



Evaluation of hydrogen absorption into steel in automobile moving environments



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ARTICLE INFO

Article history:

Received 26 January 2015

Accepted 22 May 2015

Available online 8 June 2015

Keywords:

A. Steel

B. Hydrogen permeation

C. Atmospheric corrosion

C. Hydrogen absorption

ABSTRACT

Hydrogen absorption behaviors into steel in automobile moving environments were investigated with a temperature-compensating hydrogen absorption monitoring system. On-vehicle monitoring tests of hydrogen absorption into steel revealed that the amounts of the absorbed hydrogen into steel increases remarkably with increasing corrosion mass loss of steel and the hydrogen absorption into steel is enhanced when the vehicle travels on a wet road and when chloride loading on the steel is increased. These results described that hydrogen absorption into steel in automobile moving environments can be influenced by moving states of a vehicle in addition to road surface conditions.

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1. Introduction

Recently, high-strength steel sheets over the tensile stress of 1200 MPa have been developed and applied to automobile bodies [1,2], aiming at reduction in the weight of automobile bodies and further improvement for crashworthiness [3,4]. However, to utilize the high-strength steel sheets to automobile bodies, it should be investigated whether the steels are susceptible to hydrogen embrittlement in automobile moving environments [5–9]. Since hydrogen embrittlement property of steel is associated with the strength and the amount of absorbed hydrogen into the steel [10–14], it is very important to clarify how much amount of hydrogen can be absorbed into the steel during moving of a vehicle in atmospheric environments.

In atmospheric environments, when a steel corrodes, hydrogen atoms can be generated on the steel surface by the reduction of H^+ or H_2O as one of the cathodic reactions of corrosion reaction and then they can be absorbed into the steel [15,16]. This suggests that the amount of absorbed hydrogen should be associated with the activity of corrosion reaction taking place on the steel in the atmospheric environments. Especially, since the steel used for automobile bodies will be subjected to wet and dry corrosion cycles

during moving of a vehicle, the amount of absorbed hydrogen can depend on the moving states of the vehicle, road conditions, corrosiveness of the environments and so on. According to the previous researches, corrosion environment formed on the steel can be varied during moving of a vehicle in a complex manner depending on moving states, road conditions and weather [17,18]. Therefore, in order to evaluate the susceptibility to hydrogen embrittlement of steel used for automobile bodies, hydrogen absorption behavior into the steel should be elucidated with relation to the moving state of a vehicle and further important factors which can enhance hydrogen absorption in automobile moving environments should be clarified. However, in situ monitoring of hydrogen absorption into steel during moving of a vehicle has not been carried out so far and therefore little information is available about hydrogen absorption behavior into steel in automobile moving environments.

Recently, co-workers have developed an in situ monitoring system of hydrogen absorption into steel and confirmed that the system can work in atmospheric corrosion environments prepared in a laboratory [19]. The co-workers have also indicated that one of the advantages of the system can remove the effect of temperature change in the environments on polarization current at hydrogen-withdrawal side, resulting in accurate estimation of hydrogen absorption into steel in atmospheric corrosion environments. Therefore, in this paper, the temperature-compensating hydrogen absorption monitoring cell was applied to investigate hydrogen absorption behavior into steel in environments which

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Table 1
Chemical composition of steel sheet used in this study.

C (wt%)	Si (wt%)	Mn (wt%)	P (wt%)	S (wt%)	Fe
0.02	0.01	0.15	0.01	≤0.01	Bal.

vary during moving of a vehicle. The influences of the moving state on hydrogen absorption were discussed by comparing to the previous results in a laboratory test. In addition, the relationship between corrosion of the steel and the amount of hydrogen absorption was studied during moving of a vehicle in the environments.

2. Experimental method

2.1. Sample

The material used in this study was a 270 MPa-grade cold-rolled steel sheet (thickness: 0.75 mm). Its chemical composition is shown in Table 1. The hydrogen diffusivity, D_H , of the sample used in this study was determined by Devanathan-Stachurski method [20]. D_H was evaluated to be $5 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ at room temperature. The steel sheet was machined into a small piece of a plate of 50 mm × 50 mm. One surface of the plate was abraded successively with SiC papers up to 2000 grit, and then it was immersed in a mixture of 6 mL hydrofluoric acid and 94 mL hydrogen peroxide for chemical etching. The thickness of the sheet was reduced to approximately 0.7 mm by 50- μm chemical etching treatment. A Pd film of ca. 400 nm in thickness was electroplated on the chemically etched surface. It is reported that plate thickness is influenced on an amount of absorbed hydrogen [21,22]. According to the result of Ha et al. [22], thinner foils less than 448 μm did not follow Fickian diffusion behavior. Therefore, 0.7 mm thickness plates were applied for this study. The plate prepared by the above procedure was employed to the experiments described in the following sections.

