EFFECTS OF AGING STRUCTURES AND HUMIDITY ON FATIGUE PROPERTIES OF MARAGING STEEL

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Effects of aging structures and humidity on fatigue properties of 350 grade 18% Ni maraging steel were investigated under rotating bending in relative humidity of 25% and 85%. Aging conditions tested were a conventional single aging and a double one which was aged at low temperature after the conventional aging. In each aging, under and peak aged steels were prepared. Tensile strength was increased by the double aging without reduction of the ductility. Proportional relation between fatigue limit and Vickers hardness held until 750HV in low humidity. However fatigue strength was largely decreased by high humidity, especially in the peak aged steel at the single aging. The decrease in fatigue strength by high humidity was mainly caused by the acceleration of a crack initiation due to the anodic dissolution. The acceleration of a crack initiation was larger in the steel peak aged at the single aging with larger precipitated particles.

Keywords: Maraging steel; Aging structure; Humidity; Fracture mechanism.

1. Introduction

Many high strength metals have been used as materials for machines and components operating under heavy loads in order to satisfy the demands for weight reduction and

long-term service which lead to reduce environment load. Maraging steel is an ultra-high strength steel which is hardened by the precipitation of intermetallic compounds such as Ni_3Ti , FeMo or Ni_3Mo in martensitic structure¹. The steel has both of the highest tensile strength and high ductility among practically used steels. However, the fatigue strength, which is the most important property for structural steels, is much lower than expected from its static strength similar to other high strength steels. This is caused by their high sensitivities for notch and humidity^{2,3}. Therefore many studies have been carried out to investigate the improvement methods of fatigue properties, e.g., surface treatments such as shot peening⁴ and nitriding⁵, heat treatment for modification of microstructure⁶, and so on. On the other hand, high strength steels are sensitive to hydrogen embrittlement. Therefore many studies about hydrogen embrittlement of maraging steel have been conducted⁷, but studies on corrosion fatigue are very limited.

In the present study, effects of aging structures and humidity on fatigue properties of 350 grade 18% Ni maraging steel were investigated under rotating bending in controlled humidity.

2. Material and Experimental Procedure

The material used was an 18% Ni maraging steel (350 grade) whose chemical composition in mass % was 0.001C, 0.01Si, 0.01Mn, 17.89Ni, 4.27Mo, 12.36Co, 1.3Ti, 0.08Al and remainder Fe. The material was solution treated for 5.4ks at 1123K in vacuum, followed by air cooling and age hardened at various conditions in a salt bath. Analysis of compounds precipitated by the aging was carried out by non-aqueous electrolyte extraction method⁸. Observation of precipitated particles was carried out by using TEM.

Fig. 1 shows shape and dimensions of specimen. After machining, all of the specimens were slightly electro-polished by 20 μm from the surface layer to secure the direct surface observation. Fatigue tests were carried out using a rotating bending fatigue testing machine operated at about 50Hz in relative humidity (RH) of 25 and 85 % and the environmental temperature was not controlled, but it was 25 $\pm$ 5°C. The observation of fatigue damage and the measurement of crack length were conducted under an optical microscope by using the plastic-replica technique. Surface crack length, ℓ , was measured in the circumferential direction of the specimen. Fracture surface was examined by SEM.

Fig.1. Shape and dimensions of specimen (mm).

3. Experimental Results and Discussion

3.1. Effect of aging structure on tensile properties

Fig. 2 shows aging curves of various conditions investigated in the present study. In the figure, round marks mean aging conditions selected for tensile and fatigue tests. Aging treatments were conducted at the conventional single aging condition and also at the double aging one which was aged at low temperature after the single aging to investigate the effect of low temperature aging. In the following, the single and the double aging treatments and under- and peak -aging conditions are denoted by SA and DA and U and P, respectively, e.g. DA-P means the steel peak-aged at the double aging. The mechanical properties of aged specimens are shown in Table 1. By the double aging, tensile strength is increased without reduction of ductility, meaning that the double aging at low temperature is effective to improve tensile properties.

Fig. 3 shows fracture surfaces for both of the peak aged steels after rupture. Many dimples are observed and the size is smaller in DA-P than in SA-P, suggesting that many and finer particles precipitated by the double aging.

Table 1. Mechanical properties.

Alloy	Aging condition	Yield strength $\sigma_{0.2}$ (MPa)	Tensile strength σ_B (MPa)	Reduction of area ϕ (%)	Vickers hardness HV
SA-U	753K-11ks	2194	2230	53.8	665
SA-P	753K-150ks	2300	2370	54	705
DA-U	753K-150ks + 673K-72ks	2329	2418	52	750
DA-P	753K-150ks + 673K-400ks	2420	2549	51	785

Fig. 2. Aging curves and aging conditions tested.

Fig.3. Fracture surfaces after tensile rupture.

3.2. Effect of aging structure on fatigue properties

Fig. 4 shows *S-N* curves of all steels in humidity of 25% and 85%. Fatigue strength was decreased by high humidity in all of the steels. The decrease in fatigue strength is different and is dependent on the aging condition.

Fig.4. *S-N* curves.

Fig. 5 shows relation between fatigue limit σ_w and Vickers hardness HV. Fatigue limit was defined as fatigue strength at 10^7 cycles. Proportional relation holds between fatigue limit and hardness until 750HV and endurance ratio σ_w / σ_B was about 0.28 in 25%. On the other hand, fatigue limit largely decreases in 85%, especially in SA-P. In general, many intergranular cracks are observed at fracture surfaces of high strength steels in corrosion fatigue. This is considered as fracture by hydrogen embrittlement. Susceptibility of maraging steel to hydrogen embrittlement is larger in the under-aged steel than in the peak one⁷. However the results mentioned above are different from the susceptibility to hydrogen embrittlement, meaning that effect of aging structure is different in hydrogen embrittlement and in corrosion fatigue. Actually, any brittle facets were hardly observed on the fracture surface in high humidity. In the following, reason for the decrease in fatigue strength by high humidity will be investigated through the observation of damage at the specimen surface.

Fig.5. Relation between fatigue limit and Vickers hardness.

Fig. 6 shows crack growth curves of SA-P and DA-U steels. As seen from the figure, a crack initiation is accelerated by high humidity in both steels, especially in SA-P, though the effect of humidity on the crack growth rate is very small in both steels corresponding to the result that there was little difference in fracture surface.

Fig. 7 shows an example of the surface state of a fatigued specimen in high humidity. A crack initiated from a corroded area is observed, meaning that a crack initiation is promoted by anodic dissolution.

Fig.6. Crack growth curves.

Fig.7. Crack initiated from corroded region.

From the results mentioned above, the double aging is effective to improve not only the tensile and fatigue strengths but also the resistance to corrosion fatigue. The increase in static and fatigue strengths by the double aging may be explained from the precipitation of many and finer compounds, and also the reduction of sensitivity for humidity is caused by decrease in anodic dissolution due to finer precipitates.

4. Conclusions

Effects of aging structures and humidity on fatigue properties of 350 grade 18% Ni maraging steel were investigated under rotating bending in relative humidity of 25% and 85%. Aging conditions tested were a conventional single aging and a double aging which

was aged at low temperature after the conventional aging, and in each aging, under and peak aged steels were prepared. Both of tensile and fatigue strengths were increased by the double aging. Proportional relation between fatigue limit and Vickers hardness held until 750HV in low humidity. However fatigue strength was decreased by high humidity, especially in the peak aged steel at the single aging. The decrease in fatigue strength by high humidity was mainly caused by the acceleration of a crack initiation which was related to the anodic dissolution.

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