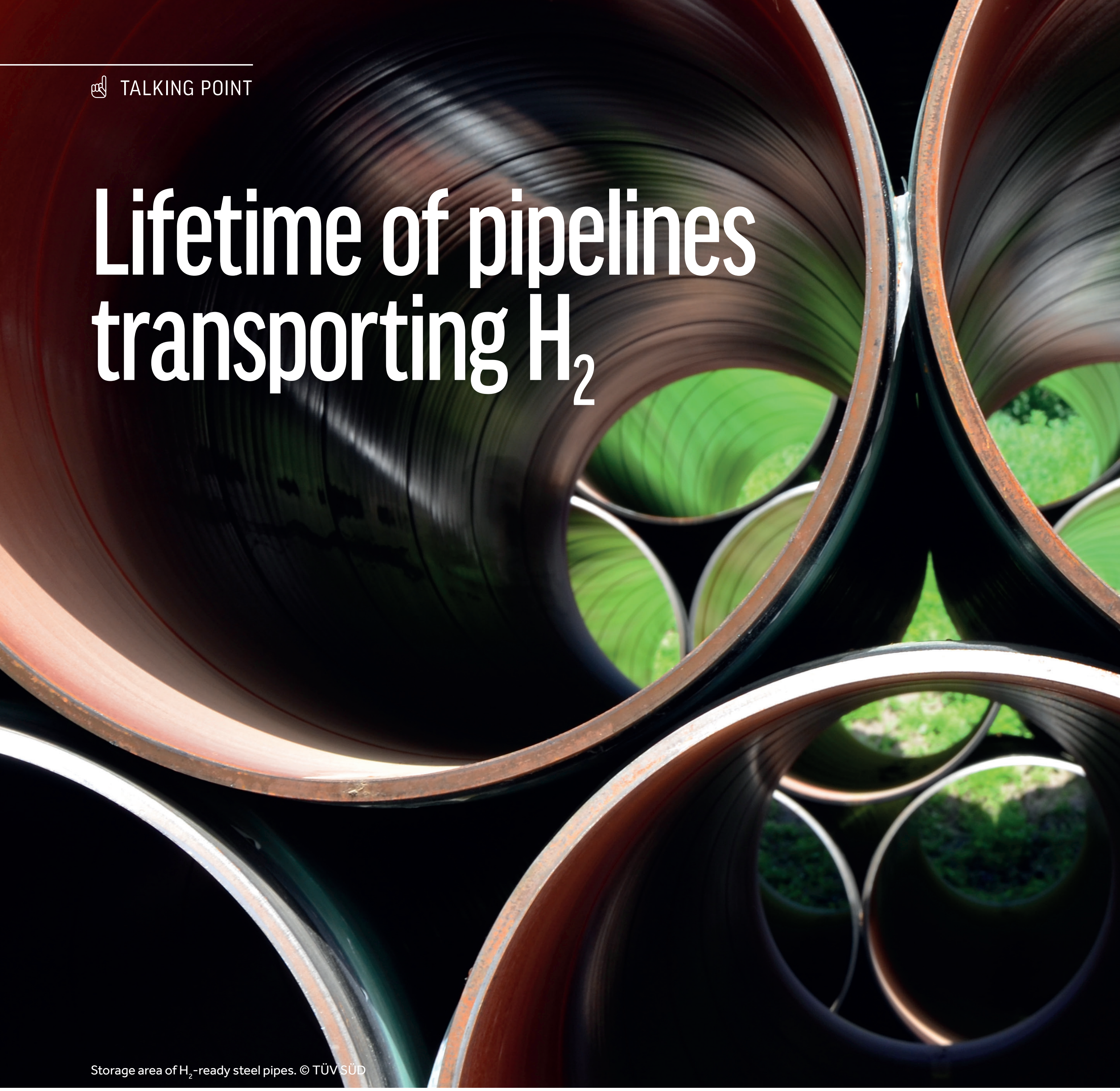
Lifetime of pipelines transporting H_2



Storage area of H_2-ready steel pipes. © TÜV SÜD

Hydrogen is regarded as the alternative energy carrier of the future. However, its transport over long distances calls for a special safety concept. Energy managers wishing to transport hydrogen in existing and new pipelines must furnish evidence of their pipeline's service life by way of fracture mechanics. TÜV SÜD's experts supply fracture mechanical analyses as well as readiness investigations and assessments.

Hydrogen Power Storage & Solutions (HYPOS), a hydrogen network in Central Germany, aims at leveraging the potential offered by a green hydrogen economy to ensure cost-effective implementation of climate-change and environmental-protection targets. The Zwanzig20 (Twenty20) programme, funded by the Federal Ministry of Education and Research, is designed to promote research and development (R & D) projects and also drives hydrogen technology from production to use. Focus topics addressed by these initiatives include the new hydrogen infrastructure and the existing natural-gas infrastructure. Blending of hydrogen into natural gas pipeline networks is another aspect investigated by the initiatives. A significant

factor in this context is how hydrogen affects other materials. The H2-PIMS project focuses on developing a pipeline integrity management system (PIMS) to operate natural gas lines with hydrogen-rich gases and on preparing a guide to converting existing pipelines to hydrogen transport.

