

# Effect of Surface Burnishing Treatment on Microstructure and Wear Performance of ZK60 Magnesium Alloy

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**Abstract.** In order to improve the surface properties of high strength magnesium alloy ZK60, the surface burnishing treatment was carried out. The effects of burnishing process parameters on surface roughness, microhardness and microstructure of ZK60 magnesium alloy were studied. And the wear performance of the untreated and the surface burnishing treated samples was compared and analyzed. A gradient microstructure layer of nanocrystalline, ultrafine, deformed and original coarse grains from the treated surface to the matrix was formed on ZK60 alloy by surface burnishing treatment. In comparison with the untreated sample, the surface roughness of the burnishing treated sample was significantly reduced and the surface microhardness was evidently improved. After surface burnishing treatment, the wear of ZK60 sample decreased by 44.58%, and the friction coefficient decreased from 0.328 to 0.293, significantly improving the wear performance.

## 1. Introduction

Magnesium alloy with a low density, high specific strength and specific stiffness, excellent electromagnetic shielding and machining properties is known as ‘the green engineering material of the 21st century’[1-3]. However, magnesium alloy parts are inevitably subjected to high temperature, corrosion, severe wear and alternating load during service. Over time, magnesium alloy parts are prone to fatigue damage and fatigue fracture.

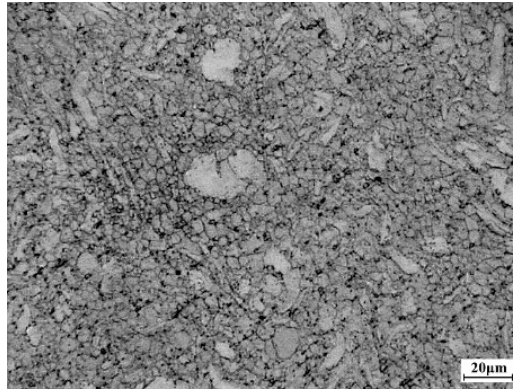
Because the fatigue fracture usually starts from the surface of the part, it puts forward more strict requirements on the surface performance of the part[4-5]. For this kind of failure, there are many existing surface strengthening methods, including burnishing strengthening[6], shot peening strengthening[7-8], laser impact strengthening[9-10] and surface mechanical attrition treatment[11]. Among them, surface burnishing strengthening technology is widely used. Surface burnishing strengthening treatment uses special burnishing tools to apply pressure on the surface of parts and conduct multiple burnishing, so as to change the microstructure and physical properties of the surface metal of parts[12]. Surface burnishing treatment has the advantages of no pollution, high efficiency and low cost, etc., which can be completed on the machine[13].

As a high-strength deformed magnesium alloy, the strength of ZK60 is close to the high-strength 7075 aluminum alloy. However, ZK60 alloy is not an invulnerable material. It has many defects such as severe thermal cracking tendency and poor plasticity[3]. At present, there are no reports on the surface burnishing strengthening of ZK60 magnesium alloy. Therefore, the surface burnishing processing of ZK60 magnesium alloy was carried out in this paper, and the effects of burnishing process parameters on surface roughness, microhardness and microstructure of ZK60 magnesium alloy were studied. Meanwhile, the effects of surface burnishing strengthening on wear and friction coefficient of ZK60 magnesium alloy were studied.



## 2. Experiment Details

The test material was ZK60 magnesium alloy bar in extrusion state with a diameter of 35mm, with the chemical composition (in wt.%) of 5.679Zn, 0.613Zr, 0.095Y, 0.085Nb, 0.04Gd and balance Mg. The original microstructure of ZK60 magnesium alloy is shown in figure 1. The mean grain size is  $\sim 7\mu\text{m}$ .



**Figure 1.** Original microstructure of ZK60 magnesium alloy

Surface burnishing treatment of ZK60 magnesium alloy was carried out by self-developed burnishing equipment. The burnishing device was installed on CAK3665 lathe. Specific burnishing process parameters are as follows. The burnishing pressure was 600N. The burnishing speed was  $6\text{m}\cdot\text{min}^{-1}$ . The number of burnishing passes was 10, 20, 30, 40, 60, 80, 100, 120 and 160, respectively.

