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Research Paper

Effects of Shot Peening Angle and Time on Microstructure and Wear Behavior of AZ31 Alloy

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Abstract

This study evaluated the effects of peening angle and time on the microstructure and wear behavior of AZ31 alloy subjected to the shot peening process. The samples were shot peened at 30° and 45° for 20 and 80 min with steel pellets. The microstructures and grain sizes of the shot peened samples were studied by scanning electron microscopy (SEM) and X-ray diffraction (XRD). In addition, the samples were characterized through hardness and wear measurements. The results showed that shot peening time had a greater effect on grain refining than shot peening angle. In addition, the hardness was increased to 206% for the sample shot peened at 45° for 80 min. This can be ascribed to reduced grain sizes on the surface (crystallite size of 169 Å) and increased micro-strains. The wear test revealed that the wear resistance of the sample was increased with increasing the peening angle and time. Furthermore, the mechanisms of adhesive and abrasive wear were observed for untreated and shot-peened specimens.

Keywords

Shot Peening, AZ31 Alloy, Peening Angle, Peening Time, Wear

1. Introduction

Magnesium is the lightest structural metal with unique properties, increasingly employed in various industries as an appealing metal in manufacturing moving objects and transportation [1]. Furthermore, in light of vibration damping, magnesium is a robust shield against electromagnetic waves and is exploited in mobile phones, military electronic equipment, and transmission wire production [2]. Thermal dimensional stability is considered an advantage of the AZ31 alloy. However, the strength of this alloy dramatically declines at high temperatures. Moreover, corrosion resistance and wear resistance are limitations of AZ31 [3]. Many metal failures, such as fatigue, wear, and corrosion, occur on the surface [4]. Hence, surface and microstructural optimization can substantially lengthen the lifecycle of metals [5]. The surface properties could be improved by reducing surface grains through plastic deformation. Such deformation techniques include severe plastic deformation (SPD), surface mechanical attrition treatment (SMAT), and shot peening [6]. Meng et al. [7] studied the deformation behavior of AZ31 through the SMAT process. They found that the surface grain size reduced to the nanoscale. They reported increased hardness, improved tensile strength, and a reduced crack length. This improvement was related to microstrains and surface microstructure in mechanical surface modification. Xia et al. [8] analyzed the effect of the SMAT process on the tribological behavior of AZ31. They improved wear resistance in a nanostructure with a thickness of 85 μm. Extensive research reported SPD-improved wear corrosion for AZ31 subjected to equal channel angular pressing (ECAP) [9], AM70 in the ECAP process [10], AZ31 in high-pressure torsion (HPT) process [11], AZ91 in surface nanocrystallization [12], AZ31 in laser shock peening process [13], and AZ31 in ultrasonic shot peening process [14]. Among these methods, shot peening is an effective technique to create nanostructure on the surface and improve the wear properties of magnesium alloys [15-17]. Zhang et al. [14] studied the effect of ultrasonic shot peening on the microstructure and fatigue crack growth rate of AZ31. Nanograins with an average size of 20 nm formed in the surface layer of the alloy subjected to the ultrasonic shot peening, and nanostructured layers with a thickness of above 20 μm appeared. Bagherifar et al. [18] evaluated the mechanical and corrosion properties of AZ31 biocompatible magnesium alloy by severe shot peening. They introduced that the repeened severely shot peening was the optimal choice for the functionality of the AZ31, considering decreased stress concentration, crack initiation and better mechanical performance as compared to the other treatments. Kumar et al. [19] investigated the effect of shot peening on the mechanical properties and ballistic resistance of AZ31B magnesium alloy. The results showed that shot peening increased the yield strength and ultimate strength of the magnesium alloy. They also recommended that the shot peening is an effective method on the ballistic resistance of AZ31B alloy. Haghighi et al. [20] investigated the effect of shot peening time on the wear behavior of AZ31 alloy. It was found that the wear resistance of specimen was increased with increasing the shot peening time. Moreover, the thickness of layer under the mechanical work increased by increasing the shot peening time. A review of the literature indicated that most studies have been conducted on the effects of shot peening time and shot size on the properties of AZ31 magnesium alloy. In addition, few studies were carried out on the effect of shot peening angle on the wear behavior of AZ31. Therefore, this study evaluated the effects of two main parameters including shot peening angle and shot peening time on the microstructure, hardness and wear behavior of AZ31.

