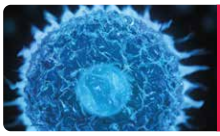


ADVANCED MATERIALS SCIENCE

Fields of Expertise TU Graz

Source: istockphoto.com

Anna Maria Coclite,
Christof Sommitsch,
Gregor Trimmel,
Advanced Materials Science

Source: Lunghammer – TU Graz

Notwithstanding the difficult situation due to the pandemic, the Field of Expertise Advanced Materials Science held the Advanced Materials Day 2020! This was done in a hybrid form: the posters were physically exposed in the halls of the Physics and the BMT buildings, but were presented and discussed online. 62 posters were registered and for each of them a short video presentation was uploaded. Then, on Sept. 28th, we hosted a Webex poster discussion from 9 am to 5:30 pm, reaching peaks of attendance of 70 people, including professors and students. We consider this a great success and thank all the participants one more time.

Another important piece of news of the past months was that two projects were awarded the Initial Funding from our Field of Expertise. Initial Funding amounts to a maximum of EUR 10,000 and is aimed at fostering the development of competitive proposals. The awardees of the 14th call were Daniel Rettenwander with the project (Electro-)Chemo-Mechanical Effects in Solid-State Batteries and Michael Haas with the project Self-Disinfecting Surfaces Made from Polysilane-Cellulose Hybrid Materials. We wish them all the best for the future proposal submission and we look forward to the next call.

With respect to the current topic Hydrogen, projects and activities in the FoE are in progress, e.g.: *Improvement of Hydrogen-Induced Stress Corrosion Cracking Resistance of Ultra-High Strength Steel Screws and Fasteners.* This project aims to enable the implementation of hydrogen crack-resistant ultra-high strength steels in automobile car body and motor applications by improving testing techniques and optimizing heat treatment and microstructure.

Influence of Sheet Metal Forming and Cutting on the Resistivity of Advanced High-Strength Steels (AHSS) to Hydrogen Embrittlement. Drawing, bending or cutting introduce zones of severe plastic deformation in sheet metal components. This increases the local hydrogen concentration and changes the microstructure, thus affecting the susceptibility of AHSS to hydrogen embrittlement. The research focus is the development of microstructurally sensitive hydrogen embrittlement testing procedures, modeling and simulation and hydrogen analytics.

Andreas Drexler, Hamdi Elsayed, Rudolf Vallant:

Hydrogen Embrittlement (HE) of Ultra-High-Strength Steel Screws in Service: Still a Development Potential?

Hydrogen embrittlement is a major concern for the automotive, construction, and energy sectors. It limits the use of new ultra-high-strength steels, which have huge advantages in reducing raw material consumption, decreasing fuel consumption, and decreasing carbon dioxide emissions. The Institute of Materials Science, Joining and Forming has carried out intensive studies underpinning the harmful effects of hydrogen on steels and to defeat hydrogen's detrimental effects. >

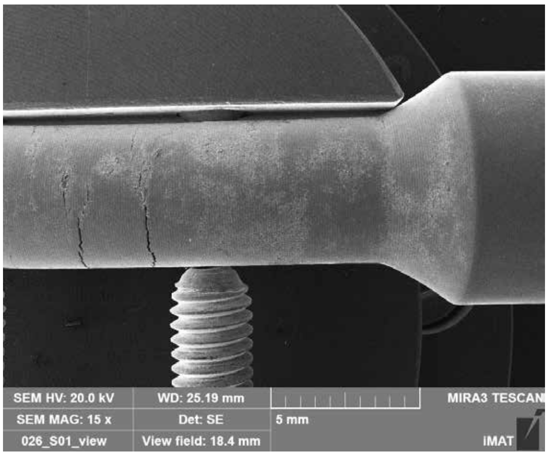


Figure 1:
HE cracks in an ultra-high-strength screw steel.

Source: TU Graz / IMAT

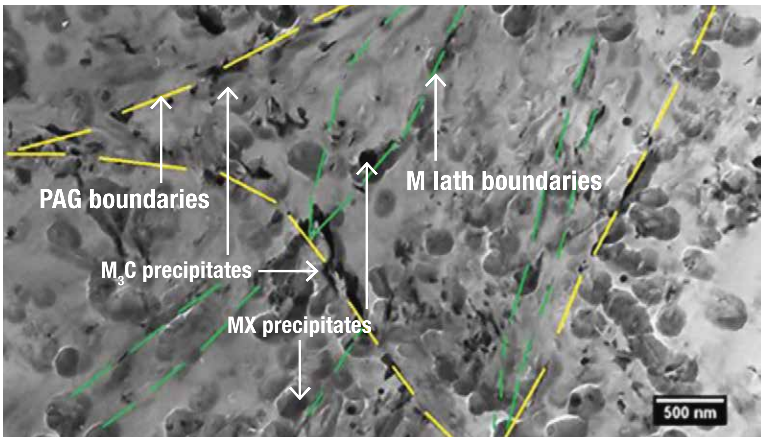


Figure 2: TEM analysis, showing high-resolution microstructural constituents and intensive precipitation [Dománková, 2019].
Source: TU Graz / IMAT

