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Three-point-bending fatigue behavior of AZ31B magnesium alloy based on infrared thermography technology

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ABSTRACT

The fatigue behavior of the AZ31B magnesium alloy subjected to three-point-bending tests was studied. Real-time recording of the surface-temperature-evolution data of specimens was obtained using the infrared thermography technology during fatigue. The characteristics of heat production and transfer were described, and the correlation between temperature and stress distribution was analyzed. The surface temperature of specimens undergoes four stages: (I) Initial rapid increase stage, (II) Decrease stage, (III) Steady-state stage, and (IV) Abrupt fracture stage during the course of the experiment. The fracture surface of specimens was observed by Scanning Electron Microscope (SEM). The result demonstrates that the AZ31B alloy possess by the quasi-cleavage fracture. The development of twins was analyzed to confirm the reason for temperature changing. An energy model based on the fatigue-damage-accumulation theory was established to predict the fatigue prediction of AZ31B-magnesium-alloy specimens. The fatigue strength of the AZ31B magnesium alloy using the Luong's method is 128.97 MPa, is close to the experimental result of 133.87 MPa, the fatigue strength of the prediction model gives 137.33 MPa, which is comparable to the experimental results.

1. Introduction

Compared with other metal materials, the magnesium alloy endowed with many advantages, includes lower density, excellent comprehensive mechanical properties, easily reused and recycled [1]. Owing to those advantages, magnesium alloys have been widely used in the transportation, aerospace, medical, and other fields. Wrought magnesium alloys, in particular have been demonstrated to be pleasurable candidates to replace other metals in load-bearing automotive components [2]. AZ31B magnesium alloy is a quintessentially extruded magnesium alloy with the widely commercial applications, mainly be applied to manufacturing automotive parts.

For further improving the application of the AZ31B magnesium alloy, scholars did immense research about its mechanical properties, etc. [3–5]. Furthermore, numerous achievements in the experiment and theoretical models about fatigue performance have been excogitated. Wu et al. [6] found the different activation sequences of twinning and detwinning mechanisms under compression and tension are determined by the initial crystallographic texture relative to the loading axis, which caused the fundamental difference in the low-cycle fatigue behaviors between the in-plane and through-thickness loadings. Huppmann et al. [7] analyze the deformation twinning in the AZ31B alloy after cyclic loading, and draw a conclusion that the amount of the residual extension twins increases with increasing number of cycles N during fatigue testing, and the twins of the tensile maximum do not detwin during the tensile half cycle when the cracks are initiated and crack propagation proceeds.

The previous research about the fatigue property paid close attention to researching fatigue behavior of either axial loading tests or rotary bending tests. Investigations related to the fatigue properties of magnesium alloys subjected to the transverse cyclic load test are infrequent [8]. In order to fill the content in the field of the mechanism of fatigue fracture, which is caused by the transverse cyclic load, this paper design an experiment of the three-point-bending test (TPBF). The three-point test is a normative test adopted by ISO 7438:2005(E) standards [9] and used to measure bending properties.

Fatigue and fracture are the main reason for the failure of engineering structures and components, scientists and engineers were aware of this trend and began to study its nature for more than

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100 years with a number of achievements [6–8]. Fatigue is a process of energy dispassion that includes energy storage and thermal dissipation. Energy storage embodies the defects or damages within materials. Those changes can be represented by observing the microscopic structure of the materials, but quantitative analysis need indirectly depicts through measuring the thermal dissipation [10]. The emergence of the infrared-thermal technique promotes the new method to study fatigue performance. Risitano [11], Luong [12], and Yang et al. are devoted to the thermography technology [13] to study fatigue performance etc of aluminum alloys, and their theoretical models are often quoted.

The energy, E_c, related to the final plastic failure, it is proved that a constant value, which is independent of the loading mode and the loading history [14]. The plastic-energy dissipation was employed as the increment of the mean temperature by Jiang et al. [15]. They proved the temperature index that associated with the steady-state mean temperature and the temperature of the initial stress-free stage has a linear relationship with the dissipated energy density, ΔW. Consequently, an efficient procedure was proposed that is used for the determination the fatigue life by the slope of the temperature rise with time in the initial stage. The energy theory successfully provides the theoretical guidance to the prediction of fatigue performance [10,13,16–18].