2. Materials and methods

AZ31 alloy with the chemical composition shown in Table 1 was used in the research. An AZ31 plate with a thickness of 5 mm was cut into five 5×5 cm samples using an electrical discharge machine. Then, the shot peening process was implemented on the samples at peening angles of 30° and 45° for 20 and 80 min. Samples of AZ31 alloy were shot-peened with steel pellets with a diameter of 2 mm. The nozzle was placed at a distance of 1500 mm from the specimen surface. The turbine power and motor speed were 15 kW and 3000 rpm. XRD analysis was carried out using a Pw1730 X-ray diffractometer to measure the grain size of the shot-peened samples. SEM investigation was performed using a Philips XI30 microscope at 1000 X magnification to evaluate the microstructure of specimens. To prepare samples, they were polished using 1200, 2400, and 5000 grit sandpapers. The polishing process was then performed using felt cloths and diamond polishing paste. Subsequently, the samples were etched using a solution of 4.5 g of picric acid, 10 mL of acetic acid, 10 mL of water, and 70 mL of ethanol. Hardness was measured using a SUNPOC micro-Vickers hardness tester at a load of 100 g and interval distances of 50 μm from the surface. Furthermore, wear testing was carried out via the pin-on-disk test using an SAT-500 abrasion tester under a load of 230 g and a distance of 1000 m.

Table 1. Chemical composition of AZ31

Mg	Al	Zn	Mn	Cu
Ball	2.89	0.85	0.32	0.002

3. Results and Discussion

3.1 Microstructure

Figure 1 shows the XRD patterns of the raw and shot-peened specimens. As shown, the peaks widened and reduced in intensity after the shot peening. This can be explained by the grain size reduction and micro-strains due to the impingement of steel pellets with the surface. The peak reduction and widening were greater for the sample shot peened at a peening angle of 45° and a peening time of 80 min than other samples. Furthermore, peak reduction and widening were enhanced for the shot-peened specimen at 30° for 80 min in comparison with the shot-peened specimen at 45° for 20 min. It can be noted that peening time had a more significant effect on grain size reduction than peening angle. According to Table 2, the crystallite size reduced from 520 Å in the raw sample to 169 Å in the shot peened sample at 45° for 80 min. Moreover, intermetallic phase Mg_2Al_3 was found and variation in peak intensities was observed for the samples with different peening angles and time. The formation of the Mg_2Al_3 phase is due to the incorporation of magnesium and aluminum atoms into the crystal structure of AZ31 alloy containing aluminum. When the sample is subjected to shot peening, aluminum, and magnesium particles interact and dissolve in the grain boundaries, forming crystalline compounds, which cause the formation of the Mg_2Al_3 phase. It was observed that this phase was formed for the samples shot peened at 30° for 80 min, 45° for 20 min, and 45° for 80 min. Furthermore, as the time and angle increased, the presence of this phase in the samples also increased.

Table 2. The crystallite size of shot peened samples

Samples	Shot peening angle (º)	Shot peening time (min)	Crystallite size (Å)
Raw sample	-	-	520
Shot peened sample 1	45	80	169
Shot peened sample 2	45	20	174.6
Shot peened sample 3	30	80	171.2
Shot peened sample 4	30	20	178.5

