Influence of shot peening on high cycle fatigue properties of the high-strength wrought magnesium alloy AZ80

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Abstract

The influence of shot peening on fatigue performance of the high-strength wrought magnesium alloy AZ80 was investigated. Shot peening effectively improved the fatigue life: an improvement of 60% in the fatigue strength was obtained at the optimum condition. In addition, the magnesium alloy reacted sensitively to shot peening. This sensitivity was attributed to the limited deformability of the hexagonal crystal structure of magnesium at room temperature. Compared to published data, the optimum condition for shot peening in the present work moves to higher intensities and the process window becomes larger.

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1. Introduction

Magnesium is the lightest structural metal with high specific strength, excellent machinability and good castability [1,2]. These advantages make magnesium alloys very attractive for the automotive industry. Die casting is the principal fabrication process for magnesium components due to the high productivity, high precision and high quality surface [3]. However, magnesium components fabricated by mechanical forming (extrusion, forging) usually exhibit higher ductility and strength than the die-cast components. Many efforts have been made to fabricate the magnesium components by mechanical forming. For example, high-strength wrought magnesium alloys are considered as potential candidates to substitute aluminium in suspension parts in future automobiles [4,5]. For this application, good high cycle fatigue (HCF) performance must be achieved.

Shot peening is a powerful method to enhance the fatigue performance of structural metallic materials such as steel, aluminium and titanium alloys [6–8]. Recently, the work by Wagner and coauthors [9,10] has shown that the fatigue life of high-strength magnesium alloys can be improved by shot peening. However, the small optimum Almen intensity of 0.05 mmN, consult Refs. [9,10] for details, and the narrow process window make it difficult to make use of this technique for practical applications.

In the present work, the fatigue behavior of the high-strength wrought magnesium alloy AZ80 after shot peening was investigated. The process parameters for shot peening were varied widely to determine the optimum conditions.

2. Experimental

The material used in this work was a high-strength magnesium alloy AZ80 (nominal composition in wt. %: 8 Al, 0.5 Zn, 0.2 Mn, balance Mg), received from Otto
Fuchs Metallwerke, Meinerzhagen, Germany. Firstly, the alloy was extruded to a cylindrical bar with an extrusion ratio of 32, then it was forged to a rectangular bar with a cross section of 60 mm × 11 mm. The material was tested in the as received condition without any heat-treatment.

The microstructure of AZ80 is shown in Fig. 1. The alloy has a single α-phase structure, no precipitation of β-phase (Mg17Al12) is observed by light optical microscopy. The shape of the fine grains is rather equiaxed, and the average grain size is about 30 μm.

Crystallographic texture ((0002) pole figure) of the magnesium alloy AZ80 was characterized by X-ray diffraction using Ni-filtered Cu-Kα radiation (Fig. 2). The basal planes are oriented predominantly parallel to the longitudinal–transversal (L–T) plane.

Specimens were machined with the load axis parallel to longitudinal direction of the rectangular bars. Tensile tests were performed on threaded cylindrical specimens having gage lengths of 20 mm at the initial strain rate of 8.3 × 10⁻⁴ s⁻¹. Tensile test results are shown in Table 1.

For fatigue testing, hour-glass shaped round specimens (6 mm gage diameter) were used. After machining, a layer with thickness of about 200 μm was removed from the surface of the specimens by electrolytical polishing (EP) in order to avoid the influence of machining on the fatigue results.

Shot peening (SP) was performed with an injector type machine using glass beads. The detail parameters of the peening medium are listed in Table 2. The distance between the nozzle tip and the specimen surface was about 80 mm. To determine the optimum shot peening condition with regard to HCF fatigue properties, specimens were shot peened to full coverage by using Almen intensities in the range of 0.04–0.4 mmN.

The surface properties of shot peened specimens were determined by roughness measurements through profilometry, measurements of the microhardness–depth profiles and residual stress measurements by means of the incremental hole drilling method [11].

Fatigue tests were performed in rotating beam loading (R = −1) at a frequency of about 100 Hz in air.

### 3. Experimental results

#### 3.1. Surface characteristics

The typical surface topography of specimens after shot peening is shown in Fig. 3. It can be seen that shot peening resulted in considerable surface damage in magnesium, e.g. pits, even at the lowest Almen intensity of 0.04 mmN. The severe defects in surface such as over-
laps and microcracks were observed when the Almen intensity is higher than 0.20 mmN.

Fig. 4 shows the results of the surface roughness measurement. It is found that the increase in Almen intensity leads to a marked increase of the surface roughness.

Fig. 5 shows the microhardness–depth profile after shot peening with different Almen intensities from 0.04 to 0.4 mmN. Owing to shot peening induced plastic deformation, there is an increase in microhardness in the near-surface region. Increasing the Almen intensity from 0.04 to 0.4 mmN leads to greater depths of plastic deformation. The thickness of plastic deformation layer resulting from shot peening can be estimated to be about 50–200 µm for the different Almen intensities from 0.04–0.4 mmN.

