MM 2: Topical session (Symposium MM): High entropy and compositionally complex alloys

Sessions: Design and Development; Properties I

Time: Monday 10:15–13:15 Location: H43

Topical Talk MM 2.1 Mon 10:15 H43

Fundamentals of deformation in high- and medium-entropy alloys — •Guillaume Laplanche[1], Joël Bonneville[2], Céline Varvenne[3], Aleksander Kostka[4], William A. Curtin[5], and Easo P. George[6] — [1]Institut für Werkstoffe, Ruhr-Universität Bochum, Germany — [2]Institut PPRIME, University of Poitiers, France — [3]CINaM, Aix-Marseille Univ. - CNRS, Marseille, France — [4]Materials Research Department and Center for Interface Dominated Materials (ZGH), Ruhr-University Bochum, Germany — [5]Institute of Mechanical Engineering, EPFL, Lausanne, Switzerland — [6]Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, USA

High-entropy alloys (HEAs) consists of five or more elements in near-equiatomic proportions and crystallize as single-phase solid solutions. This presentation focuses on one of the most thoroughly investigated HEAs, namely, the fcc CrMnFeCoNi alloys. These alloys have been shown to exhibit fascinating mechanical properties, including increasing tensile ductility and strength with decreasing temperature, with composition having a strong effect. In this presentation, two model alloys: CrMnFeCoNi (HEA) and CrCoNi (medium-entropy alloy), are selected to explain key microstructural aspects responsible for strength, ductility, and work-hardening rate. As both alloys deform by dislocation plasticity initially and deformation twinning after a critical stress has been reached, evolutions with deformation of dislocation and twin microstructures as well as activation volumes are used to identify the mechanisms responsible for macroscopic mechanical behaviors.

MM 2.2 Mon 10:45 H43

Development of New Compositionally Complex Alloys for Laser Additive Manufacturing — •Fabian Kies[1], Simon Ewald[2], Bengt Hallstedt[3], and Christian Haase[1] — [1]IEHK Steel Institute, 52072 Aachen, Germany — [2]Digital Additive Production DAP, 52074 Aachen, Germany — [3]Materials Applications in Mechanical Engineering IWM, 52072 Aachen, Germany

Exploring the field of compositionally complex alloys (CCAs) by capitalizing on the flexibility of additive manufacturing (AM) provides the opportunity to design new metals with exceptional mechanical properties. So far, efficient CCA development is held up by time-consuming manufacturing methods. Therefore, a methodology is introduced which enables flexible exploration and design of CCAs by combining theoretical and experimental approaches, thereby focusing on the Al-C-Co-Cr-Fe-Mn-Ni alloying system. A self-compiled thermodynamic database for CALPHAD was used to identify promising composition ranges for the system, which were subsequently synthesized using elemental powder blends in AM processes. Materials characterization was split into light (XRD, hardness) and deep (SEM, EBSD, tensile test) screening to increase characterization speed. Precipitate types in the manufactured samples were correctly predicted by the theoretical screening. Properties identified by light screening steps translated reliably into the deep screening stage. The applicability of the introduced methodology to identify promising CCAs well as the resulting microstructural and mechanical properties in the Al-C-Co-Cr-Fe-Mn-Ni alloying system are discussed.

MM 2.3 Mon 11:00 H43

Electrodeposition of high entropy alloy thin films and nanowires — •Mirko Gabski, Martin Peterlechner, and Gerhard Wilde — Institute of Materials Physics, University of Münster, Münster, Germany

High-entropy alloys consisting of four of more elements in nearly equiatomic concentrations have attracted attention as structural materials due to their favorable physical and mechanical properties, especially at elevated temperatures as well as improved corrosion and oxidation resistance when compared to more common alloys. The aforementioned properties make high-entropy alloy an interesting choice as a material for the coating of metal parts. In this work electrodeposition is used to obtain thin films of an AlCoCrFeNi alloy to investigate the influence of the deposition conditions on its composition and morphology using energy disperse X-ray spectroscopy and scanning electron microscopy. Furthermore the fabrication of nanowires is carried out utilizing nanostructured anodic aluminum oxide as a template to investigate the influence of the nano-confinement on the deposition process and the resulting microstructure.