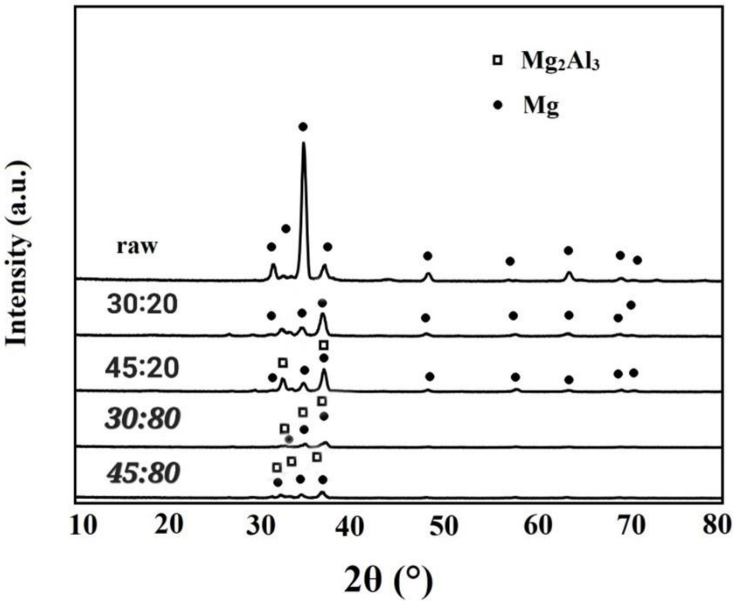

Figure 1. XRD patterns of the raw and shot-peened AZ31 alloy samples

The microstructures of the raw and shot peened samples at 30° and 45° for 20 and 80 min are shown in Figure 2. As can be seen, the grain sizes of the shot peened specimens were reduced, as compared to the coarse-grained microstructure of the raw sample. Furthermore, increasing the shot peening time and angle reduced the grains and raised the deformation layer depth, which can be attributed to mechanical cold working. According to the SEM images, it can be noted that the shot peening time had a greater effect than the shot peening angle on the depth of deformation; the penetration depth increased as the shot peening time increased.