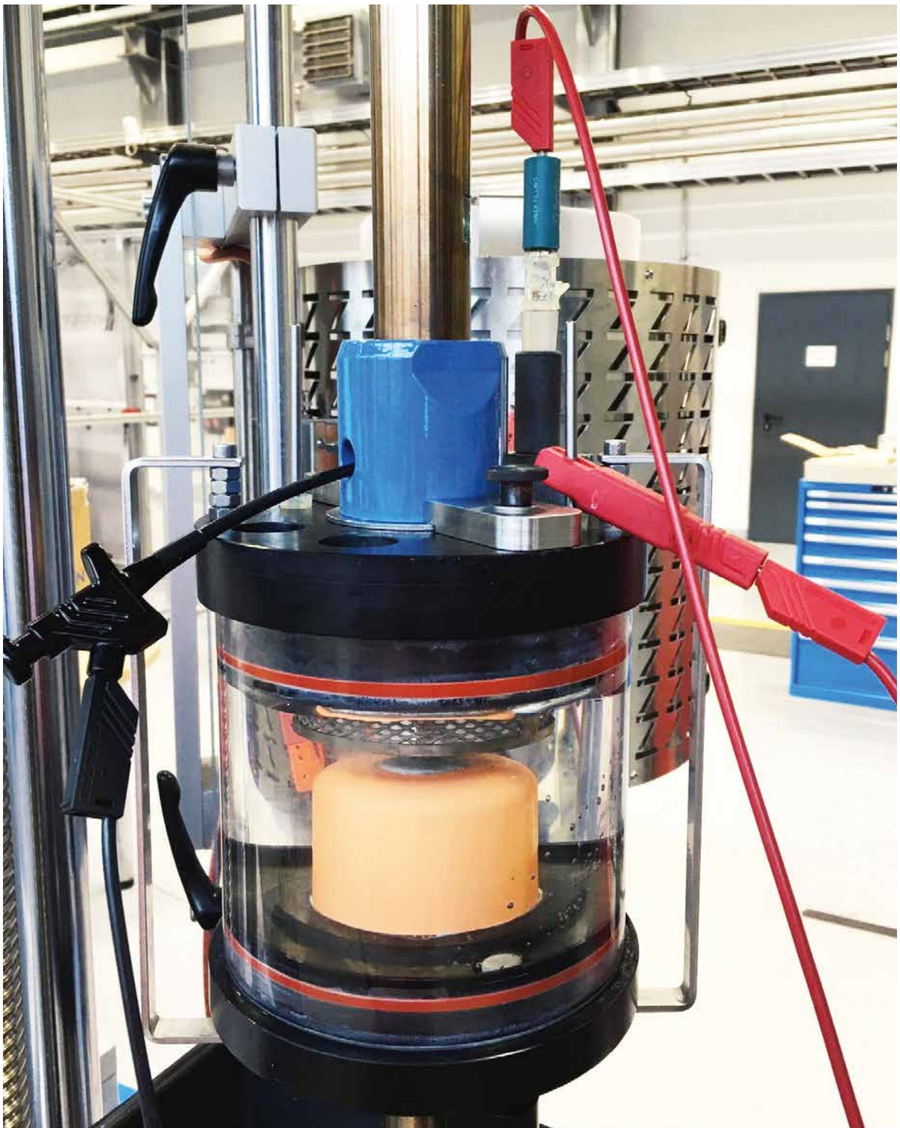
The global trend in modern lightweight steel construction in the automotive industry increases the need for ultra-high-strength steels (UHSS) with an ultimate tensile strength above 1,500 MPa. Due to the downsizing of steel structures, CO_2 emissions are significantly reduced. However, UHSS are susceptible to HE, which restricts the use of the materials and makes component assessment difficult. Hydrogen can be taken up during steel production, thermal and mechanical processing, coating, or service. Smallest amounts of hydrogen in the microstructure can lead to time-delayed and thus unexpected brittle failure of UHSS screws. The delay in time is particularly crucial because it is difficult to predict the time of critical hydrogen uptake and thus to prevent brittle failure.

In the past two years, the Institute of Materials Science, Joining and Forming at TU Graz has established an intensive research project in cooperation with voestalpine Wire Rod Austria GmbH in St. Peter-Freienstein, one of Europe's leading manufacturers of wire rod, and the Centre of Excellence for Electrochemistry and Surface Technology (CEST) in Wiener Neustadt and Linz, which is one of the Austrian COMET centers for applied research. The project combines fundamental and applied research to undermine the harmful effect of hydrogen on different microstructural constituents, to design new materials, and to optimize the heat treatment process.

