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Improving hydrogen embrittlement resistance of Hadfield steel by thermo-mechanical flash-treatment

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ABSTRACT

Nano-twins microstructures were introduced in a high carbon manganese steel by a novel flash thermo-mechanical treatment in order to achieve high resistance to hydrogen embrittlement. Nano-twinned grains decreased hydrogen diffusivity through the bulk material, although it absorbed more hydrogen than the twins-free specimens. Moreover, it was shown that after electrochemical hydrogen charging, the nano-twins microstructures can reduce dislocations glide during plastic deformation, resulting in forming of fine twin plates.

1. Introduction

Industrial applications of many components require more reliability to be operated safely under the existence of gaseous hydrogen. Hydrogen Embrittlement (HE) refers to the degradation in the mechanical properties by hydrogen which leads to premature failure of the metallic materials. Nevertheless, different grades of steels are susceptible to HE, when it services in hydrogen environment *e.g.* pressure containers, or contains free hydrogen after processing e.g. melting and pickling [1–10].

Normally, austenitic steels have higher HE resistance than their martensitic or bainitic counterparts due to the higher solubility and much lower hydrogen diffusion coefficients in FCC substrates than BCC structures [11,12]. The value of stacking fault energy (SFE) affects the deformation mode of the austenitic steels intensively [13–15], and, after H-charging, SFE decreases [16], which in role may result in martensite transformation in the low SFE ($< 18\ mJ/m^2$) austenitic steels [10].

Yamada et al. [17] found that, materials with high SFE ($> 41\ mJ/m^2$) were positively affected after H-charging, because the deformation mode was changed from slip dislocation gliding into deformation twinning. However, austenitic steels with high contents of austenite stabilizers such as nickel are not economy in industry applications. While those steels alloyed with carbon and manganese e.g. TWIP suffers HE due to promoting twinning in early stages of deformation, at where cracks are initiated at the intersections with secondary twin and/or grain boundaries [18,19].

The existing of coherent twin boundaries (CTBs) can enhance the strength and ductility of the FCC structures [20–24], since that twin boundaries are planar defects which can hinder dislocations mobility [25]. Moreover, the activation energy for desorption of hydrogen stored in dislocations and grain boundaries is equal to half the value required to desorb hydrogen from twin plates [26,27], on the other hand, internal defects like carbides precipitates, dislocations, and twins can work as hydrogen trapping sites [26–32], which can decrease hydrogen diffusivity through the matrix [33].

Hadfield steel is a traditional high carbon austenitic steel, SFE ranges between 23 and 50 $mJ\ m^{-2}$ [34–37]. According to the literature, it is worth noting that the effect of hydrogen in Hadfield steel is an interesting issue. Astafurova et al. [34] showed that, a single crystal Hadfield steel was positively affected with H-charging due to forming more deformation twins during plastic deformation. But in polycrystalline Hadfield steel, Michler et al. [3] found that hydrogen can cause intensive dislocations piling up on twins and grain boundaries and finally resulted in inter-granular and trans-granular fracture. The controversial effect of twin and grain boundaries on the plastic deformation with the help of hydrogen is crucial but not clearly demonstrated up to date.

The objective of the current study is to analyze the interaction between hydrogen and twin plates by introducing mechanical twins in advance via a thermo-mechanical process, the grain size was maintained the same and both precipitations and martensitic transitions were avoided.

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