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Effects of α′ martensite and deformation twin on hydrogen-assisted fatigue crack growth in cold/warm-rolled type 304 stainless steel

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ABSTRACT

The effects of α′ martensite and deformation twin on hydrogen-assisted fatigue crack growth (FCG) were investigated in cold/warm-rolled type 304 stainless steel in 5 MPa hydrogen and argon gas atmosphere. The rate of FCG is reduced in argon gas, while greatly enhanced in hydrogen gas after cold-rolling. The FCG rates of warm-rolled specimens, no matter tested in hydrogen gas or argon gas, are reduced comparing with as-received specimens. After cold-rolling, α′ martensite formed around the grain boundary promotes hydrogen-assisted crack initiation and propagation. The deformation twin plays an important role during FCG besides α′ martensite after warm-rolling, and hydrogen-assisted cracking along the twin boundary and slip band can enhance the FCG rate during cycle loading.

Introduction

Austenitic stainless steels (SSs) are wildly used as the material of hydrogen system due to its excellent mechanical properties and remarkable corrosion resistance. The mechanical properties of metastable austenitic SS can be greatly improved by cold work hardening because of the behavior of deformation-induced martensitic (DIM) transformation during deformation at temperatures between M_s and M_d, where M_s is the temperature for spontaneous transformation and M_d is the temperature at which the 50% austenite transforms into martensite during the tensile test at a true strain of 0.3 [1]. The mechanical properties and the strengthening mechanism in cold-rolled SS changes with differences in the dislocation density between the austenite phase and α′ martensite phase [2].

The materials of storage hydrogen tank, pressure gage, gas pipeline and so on are mostly strain-hardened austenitic SSs (such as type 304, 316, 316L). However, it is well known that the high pressure hydrogen gas can cause failure of materials because of hydrogen environment embrittlement (HEE) [3–10]. Fatigue lives of engineering materials and components can be reduced when they are exposed to gaseous hydrogen, although,

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much of the decreased life may be attributed to the enhanced stage II fatigue crack growth (FCG). The effects of hydrogen on fatigue initiation and stage I FCG seem to be less damaging, but currently there is no clear understanding of the role of hydrogen in these process [11]. The FCG rate in austenitic SS can be significantly increased in the presence of hydrogen. Murakami et al. [12,13] provided a possible process for the FCG acceleration, in which strain-induced martensite increased the hydrogen diffusivity locally and, therefore, enhanced the hydrogen concentration in a region near the fatigue crack tip. It suggested that strain-induced martensite played a key role in hydrogen-enhanced crack growth in austenitic SSs. Moreover, prior α' martensite (formed by pre-strain) and dynamic α' martensite (formed by the deformation after pre-strain) showed different characteristics in hydrogen embrittlement for austenitic SS in a certain condition [14,15].

It suggest that the composition or the temperature of deformation strongly affect the microstructures of the rolled material. Numerous researches [16–19] were carried out on the evolution of texture and microstructure in rolled SSs. While, there are few reports on the compatibility for cold/warm-rolled SS with high pressure hydrogen gas. It is unclear how the hydrogen interact with the microstructure of rolled austenitic SS. In this paper, the effects of α' martensite and deformation twin on hydrogen-assisted fatigue crack growth was investigated in cold/warm-rolled type 304 SS in 5 MPa hydrogen and argon gas atmosphere. The roles of α' martensite and deformation twin in cold/warm-rolled 304 SS during hydrogen-assisted fatigue crack growth were discussed.

