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Mesoscopic analysis of fatigue strength property of a modified 2618 aluminum alloy

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ABSTRACT

The existence of the fatigue limit and the effect of the generated texture in a modified 2618 aluminum alloy were investigated in this study. This alloy was fabricated by adding 1.0% excess Cu, 0.24% Mn, and 0.16% Zr to the standard composition. The fatigue limit was considered in terms of the fatigue crack initiation limit and fatigue crack propagation limit. To verify the former, the scatter of the fatigue crack initiation life in fatigue tests was discussed. To verify the latter, the results of a coaxing effect test and the scatter of the microstructural sensitive fatigue crack life were discussed. Moreover, the effect of texture on the fatigue strength property was studied by observing the initiation and growth behavior of cracks in a tensile test and a fatigue test by using the replica technique. The results showed that the fatigue crack propagation limit was absent in the modified alloy, whereas the fatigue crack initiation limit existed only in the material with un-textured microstructures. In addition, the distinct deviation in the mechanical properties of the modified alloy was attributed to the local stress-concentration at the boundary between the un-recrystallized and the recrystallized areas. Finally, a comparison with the 2618 alloy showed that the modified alloy had higher fatigue strength and lower notch sensitivity.

1. Introduction

It is preferable to use lightweight materials for fabricating automobile engine components because this leads to increased engine output and reduced fuel consumption, noise, and vibration. Among various lightweight materials, aluminum alloys are very attractive and in high-demand due to their excellent material properties, such as fatigue strength and formability.

In this study, a modified Al–Cu system aluminum alloy has been developed by adding 1.0% excess Cu, 0.24% Mn, and 0.16% Zr to the standard 2618 alloy without texture. As a result of this modification, the modified alloy shows an evidently different grain size and annealed texture compared with the 2618 alloy.

Many studies have reported on the influence of the texture and grain size on the mechanical properties and cyclic behavior of materials [1–4]. Llanes et al. [1] reported that it was difficult to evaluate the individual effects of texture and grain size on the fatigue property, because these two parameters are dependent on both the mechanical history and heat treatment, making it difficult to change one without affecting the other. Peralta et al. [2] reported conversely that it was possible to study the individual effects of the two through appropriate control of the microstructure. A modified precipitation-hardened aluminum alloy having a microstructure similar to the alloy investigated in this study has been fabricated by adding 0.5% excess Mg to the standard 6061 aluminum alloy, and its fatigue limit has been evaluated by using both a small-holed and a plain specimen [5,6].

In this study, to clarify the mesoscopic fatigue fracture of the developed alloy, the initiation and growth behavior of microstructural sensitive fatigue cracks were observed by the replica technique. The existence of the fatigue limit and the effect of the generated texture on this alloy were mainly investigated. However, because of the scatter of the specimens, the experimental results are not reproducible. Therefore, the results were discussed with some mechanical considerations in order to obtain the general fatigue property of this alloy. Moreover, to determine the fatigue design value of this alloy and to develop some excellent modified materials with good fatigue strength property, the scatter of the fatigue life was investigated in detail. Moreover, the fatigue limit was considered in terms of both the fatigue crack initiation limit and the fatigue crack propagation limit, and these were verified by considering the fatigue fracture mechanism.

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Table 1
Chemical composition of the material (wt%).

	Si	Fe	Cu	Mn	Mg	Ni	Zr	Al
Modified alloy	0.20	1.10	3.50	0.24	1.50	1.10	0.16	Bal.
2618	0.20	1.10	2.50	–	1.50	1.10	–	Bal.

2. Experimental material and procedures

2.1. Material

As mentioned above, the modified alloy was fabricated by adding 1.0% excess Cu, 0.24% Mn, and 0.16% Zr to the standard 2618 alloy. Table 1 lists the chemical composition of this alloy and the 2618 alloy. These two alloys were fabricated as follows. First, for both alloys, a billet with a diameter of 155 mm was obtained by a semi-continuous casting method. Then, the modified alloy and 2618 alloy were subjected to homogenization treatment at 485 °C for 6 h and 520 °C for 4 h, respectively. The billets of both alloys were then heated to 450 °C and extruded at an extrusion ratio of 9.8, with a velocity of 3 m/min. Then, the extrusion billets of the modified alloy and 2618 alloy were heat-treated as artificial ageing T6 process. Fig. 1 shows the microstructures of both alloys in two different directions. For the observed plane parallel to the extrusion direction, as shown in Fig. 1(a) and (c), the grain size in the transverse and normal directions is 5–50 μm in the modified alloy, and 50–200 μm in the 2618 alloy, which is obviously larger. This discrepancy of grain size between the modified alloy and 2618 alloy is mainly attributed to the existence of Mn and Zn [7,8], which induce the smaller grain size in the modified alloy.