2.2. On-vehicle monitoring system for hydrogen absorption

In this study, hydrogen absorption into a steel plate during moving of a vehicle was monitored in situ by using a hydrogen absorption monitoring system shown in Fig. 1 [19]. This system was assembled based on Devanathan-Stachurski method [20], which can evaluate absorbed hydrogen into metals by the measurements of so-called “permeation current” [23,24]. The steel plate prepared by the procedure described in Section 2.1 was fixed on the top of the system so that the Pd-plated surface faced on the electrochemical cells, as shown in Fig. 1. The Pd-plated surface corresponds to so-called “hydrogen-withdrawal side”. The other surface of the steel plate without Pd plating, so-called “hydrogen-entry side”, was exposed to atmospheric environments.

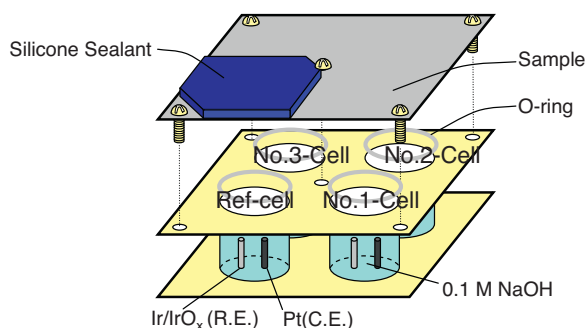


Fig. 1. Schematic drawing of hydrogen absorption monitoring system for on-vehicle monitoring test.

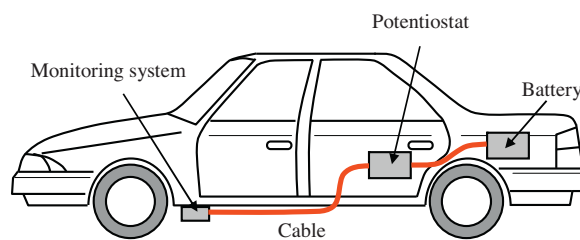


Fig. 2. Location of monitoring system installed monitored test vehicle.

As shown in Fig. 1, this system has four electrochemical cells and each cell has a Pt counter electrode and an Ir/IrO_x reference electrode. The potential of an Ir/IrO_x reference electrode can be expressed by Eq. (1) [25]

$$E = E^0 - 0.0592 \text{ pH} \quad (1)$$

where E^0 is the standard electrode potential. This reference electrode shows quasi-Nernstian response to pH in an aqueous solution.

The solution introduced into the cells was 0.1 mol/dm³ NaOH deaerated with nitrogen gas at least for 40 h. After the solution was filled in the cells, the Pd-plated surface was polarized at +0.20 V vs. Ir/IrO_x and left for sufficiently long time until the polarization current monitored at each cell decreased to less than 20 nA/cm². As shown in Fig. 1, a part of the steel surface locating on one cell was covered with silicone sealant to prevent it from being exposed to the environments. This means that this cell can be used as a reference (Ref-cell) to compensate for the change in the polarization current due not to hydrogen absorption but to temperature change and other artifacts [19].

2.3. On-vehicle monitoring test

2.3.1. Monitoring of hydrogen absorption into steel

An on-vehicle monitoring test was carried out to evaluate whether hydrogen absorption monitoring system can work in automobile moving environments. In the test, a hydrogen absorption monitoring system was set under the front bumper of a vehicle so that the steel surface without Pd plating faced earthward. A humidity and temperature sensor was also mounted in the vicinity of the system on the vehicle. Fig. 2 shows the monitoring position in the vehicle. The hydrogen absorption monitoring system was connected to an SDPS-521T potentiostat (Syrinx, Inc.). The outputs of polarization current measured at each cell were logged at an interval of 1 min and recorded in a built-in memory card. The on-vehicle monitoring tests were performed on the roads within JFE Steel Corporation's West Japan Works (Hiroshima, Japan). The roads are constructed to have surfaces similar to those of public roads. The regulation speed in the sites is 50 km/h. The location of the site is shown in Fig. 3. The on-vehicle monitoring test was carried out for 38 days in January 2011 (hereinafter, test duration I). Actually, moving of a vehicle was done intermittently during daytime on weekdays. The data such as moving distance, starting time, and moving time were also recorded together with polarization current, humidity and temperature during the on-vehicle test.

2.3.2. Evaluation of amount of absorbed hydrogen

Here, to evaluate the amount of the absorbed hydrogen into steel during moving of a vehicle, another on-vehicle monitoring test was carried out with two identical hydrogen absorption monitoring systems in the same test site as described in Section 2.3.1. The test duration was for 30 days in the beginning of July 2012 (hereinafter, test duration II). In the test, the two hydrogen absorption monitoring systems were attached under the floor behind front

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