Experimental

The experiments used a type 304 metastable austenitic SS with a composition (in mass pct) of 0.07C, 0.34Si, 1.12Mn, 0.039P, 0.023S, 8.05Ni, 18.09Cr, and bal Fe. As-received 304 SS have been solution treated at 1050 °C for 1 h and followed by water quenching to decrease the amount of δ-ferrite. As-received 304 SS plates (20 mm thick) were multi-step unidirectional rolled to the final thickness of 16 mm (20% reduction in thickness) at 25 °C, 100 °C and 200 °C respectively. The corresponding specimen is named as RXX%-TYY. For example, R20%-T100 specimen represents the as-received specimen has been rolled to 20% reduction of the initial thickness at 100 °C. The strip was soaked at 100 °C for 5 min and rolled with heated roller by about 1% reduction of the initial thickness at each pass. Repeat the step several times until the reduction reaches 20%. In this paper, R20%-T25 specimen is also defined as cold-rolled specimen and R20%-T100/R20%-T200 specimen is defined as warm-rolled

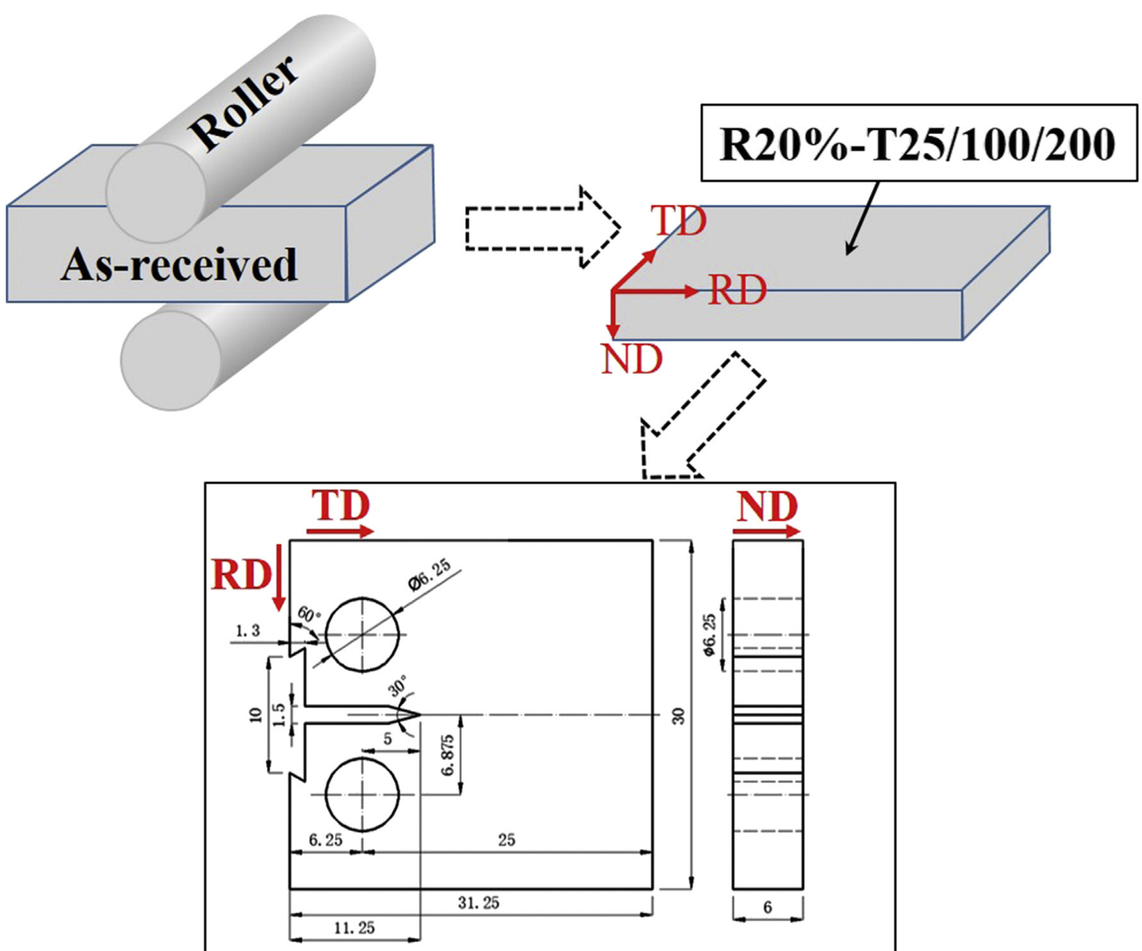

Fig. 1 – Schematic diagram of rolling process and dimensions for CT specimen.