Source: TÜV-Verband-Merkblatt MB WERK 1276, Damage to metallic materials due to the influence of gaseous hydrogen, Introduction for experts,
Version: 2025-09-01

Summary (pages: 29 to 30)

This Merkblatt is intended to provide TÜV experts with an overview of the damage mechanisms that can occur during manufacturing and during hydrogen-based system operation under particular operating conditions. The document lists the hydrogen-specific requirements valid at the time of publication and how they are evaluated with regard to the suitability of metals for use with hydrogen. Furthermore, it outlines the unique aspects of design reviews and welding processes, and addresses the application of fracture mechanics analysis and the detectability of hydrogen-induced damage using non-destructive testing. Damage to plastics due to hydrogen is not yet covered in this Merkblatt.

The impact of hydrogen on metals is diverse. While fracture toughness, fatigue crack propagation and vibration resistance are significantly reduced, strength and hardness will be barely impacted. Five key models have emerged in order to be able to describe the impact that hydrogen exercises on the materials. Among these is the pressure theory, according to which atomic hydrogen in stress fields, inclusions and pores can recombine into molecules, generating a pressure increase in the material and affecting its structural stability.

The HEDE model explains how the presence of hydrogen reduces the cohesive forces between atoms in a material, making it more susceptible to fracturing and cracking.

The HELP model describes the support of local yielding and the subsequent facilitated hydrogen-induced propagation of cracks. As part of the AIDE model, it is assumed that the absorption of hydrogen at the newly emerging surface, resulting from pores developing prior to a crack tip, will lead to a decreased surface energy and enhanced crack propagation.

The HESIV model primarily deals with high-strength martensitic structures. The presence of interstitially solved hydrogen leads to an accelerated formation of vacant positions, which weakens the material's integrity and promotes crack propagation The impact of these five damage models on metals varies depending on the type of metal, temperature, pressure and other factors.

One form of damage due to hydrogen that typically exists in refineries is the hydrogen-induced crack formation, which occurs when there are no or little external or intrinsic stresses present.

Hydrogen-induced stress corrosion requires several factors to interact. Firstly, the material must be susceptible to hydrogen-induced stress corrosion; secondly, there must be a local corrosion attack accompanied by the presence of atomic hydrogen under the influence of tensile mechanical stresses.

High-temperature hydrogen-induced damage typically occurs at temperatures above 170 °C. The hydrogen reacts with the carbon dioxide in the steel, decarbonizing it and leading to the formation of methane within its grain structure. Over time, the methane bubbles will grow and consequently lead to the formation of cracks and the loss of strength, which can result in sudden catastrophic damage.

Clause 6 of this Merkblatt lists the relevant technical rules dealing with the consideration of hydrogen embrittlement during the design review. These rules comprise important up-to-date hydrogen specifications for designing pressure equipment.

The main focus during the welding process is on the design of the weld, as welds present a particular hazard zone of pressure equipment under operational hydrogen attack. Standards and rules for avoiding hydrogen-induced damage during manufacturing shall be complied with.

In order to evaluate the safety of important components and systems affected by hydrogen, it is necessary to understand the construction details as well as the behavior of potential materials under these loads and temperatures, taking into account the influence of the medium. There are only few reliable tools available to the designers for finding or selecting

materials for hydrogen-specific applications. This is partly because credible experiences of well-established material solutions are rare.

Principally, it is possible to carry out non-destructive testing using any established NDT method in order to detect hydrogen-induced damages. Therefore, it is also important to select the most appropriate method for each use case.