MM 2.4 Mon 11:15 H43

Nanoscale, continuous phase separation of Al-containing compositionally complex alloys via Laser Powder Bed Fusion — Nicolas J. Peter[1], •Hyo Yun Jung[1], Eric Gärtner[2], Volker Uhlenwinkel[2], Gerhard Dehm[1], and Eric A. Jägle[1] — [1]Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany — [2]Leibniz IWT, Bremen, Germany

Literature shows that increasing Al-additions to the Cantor alloy transformed the initially single-phase FCC (A1) alloy to a BCC (A2 matrix/B2 precipitates) material with superior strength in casts. In contrast to such previous studies, we make use of the selective laser melting process. We investigate three different compositionally complex alloys, namely AlCoCrFeNi, AlMnCoCrFeNi and $AlCu_{0.5}FeNiCoCr_{0.75}$. The same microstructure is found for all three alloys using advanced electron microscopy consisting of a coherent two-phase structure with interwoven A2/B2 phases. Atom probe tomography confirms the nanoscale phase separation into Ni-Al and Fe-Cr domains. An effect of the intrinsic heat treatment can be excluded as the gas atomized powder used for selective melting already contained both phases. In addition, melt spun reference samples of $AlCu_{0.5}FeNiCoCr_{0.75}$ were investigated and found to adopt the same interwoven A2/B2 microstructure. Our results therefore point to a conditional spinodal decomposition process, which is currently further investigated. Finally, first results on establishing the structure-property relationships are presented.

15 min. break

Topical Talk MM 2.5 Mon 11:45 H43

Single-crystal mechanical properties of equiatomic CrMnFeCoNi high-entropy alloy and its derivative equiatomic quaternary and ternary medium-entropy alloys — •Haruyuki Inui — Department of Materials Science and Engineering, Kyoto University, Kyoto, Jpan

The plastic deformation behavior of single crystals of the FCC equatomic CrMnFeCoNi high-entropy alloy and its derivative quaternary (CrFeCoNi) and ternary (CrCoNi) medium-entropy alloys has been investigated in a temperature range of 10-1273 K. Deformation occurs via slip of the {111}<110> system exclusively in the whole temperature range for all alloys investigated. The CRSS values increase with decreasing temperature, especially below room temperature, so that the concept of *stress equivalence* is obeyed for all alloys investigated. This is a clear indication that the strength of these alloys should be described by a mechanism based on solid-solution hardening. The CRSS values at 10 K seems to be well scaled with the mean-square atomic displacement from the regular FCC lattice points (calculated based on density-functional theory). Dislocations are observed to dissociate widely into Shockley partials for all alloys investigated, indicating their low stacking fault energies (below 30 mJ/m2). Deformation twinning occurs in later stages of deformation at low temperatures below room temperature in many of these alloys. The correlation between twinning stress and the stacking-fault energy will be discussed.

MM 2.6 Mon 12:15 H43

High-pressure torsion produced lamellar structure between single phaseequiatomic FCC CoCrFeMnNi and single phase BCC HfNbTaTiZr HEAs — •Shabnam Taheriniya, Sergiy V. Divinski, and Gerhard Wilde — Institute of Materials Physics, University of Münster, Münster, Germany

High-pressure torsion (HPT) was utilized to analyze deformation induced bonding and mixing of dissimilar high entropy alloys (HEAs). A single phase equiatomic FCC Cantor alloy, CoCrFeMnNi, and equiatomic HfNbTaTiZr as a single phase BCC HEA are attached and deformed for 5, 10 and 15 revolutions using HPT with a pressure of 9 GPa. The resulting structure and the local microstructure at the interfaces are observed and analyzed using scanning electron microscopy (SEM), electron back-scatter diffraction (EBSD) and trans-

mission electron microscopy (TEM). Furthermore, the chemical composition at the interface is investigated using energy dispersive X-ray spectroscopy (EDX). The results are discussed and analyzed with respect of the mechanisms responsible for shear induced mixing/bonding at the interfaces under the specific conditions provided by high entropy alloys.

