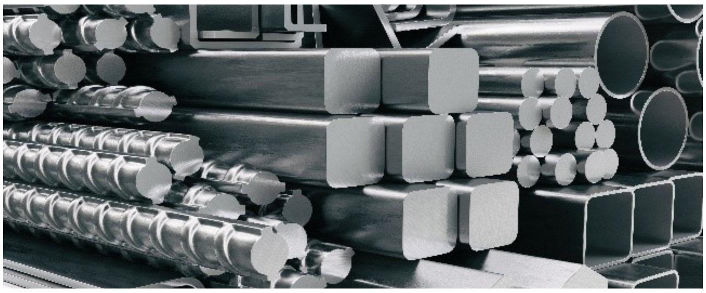
Characterizing hydrogen and strain interactions in the microstructure of duplex stainless steel

Hydrogen-induced stress has caused failure in subsea applications of duplex stainless steels which are given cathodic protection to prevent the metal surface from corrosion. Since only large components, such as forgings, have failed but not smaller components, such as seamless tubes, this has been linked to the coarseness of the microstructure. An attempt to understand the effect of hydrogen on the microstructural degradation of advanced stainless steels was made using the Swedish Material Science beamline P21.2 at the synchrotron PETRA III.



The early stages of hydrogen-induced material degradation in commercial duplex stainless steels (Credit: iStock / Bet_Noire)

CHALLENGE

The cathodic protection of steel can lead to the production of atomic hydrogen, which is small enough to be absorbed by the metal. This may cause hydrogen-induced stress cracking, a type of hydrogen embrittlement failure. The strains in the microstructure associated with hydrogen infusion are very small (in the sub-Ångström regime), which requires the lattice parameters to be measured at ultra-high spatial resolutions. Hydrogen mobility is very high in microstructures, and studying hydrogen in metals requires rapid testing while the material of interest is subject to mechanical loads. Whereas more traditional experimental techniques are unable to provide sufficient information, synchrotrons allow X-ray diffraction measurements to be taken with ultra-high spatial and temporal resolutions.

METHOD

The early stages of hydrogen-induced material degradation in commercial duplex stainless steels was investigated using high-energy XRD at small angles for surface characterization, as well as layer by layer to study the effect of hydrogen ingress and strains through the material. This was done under in operando conditions at the beamline P21.2 at DESY's synchrotron PETRA III.

The sample was subjected to a mechanical load while positioned in sodium chloride, and a cathodic protection potential was applied. Later, the results were correlated with data obtained from various laboratory techniques, e.g. electrochemical impedance spectroscopy (EIS), atomic force microscopy (AFM) and scanning Kelvin probe force microscopy (SKPFM).

INSIGHTS AND ANALYSIS

The results showed that hydrogen induces tensile strains in the microstructure and that the strain evolution was for the most part concentrated in the surface region where hydrogen first entered the material. More strains developed in the austenite phase than in the ferrite phase during hydrogen charging.

BENEFITS

The outcome has improved our understanding of the earliest stages of material degradation due to hydrogen embrittlement in stainless steel. The collaboration has set up a network whose multi-disciplinary focus lies on material research for the materials of tomorrow. The collaboration has further provided access to large-scale synchrotron facilities with a special focus on meeting industrial needs, which will be utilized for further experiments.

Funded by Vinnova, project No: 2018-03267

For more information please contact:

Deutsches Elektronen-Synchrotron DESY
Ein Forschungszentrum der Helmholtz-Gemeinschaft
Notkestraße 85 I 22607 Hamburg

DESY Innovation & Technology Transfer:
Dr. Sabine Brock
E-mail: sabine.brock@desy.de
Phone: +49 40 8998-4579
www.innovation.desy.de