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Cyclic deformation and fatigue of rolled AZ80 magnesium alloy along different material orientations

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ABSTRACT

The effect of material orientation on cyclic deformation and fatigue behavior of rolled AZ80 magnesium (Mg) alloy was experimentally investigated under fully reversed strain-controlled loading in ambient. The testing specimens were taken from a rolled AZ80 Mg plate at four orientations with respect to rolled plane: 0°(ND, normal direction), 30°(ND30), 60°(ND60), and 90°(RD, rolled direction). Fatigue fracture morphologies of specimens along different orientation were analyzed by scanning electron microscopy (SEM). Overall cyclic hardening was observed for the material loaded in different directions. For a given strain amplitude, the ND specimens had the lowest fatigue resistance among the specimens of all material orientations. The fatigue life of an ND30 specimens is similar to that of an ND60 specimen at a given strain amplitude and both are higher than that of an RD specimen when the strain amplitude is higher than 0.4%, whereas an RD specimen exhibits a better fatigue resistance when the strain amplitude is lower than 0.4%. A mixed fracture mode with transgranular and intergranular cracking related to lamellar-like features occurred during stable crack growth, and an intergranular fracture mode related to dimple-like features exhibited in the fast fracture region. A multiaxial fatigue model based on the strain energy density can correlate all the fatigue experiments of the material at different material orientations.

1. Introduction

In recent years, lightweight magnesium (Mg) alloys have been applied in transport and aerospace industries to improve energy efficiency. Wrought Mg alloys (rolled and extruded) are most promising for structural applications since they have excellent mechanical properties and fatigue resistance as compared to cast Mg alloys. In particular, wrought Mg-Al-Zn alloys are suitable for structural components because these alloys contain a small amount of manganese (Mn), which improves the corrosion resistance and the mechanical properties of the materials [1]. Structural components are usually subjected to cyclic loading, and fatigue may occur in service. Therefore, it is necessary to systemically investigate the cyclic deformation behavior and fatigue properties of Mg alloys for the design and evaluation of the Mg structures.

It is well known that wrought Mg alloys with a hexagonal close-packed (hcp) crystal structure have strong textures formed by the rolling and extrusion processes. The texture leads to a significant anisotropy due to the activation of different deformation modes such as slips and $\left\{10\bar{1}2\right\}$ tension twinning [2]. This implies that the fatigue behavior of wrought Mg alloys can be significantly influenced by the loading direction with respect to the material orientation.

Studies were conducted the fatigue behavior of wrought Mg-Al-Zn alloys including extruded AZ31 [3,4], extruded AZ61 [1,5], and rolled AZ31 or AZ31B [6–15]. Limited fatigue experiments were conducted using the rolled Mg alloys whose loading axial directions were oriented parallel to the transverse direction (TD), rolled direction (RD), and normal direction (ND). Wu et al. [6] investigated the strain-controlled low-cycle fatigue behavior of rolled AZ31B Mg alloy with RD, TD and ND orientations. It was found that the ND sample had the worst fatigue life among the three orientation samples, and the fatigue properties of the RD sample was similar to that of the TD sample. In contract, Park et al. [7–9] pointed out that the low cycle fatigue (LCF) life of an ND sample was longer than that of an RD sample. It was also reported the effect of the initial $\{10\bar{1}2\}$ twins on the fatigue deformation

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behavior of rolled AZ31 Mg alloy by pre-compressive on the ND samples. Lv et al. [12,13] compared the fatigue properties of a rolled AZ31 alloy along different orientations under both the stress-controlled and strain-controlled cyclic loading, and found that the fatigue lives of the TD samples were longer than these of the RD samples. Zhang et al. [15] reported the effects of sample orientation on the ratcheting behavior of a hot-rolled AZ31B Mg alloy. These studies indicate that the initial orientation of the testing specimen with respect to the rolled direction plays an important role on the mechanical properties and fatigue resistance of wrought Mg alloys. However, previous work entirely concentrates on typical three material orientations (TD, RD and ND). The effect of other orientations on fatigue behavior has not been well understood. On the other hand, the rolled sheet were usually used to study the influence of material orientation on mechanical properties [2,11–13,15]. The problem is that the loading path of different orientation specimens is on the same RD-TD plane, namely, loading direction is perpendicular to the *c*-axes of the crystallographical lattice. This results in the deformation mechanism of these specimens being similar due to the fact that $\{10\bar{1}2\}$ tension twinning can occur when a tensile load is applied perpendicular to the RD-TD plane. The sheets do not allow for the study of the material orientation influence because of the limited thickness that does not allow for the testing in the thickness direction. For application of the wrought Mg alloys to load-bearing components, it is important to evaluate fatigue properties along different orientations or loading paths.

In the present study, the effect of material orientation on the cyclic deformation and fatigue behavior was investigated with specimens taken from a rolled AZ80 Mg alloy thick plate with four different orientations with respect to the rolled plane: 0° (ND), 30° (ND30), 60° (ND60), and 90° (RD). Monotonic mechanical properties, cyclic stress-strain response, fractography characteristics, and fatigue life were experimentally investigated. An energy based fatigue model was evaluated for its capability to predict the fatigue life of the anisotropic Mg alloy.

