

The role of magnesium-induced work hardening on the fatigue crack growth rate scatter in new Al6061-T6 aluminum alloy

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論 文 名 : The role of magnesium-induced work hardening on the fatigue crack
growth rate scatter in new Al6061-T6 aluminum alloy

(新 Al6061-T6 アルミニウム合金の疲労き裂伝ば速度ばらつきにおける Mg 誘起加工硬化の役割)

区 分 : 甲

論 文 内 容 の 要 旨

The main objective of this thesis is to examine the advantages of newly developed Al6061-T6 alloys. For this purpose, the fatigue mechanism is clarified and a simple materials testing is proposed. The thesis consists of five 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 describes a general introduction of the research work. The motivation of the research according to the current issues in engineering materials particularly in the automotive industry is highlighted. Based on the current demand to reduce fuel consumption and CO₂-emission, the introduction to automotive lightweight construction based on the use of newly designed aluminum alloys is one of the good choices. Accordingly, Al6061-T6 alloy is one of the best solutions because of the requirements for the material properties now not only strength and formability but also included high corrosion resistance and good weldability. However, it is known that Al6061-T6 alloys are characterized by less fatigue resistance, no fatigue limit, and large scatters in the fatigue life and fatigue crack growth rate (FCGR) compared with the current automotive steel. Therefore, the development of new aluminum alloy is needed, and examination of the advantages of new alloy is compulsory.

Chapter 2 presents the experimental efforts. The research work deals with two types of newly developed precipitation-hardened Al6061-T6 alloys with an additional element of Zirconium (Zr) in both Al alloys and the presence of excess Mg in the other. The growth behavior of the microstructurally large cracks was investigated by rotating bending fatigue tests conducted at room temperature. Through analyses of the crack propagation on the surfaces of the alloy specimens, the effects of the excess Mg on the fatigue crack propagation were found to promote the occurrence of Mode I fatigue crack and to decelerate the growth of microstructurally large cracks. These facts suggest that the dynamic strain aging (DSA) due to the excess Mg induces the formation of fatigue striation and reduce the driving force of the crack propagation. The findings were supported by the analyses of the striation ratio and the striation spacing using the central limit theorem on the fracture surfaces. Furthermore, in order to understand the striation ratio mechanism, the fractographic observations were used to determine the influence of the excess Mg on the fatigue striation morphology, which represents Mode I fatigue crack growth. The analysis of striation spacing using the central limit theorem was utilized to investigate the effect of the excess Mg on the fatigue crack growth rate. Moreover, the surface roughness at the region of fatigue striations was analyzed using 3D scanning electron microscope images to examine the development of the fatigue striation profile. The results found that the excess Mg promotes a shallow fatigue striation profile and this is

believed to be due to the uneasy dislocation glides during crack growth, attributed to the DSA effect. In addition, the profile development of fatigue striations in the two investigated Al alloys produces peak-to-valley matching rather than symmetrical matching. Based on the findings of the study, this chapter proposes the reasonable model of the strain-aging-induced Mode I fatigue crack growth in the Al alloys. An understanding of the crack growth behavior of Al alloys is important for predicting the possible factors which influence the scatter in FCGR. Further study would be undertaken to examine the effects of DSA on the scatter characteristics of the two considered Al6061-T6 alloys.

Chapter 3 reports the investigation on the fatigue crack interaction. It is well known that the presence of multiple surface cracks on the structural components have a significant effect on the fatigue life and FCGR scatter because of the influence of fatigue crack interaction. Thus, understanding the interaction effect of fatigue cracks is important because the crack interaction influences the fatigue crack growth behavior, which affects the scatter in FCGR. The FCGR is increased by the presence of adjacent crack in the stress amplification region. In contrast, the FCGR is decreased when the adjacent crack is located in the stress shielding region. Since the limited information about the crack interaction between two cracks in various positions from the available literature, an estimation method is proposed by analyzing the stress distribution around a single crack to evaluate the crack interaction between two cracks in arbitrary position subjected to tension under mode I loading condition. To verify the accuracy of the present method, the results obtained by the present method are compared with the results from stress intensity factor (SIF) handbook for the simple problems involving two collinear cracks. It is found that the results of the present method are in good agreement with the exact solution from SIF handbook, for which the error is less than 4%. The results obtained show that the offset distance is an important parameter to determine the interaction between two cracks. The approximate procedures for estimating the crack interaction are not limited to the case of two dimensions, but also included the case of three dimensions.

Chapter 4 presents the influence of excess Mg on FCGR scatter. For this purpose, the rotating bending fatigue tests were performed at constant amplitude loading using smooth specimens to investigate the scatter behavior of crack growth rate. According to the fatigue crack growth, the evolution process consists of two periods, namely microstructurally small crack and microstructurally large crack. The scatter of FCGR of microstructurally small cracks can be affected by material surface conditions such as microstructure dimension, surface roughness, and defects. While, in the case of microstructurally large crack, the scatter of FCGR is influenced by material properties, in which the acceleration and deceleration of FCGR is associated with the fatigue resistance of the material. In order to investigate the scatter characteristic of fatigue crack growth, statistical analysis is generally used, and it takes a lot of time and involves a high cost of laboratory experiment due to the use a large number of the test specimens. Therefore, a method is suggested to evaluate the FCGR scatter using a limited number of the test specimens. The FCGR scatter is examined by considering the crack interaction effects of two surface cracks. The experimental results found that the influence of excess Mg promotes small scatter on fatigue crack growth rate.

Chapter 5 summarizes the results obtained by the present studies, and all findings are described in the general conclusions.