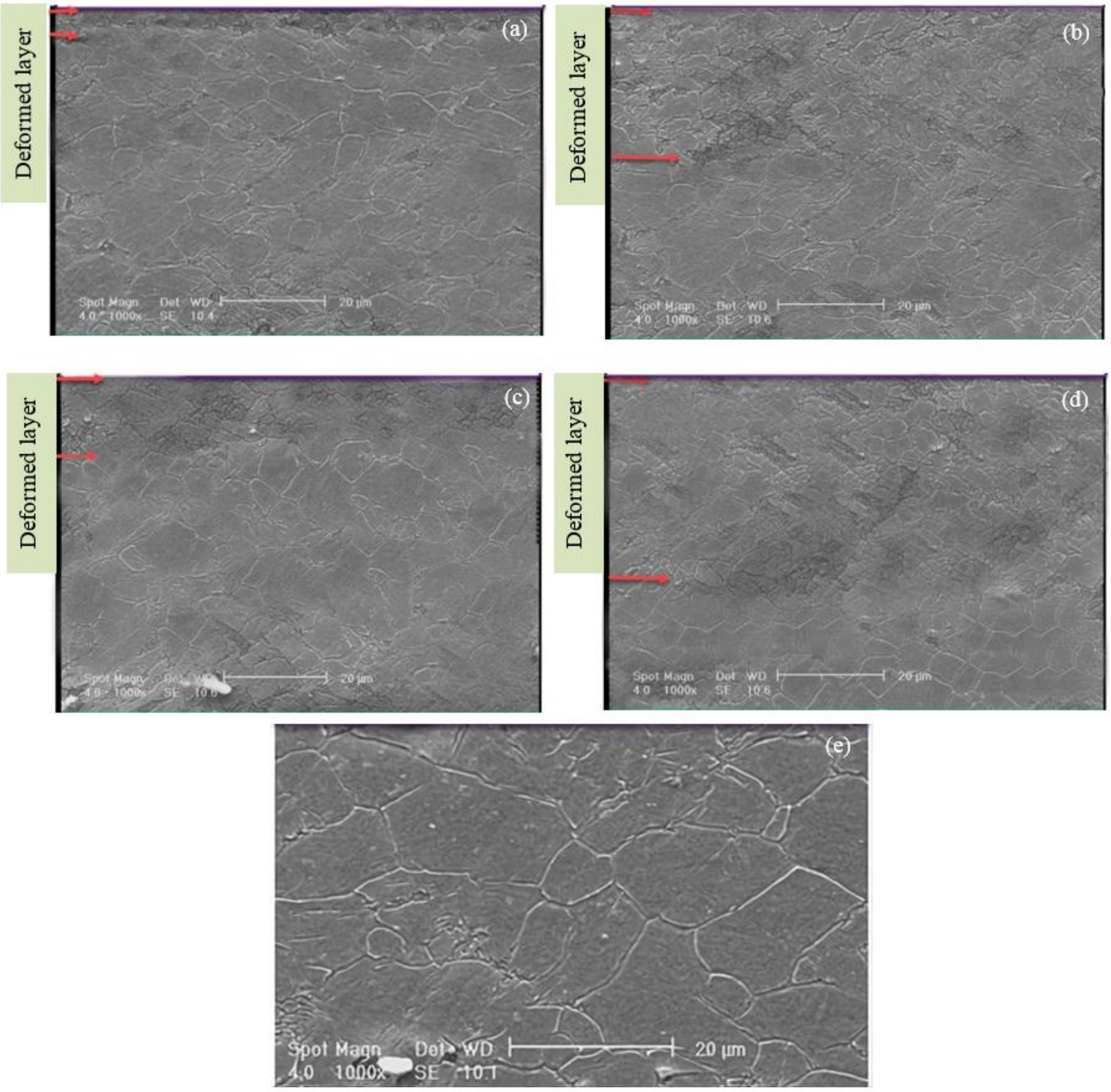

Figure 2. SEM images of shot peened AZ31 alloy samples at shot peening angle and time of: a) 30º and 20 min b) 30º and 80 min c) 45º and 20 min d) 45º and 80 min and e) the raw sample

3.2 Hardness

Figure 3 illustrates the Vickers hardness of the shot-peened specimens at a depth of up to 800 µm. As seen, hardness increased with increasing the shot peening time and angle, which can be explained by the reduced surface grain sizes and increased micro-strains. The samples shot peened at 30° and 45° for 80 min and experienced 200 and 206% hardness enhancement, respectively. The samples shot peened at 30° and 45° for 20 min showed 180% and 184% hardness enhancement, respectively.

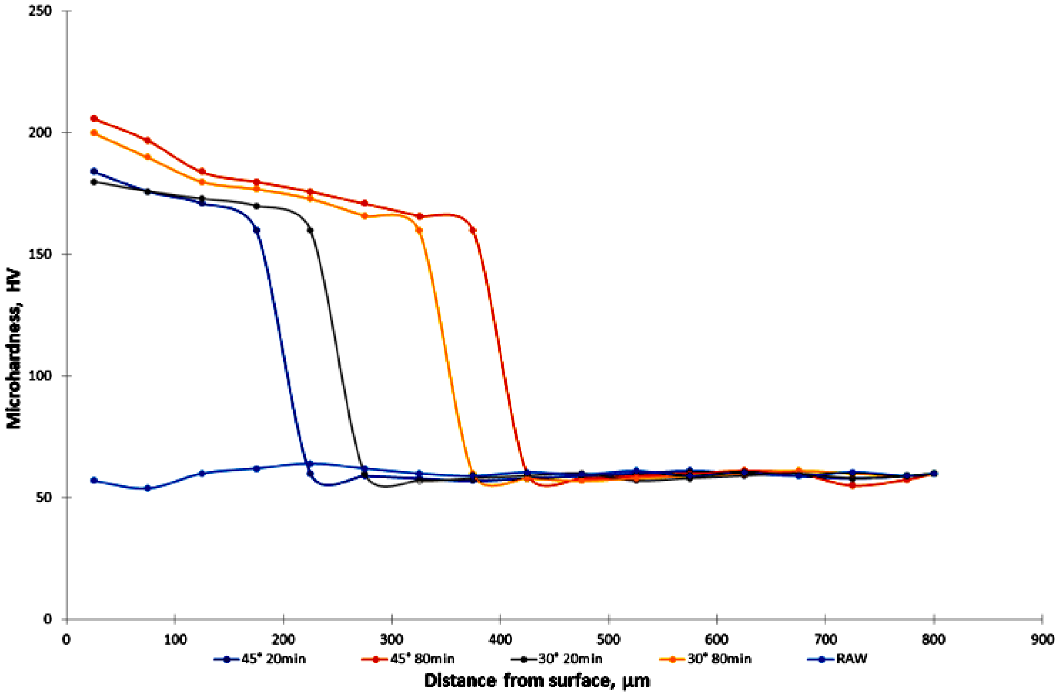

Figure 3. Vickers micro-hardness values of the raw and shot peened samples for various peening angles and times

3.3 Wear

Figure 4 shows the amount of weight loss of the samples in the wear test. It can be seen that as the sliding distance on the surface of each sample increases, the weight loss of the specimens increases. The sample shot peened at 45° for 80 min showed the least weight loss and, therefore, the highest amount of wear resistance. Moreover, evaluation of the weight loss of the samples showed that wear resistance on the surface of AZ31 alloy increased by 34%, 37%, 60%, and 67% for the specimens with the shot peening angles and times of 30º:20 min, 45º:20 min, 30º:80 min, and 45º:80 min, compared with the raw sample (the value of mass loss is 0.3 mg). The higher wear resistance of the shot peened samples than that of the raw sample can be attributed to the reduced grain sizes and increased microstrains on the surface, enhancing the hardness.

