主　論　文　の　要　約

論文題目　**Effect of High-density Pulsed Electric Current on Fatigue and Mechanical Properties of Aluminum Alloy**（アルミニウム合金の疲労および機械的特性における高密度パルス電流の影響）

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論　文　内　容　の　要　約

Aluminum alloys are the most used metallic compounds in industrial applications, such as electronics, container packaging, and transportation, etc., in addition to ferrous metals. Their usage has increased because aluminum alloys are light weight and thus reduce energy consumption and global warming gases. It is believed that long-term durability of mechanical components can significantly reduce resource consumption. Therefore, the improvement of the fatigue life of aluminum alloys is the subject of this thesis.

Fatigue fracture is an extremely important phenomenon in metal structures because most mechanical components experience cyclic loads. Therefore, fatigue life is one of the most important factors that should be considered in the application of materials. Although most mechanical components are typically subjected to cyclic loads within the allowable stress limit, they develop fractures unpredictably. Therefore, countermeasures, such as the improvement of long-term durability and reliability of mechanical structures, are required against fatigue fracture.

In addition, improving the long-term durability and reliability of mechanical components would lead to conservation of resources and energy, which may help preserve the global environment. Therefore, it is important to improve the fatigue life. In this study, fatigue-damage healing method involving the application of an electric current was investigated because of its low cost and simplicity.

Furthermore, aluminum alloys are difficult to be applied widely in mechanical components, because of their limited formability under room temperature condition in contrast to steel alloys. For example, compared to steel alloys, the formability of aluminum alloy is only approximately 66%, the modulus of elasticity is approximately 33%, and the elongation is approximately 50%. Therefore, it is difficult and expensive to process mechanical components with aluminum alloys. Several technologies were investigated to improve the formability of aluminum alloys. Typically, hot forming was used widely to increase formability. It uses the phenomenon that materials can be stretched by heating. In this process, the formability increases by recrystallization. However, these manufacturing processes require a lot of preparation time and cost. Therefore, the technology using electric current was developed to enhance the formability of aluminum alloys in this study, because the process using electric current need short processing time and low cost.

This dissertation aims to study the effect of pulsed electric current on the fatigue behavior and mechanical properties of an aluminum alloy. The application of pulsed electric current was carried out to realize the improvement of fatigue life and formability of the aluminum alloy. Furthermore, the mechanisms of the effects were investigated.

Chapter 1 presents the research background, such as the characteristics, fatigue fracture, and formability of aluminum alloys. Furthermore, the goals of this study are explained and the improvement methods of the fatigue life and formability are reviewed. The effect of electric current on the fatigue behavior and mechanical properties of materials are also discussed.

Chapter 2 introduces the materials and experimental methods used in this study. The evaluation methods, such as fatigue crack growth rate, strain energy, observation of slip bands, calculation of residual stress, observation of microstructure, and estimation of dislocation density, are also described.

Chapter 3 presents the investigation of the effect of various high-density pulsed electric currents with the density of 0–150 A/mm^2 on fatigue behavior. To examine the effect of pulsed electric currents, fatigue life was evaluated using the curve of amplitude stress versus the number of cycles to failure (*S*–*N* curve). Furthermore, the fracture surfaces were examined to analyze the mechanism of the increase of fatigue life with pulsed electric current. It was found that local melting occurred on the crack surface at the crack initiation zone due to joule heating induced by high-density pulsed electric-current plays an important role to obstruct the propagation of a fatigue crack. Besides that, thermal compressive stress induced by pulsed electric current also has the effort to increase the fatigue life. On the other hand, overly high current density can induce dimples around at the crack tip (i.e., thermal damage), thereby reducing fatigue life.

Chapter 4 describes the effect of the application frequency of high-density pulsed electric current on fatigue crack growth. The fatigue life of the specimens with applied electric current increased more than that of the untreated ones. Fatigue crack growth was delayed after the application of pulsed electric current. This delaying effect diminished with increasing crack length. It is considered that the inside crack width increase with the increase of crack length. Therefore, it became difficult to obtain the local melting effect by the electric current. Consequently, the effect of the electric current decreased as the fatigue crack length increase.

Chapter 5 presents the effect of high-density pulsed electric current on fatigue behavior of prestrained aluminum alloys. The healing effects on the non-prestrained and prestrained specimens are compared. In the fatigue tests, the fatigue properties of the prestrained specimen were similar to those of the non-prestrained specimen without the application of electric current. However, the fatigue life of the non-prestrained specimen to which an electric current was applied increased more than prestrained specimen, because the slip bands induced by a fatigue load decreased with the application of an electric current. It is considered that the decreased of slip bands delayed fatigue crack initiation in non-prestrained specimen. On the other hand, in prestrained specimen, the fatigue life with electric current was increased by delaying fatigue crack propagation. It is considered that local melting affected the delayed fatigue crack propagation. Therefore, the strain energy density was calculated to quantitatively determine the effect of local melting. The strain energy density increased with the application of an electric current.

In Chapter 6, we present the investigation of the effect of high-density pulsed electric current on the formability of the aluminum alloy. The effect of pulsed electric current on the micro-structure of the material was analyzed thoroughly in order to explain the mechanism by which the formability was improved. The dislocation density induced by the tensile stress was decreased after the application of pulsed electric current. It could be considered that the decrease of dislocation density affected the decrease of Vickers hardness and residual stress, thereby resulting in the decrease of work hardening. Furthermore, the change of crystal orientation due to the applied electric current was observed, it could be considered that the plastic damage was recovered in the material. Therefore, the decrease of work hardening and the recovery of plastic damage due to the pulsed electric current leaded to the increase of the elongation.

Chapter 7 presents the conclusion of this thesis. The fatigue life was improved by the application of a pulsed electric current. The mechanism of the improvement is the effects of delayed crack initiation and propagation. Further, the formability of the aluminum alloy was improved by the application of pulsed electric current. The improvement in formability was caused by decreasing the work hardening and recovering plastic damage of the material, which was loaded by stress.

From this study, the improvement in the fatigue life and formability of aluminum alloys were achieved. This will result in long-term use and easier manufacturing processes of aluminum alloys.