Effect of impurities contained in hydrogen gas on hydrogen-assisted degradation of material strength

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論 文 名　：Effect of impurities contained in hydrogen gas on hydrogen-assisted degradation of material strength
（水素ガス中に含まれる不純物が水素助長破壊に及ぼす影響）

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論 文 内 容 の 要 旨
Thesis Summary

This dissertation is concerned with the effect of impurities contained in hydrogen gas on hydrogen-assisted degradation of material strength. It has been clarified that some of impurities contained in hydrogen gas inhibit the hydrogen-assisted degradation. However, the effects have not been fully understood yet. In addition, the mechanism of the inhibition has not been discussed enough. Therefore, for more detailed characterization and deeper understanding of the mechanisms, systematic experiments on the fretting fatigue strength in hydrogen and the fracture toughness in hydrogen were carried out.

In this study, the fretting fatigue tests and fracture toughness tests in hydrogen environments having different impurity concentration were carried out. In the fretting fatigue test, the effects of addition of ppm-levels of oxygen and water vapor to hydrogen environment on the fretting fatigue strength in hydrogen were characterized, and its mechanism was elucidated. In the fracture toughness test, several predominant factors on the effect of impurities such as species and concentration of impurity, loading rate and material were studied.

The detailed contents of each chapter are as follows:

In Chapter 1, the background and objective of this dissertation were introduced.

In Chapter 2, a new measurement method for relative slip range during fretting fatigue test in hydrogen environment was developed. The relative slip range is one of the most important factors to elucidate the mechanism of fretting fatigue. The achievement in this chapter was used in the experiments in Chapter 3. An optical micro-encoder fabricated by MEMS technology provided by Sawada was used for the relative slip sensor. To accurately measure the relative slip range, the error due to elastic deformation around the measurement point was calibrated by both experiment and simulation. It was confirmed that this measurement method has a good reproducibility of the result. By using this method, it was found that the relative slip range during the fretting fatigue test in hydrogen environment was significantly lower than that in air.

In Chapter 3, the effects of addition of ppm-levels of oxygen and water vapor to hydrogen environment on fretting fatigue strength in hydrogen of an austenitic stainless steel SUS304 were studied. It was found that the fretting fatigue strength in hydrogen was significantly reduced by the addition of ppm-levels of oxygen and water vapor to the hydrogen environment. Since addition of oxygen to hydrogen environment generally increases fatigue strength, the reason why the opposite result was obtained in this study was investigated. The addition of ppm-levels of oxygen and humidification enhanced the fretting wear by production of oxidized fretting wear particles during the fretting fatigue test. The enhanced fretting wear resulted in change of the stress conditions at the contacting surface during the fretting fatigue test, and it caused the reduction in the fretting fatigue strength.

In Chapter 4, the effect of the unintended increase in the oxygen content in the hydrogen environment during the fracture toughness test was studied. In the closed gas system, where the test gas was held in the gas chamber without any control, the oxygen content in the hydrogen gas increased and reached 1 vol. ppm during the fracture toughness test although the initial oxygen content was less than 0.1 vol. ppm. The 1 vol. ppm oxygen partially inhibited the hydrogen-assisted degradation of the fracture toughness of A333 pipe steel. It was found that the inhibitory effect of oxygen depended on the oxygen content and loading rate. These results qualitatively corresponded to the effect of oxygen predicted by the model proposed by Somerday et al.

In Chapter 5, the inhibitory effects of carbon monoxide on hydrogen-assisted degradation of fracture toughness of A333 and A106 pipe steels were studied. The degradation of the fracture toughness in hydrogen environment decreased with an increase in the carbon monoxide content in the hydrogen environment, and more than 1000 vol. ppm carbon monoxide completely inhibited the hydrogen-assisted degradation of the pipe steels. The inhibitory effect of carbon monoxide was relatively less in the A106 than in the A333. The possible reason is the difference in the hydrogen sensitivity between the two pipe steels. The inhibitory effect of carbon monoxide was lower than that of oxygen. According to molecular dynamics calculation by Staykov et al., this result can be explained by the potential energy of hydrogen, oxygen and carbon monoxide molecules for iron surface.

In Chapter 6, the results obtained by the above studies were concluded.