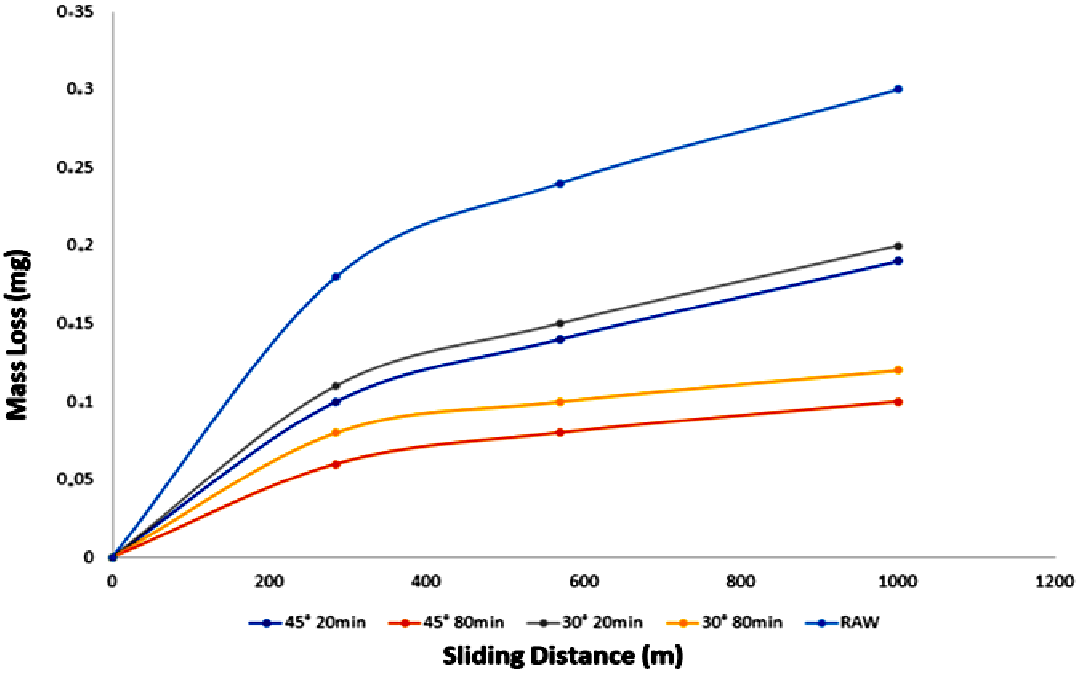

Figure 4. Mass loss values of the raw and shot peened samples versus sliding distance on the surface

- *Wear mechanism*

Figure 5 shows the SEM images of the worn surfaces of the raw and shot peened samples. The wear mechanisms are the abrasive and adhesive wear for all specimens. The scratch regions on the surface well indicate the abrasive wear mechanism. Moreover, the adhesive wear mechanism can be observed in the scattered and multi-layered areas of the specimens. The amount of abrasive and adhesive wear decreased in the shot-peened samples. Also, the specimen shot peened at 45° for 80 min showed the least adhesive and scratch wear due to higher hardness and finer grains. Srinivasan et al. [21] investigated the sliding wear behavior of AZ31 and nano-composites. They concluded that wear reduced as hardness increased. The wear results are in good agreement with earlier works [16, 22].