Fig. 2(a) and (b) shows inverse pole figure maps of the plane parallel to the extrusion direction in the modified alloy and the standard 2618, respectively, as obtained by electron backscattered diffraction (EBSD) analysis. It is seen that the modified alloy is partially textured and has two types of grains along the extrusion direction: (i) an un-recrystallized area with elongated/large grains, and (ii) a recrystallized area with equiaxed/fine grains. In addition, the un-recrystallized grains are highly textured, whereas the recrystallized grains have random orientations.

2.2. Experimental procedure

Fig. 3 shows the position at which specimens were taken from the extruded bars as well as the dimensions of the tensile and fatigue specimens. Before testing, all the specimens were electropolished to a depth of ~20 μm to eliminate the machining hardening on their surface and to make it easy to observe them by the replica technique. The fatigue property of these two alloys were evaluated in two directions, namely, longitudinal (L: specimen axis parallel to extrusion direction) and transverse (T: specimen axis perpendicular to the extrusion direction), as shown in Fig. 3(a) and (b), respectively.

Tensile tests were performed at a strain rate of $2.6 \times 10^{-4}\ s^{-1}$ at room temperature by using a specimen shown in Fig. 3(c). Although the shoulder part was very short, the specimen could be mounted in the screw-type grip and the specimen was not broken at the shoulder part. It should be noted that tensile tests were performed with two different experimental procedures: (i) without an interruption to determine the mechanical properties of the materials, and (ii) with an interruption to observe the initiation and growth behavior of cracks by the replica technique.

Fatigue tests were performed using an Ono-type rotating bending fatigue testing machine (maximum capacity: 14.8 N m) in which the stress ratio was always −1 by using a specimen shown in Fig. 3(d). All fatigue specimens were rotated by this machine at 55 rev/s at room temperature in air. Fatigue cracks on the specimen surface were observed by the replica technique. The crack length was measured as the projection length on the plane perpendicular to the loading direction, as shown in Fig. 4. Fatigue cracks initiated at the root of the defect were found to be of two types: (i) those that did not penetrate the defect, and (ii) those that penetrated the defect.

For the modified alloy, the endurance limit corresponded to the stress amplitude at which the specimen endured 3×10^7 cycles in the fatigue test and all the initiated fatigue cracks were arrested

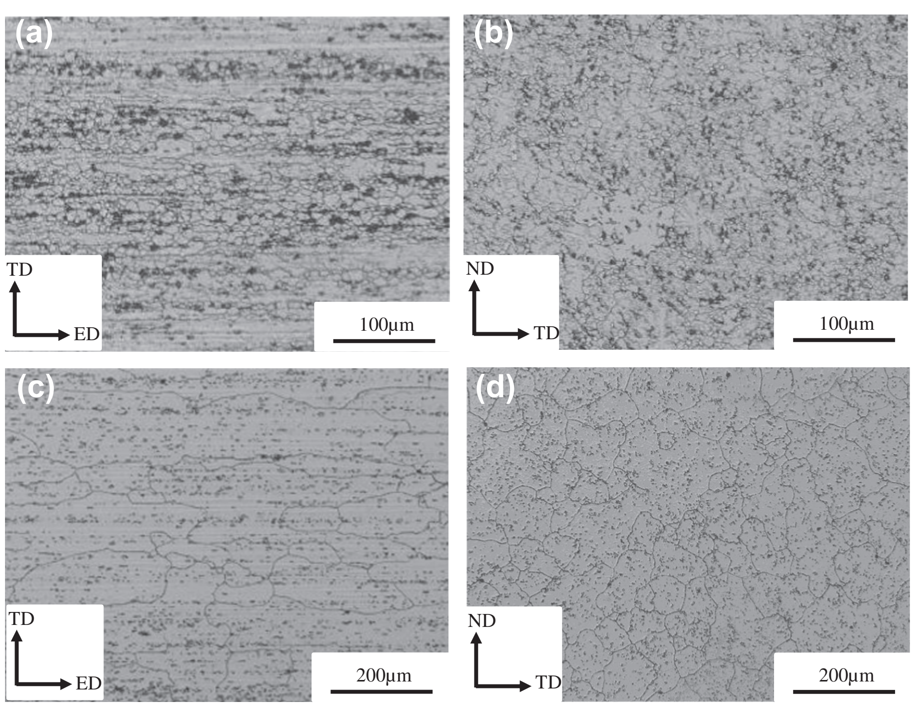

Fig. 1. Microstructures of modified 2618 and standard 2618 aluminum alloys: (a) the plane parallel to the extrusion direction in modified alloy, (b) the plane perpendicular to the extrusion direction in modified alloy, (c) the plane parallel to the extrusion direction in 2618 alloy, (d) the plane perpendicular to the extrusion direction in 2618 alloy.