It's obvious that the specimens loaded in three-point-bending have different stress distributions with the specimens loaded in axial loading. The specimens that bear the three-point-bending have a region, which has the tensile-deformation, and the three fulcrum regions which has compressive-deformation, Fig. 1. Considering that TPBF has significantly different temperature evolution processes on the samples surface, compared with axial loading tests. Heat dissipation occurred at three fulcrums and the tensile-deformation area of each sample that bears the dynamic load. Therefore, the thermal transmission effect in the four heat parts of the TPBF samples cannot be ignored. The infrared thermography was used to carry out the fatigue tests on the AZ31 magnesium alloy, this experiment determined the fatigue behavior of AZ31 by discussed the macro relationship between the temperature and stress based on their distribution and analyzed the effect of the heat-conduction mechanism in the surface-temperature-evolution progress. In addition, the fatigue fracture surfaces of samples were analyzed for explaining the fatigue-fracture mechanism. For confirming the energy theoretical model during the fatigue process is also appropriate for AZ31B alloy, the formation and evolution of microstructures in tension regions was studies by the metallographic analysis, and the relation between the twinning development and cyclic-hardening behavior was analyzed. Furthermore, an energetic damage model was developed to predict the fatigue life of the AZ31 specimen subjected to the three-point-bending test.

2. Materials and methods

2.1. Materials and equipment

Raw materials were taken from AZ31B magnesium extrusion sheet, which was 10 mm thick. The mechanical properties of the AZ31B magnesium alloy are presented in Table 1. According to the ISO 7438:2005-Metallic materials-Bend test [9], the specimens were machined into 10 mm × 30 mm (cross-sectional area) and 160 mm in length by an electrical discharge wire-cutting machine. The dimensions of the specimens are shown in Fig. 1. The edges of specimens were rounded to a radius of 1.5 mm. Furthermore, the surfaces of the specimens are polished by emery paper (400, 800, and 1200 grit, successively) in order to delay the fatigue-crack initiation by eliminating the surface-stress concentration. According to sample loading, the fulcrum areas of the sample are defined as region A and the tensile area as region B in the following discussion, Fig. 1. All the tested specimens were machined from the magnesium sheet with the length direction parallel to the rolling direction. Before fatigue tests, the surfaces that face the thermal infrared imager of all the specimens were painted a layer of matte black for improving the data quality and decreasing the errors. In addition, the experimental program consisted of fatigue tests carried out on a PLG-200D high-frequency electromagnetic resonance fatigue-testing machine. In the experimental process, the project adopted the infrared thermal imaging system to measure the temperature evolution on the surfaces of the specimens. For the investigation of metallographic phase, the Metallographic specimens were prepared using a standard metallographic technique and given final polishing with emery paper of 3000 grit in water. After that, the specimens were etched with acetic picral solution (3 g picric acid, 10 ml acetic acid, 30 ml water, and 50 ml ethanol) for 4–8 s.

2.2. Experiment procedure

Fig. 2 presents an experimental apparatus of three-point-bending fatigue tests. The apparatus includes a fatigue-limit testing system and an infrared thermal imaging system that is used to measure and record the temperature. This experiment comprises two technological parts. The first part is the

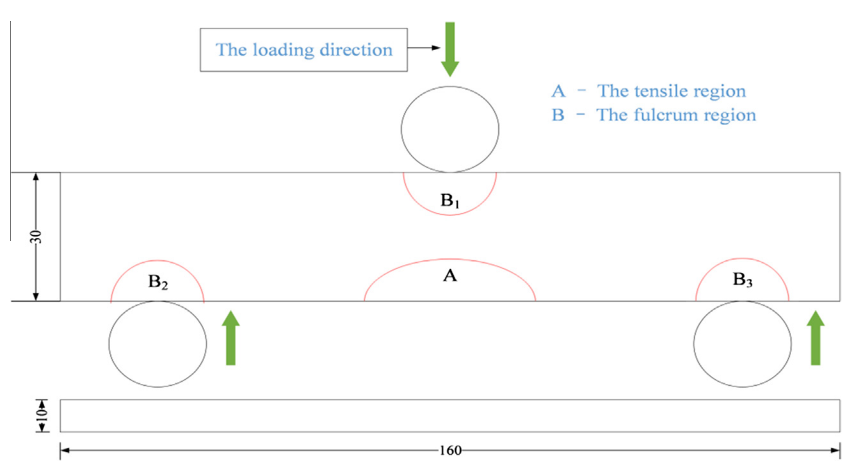

Fig. 1. The shape and dimension of specimens.