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Araştırma Makalesi

Bilyalı Dövme İşleminden sonra Ti6Al4V Alaşımının Tribolojik Özellikleri

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ÖZET

Bu makale, bilyalı dövme işlemi yapılan Ti6Al4V'nin mikroyapısını ve aşınma özelliklerini araştırmayı amaçlamaktadır. Bilyalı dövme işlemi, malzemelerin yüzey ve sürtünme özelliklerini iyileştirmek ve ayrıca Ti6Al4V alaşımının artık gerilme tabakasını iyileştirmek, mekanik özelliklerini geliştirmek için kullanılmıştır. Bilyalı dövme öncesi ve sonrasında Ti6Al4V malzemede aşınma testi yapmak için disk üzerinde pim sisteminde tribometre kullanılmıştır. Bilyalı dövme işlemi yapılan Ti6Al4V alaşımının yüzey pürüzlülüğü, mikro yapısı, sertliği ve tribolojik özellikleri incelenerek değerlendirilmiştir.

Anahtar kelimeler: Bilyalı Dövme, Ti6Al4V, aşınma, yüzey pürüzlülüğü.

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Research Article

Tribological Properties of Ti6Al4V Alloy After Shot Peening Process

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ABSTRACT

This paper aims to investigate the microstructure and wear properties of Ti6Al4V induced by shot peening. Shot peening process has been used in order to improve the surface and frictional properties of materials, and also used to develop the compressive residual stress layer and enhance the mechanical properties of Ti6Al4V alloy. A pin on disc tribometer is used to carry out the wear test in Ti6Al4V material before and after shot peening. The effects of surface roughness, microstructure hardening induced by shot peening on the tribological properties of Ti6Al4V alloy are evaluated.

Keywords: Shot peening, Ti6Al4V, wear, surface roughness.

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1. Introduction

Titanium alloys have been widely used in aerospace, aviation, and navigation, chemical and petrochemical industries due to their superior properties. In the manufacture of aircraft engines, titanium alloy can significantly improve the weight ratio and the mechanism thrust efficiency of the engine (Yao et al. 2016; Sonntag et al. 2015; Liu and Li 2019; Yıldıran et al. 2015; Xie et al. 2016). However, the further development of titanium alloys is limited by their low hardness, poor abrasion resistance, and low fatigue strength, low thermal conductivity and high coefficient of friction (Chen et al. 2014; Costa et al. 2006).

The fatigue strength of titanium alloys can be increased by surface modifications or coatings. The shot peening process has been proven an effective approach to improve the surface performance of metallic components. Shot peening is a method to improve the fatigue strength of the metallic alloys He et al. 2018; Kubler et al. 2019; Żebrowski et al. 2019; Azar et al. 2010; Kovacı et al. 2019). Surface modifications produced by the shot peening treatment are (a) roughening of the surface (b) an increased, near surface, strain hardening and (c) the development of a characteristic profile of residual stress (Azar et al. 2010). Shot-peening is used in many industrial applications, e.g. steam turbine blades, aircraft landing gear, springs, bearings, and other structural components (Marteau et al. 2015; Kumagai et al. 2014; Wiertel et al. 2017). During this process, a thin layer of cold plastic deformation near the surface is generated by bombarding the surface repeatedly with high velocity particles. By generating work hardening and introducing compressive residual stress into the material, the crack initiation and propagation are suppressed, which results in a fatigue performance improvement of the workpiece (Chen et al. 2018; Chen et al. 2019). For the conventional shot peening treatments, the magnitude of the compressive stress and work hardening capacity depend on the energy delivered by the shot as it impinges on the surface and the hardness and strain hardening properties of the material being treated (Fedoryszyn et al. 2009).

In this study, the effects of the controlled changing pressure in shot peening process on titanium alloy were discussed. The hardness, surface roughness test, Almen test, wear test of titanium alloy (Ti-4Al-6V) were performed as a result of shot peening process applied at three different pressure values and their microstructures were examined with scanning electron microscope.

2. Experimental Procedure

Specimens were cut in MAZAK FJV-250 CNC-3 axis machine and prepared according to the following parameters(Table 1) during milling process.

Table 1. Milling process parameters.

Cutting Tool	Cycle/minute	Progress mm/minute	Cutting Value (mm)
Ø10-40 mm	1200	1000	0.3 mm

The plate was cut into four equal pieces with Makino U53TJ wire erosion machine. Shot peening process was performed by the air blast machine (Sisson Lehmann MP1500 TI) using carbon steel shots (S230). Shot peening process parameters were summarized in Table 2. In order to assess the influence of shot peening intensity on the surface integrity, three different peening pressure were applied to the titanium alloy (Ti-4Al-6V).

Table 2. Shot peening process parameters.

Shot Peening Ball	S230 Steel Shot Per AMS 2431/2
Ball Hardness(HRC)	52-62
Number of Nozzles	1
Nozzle Size(mm)	9.5
Air Pressure(bar)	0.5-1-1.5

The Almen test was used to determine the shot peening process performance. Almen test verified and recorded the intensity before processing the first part, and also verified that shot peening machine was set-up and running according to the approved design parameters (Fedoryszyn et al. 2009). Almen test strips exist in three standard thickness designated as N for low, A for medium, and C for high intensity. The A strip with the thickness ±0.025mm was used. The Almen test (Mahr Federal Almen Gage) parameters were summarized in Table 3.

Table 3. Almen test parameters.

