HYDROGEN EMBRITTLEMENT BEHAVIOR OF PLASTICALLY PRE-STRAINED AND HYDROGEN-CHARGED LOW ALLOY STEEL

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The paper investigates the effect of high-temperature gaseous hydrogenation of low-alloy 22K steel on its resistance to hydrogen embrittlement (HE). The propensity to hydrogen embrittlement of the studied material was evaluated by determining the hydrogen embrittlement index based on the results of traditional uniaxial tensile tests of hydrogen-free and hydrogen-charged samples. The research was carried out for pre-strain-free and 75% pre-strained samples.

Keywords: hydrogen concentration, pre-strain, fracture energy, hydrogen embrittlement

Introduction. Hydrogen embrittlement (HE) continues to pose a significant challenge in various industries, particularly in the realm of materials engineering. Among the many materials susceptible to this insidious phenomenon, low-alloy steels have been a subject of particular interest due to their widespread use in critical applications. In recent research endeavors, attention has turned to 22K steel, a promising low-alloy variant with superior mechanical properties. However, the introduction of hydrogen, especially at high temperatures, can compromise the structural integrity of this material.

In this pursuit of understanding and mitigating hydrogen embrittlement in 22K steel, a groundbreaking study has been undertaken. The focal point of investigation lies in comprehending the impact of high-temperature gaseous hydrogenation on the material's resistance to hydrogen embrittlement. By subjecting the steel to traditional uniaxial tensile tests, the researchers have sought to establish a robust hydrogen embrittlement index for both hydrogen-free and hydrogen-charged samples.

What sets this study apart is the consideration of the pre-strain factor in hydrogen embrittlement behavior. The research delves into two distinct categories: pre-strain-free and 75% pre-strained samples. This nuanced approach aims to shed light on how plastically pre-straining the material influences its susceptibility to hydrogen embrittlement, providing valuable insights for future design and engineering practices.

Through meticulous experimentation and comprehensive analysis, the paper aims to contribute significantly to the understanding of hydrogen embrittlement behavior in 22K low-alloy steel. The findings may pave the way for novel strategies to enhance the resilience of this material when operating in hydrogen-rich environments, ultimately fostering safer and more reliable engineering applications.

Experimental part. A set of specially designed cylindrical Bridgman samples made of 22K steel were produced. The samples were exposed to hydrogen for 24, 48, and 48 hours in a special sealed chamber at the temperature of 400 °C and the pressure of 6 MPa. A stochastic dot pattern was created on the working surface of the samples using elastic aerosol paint. The samples were loaded by tensile until fracture. Hydrogen concentration was measured using a LEKO DH-603 gas analyzer, which determines the concentration of residual hydrogen.

Results and discussion. The optical-digital image correlation (ODIC) method was used to plot true stress-strain diagrams in coordinates: «S_i–e_i», where S_i – true stress values; e_i – true strain values.

The value of the energy of elastoplastic fracture was determined by the formula:

$$W(x, y, z) = \int_0^e S(e)de. \quad (1)$$

Fracture strain – hydrogen concentration and fracture energy – hydrogen concentration diagrams were plotted for pre-strain-free and 75% pre-strained samples (Fig. 1-4). As the hydrogen concentration increases, fracture strain and fracture energy decrease. For 75% pre-strained samples, the effect is steeper compared to pre-strain-free ones.

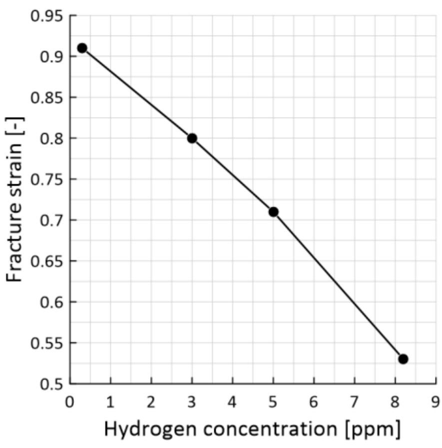

Fig. 1. Hydrogen concentration effect on

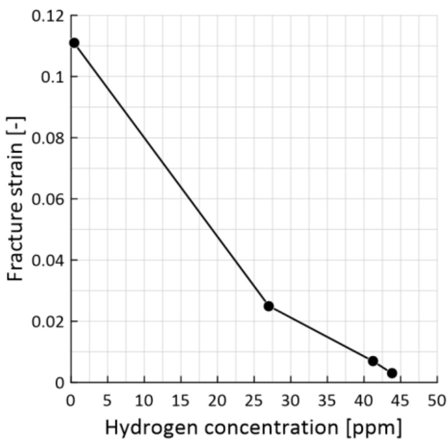

Fig. 2. Hydrogen concentration effect

fracture strain for pre-strain-free samples.

on fracture strain for 75% pre-strained samples.

