and subsequent growth of recrystallized nuclei. Avrami analysis of the recrystallized volume fraction after each step confirms that the onset of nucleation is captured with high temporal resolution.
By correlating nucleation sites with local intragranular misorientation, grain boundary curvature and dislocation density, we directly link the deformed microstructure and emergence of recrystallized grains. The nucleation sites appear to be predominantly located areas with high misorientation, consistent with theoretical predictions but visualized here non-destructively and in 3D for many grains for the first time in a highly deformed polycrystalline material. This work establishes a mechanistic and predictive framework for annealing phenomena, providing critical validation data for industrial microstructural control.

Friday, 11:20-11:40

Michael Mayer: Materials Center Leoben Forschung

Linking Processing, Microstructure, and Flow Behavior in C43 Steel through Uncertainty-Aware Recrystallization Modeling

Bernd Schuscha, Gerald Ressel, Daniel Scheiber.

Recrystallization plays a key role in the evolution of microstructure and flow stress during thermo-mechanical processing. However, modeling this process is challenging because recrystallization strongly depends on temperature and deformation rate. Furthermore, the investigated C43 steel presents an additional difficulty: during water quenching, ferrite formation can occur, so the prior austenite grain size is not fully preserved. This transformation partially obscures the high-temperature austenitic state and introduces additional uncertainty in the interpretation of prior-austenite recrystallized fractions and grain sizes. In this work, we present a hybrid modeling framework calibrated with experimental data. The model describes the coupled evolution of recrystallized fraction and grain size as internal state variables that directly influence the macroscopic flow response in the austenitic phase region. Calibration is performed using flow curves obtained from Gleeble compression tests, together with microstructural information derived from EBSD measurements, which provide recrystallized fractions, phase composition, and grain size distributions of the room-temperature martensitic and ferritic fraction after compression tests at different temperatures and deformation rates. The framework allows the high-temperature investigation of steels, even though the prior-austenite information is not fully preserved and also includes uncertainty. The calibrated model enables consistent prediction of both flow stress and microstructural evolution across a range of processing conditions, providing a physically interpretable and uncertainty-aware constitutive description suitable for continuum-scale simulations.

Keywords: Recrystallization, Modeling, Flow-Behavior, Steel.

Friday, 11:40-12:00

Takaaki Tanaka: JFE Steel Corporation

Evaluation of Orientation Dependent Dislocation Density in Cold Rolled Pure Iron

S. Takajo, Y. Onuki, S. Sato.

This study presents methods for evaluating the orientation-dependent dislocation density in heavily cold-rolled pure iron using two approaches.
In the first approach, the geometrically necessary dislocation (GND) density was assessed by kernel average misorientation analysis within a restricted orientation area using a SEM-EBSD method. By combining this with orientation determination at each scanning point, the GND density distribution is represented in a stereographic projection.
In the second approach, the total dislocation density, i.e., the sum of GND and statistically stored dislocation densities, was evaluated through line profile analysis using TOF neutron diffraction at J-PARC MLF BL20 (iMATERIA). By controlling the geometry between the sample and the measurement system, a wide range of diffraction vectors was sequentially covered, enabling the construction of a dislocation density map in stereographic projection. Furthermore, a method to expand the stereographically projected dislocation density information into Euler space is being developed.
These two evaluations revealed that the dislocation density varies by more than one order of magnitude depending on crystal orientation.
The newly established methods enable visual and quantitative understanding of the orientation dependence of dislocation density and are expected to serve as an effective new tool for texture analysis.

Friday, 12:00-12:20

Estefania Sepulveda Hernandez: Ghent University

Orientation-resolved stored energy mapping by Misorientation Gradient in IF steel manufactured through different thermomechanical routes

Felipe Castro Cerda, Tuan Nguyen Minh, Leo A.I Kestens.