The microstructure of the cross-section of the sample with different burnishing process parameters was observed by using 4XC metallographic microscope, and the microstructure at different depths from the burnishing surface was characterized by using a JSM-7610F scanning electron microscope (SEM). Mitutoyo SJ-410 portable surface roughness tester was used to measure the surface roughness, and the probe stroke was set at 4mm. A 402MVD vickers hardness tester was used for the microhardness test. The test load was 0.25N and the retention time was 15 seconds. The friction and wear test was carried out on MFT-50 friction and wear test machine. The friction ball was Cr15 bearing steel with diameter of 6mm, applied load of 5N, running time of 10 minutes, reciprocating running distance of 4.5mm and frequency of 2. USP-Sigma white light interferometer was used to measure the three-dimensional surface morphology characteristics of the sample after friction and wear test, and the sampling area was  $5.7\text{ mm}\times 1.08\text{ mm}$ .

## 3. Results and Discussions

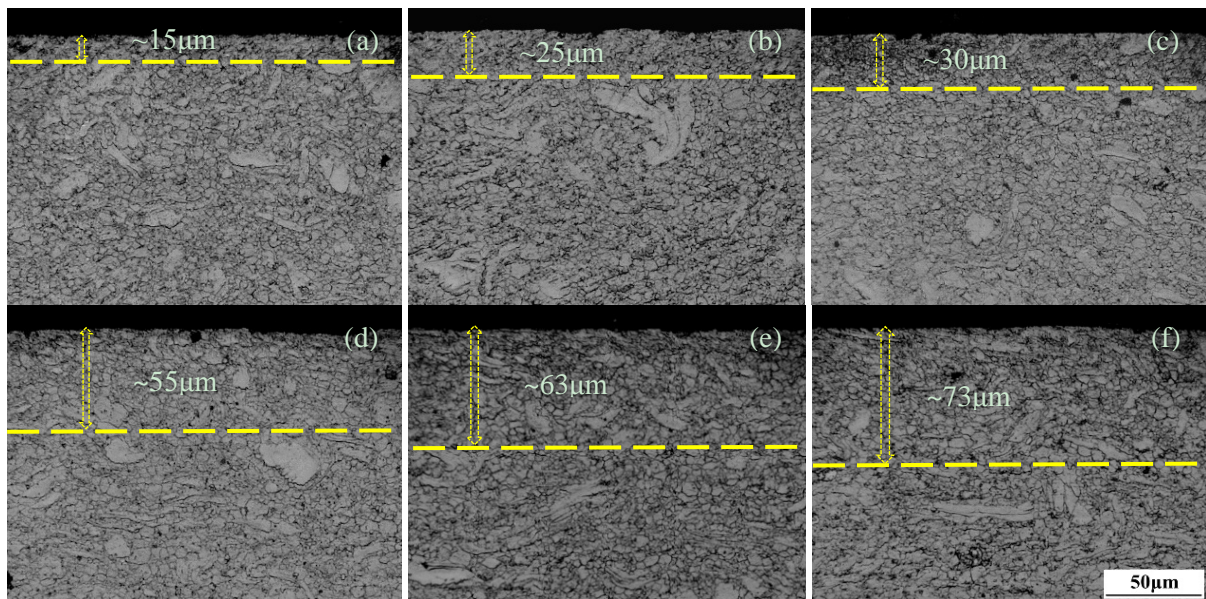
### 3.1. Effect of Different Burnishing Parameters on Microstructure of ZK60 Alloy

Figure 2 shows the effects of the number of burnishing passes on surface microstructure of ZK60 samples under the same burnishing pressure (600N) and burnishing speed ( $6\text{m}\cdot\text{min}^{-1}$ ). The results show that the thickness of grain refinement layer increases with the increase of the number of burnishing passes (from 10 to 160). However, when the number of burnishing passes reached 80, the grain refinement layer did not increase significantly. This is because the increase of the number of burnishing passes leads to the increase of twins and dislocation density in the surface layer, that is, the appearance of work hardening layer increases the resistance to further plastic deformation of the surface layer. When the resistance of plastic deformation of the surface material is in balance with the burnishing pressure applied by the test, the material cannot be further deformed. Therefore, the thickness of grain refinement layer does not increase linearly with the increase of the number of burnishing passes, but tends to a stable range ( $\sim 73\mu\text{m}$ ).

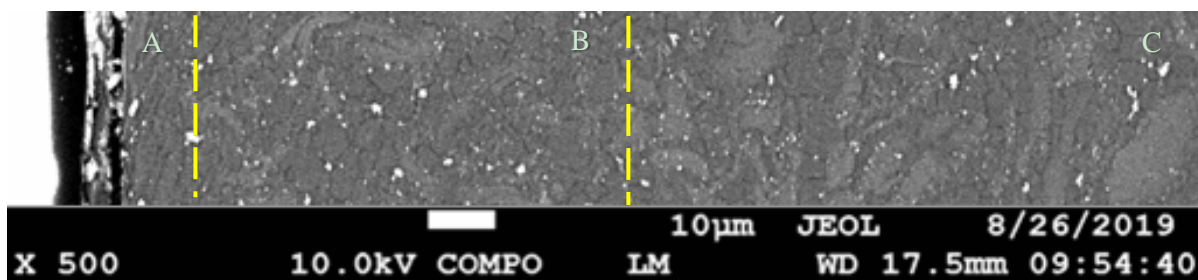
### 3.2. Microstructure of the Burnishing Treated Surface Layer

