Fall 10-6-2015

High-temperature small-scale fracture mechanics and plasticity of a hardcoating system

James Best
EMPA – Swiss Federal Laboratories for Materials Science and Technology, james.best@empa.ch

Johannes Zechner
EMPA – Swiss Federal Laboratories for Materials Science and Technology

Juri Wehrs
EMPA – Swiss Federal Laboratories for Materials Science and Technology

Johann Michler
EMPA – Swiss Federal Laboratories for Materials Science and Technology

Jeffrey Wheeler
ETH Zurich

See next page for additional authors

Authors
James Best, Johannes Zechner, Juri Wehrs, Johann Michler, Jeffrey Wheeler, and Marcus Morstein

HIGH-TEMPERATURE SMALL-SCALE FRACTURE MECHANICS AND PLASTICITY OF A HARD-COATING SYSTEM

James P. Best, Johannes Zechner, Juri Wehrs, Johann Michler - Laboratory for Mechanics of Materials and Nanostructures, EMPA – Swiss Federal Laboratories for Materials Science and Technology, Feuerwerkerstrasse 39, CH-3602, Thun, Switzerland
james.best@empa.ch

Jeffrey M. Wheeler - Laboratory for Nanometallurgy, Department of Materials, ETH Zürich, Vladimir-Prelog-Weg 5, CH-8093 Zürich, Switzerland

Marcus Morstein - PLATIT AG – Advanced Coating Systems, Eichholzstrasse 9, CH-2545 Selzach, Switzerland

Forging and cutting tools for high-temperature applications are often protected using hard nanostructured ceramic coatings. While a moderate amount of knowledge exists for material properties at room temperatures, significantly less is known about the system constituents at the elevated temperatures generated during service. For rational engineering design of such systems, it is therefore important to have methodologies for testing these materials to understand their properties under such conditions. Additionally, small-scale mechanical testing is of inherent importance for thin-films systems and materials subject to surface modification or treatment as for plasma nitrided steels.

In this work, we present results on both the hard ceramic coating and the nitrided steel substrate using in situ micro-mechanical measurements at temperatures to 500 °C. The fracture and plastic yield behavior of FIB milled micro-pillars of plasma-nitrided tool steel was first investigated using in situ compression experiments. It was found that the yield strength of nitrided steel is particularly sensitive to temperatures within the service range. Elevated temperature led to significant softening of the nitrided steel and transition from slip-based to more ductile plastic flow. A 70% reduction in yield stress was observed when transitioning from room-temperature to 500 °C, which was then recovered upon cooling back to RT indicating a mechanistic activation at high temperature.

The fracture toughness behavior of a hard CrN coating was then investigated using various micro-geometries and notching parameters. Toughness measurements at high temperatures highlighted the profound effect of the notching ion during small-scale fracture measurements. It was found that gallium ion implantation led to significant toughening of CrN, based on gallium dosage experiments and alternative notching using both xenon and helium sources. The effect of different notching ions was additionally understood through Monte Carlo simulations of energetic ion interactions in a dense ceramic matrix.

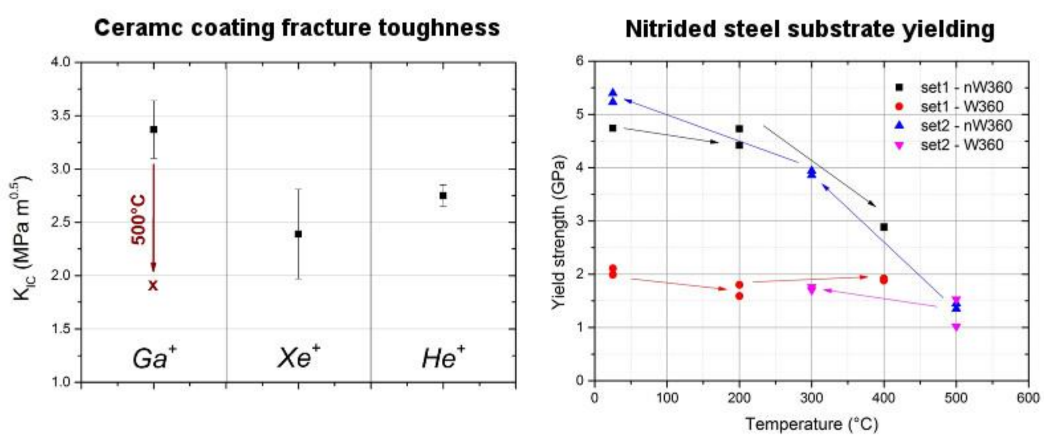

Figure 1 – Small-scale mechanical properties of constituent hard-coated system materials.