Stored energy from plastic deformation, related to dislocation density and lattice curvature, is crucial for recovery kinetics, recrystallization nucleation, and grain growth. Current methods often overlook the effects of detailed crystallographic orientations on stored energy proxies, focusing instead on broad texture fibers. This study attempts to quantify the stored energy distribution in orientation space for an IF steel processed under various thermomechanical conditions, including temperature variations and deformation paths. The findings clarify the link between microstructural features and thermomechanical processing, improving understanding of texture evolution in IF steel. In this study the orientation gradient $\Delta\theta/\Delta x$ is considered as a measure of stored energy of plastic deformation. The orientation data of the high resolution EBSD scans are binned on a 5deg grid in Euler space and for each bin with sufficient data points the average $\Delta\theta/\Delta x$ value and its standard deviation is calculated. The distributions thus obtained provide quantitative comparisons for the various thermomechanical processing. The results indicate that cold rolling maintains the highest $\Delta\theta/\Delta x$ values on the γ-fibre (<111>//ND) with an ascending evolution along the α-fibre (<110>//RD) with increasing values of Φ . Static recovery leads to moderate reductions of the stored energy with a more equal distribution along both the γ and α fibres, while dynamic recovery shows the lowest levels overallbut with a local increase in mean $\Delta\theta/\Delta x$ for very low Φ angles (≈0–5°), suggesting that the θ-fibre neighborhood ({100}//ND) retains the higher stored-energy compared to other regions of Euler space.

Keywords: Recovery; misorientation gradient; recrystallization texture; IF steel.

Grain Growth V (MDCL 1105)

Friday, 10:30-11:00

Hossein Beladi: Ghent University

∑9 Boundary Plane Orientation

Tari Vahid and Rohrer Gregory.

Previous measurements of ∑9 grain boundary plane orientation have shown a wide range of symmetric and asymmetric tilt characters under different processing conditions. In this study, the ∑9 grain boundary plane orientation distribution in a Ni-30Fe alloy was measured as a function of ∑3 coherency using the five-parameter grain boundary characterization approach. The ∑9 boundary plane orientation was influenced by the degree of ∑3 boundaries coherency meeting the ∑9 boundary at triple junctions. A ∑9 boundary connected to two ideal coherent ∑3 boundaries at triple junctions exhibited a $(11\bar{4})//(11\bar{4})$ symmetric tilt grain boundary orientation, which is presumed to be the minimum energy configuration. For boundaries other than coherent ∑3 boundaries, the ∑9 boundary can adopt a range of orientations in the [110] zone, which has a relatively flat energy landscape. Although these other orientations are not the minimum energy ∑9 orientation, they presumably satisfy the Herring condition at the triple junction.

Keywords: ∑9 boundary, Plane orientation, ∑3 coherency, 5-parameter characterization.

Friday, 11:00-11:20

Ryota Nagashima: Institute of Science Tokyo

Variant selection of grain boundary precipitation and its effect on grain boundary coverage in Ni–Cr alloy

Nakada Nobuo.

Crystallographic aspects of grain boundary (GB) precipitation is a promising approach to enhance creep resistance through grain boundary precipitation strengthening, which depends on increasing the fraction of GB area covered by precipitates. Conventionally, the GB coverage fraction is controlled by the degree of supersaturation of solute elements; however, excessive supersaturation often results in intergranular and discontinuous precipitation. Previous studies have reported variant selection of bcc α-Cr precipitates at GBs in fcc matrix in Ni–Cr alloy, suggesting that crystallography may play a key role in determining GB coverage. Clarifying the relationship between variant selection and GB coverage fraction could therefore provide a novel microstructural design strategy. In this study, solution-treated Ni–46at.%Cr alloys were aged at 1223 K for 259.2 ks. Microstructural observation and crystallographic analysis were conducted using scanning electron microscopy equipped with electron backscattered diffraction (EBSD). Orientation analysis revealed that the α phase at GBs exhibits either the Kurdjumov-Sachs (KS) or Nishiyama-Wasserman (NW) relationship with one of the adjacent grains. The GB coverage fraction increases when a habit plane nearly parallel to the GB plane is preferentially selected among the $\{111\}_\gamma$ of the matrix. Furthermore, GBs exhibiting the KS or NW orientation relationship with both adjacent grains (double-OR) show a markedly higher GB coverage fraction. These results suggest that improving the GB coverage fraction requires design of the GB character by increasing the frequency of GB pairs that promote the formation of the α phase with a double-OR relationship and GB planes closely parallel to the habit plane.