Fig. 6 shows the residual stress distribution in AZ80 after shot peening. It can be seen that the shot peening induced compressive residual stresses. The maximum compressive residual stress increases with the increase in the Almen intensity. However, increasing the Almen intensity also leads to the surface quality loss (see Fig. 3). The maximum compressive stresses of 45–100 MPa are about 60–80 µm below surface for the different Almen intensities ranging from 0.04 to 0.4 mmN.
3.2. High cycle fatigue

Fig. 7 shows the fatigue life as a function of Almen intensity for AZ80 at different stress amplitudes of $\sigma_a = 175$ and 200 MPa. Compared to the reference EP specimens, the fatigue life is improved by shot peening. One can see that the fatigue life depends on the Almen intensity at all tested stress amplitudes. Especially at the stress amplitude of 175 MPa, the dependence is more evident, i.e. with increase in the Almen intensity, the fatigue life first dramatically increases, then drops drastically. An improvement in the fatigue life by approximately two orders of magnitude is obtained by shot peening with the Almen intensities between 0.10 and 0.20 mmN at the stress amplitude of 175 MPa. With regard to the fatigue performance, the Almen intensity of 0.15 mmN is taken as the optimum.

The stress–life ($S–N$) curve at the optimum condition (Almen intensity of 0.15 mmN) for shot peening is shown in Fig. 8. Compared to the reference specimens (EP), the fatigue limit increases from 100 to 160 MPa after shot peening.

3.3. Fractography

Fracture surface of reference condition (EP) is shown in Fig. 9a. It is found that the fatigue cracks nucleated at the surface. In contrast, for the specimens after shot peening at optimum peening condition, subsurface fatigue crack nucleation is observed (Fig. 9b). The depth of the crack nucleation site is about 100 $\mu$m below the surface, in agreement with the depth of plastic deformation estimated by the microhardness measurements. In addition, at high Almen intensities, a significantly higher number of fatigue cracks can be seen.

4. Discussion

The present results clearly show that shot peening effectively improves the fatigue life of the high-strength wrought magnesium alloy AZ80. It appears that work hardening and residual compressive stresses induced by shot peening in the subsurface region retard crack nucleation and/or propagation [7,10]. The fatigue limit increases from 100 to 160 MPa after shot peening with the optimum Almen intensity of 0.15 mmN, i.e. the improvement of 60% in fatigue limit has been achieved. In addition, magnesium alloy AZ80 reacts sensitively to Almen intensity. Highest fatigue lifes are obtained at intermediate Almen intensities (0.1–0.2 mmN), while increasing the Almen intensity (>0.2 mmN) leads to a
pronounced drop in life (see Fig. 7). It is well known that the heavier shot peening not only results in lower near surface residual compressive stresses, but also increases roughness and induces microcracks [10]. For magnesium alloys, due to the limited deformability of HCP crystal structure at room temperature, surface damages are aggravated. At the intermediate Almen intensities (0.10–0.20 mmN), the life benefit outweighs the debit due to additional surface damages. However, with the increases in Almen intensity (>0.20 mmN), more severe defects such as overlaps and microcracks occur, and the life improvement dramatically decreases.

The sensitive response of magnesium alloys to shot peening was also observed by Wagner [10]. The significant life improvement was obtained on the high-strength AZ80 only at a very low intensity of 0.05 mmN, as shown in Fig. 10. Compared to the data in Refs. [9,10], the present results show a similar HCF resistance at the optimum SP condition (see Fig. 8). Meanwhile, the higher optimum intensities and the broader process window are achieved (see Fig. 10). It is noted that the material used by Hilpert and Wagner [9] is an extruded magnesium alloy AZ80, which has the same composition, similar grain size and texture, similar tensile and fatigue strength as the material used in the present work. Therefore, the differences in fatigue behaviour after shot peening are possibly associated with the different micro-structures in the two materials. As shown in Fig. 1, the material used in the present work exhibits a single phase structure, aluminium is dissolved in the a-phase. However, discontinuous β-phase is found in the extruded AZ80 due to the relatively lower cooling rate [9]. Since it is known that the β-phase is rather brittle at room temperature, it can probably be broken during shot peening even at low intensities. In the fatigue tests followed, the broken β-phase may act as the crack source to deteriorate the fatigue properties. The effect of the brittleness of the β-phase is also reflected in the tensile properties: the elongation of the extruded AZ80 from Ref. [9] is only 9%.

5. Conclusions

The influence of shot peening on fatigue performance of the high-strength wrought magnesium alloy AZ80 was studied.

It was found that shot peening improved fatigue life of magnesium alloy AZ80, the fatigue strength increased from 100 to 160 MPa at the optimum condition. The improvement in the fatigue strength was about 60%.

The magnesium alloy was very sensitive to shot peening. The fatigue life first dramatically increased with the increase in Almen intensity compared to an electropolished specimen, then drastically dropped as the intensity further increased. This sensitivity was attributed to the limited deformability of the hexagonal crystal structure of magnesium at room temperature.

In comparison with the published data, the optimum condition in the present work moves to higher intensities and the process window becomes larger. The present results show that it is promising to apply shot peening process into practical magnesium applications.
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