

Faculty of Engineering

Fatigue and Fracture of Materials Laboratory

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How and why hydrogen can weaken steels?

Steels are widely used for machine components and structures since they have superior strength as well as high toughness, which are however affected by impurity elements. It is well-known that HYDROGEN can be one of the deleterious elements for these properties of steels, and such a degradation is termed "Hydrogen Embrittlement (HE)"

As we move towards the commercial use of hydrogen stations and fuel cell vehicles (FCVs) in the near future, there are a number of technological and scientific issues to be overcome. Among them, our task is to build and/or design methodology to use commercial steels safely under high pressure hydrogen gas. For example, in the current regulation in Japan, a limited number of high grade austenitic stainless steels (*e.g.* type 316L) that has been proved to possess a sufficient resistance against HE, are permitted to be used for high pressure hydrogen gas applications. However, these stainless steels are expensive due to the large amounts of alloying elements such as Cr and Ni required during their production. To reduce the manufacturing cost of the system, the use of lower-cost materials (*e.g.* lower grade stainless steels, low alloy steels, cast iron *etc.*) is strongly required in industries. To ensure the safer use of such low-cost materials, it is essential to understand the mechanism of HE as well as to obtain reliable data for various materials when they are exposed to hydrogen.

In general, steels are not homogenies but heterogeneous in microstructure; they have secondary particles, inclusions, and lattice imperfections such as grain boundaries. Accordingly, crack initiation and propagation occurs locally; the so-called weakest link. Thus, it is important to clarify how hydrogen intrudes into steels as well as how hydrogen facilitates the process of crack initiation and propagation. We tackle the underlying problems with the aid of advanced experimental equipment in the Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS), *e.g.* fatigue and tensile testing machines with high pressure hydrogen gas up to 120 MPa, precise hydrogen analyzer, microstructure characterizer such as SEM and TEM, *etc.*

●Visualization where hydrogen atoms locate

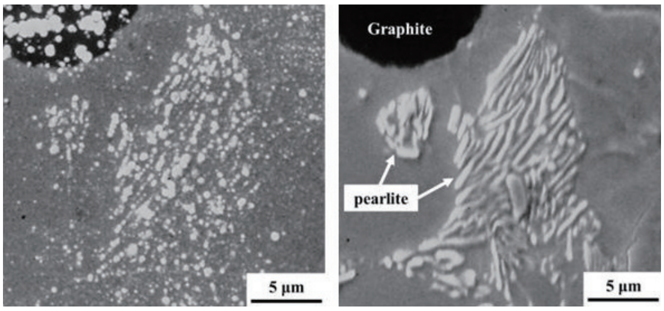


Fig.1 SEM images showing hydrogen segregation in the microstructure of a cast iron; Ag decoration method.

●Observation how cracks propagate

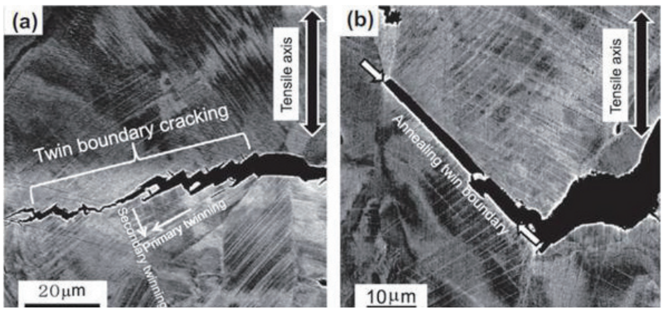
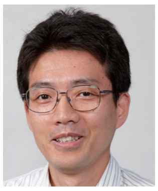


Fig. 2 ECC images showing crack propagation along twin boundaries in a high Mn austenitic steel under hydrogen atmosphere.


Faculty of Engineering

Hydrogen Utilization Processes Laboratory

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Advanced Fuel Cell Materials and Systems

Fuel cells are promising environmentally-compatible technologies for this century. For technological development and their commercialization, however, various scientific as well as engineering aspects should be clarified and established. Our laboratory, the Hydrogen Utilization Processes Laboratory, wishes to contribute to this promising technological field, based on more than 20 years of research experience in the field of fuel cell technology.

So far, we have built up the highest level research infrastructure in Japan, and our own facilities enable us to conduct a wide range of fuel cell R&D, from materials to systems. Fuel cell fabrication equipment, facilities for electrical, thermal, and electrochemical analysis including 55 fuel-cell evaluation systems and characterization instruments, such as the highest-resolution FESEM-EDX and STEM-FIB systems are available exclusively to our group members. At this moment, we address the development of novel electrode materials, establishment of system design criteria, elucidation of mechanisms and processes and breakthroughs in technical issues concerned.

01 Research on electrode materials and reaction processes for Solid Oxide Fuel Cells (SOFCs)

One of the most appealing benefits of the solid oxide fuel cell (SOFC) over other types of fuel cells is the fuel flexibility: producing electricity from a variety of fuels, including renewable biomass, natural gas, or even gasoline with less pollution-forming emissions. Nevertheless, it is likely that various kinds of minor fuel impurities could cause fatal degradation of cell performance or affect overall SOFC system durability. Since 2008, we have been involved in a national project supported by NEDO and are formulating the world's first database concerning the long-term impurity tolerance of SOFC.

02 Application of bio-fuels to SOFC

Biogas, generated by anaerobic fermentation of organic wastes, consists of 60% CH4 and 40% CO_2. In principle, biogas containing natural reforming agent, CO_2, can be directly fed into high temperature SOFC without pre-reformer to obtain electricity. Therefore, hydrogen production and purification systems can be simplified leading to cost cutback and enhancement of overall system efficiency. Our group has demonstrated the long-term stability of internal reforming SOFC running on biogas using anode-supported single cell. At this moment, thermomechanical reliability of internal reforming SOFC is being evaluated using a SOFC visualization system which enables us to perform in-situ measurement of temperature distribution in SOFC.

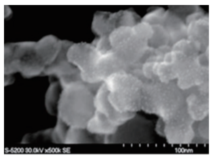
Visualization system of SOFC

03 Development of metal supported SOFC

We are also conducting research and development of metal supported SOFC cell using heat-resistant stainless steel for substrate, aiming to create a highly-robust SOFC cell which withstands thermal shock, fuel shortage, etc.

04 Research on electrode materials and reaction processes for Polymer Electrolyte Fuel Cells (PEFCs)

We are focusing on the development of novel electrocatalysts and formulation of electrode design for polymer electrolyte fuel cells (PEFCs), a promising energy conversion system in hydrogen-related technologies. Recently, we have made considerable progress in the development of a carbon-free electrocatalyst to fundamentally reduce the problem of carbon corrosion.



Carbon-free electrocatalyst for PEFC

05 Fundamentals of hydrogen related engineering

We wish to establish scientific principles of fuel cells and related hydrogen technologies. Such activities include defect chemistry on ionic, electronic, and molecular levels; solid state electrochemistry; thermodynamics and transport phenomena; electrode processes; acceleration testing; and experimental techniques for electrochemical characterization, advanced microscopy, and simulation.