Keywords: Microstructure design, Variant selection, Grain boundary, Crystallography, EBSD.

Friday, 11:20-11:40

Madhumanti Bhattacharyya: Indian Institute of Technology (Indian School of Mines), Dhanbad

Understanding Grain Growth Phenomenon in a High Manganese Steel

Brian Langelier, Yves Brechet, Hatem Zurob.

Due to its environment friendly behavior, there has been a great surge in the use of liquefied natural gas (LNG) in global energy supply chain. This demands the development of robust materials suitable for its storage. Although 9% nickel steels are currently being used in the fabrication of LNG tanks, price volatility and unavailability of nickel make this steel highly expensive. A decade of research work has proven that high manganese steels (HMS) have a potential to be a low-cost alternative to the existing nickel bearing steels for this cryogenic application owing to their excellent formability and low temperature toughness which can be achieved through grain refinement. This necessitates the understanding of the grain growth (GG) phenomenon in HMS to better comprehend the microstructure evolution during exposure to high temperature. While investigating GG in a Fe-30%Mn steel, the current work highlighted a 2 order slower kinetics as compared to a conventional low Mn steel. No manganese (Mn) segregation at random boundaries, revealed from atom probe studies, ruled out the effect of Mn solute drag on growth kinetics in Fe-30%Mn steels. This drop has been attributed to the inhibiting effect of Mn through increasing the twinning frequency which resulted in low-mobility boundary segments in global boundary network. A first-order model of GG kinetics in the presence of annealing twins was proposed which shown to be in reasonable accord with the experimental data. Further possibility of lowering GG has also been explored through niobium addition leveraging its solute drag effect.

Keywords: LNG tanks, Grain Growth, Manganese, Boundary.

Friday, 11:40-12:00

Mehmet Can Dursun: Carnegie Mellon University

Multi-scale characterization of Σ3 grain boundaries to elucidate abnormal grain growth in Ni

Yi Wang, Amanda R. Krause.

In a recent study, abnormal grain growth (AGG) was observed in high purity Ni that contained a high population of coherent and, surprisingly, incoherent Σ3 boundaries. Here, a multi-length-scale characterization approach is performed to identify a correlation between the high density of incoherent GB and AGG and explore why energetically unfavorable incoherent Σ3 boundaries persist. Laboratory x-ray diffraction contrast tomography (LabDCT), a non-destructive, 3D microstructure characterization method, is used to track grain growth and GB motion. Transmission electron microscopy (TEM) lamellae are prepared from the same microstructures characterized by LabDCT. Structural and chemical characterization of GBs is done using TEM and scanning TEM. The imaging of GB structure will test the hypothesis that incoherent Σ3 boundaries persist by faceting into lower energy configurations and, subsequently, influence the growth behavior. The advantages and implications for using this multi-length scale characterization approach to correlate GB macroscopic character, velocity, and atomic structure will be discussed.

Keywords: Abnormal grain growth, Σ3 twin boundaries, Laboratory Diffraction Contrast Tomography, TEM.

Friday, 12:00-12:20

Louis Lesage: European Synchrotron Radiation Facility - ESRF

Dislocation dynamics during grain growth in Aluminium

Zipeng Xu, Aditya Shukla, Virginia Sanna, Abderrahmane Benhadjira, Leora Dresselhaus-Marais, Can Yıldırım.