Figure 3 shows the SEM microstructure of ZK60 alloy sample after surface burnishing treatment (160 passes). A gradient microstructure layer of nanocrystalline/ultrafine, deformed and original coarse

grains from the treated surface to the matrix were formed on ZK60 alloy by surface burnishing treatment. The A region in figure 3 is the nanocrystalline/ultrafine grain region of  $\sim 12\mu\text{m}$  in thickness. The B region is the deformed grain layer with a depth range of  $12\sim 75\mu\text{m}$ . In this region, the grain boundary was severely distorted and grains were irregularly distributed. The matrix was the original extruded structure, and grains were mainly isoaxial and coarse grains that were not completely broken (region C in figure 3). It can be seen from figure 3 that the grain size from the surface to the matrix gradually increases with the increase of depth, showing a gradient structure with continuous changes.



**Figure 2.** Cross-section morphologies of ZK60 alloy after surface burnishing treatment with different burnishing passes: (a) 10 passes; (b) 20 passes; (c) 40 passes; (d) 80 passes; (e) 120 passes; (f) 160 passes

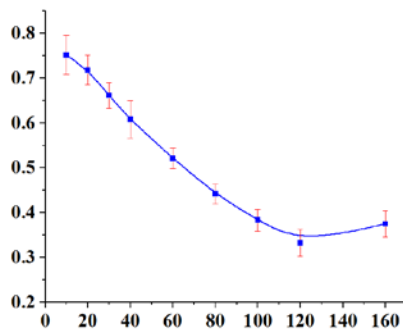


**Figure 3.** Cross-section SEM image of burnishing treated surface of ZK60 sample (160 passes)

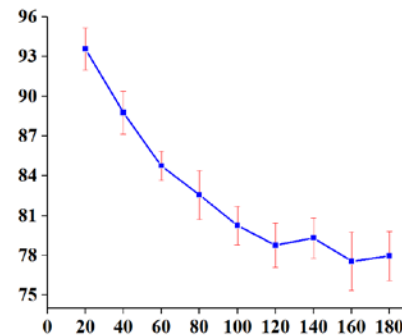
### 3.3. Analysis of Surface Roughness and Microhardness

Contour arithmetic mean deviation  $R_a$  is a widely used basic evaluation parameter of surface roughness, which can directly reflect the peak-valley amplitude variation of the detected contour. The effect of burnishing passes on surface roughness of ZK60 magnesium alloy samples in figure 4. The  $R_a$  value of ZK60 samples was  $1.258\mu\text{m}$ . After surface burnishing treatment, the  $R_a$  of the corresponding sample decreased the least when the number of burnishing passes was 10, down to  $0.751\mu\text{m}$ , which was 40.3% lower than that of turning. When the number of burnishing passes was 120, the  $R_a$  of the sample decreased the most, to  $0.333\mu\text{m}$ , which decreased by 73.5% compared with the untreated sample. Within the value range of burnishing passes, the surface roughness decreases first and then increases with the increase of the number of burnishing passes. The change in  $R_a$  value due to the change of the number of burnishing passes was  $0.418\mu\text{m}$ .

Dependence of microhardness on depth is determined in the burnished surface layer of ZK60 sample, as shown in figure 5. Due to the low hardness of ZK60 magnesium alloy, 0.25N loading force was adopted. The diagonal length of the square indentation obtained under this load was about 23 $\mu$ m. When the measuring center was selected within 20 $\mu$ m from the surface of the workpiece, the indentation image obtained at the test point will be seriously deformed (indentation is irregular), resulting in distortion of the measurement results. Therefore, the measurement starting point was selected 20 $\mu$ m away from the sample surface and the interval between adjacent measuring points was 20 $\mu$ m.



**Figure 4.** Effect of different burnishing passes on surface roughness of ZK60 alloy



**Figure 5.** Variations of microhardness with distance from treated surface of the burnished sample

Turning leads to the cold hardening of the surface metal of the sample, and then the surface microhardness is improved. The microhardness of the turning sample at 20 $\mu$ m away from the surface was 82.07HV<sub>0.25</sub>, which was 4.55% higher than that of the matrix material. After 120 burnishing passes, the microhardness reached 93.58HV<sub>0.25</sub>, which increased 19.21% compared with the microhardness of the matrix material. As can be seen from figure 6, the microhardness from the surface to the matrix decreased gradually with the increase of depth.

