EFFECT OF HYDROGEN CONCENTRATION ON FRETting FATIGUE STRENGTH

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1. Introduction

Hydrogen is expected to be one of the solutions against the problems of exhaustion of fossil fuel and increase of carbon dioxide emissions. The effect of hydrogen on the strength of materials is one of the most important issues for safety operation of hydrogen utilization machiens, since it has been known that hydrogen has detrimental effect such as hydrogen embrittlement. The authors have reported the reduction of fretting fatigue strength caused by hydrogen gas [1]. This study was focused on the effect of concentration of hydrogen absorbed into the material on fretting fatigue strength.

2. Experimental procedure

The material was SUS304. The specimen was made of 40% pre-strained material whose proof strength, tensile strength and Vickers hardness were $\sigma_{0.2}=955$MPa, $\sigma_B=1027$MPa and $HV=358$. The pre-strain was applied by tensile test so that the specimen axis coincided with the tensile load axis. The pad material was the same as the fatigue specimen.

Figure 1 shows the fretting fatigue test method. The nominal contact pressure was 100MPa. Fatigue loading type was tension and compression. The test was done with completely reversed loading at a frequency of 20Hz at ambient temperature. The failure of specimen was defined as a 10% drop in the stress amplitude compared to the initial value. The test environments were 0.22MPa absolute hydrogen gas and air. The purity of hydrogen gas was more than 99.99%.

The shapes and sizes of the specimen and contact pad are shown in Fig. 2. A bridge type contact pad which has recessed part of the contact surface was used to measure tangential force. The contact surfaces of the specimen and contact pad were polished by #400 Emery paper along the slip direction.

To increase the hydrogen concentration in the material, the specimen was pre-exposed in approximately 75MPa hydrogen gas at 378K. The holding time was 100, 300 and 500h. Because
the hydrogen charge method using high pressure hydrogen gas requires very high cost, cathodic polarization was also used. The specimen was cathodically polarized in 0.005mol/l dilute sulfuric acid at a temperature of 337K for 100h with a cathodic current density of 78.6A/m². The pH of electrolyte was adjusted to 2.0.

3. Results and discussions

The amount of absorbed hydrogen was measured by thermal desorption spectroscopy. 5 × 10mm chips having different thickness \( t \) were used for the measurement. Figure 3 (a) shows the relationship between average hydrogen concentration of each plate \( C_{H} \) and inverse of thickness \( 1/t \). \( C_{H} \) of the specimen charged by gas was leveled off in the thin plates. This means the hydrogen amount achieved the saturated concentration for the test condition. The subsurface distribution of hydrogen concentration was estimated by the difference of hydrogen amount among chips. As shown in Fig. 3 (b), the hydrogen concentration at surface was estimated to be approximately 60 - 70ppm. This was more than 50 times compared with the uncharged specimen. The hydrogen concentration of cathodically charged specimen was increased approximately 16 times of the uncharged specimen. The depth of absorption was relatively shallow.

Figure 4(a) shows the S-N curves obtained in hydrogen gas. The important point was that the amount of fretting fatigue strength reduction was dependent on hydrogen concentration. The fretting fatigue strength reduced as the surface hydrogen concentration increased. However, 500h charged specimen had the same fretting fatigue limit as 300h charged specimen. This is another important point that the effect of hydrogen charge on fretting fatigue strength becomes saturated. Figure 5 shows the ratios of fretting fatigue limit. Fretting fatigue limit decreased with increase of charge time, and it then became constant. In comparison to uncharged specimen tested in air, the fretting fatigue limit of hydrogen charged specimen went down to about 60%.

The fretting fatigue strengths shown in Fig. 4(a) were influenced by not only absorbed hydrogen but also hydrogen gas. One of the mechanisms that causes the reduction of fretting fatigue strength in hydrogen gas was examined in another report [2]. In hydrogen gas, the dominant process that produces fretting wear damage changes from abrasion to adhesion. Because of the adhesion, many small cracks were generated and stress condition in the vicinity of small crack is severer.

In Fig. 4(b) which is the result of fretting fatigue test in air using hydrogen charged specimen, the effect of absorbed hydrogen was clearly shown. The amount of reduction was dependent on the

![Figure 3](image-url)  
Figure 3 Relationship of hydrogen concentration with a) thickness; and b) depth below surface.
hydrogen concentration. The fretting fatigue limit of 500h charged specimen is lower than that of 300h specimen. But the reduction tends to have a lower limit. The acceleration of crack propagation [3]-[5] and the reduction of $\Delta K_{th}$ [6][7] due to absorbed hydrogen have been reported. These are considered to be possible causes of the reduction of fretting fatigue strength.

The amount of fretting fatigue strength reduction was greater in hydrogen gas than in air. This implies that the change of friction and crack formation behaviors due to hydrogen gas is very important.

Figure 6 shows the contact surfaces. In air, roundish dimples which elongated in slip direction were formed. Diamond shape marks with small cracks at its bottom were observed in hydrogen gas. In the previous report [2], the formation mechanism of these marks was examined. The marks were produced by adhesion and crack propagation from the tips of adhered part. Figure 7 shows the longitudinal section of the specimen cut after the fretting fatigue test in hydrogen gas without disassembling of the specimen and contact pad. There are adhered parts at the contacting surfaces and small cracks emanated from both tips of the adhered part. The cracks propagated obliquely into the specimen as well as into the contact pad. The contact damage shown in Fig. 7(b) was produced by crack propagation not just plucking the adhered part off.

![Fig. 4](image_url) Fig. 4  Fretting fatigue S-N curves of hydrogen charged specimens tested in a) $H_2$; and b) air.

![Fig. 5](image_url) Fig. 5  Reduction rate of fretting fatigue limit in the relation with a) charge time; and b) surface hydrogen concentration.
4. Conclusions

1. Fretting fatigue strength decreased with increase of hydrogen concentration at surface. But there was a lower limit. The fretting fatigue limit of hydrogen charged specimen in hydrogen gas reduced to 60% of that of uncharged specimen in air.

2. In hydrogen gas, adhesion between contacting surfaces occurred, and it generated many small cracks. These small cracks has extremely important role in the reduction of fretting fatigue limit in hydrogen gas with superimposing the effect of absorbed hydrogen in metal.

5. References