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Review of Experimental Methods for Hydrogen Embrittlement Susceptibility Assessment of Press-Hardened Steels

David Frómeta[1], Sílvia Molas[1], Amadeu Concustell[1], Laura Grifé[1], Daniel Casellas [1,2], Mélodie Mandy[3], Anis Aouafi[4], Thierry Sturel[4], Andreas Muhr[5]

Abstract

Press-hardened steels (PHSs) are one of the dominant materials of choice for the lightweight construction of structural and safety-related automobile components. However, due to their high strength, exceeding 1500 MPa, PHSs may be susceptible to hydrogen embrittlement (HE) when they are exposed to hydrogen-containing environments, increasing thus the risk of delayed fractures or catastrophic failure in a crash event. Therefore, evaluating the HE susceptibility of PHS is crucial to guarantee the safe application of these steels and predict potential fractures that can compromise structural integrity. The present study compares different state-of-the-art methods to assess the HE susceptibility of a PHS 1500 grade. Four-point bending tests, Slow Strain Rate Tests and Constant Load Tests are performed in hydrogen-charged samples with different H concentrations to evaluate the critical H content that causes a significant loss of mechanical properties. The results of the different experimental procedures are discussed, and the main advantages and drawbacks are reviewed. Additionally, a novel test based on the essential work of fracture methodology is proposed. The method uses sharp-notched specimens prepared by a shear-cutting tool, which are subsequently tested up to fracture in a universal tensile machine. The new test offers a fast and cost-effective solution to estimate the HE susceptibility of PHS and assess the degradation of fracture resistance.

1 Introduction

Press-hardened steels (PHS) are extensively used in body-in-white applications, especially for structural components with high anti-intrusion requirements (impact beams, bumper beams, A- and B-pillars, etc.) [1]. The most common PHS grade is the 22MnB5, which is a low-carbon steel, with Mn and B alloying. In the fully hardened condition, PHS1500 has a martensitic microstructure with a tensile strength up to 1500 MPa, and a total elongation about 5% [2].

One of the limiting factors on the application of these martensitic ultra-high strength steels is their higher hydrogen embrittlement (HE) susceptibility compared to conventional steels. HE in PHS refers to ductility and toughness degradation caused by the synergic influences of diffusible hydrogen and residual (or applied) stress [3]. The diffusible hydrogen can be introduced during different phases of steel production, component manufacturing or vehicle life [4,5]. In PHS, diffusible hydrogen absorption may occur during austenitization in open furnaces. The hydrogen uptake is associated with high-temperature atmospheric corrosion by water vapour [6]. Once absorbed into the steel, when the material is exposed to external stresses or even residual stresses, diffusible hydrogen will diffuse and segregate to locations having high hydrostatic stress, resulting in a local increase of hydrogen concentration, and leading to hydrogen-induced delayed fracture [3]. According to this and considering that PHSs are mostly intended for structural and safety applications, it is evident that understanding their HE susceptibility is of utmost importance to guarantee their safe implementation and minimize the risk of delayed fractures or catastrophic failures in a crash event.

Although many efforts have been devoted to defining test methods to characterize the HE susceptibility of advanced high-strength steels (AHSS) and PHS sheets, no standard procedure has been established yet. The most common tests used to evaluate HE of automotive steels are the four-point bending test (4PBT), the Constant Load Test (CLT), the Slow Strain Rate Test (SSRT), the Linearly Increasing Stress Test (LIST) and the U-bend test [4,7,9, 10]. Various studies have been conducted with