HYDROGEN EFFECTS ON STRAIN-INDUCED MARTENSITE FORMATION IN TYPE 304L STAINLESS STEEL

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Abstract

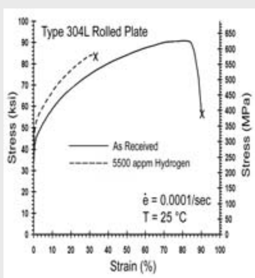
Strain-induced martensite may play an important role in the mechanism of hydrogen embrittlement of metastable austenitic stainless steels. Strain-induced martensite near crack tips provides a path of high hydrogen diffusivity and is intrinsically more brittle than austenite. In this study, the effect of hydrogen on strain-induced martensite formation and embrittlement of Type 304L stainless steel was investigated. Tensile samples were fabricated from rolled plate and were thermally saturated with hydrogen at a pressure of 69 MPa and a temperature of 623 K for three weeks to produce a hydrogen content of 5500 appm. Unexposed and hydrogen-exposed samples were then tested in air at room temperature using a strain rate of 10^{-4} / s. Transformation to martensite during the tensile test was monitored in-situ but the results were inconclusive because ferrite probe could note be placed reliably at the point of fracture. However, metallographic examination indicates that hydrogen increased slightly the formation of martensite at equivalent levels of plastic strain. The more important effect of hydrogen was on the embrittlement and fracture mode of the steel. Hydrogen-charged steels had reduced elongations and fractured by a combination of twin-boundary parting and quasi-cleavage of the transformed martensite. Although martensite plays an important role in the hydrogen-induced fracture of Type 304L steel, metallographic observations do not indicate a significant hydrogen effect on the formation of strain-induced martensite.

Purpose

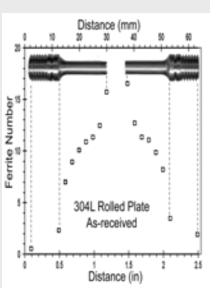
The purpose of this study was to investigate the effect of hydrogen on strain-induced martensite formation and embrittlement of Type 304L stainless steel.

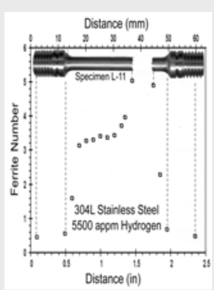
Experimental Procedure

- Type 304L Plate Grade Steel
- Exposed to 69 MPa Hydrogen Gas at 350 C for four weeks
- 5500 appm hydrogen dissolved in steel
- Samples were tensile tested at room temperature in air at an initial strain rate of 10^{-4} / sec
- Formation of ά-martensite was monitored in situ by recording the change in the magnetic phase of the sample by using a ferrite probe mounted to the center of the tensile specimen (Ferrite # of 30 = 100% = Martensite)

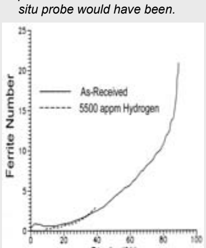


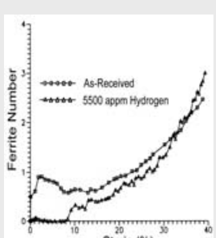
Tensile Behavior of as-received and hydrogen-charged specimens. Hydrogen-charged samples had higher yield strengths and lower elongation





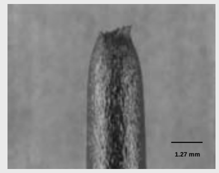
Measurements after the tensile test indicated that ferrite was higher at the point of fracture than it was at the center of the gage section where the in situ probe would have been.



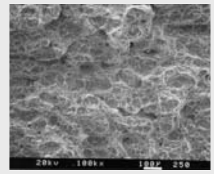


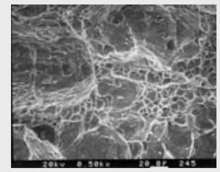
Increase in Ferrite Number With Increasing Strain During Tensile Test for As-Received and Hydrogen-Charged Samples. Hydrogen-charged samples had somewhat smaller amounts of transformed martensite for a given strain state but the results are obscured because the probe could not be placed at the exact point of failure..

Results



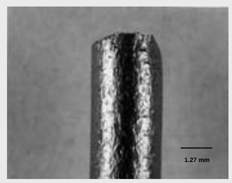
Uncharged



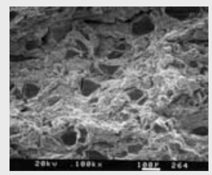


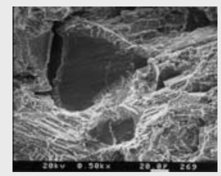
Uncharged

Uncharged samples failed by dimpled rupture ; i.e., microvoid nucleation, growth, and coalescence



Hydrogen Charged

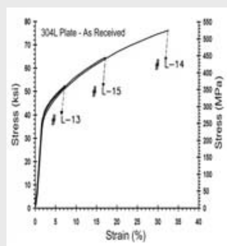


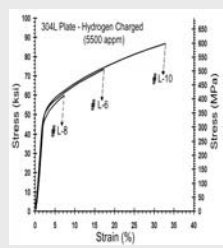


Hydrogen Charged

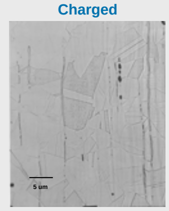
Hydrogen charged samples failed by isolated patches of separated twin boundaries connected by regions of dimpled rupture or quasi-cleavage of transformed martensite.

Interrupted Tensile Tests

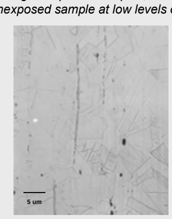
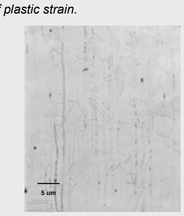
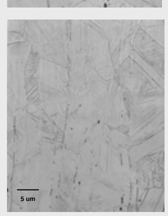




Tensile Specimens were Interrupted after loading to 5, 15, and 30% Values of Plastic Strain Values and Examined Metallographically.

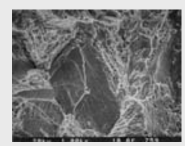
	Uncharged	Hydrogen Charged
5 % Strain		

A very small amount of martensite could be seen in a few grains for the hydrogen-exposed samples, whereas no martensite was seen in the unexposed sample at low levels of plastic strain.

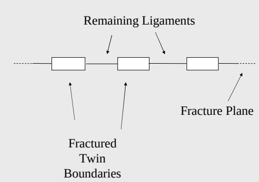
15 % Strain		
30 % Strain		

For higher levels of plastic strain (up to 30% ε_p), the hydrogen-exposed samples had slightly more transformed martensite than the unexposed samples.

Fracture Mechanism



Hydrogen-charged sample fracture features. A particle on the twin boundary facet apparently acted as a crack nucleus.



Schematic showing the apparent fracture mechanism of hydrogen-charged samples. Hydrogen apparently lowered the cohesion of twin boundary interfaces which cracked near maximum load. The remaining ligaments fail by ductile fracture modes, i.e., dimpled rupture or quasi-cleavage of transformed martensite.

Summary and Conclusions

1. Metallographic observations indicate that hydrogen-charged samples had slightly more material transformed to martensite than uncharged samples and equivalent levels of strain.
2. Hydrogen-charged samples had higher yield strength, lower elongation and different fracture modes than uncharged samples.
3. Uncharged samples failed by the microvoid nucleation and growth process. Hydrogen-charged samples failed by isolated twin-boundary cracking near maximum load followed by quasi-cleavage of transformed martensite of the ligaments between the twin-boundary facets.

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

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