Advanced Characterization Techniques for Coatings, Thin Films, and Small Volumes
Room Pacific D - Session H2-2-WeM

Advanced Mechanical Testing of Surfaces, Thin Films, Coatings and Small Volumes II

Moderators: James Gibson, RWTH Aachen University, Germany, **Olivier Pierron**, Georgia Institute of Technology, USA

9:40am **H2-2-WeM-6 Abnormal Grain Growth in Ultrafine Grained Ni Under High-Cycle Loading**, ***Olivier Pierron (olivier.pierron@me.gatech.edu)***, Georgia Institute of Technology, USA

Abnormal grain growth can occur in polycrystalline materials with only a fraction of grains growing drastically to consume other grains. Here we report abnormal grain growth in ultrafine grained metal in a rarely explored high-cycle loading regime at ambient temperature. Abnormal grain growth is observed in electroplated Ni microbeams with average initial grain sizes less than 640 nm under a large number of loading cycles (up to 10^9) with low strain amplitudes (< 0.3%). Such abnormal grain growth occurs predominantly in the family of grains whose <100>orientation is along the tensile/compressive loading direction. Micromechanics analysis suggests that the elastic anisotropy of grains dictates the thermodynamic driving force of abnormal grain growth, such that the lowest strain energy density of the <100>oriented grain family dominates grain growth. These results are compared to other recent investigations of cyclic-induced grain growth in metals. In order to establish the general applicability of abnormal grain growth in metals controlled by the elastic anisotropy of single-crystal grains, a high-throughput technique to perform systematic characterization of cycle-induced grain growth in ultrafine grained metallic films with varying degrees of elastic anisotropy is presented.

11:00am **H2-2-WeM-10 Superlattice Effect on the Mechanical Properties of Transition Metal Diboride Coatings**, ***Rainer Hahn (rainer.hahn@tuwien.ac.at)***, *A. Tymoszuk,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien, Austria*; O. Hunold,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein*; P. Polcik,* Plansee Composite Materials GmbH, Germany*; P. Mayrhofer,* Institute of Materials Science and Technology, TU Wien, Austria*; H. Riedl,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien, Austria

PVD deposited superlattice structures enable the simultaneous enhancement of hardness and fracture toughness of thin ceramic coatings – evading the strength-ductility trade-off dilemma [1]. While a deeper understanding of this effect has been gained for transition metal nitrides (TMN) [2], hardly any knowledge is yet available for diborides (TMB_2). Here we show that superlattices can—similarly to the nitrides—increase both mechanical properties of diboride coatings. For this purpose, we developed non-reactively sputtered TiB_2/WB_2 and TiB_2/ZrB_2 superlattice coatings, the former is characterized by a high difference in shear modulus (ΔG ~112 GPa), and the latter features a high lattice mismatch (Δa ~0.14 Å) of the participating layer materials.

Nanoindentation, as well as in-situ microcantilever bending tests, yield a distinct increase in hardness (up to 45.5 ± 1.3 GPa) for the TiB_2/WB_2 system but no increase in fracture toughness. Contrary, TiB_2/ZrB_2 shows no increase in H, while K_{IC} increases by ~ 20% up to 3.70 ± 0.26 MPa·$m^{1/2}$. Similar behavior is observed for cube-corner-based fracture toughness evaluation, however, under the influence of corresponding residual compressive stresses. X-ray diffraction studies show a preferred (001) orientation for most of our coatings, the only exception thereby are the TiB_2/WB_2 superlattices with a bilayer period Λ > 9 nm, where we observe increasing (101) orientation with an increasing bilayer period. Furthermore, the number of satellite peaks and their intensity hints towards sharp interfaces, later confirmed by our HR-TEM studies. These results are discussed and complemented by an extensive literature review.

Keywords: Hard Coatings, Diborides, Physical Vapor Deposition, Micromechanical Testing, Fracture Toughness

[1] R. Hahn, M. Bartosik, R. Soler, C. Kirchlechner, G. Dehm, P.H. Mayrhofer, Scr. Mater. 124 (2016) 67–70.

[2] R. Hahn, N. Koutná, T. Wójcik, A. Davydok, S. Kolozsvári, C. Krywka, D. Holec, M. Bartosik, P.H. Mayrhofer, Commun. Mater. 2020 11 1 (2020) 1–11.

11:20am **H2-2-WeM-11 Fatigue Behavior of Gold Thin Films at Elevated Temperature Studied by Bulge Testing**, ***Anna Krapf (anna.krapf@fau.de)***, Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Germany

Microcomponents, such as microchips, actuators and sensors, are often based on metallic thin films that must endure cyclic thermomechanical loading during their lifetime. The mechanical properties of these thin films are usually different from bulk materials and so are their thermomechanical fatigue mechanisms. For this reason, an advanced bulge setup was used to cyclically load gold thin films of 150 nm thickness at temperatures in the range 25 °C – 100 °C. The stress-controlled experiments highlight the significance of the interface character for the fatigue lifetime. The presentation will discuss the fatigue properties and damage mechanisms of gold thin films – freestanding and with brittle sublayer - as a function of the microstructure, temperature and stress amplitude.

11:40am **H2-2-WeM-12 Tensegrity Metamaterials - Towards Failure Resistant Engineering Systems**, ***Jens Bauer (jens.bauer@uci.edu)***, University of California, Irvine, USA **INVITED**

Failure of materials and structures, including ductile metals, brittle ceramics, discrete foams and space-trusses, is typically preceded by highly localized deformation. Formation of shear bands and crack surfaces, and buckling of walls and struts thereby cause a chain reaction of locally confined damage events, while large parts of the system do not experience critical loads. In lightweight structures, localized deformation causes catastrophic failure, limiting application to small strain regimes. To ensure robustness under real-world non-linear loading scenarios, over-designed linear-elastic constructions are adopted.

Breaking with this established paradigm, we present three-dimensional (3D) tensegrity metamaterials which delocalize deformation, demonstrating a pathway towards superior, failure resistant load bearing systems. In a tensegrity system, isolated rigid compressive bars stretch a continuous mesh of tethers forming a free-standing lightweight, truss structure. We demonstrate that the unique isolation of compressive members in tensegrity systems suppresses the propagation of instable deformation mechanisms. This facilitates a delocalized deformation pattern, which is free from localized under- or over-use. As a result, tensegrity metamaterials possess unprecedented failure resistance, with up to 25-fold enhancement in deformability and orders of magnitude increased energy absorption capability without failure over same-strength state-of-the-art lattice architectures. These findings provide important groundwork for design of superior engineering systems, from reusable impact protection systems to adaptive load-bearing structures.

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