When is infrastructure suitable?

Germany has a track record of changing the fluid transported in pipelines. When first installed, pipelines transported what was known as 'town gas' produced from coal, already containing hydrogen to a certain percentage. However, they have carried natural gas since the 1950s. In the event of a transition to hydrogen, the tried-and-tested pipeline infrastructure can also be used to transport this new form of energy, a major advantage for the managers of the German pipeline network. However, in spite of the pipeline network's general suitability, some aspects need to be considered.

The installation and operation of energy-supply infrastructure falls under the scope of the Energy Management Act (EnWG) [3]. Applications involving a maximum permissible operating pressure exceeding 16 bar additionally fall under the scope of the High Pressure Gas Pipelines (GasHDrLtgV) [4]. The technical requirements have been defined in the standards of the German Association of the Gas and Water Industry (Deutscher Verein des Gas- und Wasserfachs e.V. (DGVW)). At present a change in fluid, which may adversely affect the pipeline, is considered a major change and necessitates notification in accordance with EnWG/ GasHDrLtgV. The technical specification relevant to the conversion of an existing pipeline to hydrogen or the construction of a new pipeline are described in DVGW Worksheets G409 [6] and G463 [5].

The right type of steel is essential

The harder the steel and the rougher its surface, the more susceptible it is to hydrogen embrittlement. This process occurs when hydrogen atoms form on the metal's surface. If this atomic hydrogen starts to diffuse into the metal lattice, instead of forming H2 molecules on the material's surface the hydrogen atoms will recombine into molecules inside the material, resulting in gas bubbles or material separation (cracking) and thus ultimately embrittlement. Defects in other words, locations with high mechanical stresses are particularly vulnerable to hydrogen embrittlement and hydrogen-induced cracking. Carbon steels display particularly reduced fracture resistance and accelerated crack propagation even at low partial pressure. The German Association of the Gas and Water Industry (DVGW) is subjecting pipeline steels to comprehensive experiments to test their properties under exposure to hydrogen. Initial material parameters are expected to be published shortly.

Fracture mechanics: the gold standard

Prediction of the pipeline service life requires detailed information concerning the materials used and the pipeline's state of condition. All influencing factors need to be taken into account, including assessment of the installed components and their state of condition, but also the materials used and the actual stress to which they are exposed. TÜV SÜD reviews the documentation of the planning, installation and operation of the pipelines to be converted and also performs non-destructive and destructive testing of materials.

Using fracture mechanics, which describes the failure of cracked components under static and cyclical loads, the experts furnish evidence of pipeline safety and function. If the fracture-mechanics parameters required for the prediction of service life (fracture resistance and the parameters of the crack growth rate) of the materials used are not known, these parameters need to be determined in the laboratory under hydrogen atmosphere. Depending on the number of load cycles during the service life, the experts then determine the residual service life of the pipeline and define the intervals for the periodic inspections during operation.

The failure assessment diagram (FAD) shown in the following figure is one of the key components of fracture mechanics analysis. The FAD limit curve draws the line between the acceptable (below) and the unacceptable crack size (above). The blue point in the Figure 1 identifies a specific case of assessment (defect geometry, load, component geometry and fracture resistance). This can be used to draw conclusions about critical crack depths and critical static load or critical fracture toughness (three points on the FAD limit curve). Working with the consideration of a semi-elliptical internal axial crack, the

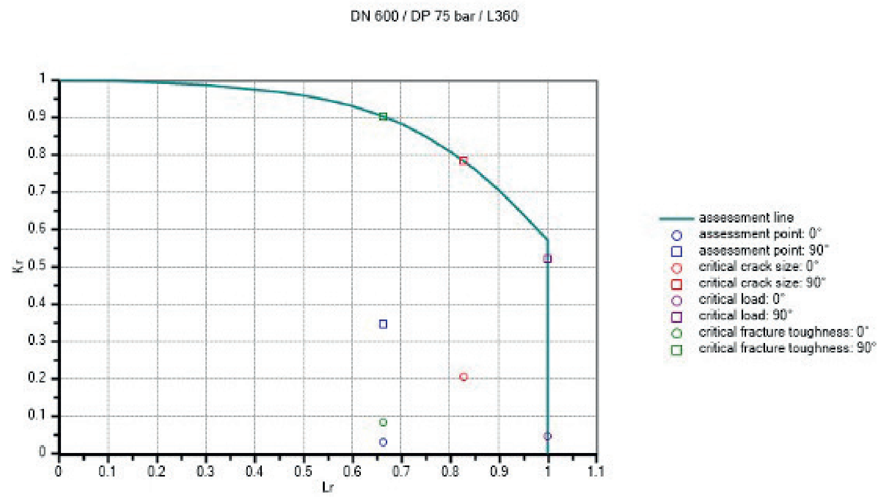


Figure 1: Sample calculation/analysis of integrity for a defined defect with the help of an FAD diagram.
© TÜV SÜD

Dr Albert Großmann

Jan Sachse

Dr Johanna Steinbock

acceptability is analysed for the crack start at the internal surface 0° and the deepest point of the crack 90°.