At very high temperatures (>0.9 T_m), grain growth is accompanied by an important rise in dislocation activity. However, direct measurements of dislocation forces and mobilities inside bulk polycrystals have remained out of reach. In this study, we introduce an operando methodology that integrates multiple synchrotron X-ray techniques on the ESRF ID03 beamline to monitor dislocation dynamics within an embedded grain of a polycrystalline Al 1050 specimen at high temperature. Dark-Field X-ray Microscopy (DFXM) captures real-space images of individual grains with ~150 nm spatial resolution and a temporal resolution of 5 Hz, enabling direct observation of dislocation-dislocation and dislocation-grain-boundary interactions in a grain cross-section at 630 °C. Diffraction Contrast Tomography (DCT), performed on the same specimen, yields the three-dimensional grain structure before and after heat treatment, including grain orientations and morphologies,

enabling the calculation of grain-boundary energies and their correlation with the measured dislocation displacements. The combined DFXM-DCT dataset disentangles the distinct roles of grain-boundary energy, internal stress, and thermally activated processes in governing dislocation motion, allowing us to quantify the relative contributions of climb and glide at near-melting temperatures and to estimate Peach-Koehler forces on individual segments. The dataset also enables investigating the impact of dislocation–grain-boundary interactions on grain-boundary mobility and the resulting grain growth. These quantitative insights aim to provide new constraints for grain-growth models.

Keywords: Dislocation dynamics, Synchrotron X-ray diffraction imaging, Aluminium, Grain growth.

Recrystallization VI (MDCL 1105)

Friday, 10:30-11:00

ShiHoon Choi: Sunchon National University

Self-Annealing and Recrystallization in Cryogenically Deformed Copper Alloys: Mechanisms and Implications for Microstructure Control

Aman Gupta, Tae-Hyeon Yoo, Abhishek Kumar Singh, Ki-Seong Park, Yoon-Uk Heo, Lalit Kaushik.

Recent investigations on copper and copper-based alloys have revealed an unusual self-annealing phenomenon, where static recrystallization occurs spontaneously at room temperature following severe deformation. This presentation will discuss the mechanistic origins and kinetics of this phenomenon under both room-temperature and cryogenic deformation conditions. By integrating advanced EBSD, TKD, and HR-TEM analyses with crystal plasticity modeling (VPSC, CPFEM), the study demonstrates how deformation heterogeneity, stored energy distribution, and orientation-dependent slip activity govern discontinuous and continuous recrystallization. Special emphasis will be placed on the role of strain localization zones and shear bands as dominant nucleation sites and the evolution of Copper-, Brass-, and S-type recrystallization textures. The talk will highlight new insights into the coupling between cryogenic deformation, self-annealing, and texture development—providing guidance for designing high-strength, thermally stable copper alloys through controlled recrystallization and grain growth behavior.

Keywords: Self-annealing, Cryogenic deformation, Recrystallization kinetics, Texture evolution.

Friday, 11:00-11:20

Hisashi Sato: Nagoya Institute of Technology

Recrystallization behavior by heat treatment for shot-peened pure Fe sheet and its magnetic property

Marie Kondo, Takuma Kishimoto, Yoshimi Watanabe, Satoshi Motozuka.

The recrystallization behavior of shot-peened (SPed) pure Fe sheets during subsequent heat treatment was investigated. The SP produces a deformation-induced layer (DIL) with ultrafine grains around the peened surface. A pronounced {001}+{111} double fiber texture, in which <001> and <111> directions of Fe are aligned parallel to the peening direction, was observed. In addition, the geometrically necessary dislocation density (GND) around the peened surface was found to be lower than that in the interior region. This difference of the GND comes from the dynamic recrystallization activated by the extremely huge strain induced by SP. As a result, during the heat treatment, recrystallization and subsequent grain coarsening progressed from the interior region toward the peened surface. In addition, the crystallographic texture around the peened surface changes from {001}+{111} double fiber texture to {001} fiber texture. Notably, the {001} fiber texture is known as the ideal texture of the non-oriented electromagnetic steel. From the results of the magnetic evaluation, it is found that the core loss of the pure Fe sheet subjected to both SP and heat treatment is lower than that of the sheet processed

by only heat treatment. Hence, the formation of the {001} fiber texture by the SP and heat treatment for the pure Fe sheet improves its magnetic property.

Keywords: Shot-peening, Recrystallization, Texture, Fe.