MM 2.7 Mon 12:30 H43

Tunable optical properties of (Mg-Co-Cu-Ni-Zn)O High Entropy Oxide thin films — •Emeline Michel — I. Physikalisches Institut (IA), RWTH Aachen University, D-52056 Aachen, Germany

Multi-component High Entropy Alloys have been shown to be interesting for their favorable mechanical properties, e.g. high fracture toughness, and resistance to oxidizing or corrosive environment. The enhanced properties of High Entropy Alloys are due to the entropy-driven formation of simple phases. However, the oxidation of these materials, leading to High Entropy Oxides, is poorly understood. High Entropy Oxides have been recently studied by Rost et al., who verified the entropy stabilization ansatz and showed that configurational disorder provides an alternative route to new materials discovery.

Here we investigate the oxidation behaviour of High Entropy Alloys from the Mg-Co-Cu-Ni-Zn metallic system. Therefore, thin films of High Entropy Oxides are deposited by reactive sputtering. Surprisingly, we observe that the system exhibits a pronounced, broad sub-bandgap absorption. Moreover, the oxygen partial pressure used to deposit the (Mg-Co-Cu-Ni-Zn)O thin films is a tuning parameter of the optical properties of the system. The correlation between the tunable optical properties of (Mg-Co-Cu-Ni-Zn)O thin films and its structural changes is investigated.

MM 2.8 Mon 12:45 H43

The effect of magnetism on the stability of high entropy alloys — •Jakub Šebesta[1,2] and Dominik Legut[1] — [1]IT4Innovation, VŠB-TU Ostrava, 17.listopadu 15, 708 33 Ostrava-Poruba, Czech Republic — [2]Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, 121 16 Praha 2, Czech Republic

Multi-principal elements alloys, called as 'High Entopy Alloys', represent a promising group of materials, due to its possible applications in the industry. They form a single phase solid solution based on high number of components in near-equimolar composition, that often brings a high entropy contribution to the Gibbs free energy. It is considered as the main contribution stabilizing the alloy at higher temperatures. In the current work we'd like to focus on another contributions, which could affect stability of the system, i.e magnetic interactions among all atoms. Using ab-initio calculations based on TB-LMTO-ASA within CPA we studied the stability of the well known 'Cantor alloy' CoCrFeMnNi as well as related phases with a nonmagnetic substitution were calculated. For a similar reason non-homogeneous structures and magnetic exchange interactions were studied as well. We show strenghts of the mutual interactions between the elements and their impacts on the stability of the alloy. Further we discuss the importance and its contribution of mutual exchange ineraction to the final preferred magnetic ordering of studied phase. Finally we'll suggest possible way for stabilizing the parent structure.

MM 2.9 Mon 13:00 H43

On the mechanism of displacive phase transformation in metastable high entropy alloys — •Jing Su, Dierk Raabe, and Zhiming Li — Max-Planck-Institut für Eisenforschung GmbH, Dusseldorf, Germany

High-entropy alloys (HEAs) have drawn increasing attention in the past decade due to their massive solid-solution compositional space and promising mechanical properties. Recently, non-equiatomic metastable HEAs with tunable stacking fault energy have shown improved mechanical properties with an even larger compositional freedom and a broader range for microstructure design compared to the equiatomic stable HEAs. This is related to the joint activation of multiple deformation mechanisms including transformation induced plasticity (TRIP) and/or twinning induced plasticity (TWIP). In the current study, a metastable interstitial carbon-doped HEA (iHEA) has been chosen and subjected to cold rolling. Interestingly, deformation-driven forward and reverse (bidirectional) martensitic transformation has been observed in the current iHEA with a well-tuned stacking fault energy. The mechanisms of such bidirectional displacive transformation and the associated nanostructure formation have been investigated by electron channeling contrast imaging (ECCI), electron backscattered diffraction (EBSD) and high-resolution transmission electron microscopy (HR-TEM). We also discuss the mechanical properties of the nanostructured specimens and the corresponding work hardening behavior to shed light on the design of strong and ductile bulk nanostructured HEAs via displacive transformation.