2. Materials and experimental

2.1. Materials and specimens

The Mg alloy used in the study is a hot-rolled AZ80 Mg plate (Mg-7.8% Al-0.36% Zn-0.04%Mn, in wt%) with a thickness of 60 mm. The material was homogenized at 340 °C for 2.5 h. Fig. 1 shows the original microstructure of the material. The three-dimensional stereography was obtained using an optical microscope (OM). The microstructure and the pole figures observed by electron back scattered diffraction (EBSD) on the ND–TD plane are shown in Fig. 1b and c, respectively. The microstructure was characterized by equiaxed grain α-matrix and β-$Mg_{17}Al_{12}$ phases distributing along the grain boundaries. The average gain size was approximately 50 μm measured by the linear intercept method. The {0002} pole figure exhibits an intense basal texture with *c*-axes aligned parallel to the ND. There was no preferred orientation for the $\{10\bar{1}0\}$ prismatic plane or the $\{10\bar{1}1\}$ pyramidal plane, indicating that the *a*-axes were randomly oriented on the RD–TD rolled plane.

To investigate the effect of material orientation on cyclic deformation and fatigue behavior, specimens were machined from the rolled plate with the loading axes of the testing specimens along 0° (ND), 30° (ND30), 60° (ND60) and 90° (RD) with respect to the rolled direction as shown in Fig. 2. The dog-bone shaped plate specimens for monotonic tensile and fatigue tests have a gage section of 8 mm × 4 mm × 4 mm. In order to avoid bulking, cylindrical specimens with a diameter of 10 mm and gage length of 15 mm were used for monotonic compression tests. Before testing, the surface of the gage section of the specimen was polished by using silicon carbide papers with grit No. from 400 up to 1200.

2.2. Experiments

All the monotonic and strain-controlled cyclic loading

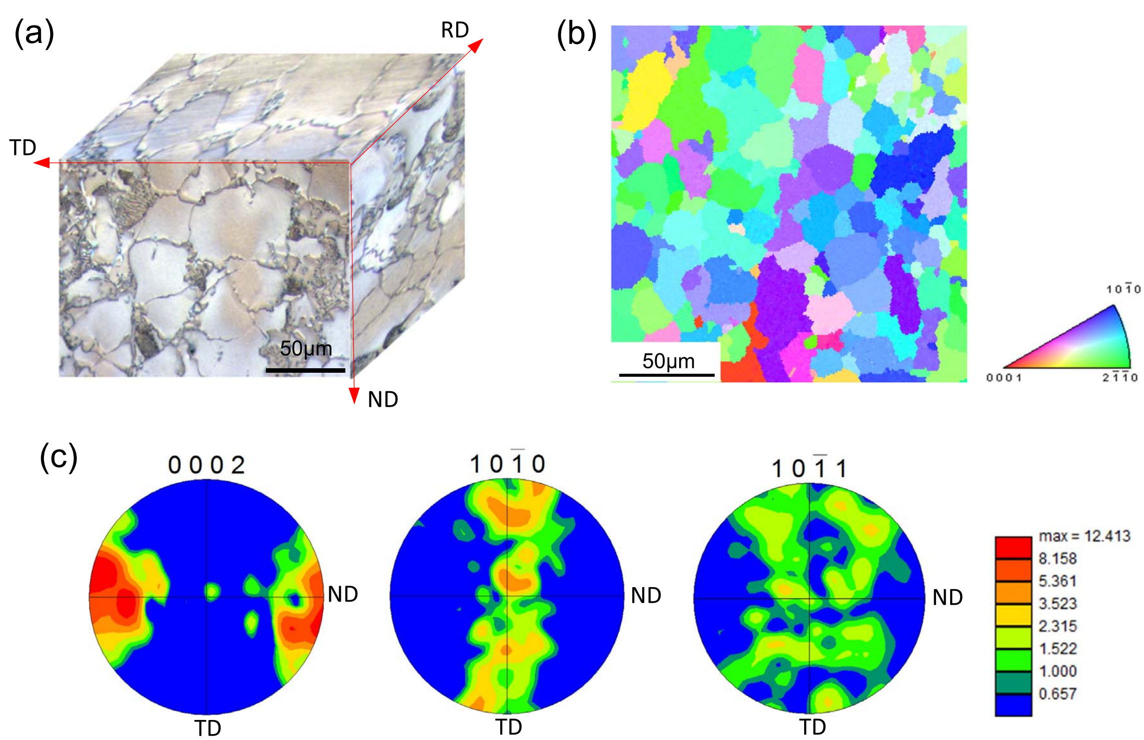

Fig. 1. Initial microstructure and texture of rolled AZ80 Mg alloy: (a) three-dimensional optical image; (b) microstructure obtained by EBSD; and (c) (0002) $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ pole figures measured by EBSD.