A Study on Hydrogen Discharge by Electrochemical Technique

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1. Introduction

It is well known that there can be some delay of the completion of welding and the formation of hydrogen induced cracking (HIC) in low alloy steel. If, therefore, inspection is carried out too soon after welding, crack may not be detected. On the other hand, excessive delays after welding prior to inspection can have financial problem due to the extension of work period. In the repair welding of low alloy steel in nuclear power plant, ASME Section XI requires that non-destructive testing shall not be carried out until at least 48 hours after completion of welding due to the risk of this delayed phenomenon [1]. If we can shorten the delay time before inspection, it will contribute to enhance the plant availability [2].

The purpose of this study is to present electrochemical technique for hydrogen embrittlement mitigation that can replace conventional heat treatment. Then, the technique was proposed as a potential method for reducing HIC susceptibility in nuclear industry.

2. Methods and Results

To demonstrate the validation of electrochemical method, experimental approach including hydrogen analysis and slow strain rate test were conducted in this study.

2.1 Material and Specimen

Low alloy steel designated as SA-508 Grade 1A was used to fabricate the experimental specimen, which is plate and tensile specimen. The plate specimen was prepared to measure the hydrogen content and thus determine the applicability of electrochemical method. Tensile specimen was utilized to characterize the mechanical properties depending on electrochemical treatment.

2.2 Hydrogen Charging

Weld hydrogen mainly comes from the moisture in the electrode and wet weld surface. Based on this consideration, galvanostatic test was used to simulate the phenomenon in this study. Hydrogen charging onto SA-508 plate and tensile specimen was conducted in a 1M H_2SO_4 solution using computer-controlled test cell. It was programmed to apply a constant current to the specimen at a 3 mA/cm^2 so as hydrogen enters the metal as atomic hydrogen. Poison of As_4O_3 was added in the H_2SO_4 solution to retard the formation of hydrogen molecular.

2.3 Electrochemical Treatment

Electrochemical treatment for HIC mitigation is described as hydrogen diffusion in metal surface under the influence of electrochemical potential. If a constant potential of controlled magnitude is applied to metal surface, the transportation of hydrogen can be made to move from inside to outside. Electrochemical treatment on SA-508 specimens was performed to identify its effectiveness in mitigating the sensitivity of hydrogen induced cracking. On the basis of electrochemical theory, hydrogen generated in metal surface can be removed by following oxidation reaction.

$$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$$

By applying electrochemical potential of beyond hydrogen equilibrium potential (eH^2/H^+), hydrogen can be removed. Therefore, determination of applied potential plays in important role in this electrochemical treatment. Applied potential (E_{app}) for removing hydrogen was determined by identifying stabilization of passive film, equilibrium hydrogen potential, and exchange current density. Figure 1 shows that anodic and cathodic polarization curve of SA 508 Grade 1A steel in borate buffer solution (0.3M H_3BO_3 + 0.074M $Na_2B_4O_7$). Electrochemical properties of the low alloy steel showed passive behavior in this solution. The solution is enable to form passive film on the low alloy steel surface and thus protect the metal from the corrosion. As shown in this figure, passive film was made in a range of 360mV - 900mV. Of this passive range, +630mV was selected as critical applied potential enough to have the oxidation reaction of hydrogen to occur in metal surface. By applying the potential of +630mV, the accumulated hydrogen can be eliminated electrochemically.

2.4 Hydrogen Analysis

The hydrogen content can be evaluated either glycerine method or gas chromatography. Glycerine method is more simple and economical than gas chromatography. However, gas chromatography gives more accurate evaluation. In consideration of site applicability, glycerine method was selected to measure the hydrogen content in specimen. The effectiveness of electrochemical treatment to alleviate hydrogen will depend on two major factors such as applied potential and time of application. As the applied potential is already established as +630mV, hydrogen content was measured depending on the time of application, 1 hours, 12 hours and 24 hours.

Figure 2 shows that the results of hydrogen measurement for plate specimen as a function of time of application, The lowest value of hydrogen content appears at 24 hours.