Expertise along the value chain

TÜV SÜD offers third-party expertise, supporting safety concepts and fracture-mechanical analysis of hydrogen pipelines and thereby contributing significantly to the development and establishment of safe and climate-friendly future energy supply. In feasibility studies, the international provider of testing, inspection and certification (TIC) services investigates whether the fluid in existing natural-gas pipelines can be changed to hydrogen. TÜV SÜD also supports managers with defining specific measures to establish an integrity concept for operations. However, the experts also address new pipelines as well as putting existing pipelines through their paces. The specialists sit on all relevant committees and carry out their own research on the topic, from design to market launch.

References

[1] API 579-1/ASME FFS-1 (2016), 'Fitness-For-Service', ASME - The American Society of Mechanical Engineers, Washington D.C., 06/2016.

[2] ASME B31.12 (2019), „Hydrogen Piping and Pipelines', ASME - The American Society of Mechanical Engineers, New York, 12/2019.

[3] BMWi (2020), Bundesministerium für Wirtschaft und Energie, 'Energiewirtschaftsgesetz – Gesetz über die Elektrizitäts- und Gasversorgung (EnWG)', 07/2005, mit Änderung 08/2020.

[4] BMJV (2019), Bundesministerium der Justiz und für Verbrauerschutz, Verordnung über Gashochdruckleitungen (GasHDrLtgV),05/2011, mit Änderung 05/2019.

[5] DVGW G463 (2020), Arbeitsblatt: „Gashochdruckleitungen aus Stahlrohren für einen Auslegungsdruck von mehr als 16 bar; Errichtung', 02/2020.

[6] DVGW G409 (2020), Merkblatt: „Umstellung von Gashochdruckleitungen aus Stahlrohren für einen Auslegungsdruck von mehr als 16 bar für den Transport von Wasserstoff', 09/2020.

Words:

Dr Albert Großmann,
Expert High-Pressure Gas Pipelines,
TÜV SÜD Industrie Service

Jan Sachse, Team Lead Pipelines,
TÜV SÜD Industrie Service

Dr Johanna Steinbock,
Expert Fracture Mechanics Analysis,
TÜV SÜD Industrie Service

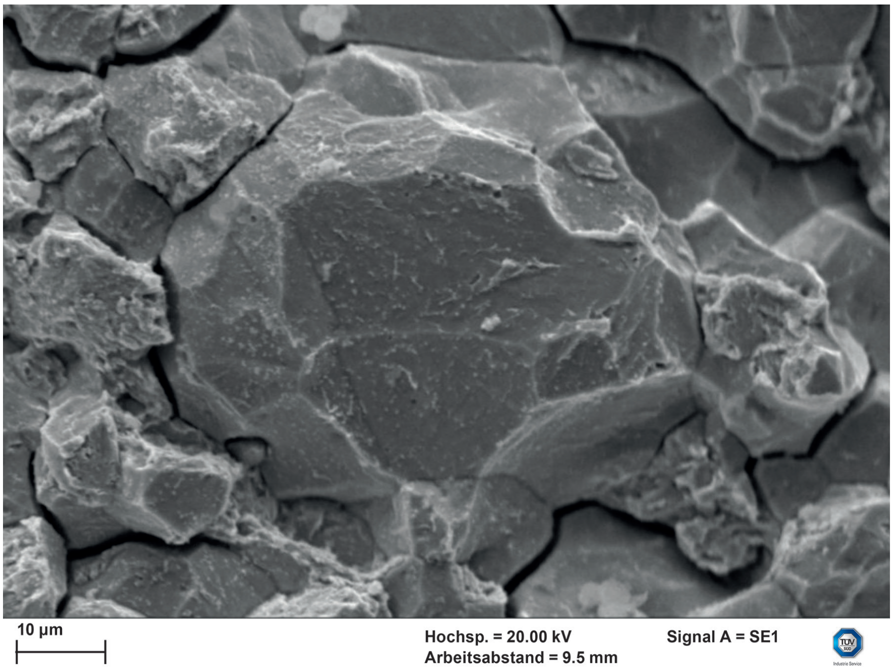
Contact:

TÜV SÜD Industrie Service GmbH
Westendstraße 199
80686 Munich
Germany

+49 89 5791-2176

jan.sachse@tuvsud.com

www.tuvsud.com/de-pipelines



The scanning-electron microscope image shows hydrogen pores, hairlines: crow's feet, and open grain boundaries. © TÜV SÜD