The key development activities in the research project are

- the experimental techniques for the microstructural sensitive evaluation of HE resistivity and
- the validation of integrated multiscale material models.

Figure 3: In-situ HE testing cell during mechanical loading.
Source: TU Graz / Hamdi Elsayed



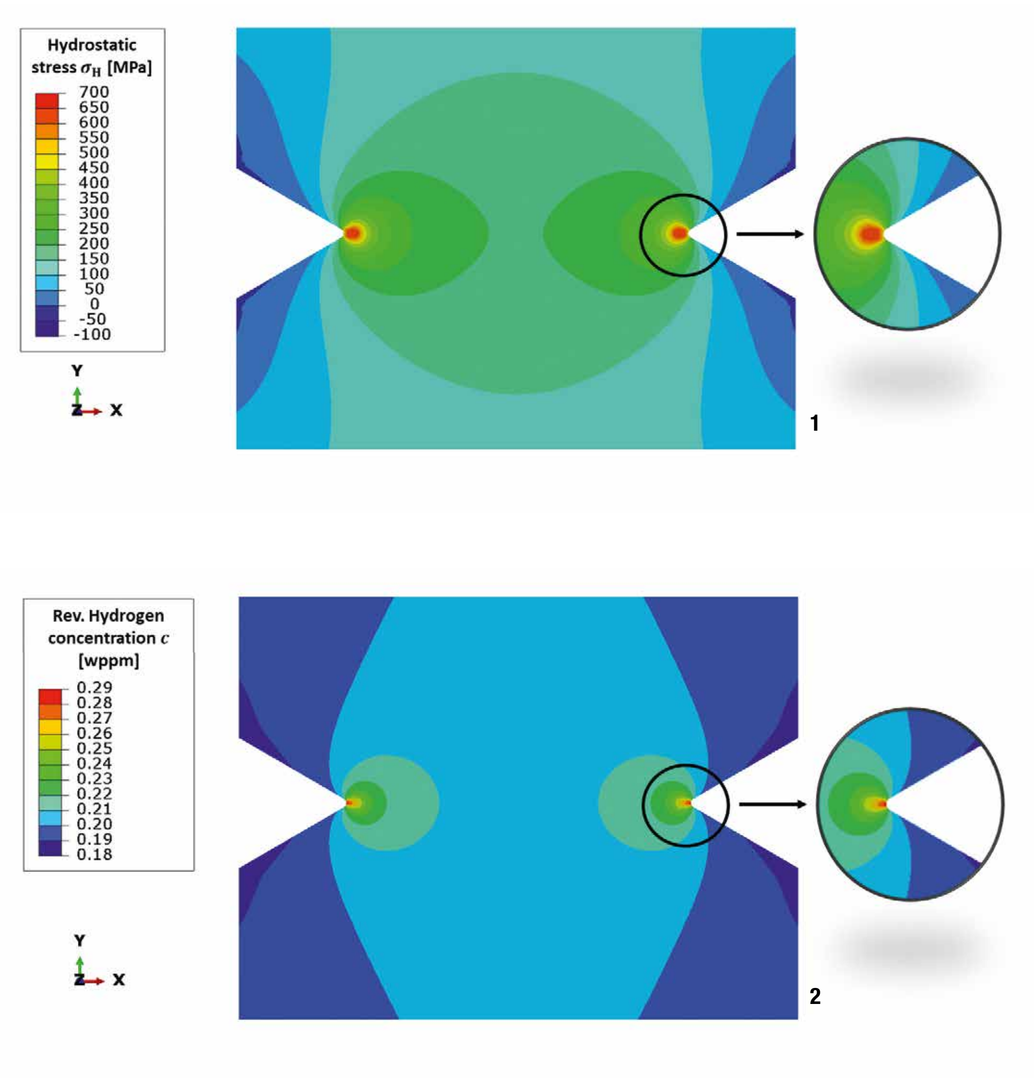


Figure 4: Development of a digital twin of the in-situ HE testing cell. 1: Mechanical simulation of the hydrostatic stress field at a screw notch. 2: Diffusion simulation of the hydrogen accumulation in the strained area during mechanical loading.
Source: TU Graz / Andreas Drexler

ADVANCED MICROSTRUCTURAL CHARACTERIZATION

With proper alloy chemistry and heat treatment, it is possible to reduce HE susceptibility and increase steel strength.

To this end, changes are made to the microstructure concerning the following mechanisms:

- beneficial hydrogen trapping by nano-precipitates
- grain refinement and
- reduction of internal micro-stresses.