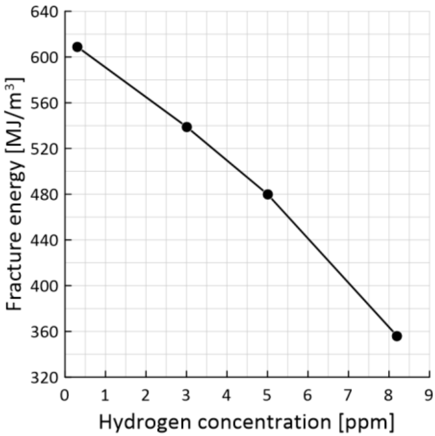

Fig. 3. Hydrogen concentration effect on fracture energy for pre-strain-free samples.

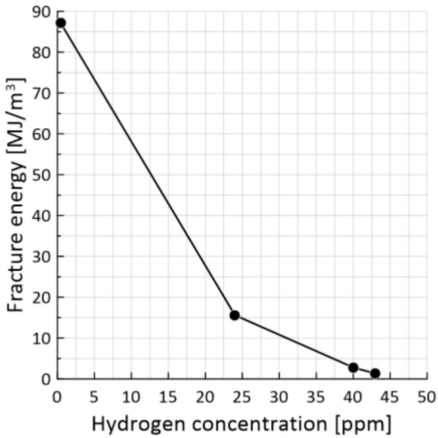

Fig. 4. Hydrogen concentration effect on fracture energy for 75% pre-strained samples.

The hydrogen embrittlement index (HE index) has been used for quantitative analysis. According to the NASA standard, the index is calculated by the loss of plasticity:

$$\omega_\varepsilon = (\varepsilon_C - \varepsilon_H) / \varepsilon_C, \qquad (2)$$

where $\varepsilon_C, \varepsilon_H$ – fracture strain of hydrogen-free and hydrogen-charged samples, respectively.

However, hydrogen affects both strain and stress therefore this index calculated by the loss of energy reserves was introduced according to:

$$\omega_W = (W_C - W_H) / W_C, \qquad (3)$$

where W_C, W_H – fracture energy of hydrogen-free and hydrogen-charged samples, respectively.

HE index – hydrogen concentration diagrams were plotted for pre-strain-free and 75% pre-strained samples (Fig. 5, 6). As the hydrogen concentration increases, HE index increase.

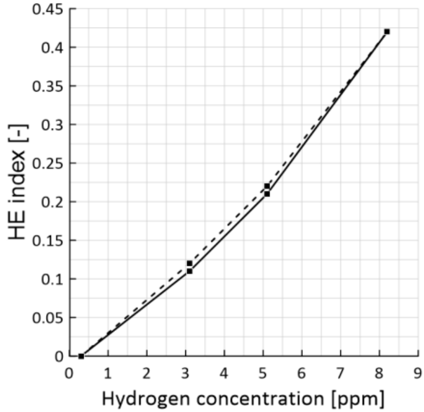

Fig. 5. HE index – Hydrogen concentration experimental diagrams of pre-strain-free sample using the strain approach (dashed line) and the energy approach (solid line).

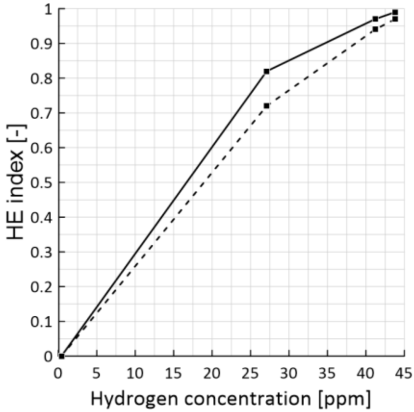

Fig. 6. HE index – Hydrogen concentration experimental diagrams of 75% pre-strained sample using the strain approach (dashed line) and the energy approach (solid line).

Conclusions. It has been established that there is a difference between calculating the hydrogen embrittlement index using the strain and the energy approaches, especially when it comes to pre-strained material. It is more appropriate to use such an integral characteristic as the energy of elastoplastic deformation, which depends on both stress and strain.

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