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Ultra-grain refinement effect on tensile and phase transformation behaviour in a metastable austenitic steel charged in hydrogen gas

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Abstract

To ensure the safety of hydrogen systems, materials must be selected according to strength levels and susceptibility to hydrogen. Austenitic steels are notoriously resistant to hydrogen embrittlement, but usually suffer from relatively low strength levels.
In this study, the material used is Fe-16Cr-10Ni, a metastable stainless steel. A slab was cold-rolled to 1.5 mm thickness and annealed to produce two different austenite grain sizes (1 μm, ultra-fine grain, and 50 μm, coarse grain). The plate material was charged in hydrogen gas (10 MPa, 270ºC, 72 hours) and the mechanical properties were evaluated by tensile testing in air.
Thermal desorption spectrometry was used to confirm that there is no significant difference in hydrogen content between the two materials and that therefore grain boundaries do not play a significant role in trapping hydrogen. Tensile testing showed that the strength was increased by grain refining but that the increase in strength did not enhance the material's susceptibility to hydrogen embrittlement. Ductility, evaluated by elongation and reduction of area, decreased in both ultra-fine-grained material and coarse-grained material. Cold-rolling coupled with saturated magnetization measurements of BCC phase content showed little difference in phase transformation for hydrogen-charged and uncharged material.

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Keywords: Austenitic; metastable; hydrogen embrittlement; grain refinement.

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1. Introduction

Hydrogen-assisted cracking, and more generally the effects of hydrogen on metals are still being actively investigated. It is necessary to ensure the tools to design materials and structures to be used in the hydrogen systems and infrastructures required for hydrogen-based transportation. In the case of austenitic stainless steels, while the formation of martensite is not a prerequisite for the so-called hydrogen embrittlement (SanMarchi et al., 2010), deformation-induced martensitic transformation does play a critical role in the hydrogen-assisted cracking (Kanezaki et al., 2008).

As the construction of a hydrogen-based infrastructure nears, the need for cost reduction without compromising the properties of the materials becomes more pressing. Here, the use of an austenitic alloy is proposed, due to austenitic stainless steels inherent resistance to hydrogen, partly due to the low hydrogen diffusivity inside FCC metals. Using a combination of cold-rolling and annealing, the strength of the alloy will be raised through grain refinement. The thermal stability of the alloy used here, Fe-16Cr-10Ni, is known to be greatly increased through ultra-grain refinement (Tomimura et al., 1993); the effect on the mechanical stability will therefore be shown here. Furthermore, the effect of solute hydrogen, charged into the material, on the mechanical stability will be also investigated.

Nomenclature

d	average grain size (μm)
r	percentage of reduction by cold rolling (%)
σ	stress (MPa)
ε	strain (-)
σ_Y	yield stress (MPa)
σ_{UTS}	tensile strength (MPa)
δ	elongation (%)
RA	reduction of area (%)
C_H	average hydrogen content (weight ppm, wppm)
M_{d30}	Temperature at which 50% of the material is transformed into martensite under 30% strain (K)

2. Experimental procedures

In this study, the material was a laboratory-developed metastable austenitic stainless steel, Fe-16Cr-10Ni. The composition is 0.002 C, 16.4 Cr, 10.1 Ni, 0.011 Si, 0.08 Mn, 0.003 P, 0.002 S, and 0.032 N (in mass %) and the balance is Fe. This composition allows more than 90% of the material to transform into deformation-induced martensite upon 90% cold-rolling. The sheet thus obtained is then annealed to different temperatures, which reverses the martensite back to austenite, with a grain size slightly smaller than the martensite block (Tomimura et al., 1993). A 15-mm thick ingot is cold-rolled to reduce its thickness by 90% to about 1.5 mm. To obtain coarse grains, the sheet is then annealed at 1173 K for 1.8 ks, and to obtain ultra-fine grains, the annealing treatment is conducted at 923 K for 0.6 ks. The resulting average grain sizes are d = 1 μm for ultra-fine grains and d = 20 μm for coarse grains. EBSD micrographs are shown in Figure 1.

After the final heat treatment, tensile specimens were cut out by Electrical Discharge Machining and polished with emery, followed by buff. The specimens were given a final electro-chemical polishing treatment in a chromic-phosphoric acid solution, which helped remove any martensite that may have formed on the specimen surface during processing.