New alloy concepts can be investigated with a new smelting device available at voestalpine for very small melt batches of 45kg. To apply different heat treatments, ovens with oil and salt baths are used. The investigation of the microstructure was applied using many techniques such as LOM, SEM, TEM, XRD, and EBSD, to determine the phases, grain size, sub-grain size, dislocation density, precipitates (size, shape, and chemical composition).

In addition, thermal desorption spectroscopy (TDS) was performed to investigate the hydrogen distribution in the microstructure. It was found that hydrogen segregates at the precipitate-matrix interfaces and the dislocations.

To optimize the industrial heat treatment process concerning the total precipitate-matrix interface area, a MatCalc routine was developed. MatCalc is a thermodynamic software which includes physical principles and is thus capable of handling complex alloy systems and complex heat treatments. For calibration, the necessary parameters are obtained from TEM and TDS analysis.

HYDROGEN EMBRITTLEMENT (HE) TESTING AND SIMULATION

To understand the effects of hydrogen accumulation at a notch, a new in-situ HE testing cell was designed and established to evaluate the resistivity to HE and stress corrosion cracking. The special feature of this cell is that it allows the precise >

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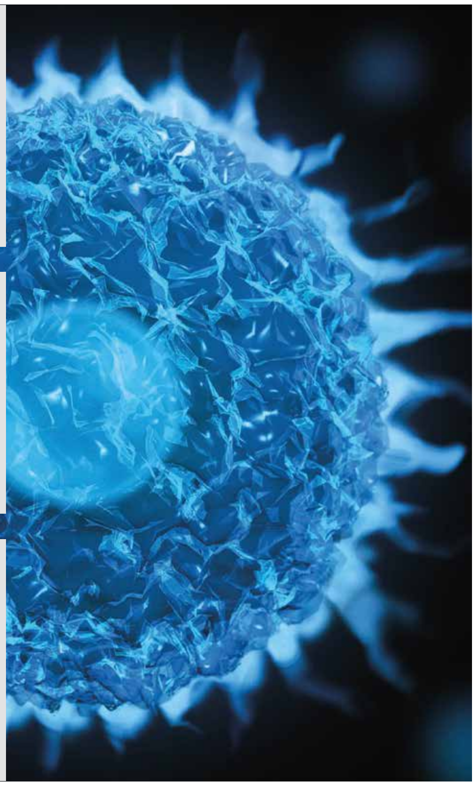
Source: Hamdi Elsayed

Andreas Drexler
is a university assistant at the Institute of Materials Science, Joining and Forming, focusing on hydrogen-metal interactions, hydrogen embrittlement testing, and simulations.

Source: Andreas Drexler

Rudolf Vallant
is a project senior scientist at the Institute of Materials Science, Joining and Forming, working in different metal-joining projects, and is responsible for the corrosion lab development and failure case analyses.

Source: Rudolf Vallant



control of the hydrogen uptake by cathodic polarization or under corrosive conditions.

A new 250kN electro-mechanical machine currently performs slow strain rate tests (SSRT) and incremental step load tests (ISLT). In addition, a multiphysical finite element model (FEM) of the in-situ testing device was developed and parametrized. This model allows the hydrogen accumulation at the notch during SSRT to be simulated as a function strain rate. It was found that the strained area at the notch can increase local hydrogen concentration up to five times compared to the measured average bulk concentration.

In an initial study, the beneficial role of nanoprecipitates, which is still under debate in the literature, was evaluated. For this purpose, two different steel alloys were produced: one precipitation rich (containing Cr-Mo and V) and one precipitation free (containing Si and Mn) steel. The former alloy can trap hydrogen and the latter can dissolve it in the microstructure. The investigations always focus on the goal to prevent a movement of atomic hydrogen, especially from corrosion reaction during loading, which can happen in service within the steel microstructure.

In a second study, the Quenching and Partitioning (Q&P) heat treatment was intensively studied. It is a promising approach for producing a microstructure of martensite (M) and carbon-enriched retained austenite (RA). This complex microstructure imparts high strength to the steel due to the presence of M and high ductility due to the presence of a considerable amount of RA. Because of the high solubility of hydrogen in RA, which acts as a strong trap, the resistance against HE should be increased, but this is not the case. There is a contradiction between results from different investigations in this area. The crucial factor, however, is the RA stability and shape. When the RA is stable and in thin layers around the tempered M, it acts as a barrier and binds the hydrogen, thus preventing it from reaching sensitive phases; in turn, the HE susceptibility should decrease.

OUTLOOK

The simultaneous use of microstructural sensitive testing procedures and integrated physically based material models make a contribution to our project by reducing the HE of the high strength screws and fasteners applied in lightweight mobility and the planned CO_2-free energy production. Our understanding of different microstructural constituents regarding the hydrogen distribution and HE contributes sustainably to making a safe use of UHSS possible – and has in this way still a huge development potential.