Friday, 11:20-11:40

Zackery Thune: Michigan State University

Recrystallization and Grain Growth in Texturally Banded High Purity Niobium Sheet After Axisymmetric Deep-Drawing into a Superconducting Cavity Half-Cell

Philip Eisenlohr, Balachandran Shreyas, Eric Taleff, Thomas Bieler.

Superconducting high purity niobium cavities are the fundamental building block for particle accelerators. Advancements in accelerator performance and technology depend on the ability to produce cavities with consistent high performance. However, the properties and performance of cavities produced via axisymmetric deep-drawing and strategic heat treatments can vary significantly despite having the same manufacturing path. Whether this variance is due to the initial microstructural state, the processing standards, the intrinsic properties of the material, or a combination thereof is an active research topic in the accelerator community. Electron backscatter diffraction analysis on cold-rolled high purity niobium sheet typically exhibits textural banding (different texture in near-surface than center). Improved cavity performance is often observed following higher heat treatment temperatures resulting in more recrystallization and grain growth that reduces crystal defects that degrade performance. In an axisymmetric formed half-cell, the recrystallized fraction varies with texture bands and strain path, with more grain growth in material deformed in the original rolling direction than the transverse direction of the sheet. The effects of heating rate (5 and 250°C/min), annealing temperature (800 and 900°C), texture bands, strain path, and strain magnitude on the recrystallization and grain growth were quantitatively assessed using electron backscatter diffraction on through thickness sections 0°, 45°, and 90° from the initial sheet rolling direction in samples from the iris, equator, and a lesser-strained region of the half-cell in between. Insights gained from these microstructural observations can guide novel heat treatment strategies that could improve the consistency of cavity performance.

Keywords: Strain-Path, Texture-Banding, EBSD, Niobium.

Friday, 11:40-12:00

Zhang-Zhi Shi: University of Science and Technology Beijing

Zn-0.8Mn alloy for degradable structural applications: Hot compression behaviors, four dynamic recrystallization mechanisms, and better elevated-temperature strength

Meng Li, Lu-Ning Wang

Environmentally degradable Zn–0.8Mn alloy is highly ductile, which lays the foundation for developing high-performance Zn–Mn-based alloys. However, not only constitutive equation of this alloy is unknown, but also its dynamic recrystallization (DRX) behavior is unclear, which makes optimization of hot processing parameters of this alloy almost dependent on trial-and-error. This work aims to tackle these problems. A processing map of the alloy was obtained for the first time, which shows that it has excellent hot formability with narrow instability zones. At a final true strain of 0.8, the volume fraction of DRX grains increased from 37% to 79% with temperature increasing from 150 °C to 350 °C and strain rate decreasing from 10 s^{-1} to 10^{-3} s^{-1}. Discontinuous DRX (DDRX), continuous DRX (CDRX), twinning-induced DRX (TDRX), and particle stimulated nucleation (PSN) were activated during hot compressions. DDRX was always the main

mechanism. TDRX was completely suppressed at 300 °C and above. PSN arose from dispersed $MnZn_{13}$ particles. Furthermore, Zn–0.8Mn alloy exhibited elevated-temperature strengths better than pure Zn and Zn–Al-based alloys. At 300 °C and 0.1 s^{-1}, its peak stress was 1.8 times of pure Zn, owing to $MnZn_{13}$ particles of 277 ± 79 nm impeding the motion of grain boundaries and dislocations.

Keywords: Hot deformation; Dynamic recrystallization; Constitutive equations; Microstructure.

Friday, 12:00-12:20

Donghwi Kim: POSCO Technical Research Lab

Effect of Solute Concentration Gradient and Cold Rolling Reduction Rate on Recrystallization and Texture Evolution in Ultra-Low Carbon Steel

Min Serk Kwon, Namsuk Lim, Sangseok Kim.

This study investigates the recrystallization behavior and texture evolution in steel sheets, where shear deformation is maximized via through-thickness strength gradients. Specifically, the influence of secondary cold rolling reduction and internal solute concentration gradients on the post-annealing microstructure was examined.

Keywords: Secondary cold rolling, Texture evolution.