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Cracks are Dangerous: Avoiding Costly Failures in Welding

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Introduction

Hydrogen, the lightest and smallest of all elements, is also the most fascinating one and dominated the known universe since the beginning of all time. Hydrogen was the first element formed after the Big Bang, and is the nuclear fuel that formed stars and drives their nuclear fusion process to yield helium and later carbon, nitrogen and oxygen – elements that became the building blocks for life. Elements heavier than iron are thought to be fusion products created and distributed during supernovae, stellar explosions. The well-known saying "we are all made of stardust" is not only philosophical but true.

We find hydrogen has the power to create as well to destroy. It is up to us and our application of hydrogen, to use this element in a senseful manner and to limit its destructive potential. Hydrogen produced by green, regenerative sources is the biggest hope to lower the CO_2 footprint and replace coal/coke in energy intensive processes like steel production, or combustion engines in vehicles. On the other hand, hydrogen contributes to material failures by so-called hydrogen induced cracking.

Make sure it's welded to last

Hydrogen-induced damage is a widespread and dreaded phenomenon. During welding, hydrogen is generated from the dissociation of water vapor (e.g. humidity) or hydrocarbons in the welding arc, and the molten metal can rapidly pick up hydrogen.

Once in the weld metal, hydrogen atoms can diffuse swiftly into the heat-affected zone of the base metal as diffusible hydrogen. During cooling and phase transformation of the matrix, the residual hydrogen accumulates at microstructural dislocations and voids as molecular hydrogen, resulting in localized tensile stress adding to the residual tensile stresses. Diffusible hydrogen causes hydrogen induced cracking (also known as cold or delayed cracking), where components fail under the influence of mechanical stress – suddenly and without prior indication. Diffusible hydrogen generation followed by damage is not limited to welding but might affect similar processes like 3D metal printing as well.

Bruker's [G4 PHOENIX] was developed for the fast and easy determination of diffusible hydrogen in welds and other sample matrices using the carrier gas hot extraction method.

The G4 PHOENIX and the [G8 GALILEO] equipped with an external infrared heated furnace, comply to the rapid method described in the norms EN ISO 3690 but also AWS A4.3 (recent amendment). Their fast analysis times, and elimination of toxic and banned mercury, make these instruments the first

choice for quality and process control for diffusible hydrogen, allowing even pre-welding testing. More detailed information about diffusible hydrogen determination can be found in [Lab Report CS/ONH 27 G4 PHOENIX Diffusible Hydrogen Analysis in Weld Seams].

FAQs of diffusible hydrogen determination

For more than three decades, Bruker has pioneered the assessment of diffusible hydrogen. During this period, we received a lot of user questions concerning sample preparation, storage, and conservation. Our application labs also receive frequent requests for sample measurements, where users new to this topic simply underestimate the meaning of the wording "mobility" and "diffusion". The diffusion of hydrogen out of the workpiece or specimen starts immediately after its preparation. The ideal and confirmed way to guarantee its conservation for measurement is immediate cryogenic cooling with liquid nitrogen (LN_2) to -196 °C. There will be a significant decrease during storage over dry ice (-72 °C) and almost a complete loss, if stored at room temperature. In addition, the diffusion rate is heavily dependent on the individual material and its microstructure, but also on the sample shape and its surface distribution. Therefore, every approach to deduce diffusible hydrogen concentrations based on measurements of samples handled under non-controlled conditions will fail and lead to erratic estimations.

This challenge and other aspects of sample preparation, conservation and measurement are reviewed in a collaborative study together with the institute for materials and material testing, around Prof. M. Pohl, inside the faculty for mechanical engineering of the Ruhr-University of Bochum (RUB). Results from this collaboration are published in the form of an Application Note for the first time and included in the following section.

The answer to analytical challenges with diffusible hydrogen determination

The Application Note investigates the effect of galvanization with Zn on storing the hydrogen content within the sample, by measuring charged galvanized and charged non-galvanized samples two and seven days after charging. The second part focuses on the capability of absorbing hydrogen by simply "charging" blank samples with concentrated hydrochloric acid. Further it is demonstrated that measurable differences can be resolved for different charging intervals.

- Different methods to charge steel samples with hydrogen are outlined in detail.
- It is shown that untreated samples, stored at room temperature, lose almost all diffusible hydrogen after 7 days. It is concluded the rate will further depend on the individual sample shape and constitution.
- It is shown that samples stored under LN_2 show no detectable loss, even after 7 days of storage.
- A method to conserve hydrogen inside the sample by galvanic zinc plating is described.
- A method to remove the Zn-plating before the measurement using an inhibitor is described.
- It was verified that charged steel samples, prepared by the outlined methods, do not lose a significant amount of hydrogen during shipment and storage. It was also verified that there was no falsification of the initial value, e.g. due to the Zn-removal process.

The entire Application Note with detailed descriptions, results and references is available here: [AN Challenges in Diffusible Hydrogen (Bruker-RUB).]

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