Roles of interstitial carbon on transgranular fatigue crack resistance of ferritic steels

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論 文 名　：Roles of interstitial carbon on transgranular fatigue crack resistance of ferritic steels

（フェライト鋼における粒内疲労き裂伝ぱ抵抗に及ぼす格子間炭素の役割）

区　　分　：甲

論 文 内 容 の 要 旨

The main objective of this thesis is to analyze the solute carbon concentration dependence of fatigue performance for ferritic steels. For this purpose, the fatigue mechanism is clarified and a simple materials testing is proposed. The thesis consists of six chapters. All the chapters are arranged in order to achieve the main objective of the research work. The thesis is organized as follows:

Chapter 1 described a general introduction of the research work. The motivation of this research is based on the current issues in material science to investigate how to improve the fatigue performance by using dynamic strain aging (DSA) effect during cyclic loading. Based on the further requirement for low energy consuming, safety, environment-friendliness, the fatigue performance of materials should be enhanced directly rather than improving the tensile properties of materials to increase the fatigue strength indirectly. As DSA characteristic can be utilized as one of effective means to make an improvement for the fatigue strength, it attracts much attention. However, almost all attention is paid to temperature dependence of DSA, while few studies about the influence of solute atom concentration are investigated. Therefore, this thesis mainly focuses on the iron steels with different interstitial solute carbon contents and investigates their fatigue crack propagation resistance, namely, the threshold stress intensity factor ranges of small crack under different conditions.

Chapter 2 firstly reveals the model steel preparation for five ferritic steel with different interstitial carbon contents varying from 0% to 0.017% and introduces the corresponding heat treatment for five steels in detail. Then, the tension tests under different strain rates from 2.5×10^{-5} s^{-1} to 1.0×10^{-2} s^{-1} for five ferritic steels are conducted. Besides the normal tension test, the Vickers hardness for static strain aging specimens after pre-strain of 4% and 8%, respectively, is measured in different aging time. Finally, the dynamic strain aging is verified for four ferritic steels whose interstitial carbon content is larger than 0% at room temperature.

Chapter 3 reported the comparison of threshold stress intensity factor ranges of small notch by using Murakami's equation between interstitial-free steel and Fe-C binary steel with interstitial carbon content 0.017%. Fatigue tests were carried out by using rotating bending fatigue machine with stress ratio R=-1 and frequency of 50 Hz. In the center of specimen, three kinds of micro-notches were introduced by using the FIB technique and drilling hole machine. In terms of the first two kinds of micro-notches of Fe-0.017C alloy with notch size $\sqrt{area}$ of 100 μm and 227 μm , respectively, the specimen did not become fracture even though the stress amplitude was equal to the fatigue limit (210 MPa) in smooth specimen. Finally, the threshold stress intensity factor range $\Delta K_{\rm th}$ of both two materials were determined with notch size $\sqrt{area}$ of 337 μm and the prediction error of Fe-0.017C was around 40% higher than that of predicted results by using Murakami's equation, while the prediction error of IF steel was only around -9%. The outstanding transgranular fatigue crack propagation resistance probably was due to the influence of DSA contribution.

Chapter 4 illustrated the correlation between the $\Delta K_{\rm th}$ and interstitial carbon content varying from 0% to 0.017% for five iron steels with single ferrite phase. The $\Delta K_{\rm th}$ value, at first, increases significantly when carbon content was from 0% to 0.0021% and then moderately. With the increase of interstitial carbon concentration, the DSA influence to strengthen the material properties in front of crack tip gradually became saturation. In addition, when the solute carbon content was relatively low, intergranular fracture feature dominated the fatigue crack behavior, while transgranlur crack propagation behavior became popular step by step when carbon content was increased. This phenomenon was due to the carbon segregation to grain boundary. Lastly, as carbon segregated to grain boundary, the called solute poor zone in the vicinity of grain boundary was the weakest zone where micro-crack always initiated. As the carbon content grew, both the DSA influence and strength in solute poor zone were improved to some extent.

Chapter 5 compared both the tension and fatigue results at three temperatures between Fe-0.017C and IF steels. Furthermore, the mechanical properties of Fe-0.017C steel after corresponding heat treatments were also examined. The controlling factors that dominate the higher $\Delta K_{\rm th}$ value in Fe-0.017C steel compared with IF steel were analyzed. Solid solution hardening and DSA hardening, resulting in plasticity-induced crack closure contribution to $\Delta K_{\rm th}$, is the crucial factor at room temperature, while three kinds of hardening mechanisms including under-aged precipitation hardening play a key role in $\Delta K_{\rm th}$ at 333 K. Comparatively, the extent of asperity of fracture surface, leading roughness-induced crack closure contribution to $\Delta K_{\rm th}$, and over-aged precipitation hardening result in stronger fatigue strength of Fe-0.017C steel than IF steel at 433 K. The main reason for the $\Delta K_{\rm th}$ reduction is because of a large amount of cementite precipitation and DSA hardening disappearance, which results in the decrease of PICC influence.

Chapter 6 summarized the results obtained by the present studies, and all findings were described in the general conclusions.