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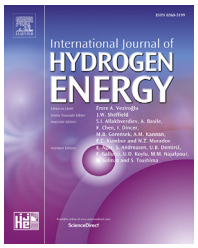

Short Communication

Influence of hydrogen on electrochemical behavior of Ni-based superalloy 718

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ABSTRACT

Numerous studies have shown that Ni-based superalloy 718 may be sensitive to hydrogen embrittlement and have highlighted the dominant roles played by the hydrogen solubility and the hydrogen trapping. Samples were hydrogenated by cathodic polarization in molten salts under different conditions to vary the diffusible hydrogen content and to saturate the different hydrogen traps present in the microstructure strengthened by precipitation. Open circuit potential and galvanic coupling measurements were conducted in order to characterize the effect of diffusible and trapped hydrogen on electrochemical behavior and to discuss the possibility of galvanic coupling between zones with different hydrogen contents.

Introduction

Alloy 718 is a Ni-based superalloy that is widely used for high-temperature applications, particularly for structural components in the aeronautic and nuclear industries, due to its good mechanical properties. This alloy is strengthened both by structural hardening and by solid solution hardening [1]. The typical strengthening heat treatment applied to alloy 718 consists of a dwell of 8 h at 720 °C, followed by cooling at 50 °C/h and a final dwell of 8 h at 620 °C. This process leads to the precipitation of γ'' (metastable and coherent with the matrix, tetragonal $D0_{22}$ structure, Ni_3Nb composition, disc-shaped (20 nm diameter × 10 nm thickness)) and γ' (stable and coherent with the matrix, cubic $L1_2$ structure, $(Al,Ti)Ni_3$ composition, spherical shape (20 nm)) phases embedded in a γ matrix (volume fraction of $\gamma'-\gamma''$ = 16% and γ'/γ'' ratio = 1/4). Some primary carbides precipitates are also present in the microstructure [2].

Under operating conditions, despite a good resistance to stress corrosion cracking (SCC), corrosion processes may induce local hydrogen enrichment at the material surface and/or in the vicinity of localized corrosion defects. Consequently, a hydrogen-assisted SCC phenomenon can occur under complex stress and strain states [3]. The hydrogen embrittlement (HE) of Ni-based alloys is generally exacerbated when the alloys are submitted to mechanical loading, suggesting that hydrogen diffusion occurs along stress gradients as well as hydrogen transport by dislocations during plastic deformation [4–14]. Hydrogen transport by mobile dislocations can lead to local hydrogen enrichment in the dislocation pile-ups close to precipitates/interfaces, which favors crack initiation. Galliano

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et al. have confirmed this point and have shown a strong susceptibility of the strengthened alloy 718 to HE after cathodic hydrogen charging [2].

Effect of hydrogen on rupture modes

In this work, samples were hydrogenated by cathodic charging in molten salts at 150 °C as done by Galliano et al. [2]. All the characteristics of these chargings are detailed in this previous work as well as hydrogen content measurements using a Galileo Bruker analyzer and the procedure of hydrogen desorption tests [2]. The fracture surfaces obtained after tensile tests performed at 25 °C and $\dot{\varepsilon} = 10^{-3}\,s^{-1}$ for pre-hydrogenated samples of strengthened alloy 718 are presented in Fig. 1 and showed both transgranular (cleavage) (Fig. 1a and b) and intergranular brittle fracture (Fig. 1c).

Two main HE mechanisms in relation to the hydrogen-trapping mechanism are generally considered to explain the fracture surfaces: the hydrogen-enhanced localized plasticity (HELP) and hydrogen-induced decohesion (HID) mechanisms [15]. The HELP mechanism corresponds to an increase in dislocation mobility by the reduction of the elastic interactions between obstacles and perfect and partial dislocations [16]. Associated with a hydrogen transport phenomenon facilitated by dislocations, this mechanism leads to local segregation of hydrogen on {111} planes, inducing cleavage, as well as the decohesion of particles/matrix interfaces (HID mechanism) [17,18].