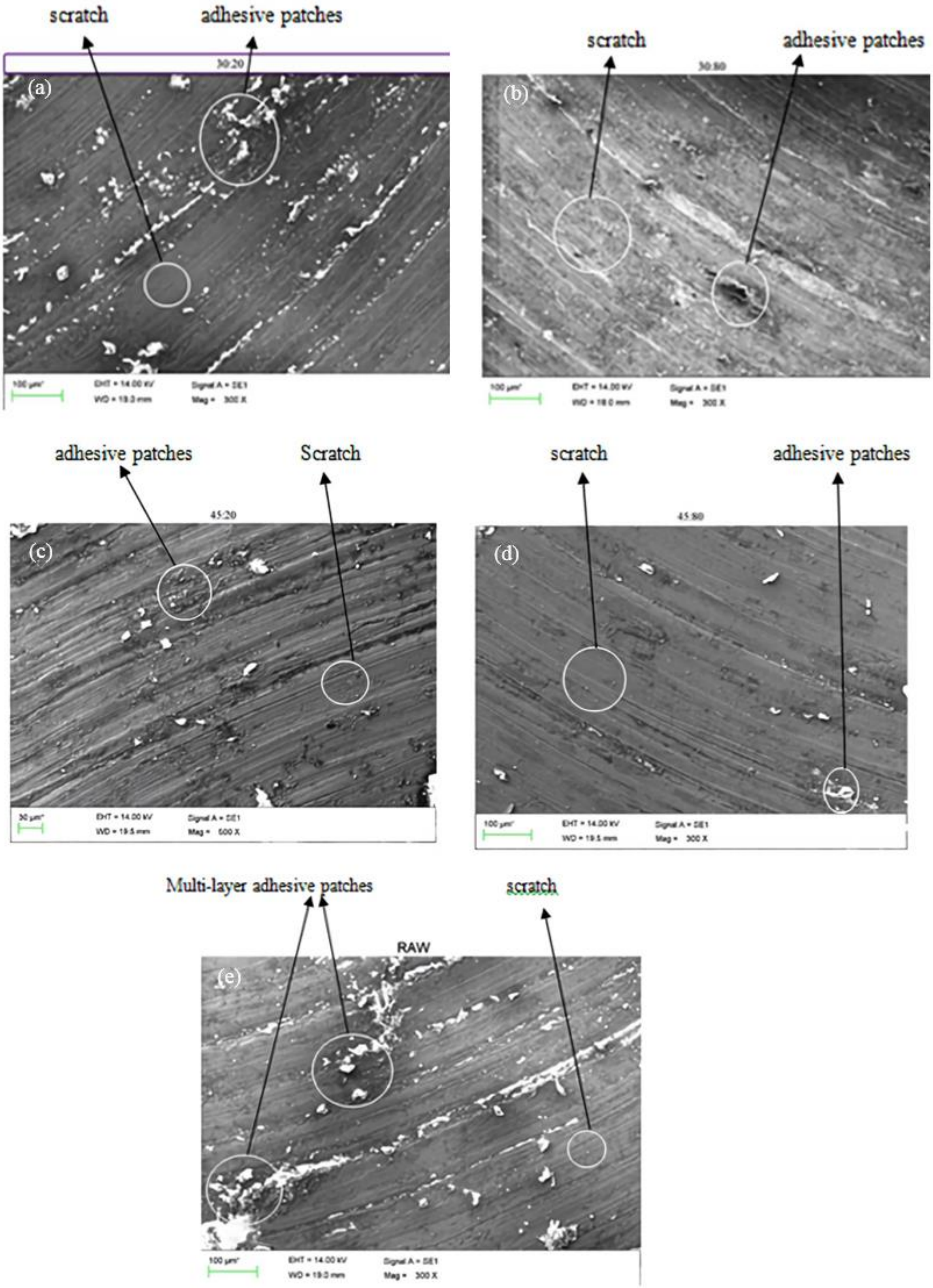

Figure 5. SEM images of the wear mechanisms of shot peened AZ31 alloy samples at shot peening angle and time of: a) 30º and 20 min b) 30º and 80 min c) 45º and 20 min d) 45º and 80 min and e) the raw sample

4. Conclusions

This paper investigated the effects of the shot peening angle and time on the microstructure and wear behavior of the AZ31 alloy. The results can be summarized as follows:

- Shot peening widened and reduced the XRD peaks, representing grain size reduction in the shot peening operation.
- Grain sizes were reduced with increasing shot peening angle and time. The crystallite size was reduced from 520 Å in the raw sample to 169 Å in the sample shot peened at 45° for 80 min. However, shot peening time had a greater effect than shot peening angle.
- Shot peening at 45° for 80 min resulted in a 206% hardness enhancement. Shot peening improved grain refinement through cold working, enhancing surface hardness.
- The wear resistance of the shot-peened samples increased as the peening angle and time increased. The wear resistance on the surface of AZ31 alloy increased by 67% for the specimen shot peened at 45° for 80 min.
- The adhesive and abrasive wear mechanisms were observed in all samples. Furthermore, the amount of adhesive and abrasive wear was reduced in the shot-peened samples.

5. References

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