Based on the result of hydrogen analysis, efficiency of electrochemical treatment was calculated. 65% of hydrogen was removed after 1 hour. 97.5% of hydrogen was removed after 12hours. Finally 99% of hydrogen was eliminated after 24 hours. Therefore, it can be noted that the intensity of removal of hydrogen is proportional to the time of application.

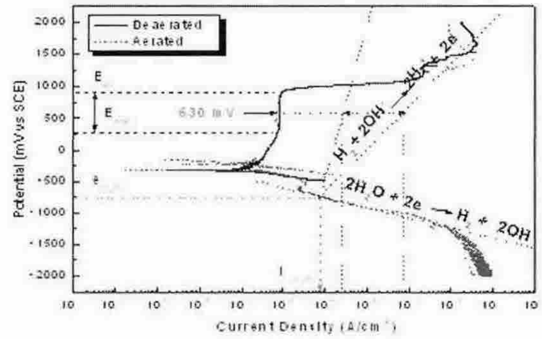

Figure 1. Determination of Applied Potential

2.5 Slow Strain Rate Test

Slow strain rate test was conducted on the SA 508 low alloy steel tensile specimen to characterize the mechanical properties as a function of hydrogen charging condition. Figure 3 showed stress strain curve for each specimen. The specimen tested during hydrogen charging (On charging) showed brittle failure. However, specimen tested during and after electrochemical treatment (On discharging, After 1 hour-discharge) indicated a different behavior. The specimen tested after 1 hour-discharge was not susceptible to hydrogen embrittlement. This stress strain curve was similar with that of tested in air. Slow strain rate test results showed that a specimen with higher hydrogen concentration revealed inferior mechanical properties such as shorter time to fracture and lower elongation. Thus these observation support that the susceptibility of hydrogen induced cracking could be eliminated by the electrochemical treatment.

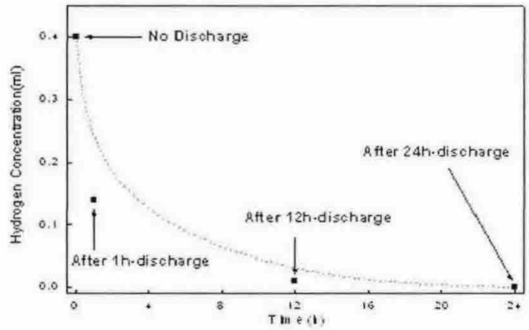

Figure 2. Effect of Hydrogen Discharging Time on Hydrogen Concentration

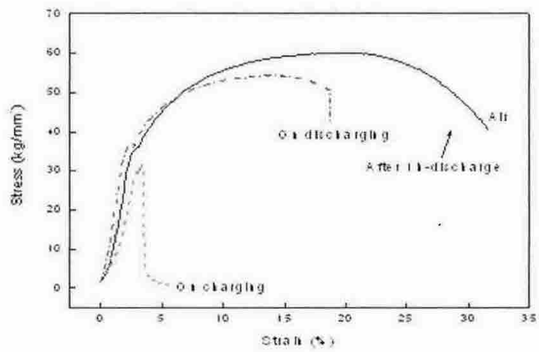

Figure 3 Stress Strain Curve for SA-508 Depending on Hydrogen Charge and Discharge Condition

3. Conclusion

Hydrogen induced cracking mitigation on the low alloy steel was presented using electrochemical technique. By applying the potential of 630mV onto the metal surface, hydrogen was substantially eliminated. The specimen discharged for 24 hours indicated that the efficiency of the hydrogen discharge become 99%. These experimental results suggest that electrochemical method can be a potential method to mitigate the sensitivity of hydrogen induced cracking and it can be applied to nuclear industry.

REFERENCES

[1] ASME, ASME Boiler and Pressure Vessel Code Section XI, In-service Inspection of Nuclear Power Plant Components, IWA-4600, 1989.

[2] Richard Pargeter, Evaluation of Necessary Delay Before Inspection for Hydrogen Crack, Welding Journal, October 2001. Journal of Korean Metal and Material, 1997.