Intergranular brittle fracture suggested that hydrogen preferentially diffused/segregated along grain boundaries, partly due to the hydrogen-trapping mechanism on carbides that reduced the cohesive strength of the grain boundaries structure. But, the low density of intergranular carbides suggested rather that the grain boundaries chemistry and crystallographic relations could have a strong effect on intergranular rupture too as well as the possibility of intergranular element segregations such as Nb or P [19–21].

Study of hydrogen trapping reversibility

So these results have shown the strong influence of hydrogen traps on HE susceptibility of the alloy 718 and particularly on the rupture modes. For a better understanding of the hydrogen desorption phenomena in relation with hydrogen trapping, desorption heat treatments were conducted at two temperatures, i.e. 25 °C and 320 °C, during 300 min for samples all pre-hydrogenated in molten salts at 150 °C for 8 h. To compare the evolution of the hydrogen content between each desorption temperature, the hydrogen content was measured relative to the initial hydrogen content [H_0] measured for a pre-hydrogenated sample immediately after charging. All hydrogen contents were measured using a Galileo Bruker analyzer [2]. The results of this analysis are given in Fig. 2.

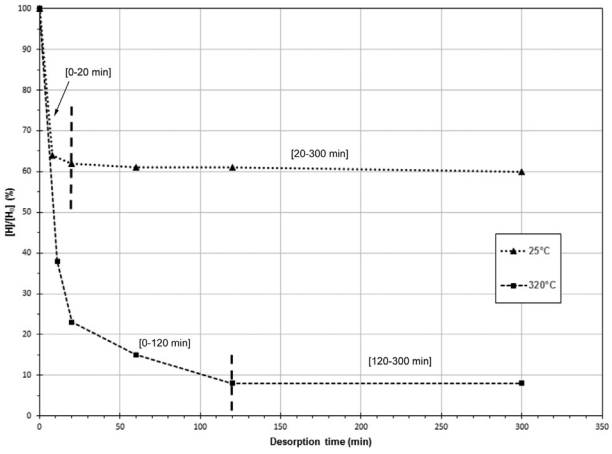

Fig. 2 – Evolution of hydrogen content in 8 h H-charged alloy 718 during 300 min at 25 °C and 320 °C.

For both temperatures, two successive regimes were characterized. A preliminary step characterized by a strong hydrogen desorption followed by a second step corresponding to a stagnation of the hydrogen content:

- Hydrogen desorption regime: [0–20 min] at 25 °C and [0–120 min] at 320 °C.

The hydrogen desorption was relatively rapid, and the level of desorption was dependent on the temperature. Considering that the main hydrogen traps characteristic of the strengthened alloy, i.e. carbides and strengthening precipitates/matrix interfaces, are irreversible [5,22], the rapid and strong hydrogen content decrease observed in the desorption curves

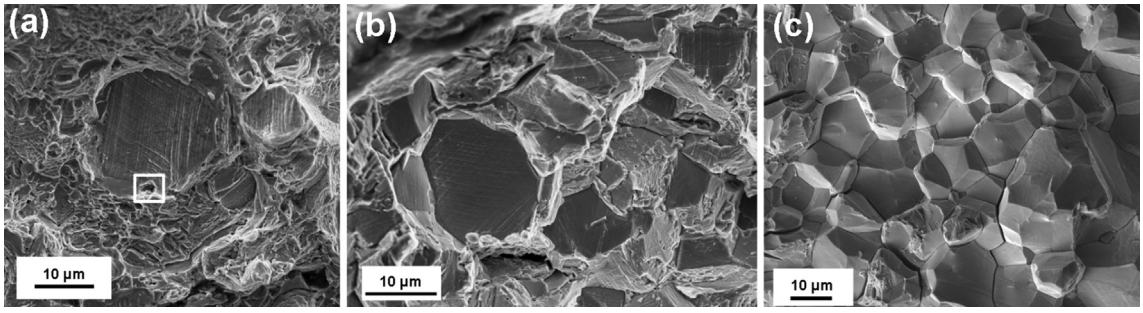

Fig. 1 – Fracture surfaces observations of pre-hydrogenated samples of strengthened alloy 718 after tensile test. Transgranular rupture (cleavage) related to hydrogen trapping (a) on carbide/matrix interfaces and (b) on strengthening precipitates/matrix interfaces and (c) intergranular rupture related to hydrogen diffusion/segregation along grain boundaries.