HYDROGENIUS研究の進捗と
水素脆化基本原理

Yukitaka Murakami
Kyushu University
The Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS),
National Institute of Advanced Industrial Science and Technology (AIST)

Outline

1. INTRODUCTION : BACKGROUND OF HYDROGEN ENERGY TECHNOLOGY DEVELOPMENT IN JAPAN AND HYDROGENIUS PROJECT

2. EFFECT OF HYDROGEN ON STRENGTH OF MATERIALS
   2.1 Effect of Hydrogen on Static Strength of Steels
   2.2 Effect of Hydrogen on Fatigue Crack Growth
      2.2.1 Cr-Mo steel: JIS SCM435
      2.2.2 Effect of Hydrogen on Fatigue Crack Growth Behavior of Austenitic Stainless Steels
         A. Hydrogen entry into austenitic stainless steels.
         B. Effects of hydrogen and test frequency on fatigue crack growth.
         C. Effects of hydrogen on striation formation.
         D. What happens if non-diffusible hydrogen is removed by the special heat treatment?

3. CASE STUDIES
   3.1 Dispenser Failure at the Hydrogen Station of EXPO 2005 in Nagoya
   3.2 Hydrogen Storage Cylinder at Kasumigaseki Hydrogen Station, Tokyo

4. CONCLUSIONS

Hydrogen and Fuel Cell Research Projects in AIST

- Fuel Cell Commercialization Task Group
  - Polymer Electrolyte Fuel Cell (PEFC)
  - Cutting-Edge Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS)
  - Advanced Fundamental Research on Hydrogen Storage Materials (HYDROSTAR)

- Ministry of Economy, Trade and Industry Agency for Natural Resources and Energy
  - Solution of Mechanism of Hydrogen Embrittlement
  - Establishment of Database and Basic Technologies for Achieving Hydrogen Society
  - Establishment of Compact and Energy Efficient Hydrogen Storage System through Fundamental Studies of Materials

NEDO – HYDROGENIUS Project

- Hydrogen Fatigue and Fracture Team
- Hydrogen Tribology Team
- Hydrogen Thermophysical Properties Team
- Hydrogen Simulation Team

HYDROGENIUS Lab. Building

- Experiments under 100 MPa high-pressure hydrogen gas environment
- High-sensitive and accurate analysis for solution of basic principles in hydrogen-material interaction problems

Workshop

High pressure autoclaves

Fatigue test

Micro structural analysis, measurements

Original materials

Workshop

High pressure autoclaves

Fatigue test

Micro structural analysis, measurements
2.1 Mechanism of Hydrogen Embrittlement in Tensile Fracture

Hydrogen effects
- Hydrogen enhances localized slip deformation.
- Hydrogen exists only in the surface layer.

Mechanism of Hydrogen Embrittlement in Fatigue Crack Growth

Hydrogen and Frequency Effects on Plastic Zone Size

- The crack growth rate increases with decreasing frequency of cyclic loading.
- There is an upper limit of the hydrogen induced crack growth acceleration.

Effect of Hydrogen on Fatigue Behavior of Austenitic Stainless Steels

Hydrogen thermal desorption spectrum of Type 316L

Influence of hydrogen charging on crack growth from 100 μm hole for austenitic stainless steels SUS304, SUS316 and SUS316L. Hydrogen charging was carried out at 50 °C for 672 hours. Charging method: cathodic charging.
Influence of hydrogen and test frequency on crack growth from $2a = 200$ mm, of 
(a) type 304 (σ = 280 MPa),
(b) type 316L (σ = 280 MPa), and
(c) effect of hydrogen and test frequency on crack growth rate of type 316L

Murakami et al. (2008)

Difference in crack growth behavior between hydrogen-charged specimens and 
uncharged specimens of type 304 (σ = 280 MPa):
(a) uncharged ($f = 0.12$ Hz, $2a = 782$ mm, $N = 11,000$, $2.2$ wppm),
(b) uncharged ($f = 0.0015$ Hz, $2a = 778$ mm, $N = 8,300$, $2.2$ wppm), and
(c) H-charged ($f = 1.2$ Hz, $2a = 801$ mm, $N = 5,150$, $3.7$ wppm)

Murakami et al. (2008)

Relationship between ratio of striation height $H$ to spacing $s$, $H/s$, and stress ratio $(1-R)$.

Murakami et al. (2008)

What Happens When Nondiffusible Hydrogen is Removed by Special Heat Treatment?

Hydrogen thermal desorption spectrum of Type 316L

Murakami et al. (2008)
Hydrogen Trapped at O-site of FCC Metals

Crack tip opening and striation formation mechanism in fatigue: (a) no hydrogen effect, (b) hydrogen effect, (c) schematic image of thick plastic zone wake produced at a crack under no hydrogen, and (d) schematic image of shallow plastic zone wake produced at a crack under hydrogen effect.

Effect of Hydrogen on Fatigue Behavior of Austenitic Stainless Steels

Influence of hydrogen and test frequency on crack growth from $2a = 200\text{mm}$, of (a) type 304 ($\sigma = 280\text{MPa}$), (b) type 316L ($\sigma = 290\text{MPa}$), and (c) effect of hydrogen and test frequency on crack growth rate of type 316L.