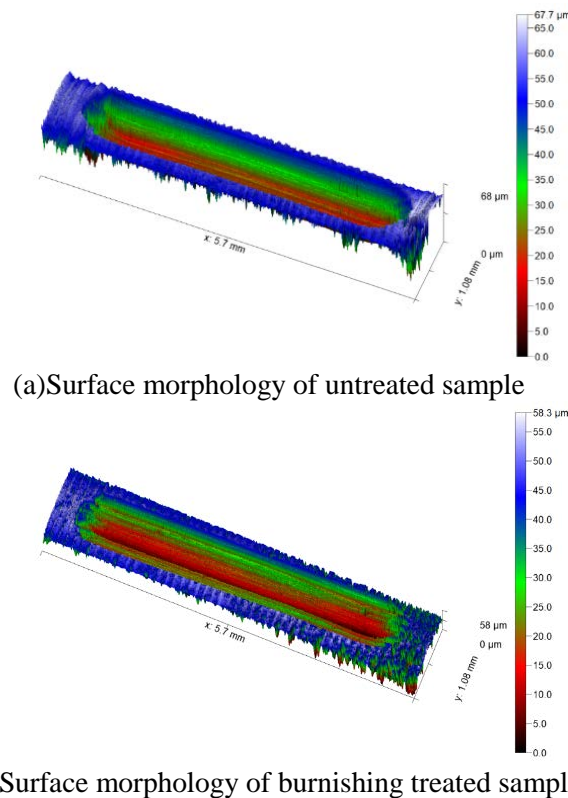
### 3.4. Analysis of Wear Performance

#### 3.4.1. Wear of ZK60 samples

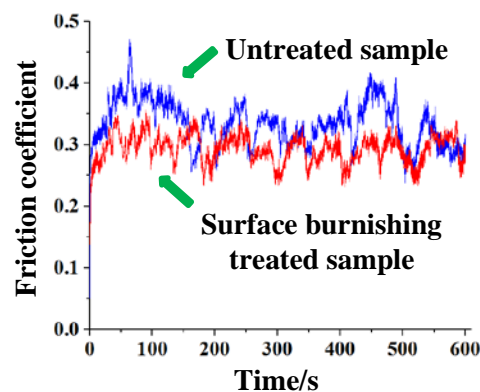
Figure 6 shows the three-dimensional surface morphology of ZK60 samples after friction and wear test. The wear amount of the untreated sample was  $1.66 \times 10^{-4}$ g. After surface burnishing treatment (120 passes), the wear amount of the sample decreased to  $9.2 \times 10^{-5}$ g, reducing the wear amount by 44.58%. Therefore, surface burnishing treatment can effectively reduce the wear of ZK60 magnesium alloy and improve its wear performance.

#### 3.4.2. Friction coefficient of ZK60 samples

The curves of the friction coefficients over time of untreated and surface burnishing treated samples is shown in Figure 7. The average friction coefficient of the untreated sample was 0.328, and it changed to 0.293 after surface burnishing treatment. After surface burnishing treatment, the friction coefficient of the sample becomes smaller. This is because a hardened layer on the surface of ZK60 samples was formed by the surface burnishing treatment which improves the surface microhardness and thus improves its wear performance.



**Figure 6.** The three-dimensional surface morphology of ZK60 sample after friction and wear test



**Figure 7.** Friction coefficients of untreated and surface burnishing treated samples

#### 4. Summary

A gradient microstructure layer of nanocrystalline, ultrafine, deformed and original coarse grains from the treated surface to the matrix was formed on ZK60 alloy by surface burnishing treatment. The thickness of nanocrystalline/ultrafine grain region was  $\sim 12\mu\text{m}$ . And the thickness of the deformed grain layer was  $\sim 63\mu\text{m}$ .

In comparison with the untreated sample, surface roughness of the burnishing treated sample was significantly reduced and the surface microhardness was evidently improved. When the number of burnishing passes was 120, the  $R_a$  of the sample decreased to  $0.333\mu\text{m}$ , which decreased by 73.5% compared with the untreated sample. And the microhardness reached  $93.58\text{HV}_{0.25}$ , which increased 19.21% compared with the microhardness of the matrix material.



After surface burnishing treatment (120 passes), the wear amount of the sample decreased to  $9.2 \times 10^{-5}$  g, reducing the wear amount by 44.58%. Friction coefficient decreased from 0.328 to 0.293. The wear performance of ZK60 alloy was improved obviously.

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