Effect of strain localization on tensile and fatigue characteristics in precipitation-strengthened steels

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（様式２）

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論 文 名　：　Effect of strain localization on tensile and fatigue characteristics in precipitation- strengthened steels
（析出強化鋼の引張および疲労特性に及ぼすひずみの局所化の影響）

区　　分　：　甲

論　文　内　容　の　要　旨

The present study deals with the mechanical behaviour of precipitation-strengthened steels under different loading conditions and environments. Precipitation-strengthened steel has fine precipitates and the precipitates interfere with the movement of dislocations, i.e., the precipitation strengthening makes the steel significantly higher than the base metal. However, these steels often exhibit unusual strength properties that deviate from conventional experience. As a result, the safety design of machine cannot be ensured, and the practical application has not been achieved. In this study, the author focused on strain localization as a unique phenomenon in the precipitation-strengthened steels and aimed to clarify the effect of strain localization on strength properties.

Then, there are three different types of steel chosen for this purpose. All the three steels differ in the nature of precipitates they bear. Since the nature of precipitates is different, their influence on the mechanical behaviour of the material is also different. The steels having copper (Cu) precipitate, titanium carbide (TiC) precipitate and γ' [Ni3(Al, Ti)] precipitates are designated here as C6, T6 and SUH 660 respectively. C6 and T6 are the two special steels developed to have the same tensile strength properties and micro-hardness. While SUH 660 is commercial austenitic stainless steel having γ' precipitates and is a candidate material for hydrogen environment.

The study is broadly divided into four parts. The first part, studies about the fatigue limit properties of C6 and T6 for an arbitrary crack length. The second- and third-part studies the damage evolution behaviour of SUH 660 under uniaxial tensile loading in ambient environmental conditions and in hydrogen environment, respectively. The fourth part studies the evolution of fatigue crack in SUH 660 under ambient environmental conditions.

This thesis consists of 6 chapters. The chapters are arranged in order to achieve the basic objective of this study. The following paragraphs will give a glimpse of the work content of each chapter:

Chapter 1 introduced the work done by the previous researchers in the respective field. An overview of the precipitation-strengthening in steels was presented. The basic mechanics of dislocation motion around precipitates was also explained. The effect of arbitrary crack length on the fatigue properties was discussed. The effect of a short and long crack was presented separately. The theories governing the short crack and long crack propagation behaviour was also postulated. This chapter also includes the effect of strain localization on the tensile and fatigue properties of precipitation-strengthened steels. The effect of hydrogen environment on the damage evolution behaviour based on previous findings is reported.

Chapter 2 dealt with fatigue limit properties for C6 and T6 with an arbitrary initial crack length. Since for C6 and T6 tensile strength properties are the same, the difference arises out of the nature of precipitate and microstructure. From previous studies, T6 was expected that strain localization would occur. Thus, a transition is forecasted in the fatigue behaviour. This leads to carrying out the fatigue experiments for C6 and T6 for an arbitrary initial crack length. It was found that the superiority of the fatigue limit of each precipitation-strengthened steel depends on the initial crack size. Strain localization in T6 was confirmed by tensile test and digital image correlation (DIC) results. Therefore, the causes of the superiority of the fatigue limit were discussed as follows. The plastic zone in the case of T6 becomes narrow and asymmetrical. Better fatigue performance of C6 in short crack regime is because of effective plasticity induced crack closure (PICC), because of uniform and symmetric plastic zone formation. However, for the long crack regime, T6 develops a more uniform plastic zone, thus neutralizing the advantage of C6. In this regime, the hard precipitates and fine grain is held responsible for better fatigue performance of T6.

Chapter 3 addressed the damage evolution mechanism in SUH 660 in air. Specifically, damage quantification and associated microstructure characterization were performed. From the result, the author concluded as follows: In the case of SUH 660, the precipitates have an indirect influence on the damage evolution behaviour. The precipitates result in anti-phase boundary formation, which suppresses the tendency of cross-slipping. This inefficiency of cross-slip result in strain accumulation, as the stress accommodation capability is reduced because of slip planarity. This results in the damage initiation at the inclusions and grain boundary. The voids thus generated successively grows by coalescence and shearing of the ligament.

Chapter 4 aimed at understanding the change of the hydrogen embrittlement mechanism with respect to the hydrogen content of SUH 660. The author found that the phenomenon which was found in the previous chapter for SUH 660 is highly aggravated in hydrogen environment as the tendency of crack initiation resistance, and propagation resistance is reduced. The cracks formed are relatively sharp and wide open. As the hydrogen charging current density is increased the nature of fracture shows a transition from quasi-cleavage to inter-granular fracture. Transportation of hydrogen, to the grain boundary, with the help of dislocation motion, results in inter-granular fracture when the concentration of hydrogen reaches a critical concentration.

Chapter 5 dealt with the fatigue characteristics of SUH 660. To investigate why the fatigue limit of this material is lower than the empirical estimates, the author focused on the crack initiation. It is observed that the crack initiation is mainly at the grain boundaries contrary to inclusions. This gives an idea of self-generated initial flaw due to considerable strain localization in the grain. There were multiple self-generated crack initiation sites. The initial crack grows and coalescence with the neighbouring crack, which results in the final failure. It was assumed that the $\sqrt{area}$ in this case was the combined area of the observed multiple cracks. This cumulative area will result in the fatigue limit prediction by Murakami's equation, and this is the reason why SUH 660 show low fatigue limit, as expected from its tensile strength.

Chapter 6 summarized the findings of the studies by general conclusions.

Chapter 7 addressed the future plan.