Application Time (sec)	Shot Peening Angle (°)	Shot Peening Pressure(bar)
20	90	0.5
20	90	1
20	90	1.5

Hardness of the samples was determined via Mitutoyo Hardness Testing Machine using diamond tip HRC/HR15N. The hardness tests were repeated three times to get the most accurate result. Surface roughness tests were performed by using Mahr Perthometer S2 PGK 120. A total of three measurements were made on each sample at different areas and average value with the standard deviation was reported. The surface topography was characterized by scanning electron microscope (SEM, JEOL JEM-700F).

The work specimen was undergone to wear test in ball on plate tribometer (UTS Tribometer T10/20) before and after shot peening process. 100Cr6 balls were used as the counterface material during dry sliding. Test parameters were given in Table 4.

Table 4. Wear test parameters.

Load (N)	2	5
Sliding Distance (m)	50	50
Velocity (mm/s)	20	20

3. Results and Discussion

The hardness measurement results of the shot peened Ti6Al4V and the reference Ti6Al4V samples were given in Figure 1. The effect of shot peening parameters on hardness values was evaluated. The maximum hardness value was obtained by the increase of the spray pressure. While the hardness value of the reference sample was 33.40 HRC, the hardness values of the samples shot peened with 0.5 bar, 1 bar, 1.5 bar were measured as 34.10 HRC, 34.30 HRC and 34.60 HRC, respectively. According to these results, it was seen that the increase in pressure together with the increase in hardness was effective.

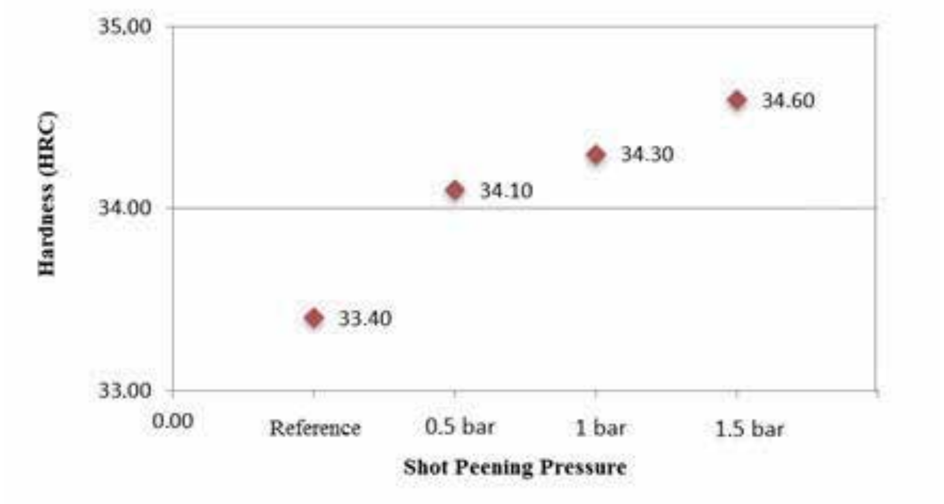


Figure 1. The diagram of hardness-shot peening pressure.

There is a relation between surface hardening and roughness induced by shot peening, pressure increase in course of shot peening process causes the increase of surface roughness (Żebrowski et al. 2019; Azar et al. 2010).

As a result of the surface roughness tests (Figure 2), it was observed that the surface roughness of the samples increased with the increase of the pressure in the shot peening process and the increase of the shot peening intensity in direct proportion. Since Ra value increased with increasing severity, deterioration was observed not only with the roughness measurement result but also after microstructural investigation. The surface roughness value Ra increased significantly after shot peening process, compared to the reference sample (Ra = 14.30 µm). Ra values were 18.50 µm, 28.30 µm, 45.30 µm respectively, in the samples shot peened with 0.5 bar, 1 bar, 1.5 bar pressure. Ra had a major effect on the fatigue performance. Rough surface profiles increased the local stress reported by Kumar, et al.

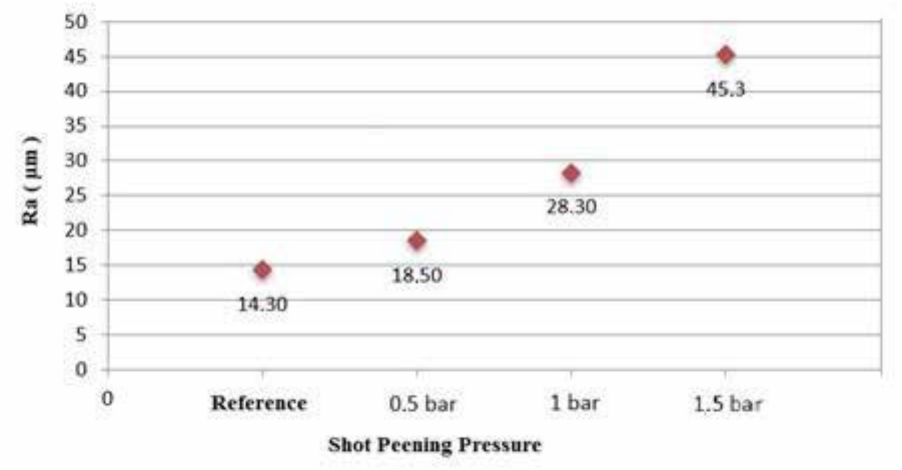


Figure 2. Correlation between the surface roughness and shot peening pressure.

The correlation between the arc height (Almen Intensity) and shot peening pressure were given in Figure 3. According to Almen Test, as the shot peening pressure increased, the arc height increased. It was observed that for a different peening pressure conditions, Almen intensity values increased. The arc height values increased as the pressure was increased from 0.5 to 1.5 bar. The peening pressure showed a linear trend with the Almen intensity. The influence of shot peening pressure exhibited in the Almen curvature arc height may be correlated to the absorbed energy in the Almen strips employed (Kumar et al. 2019).

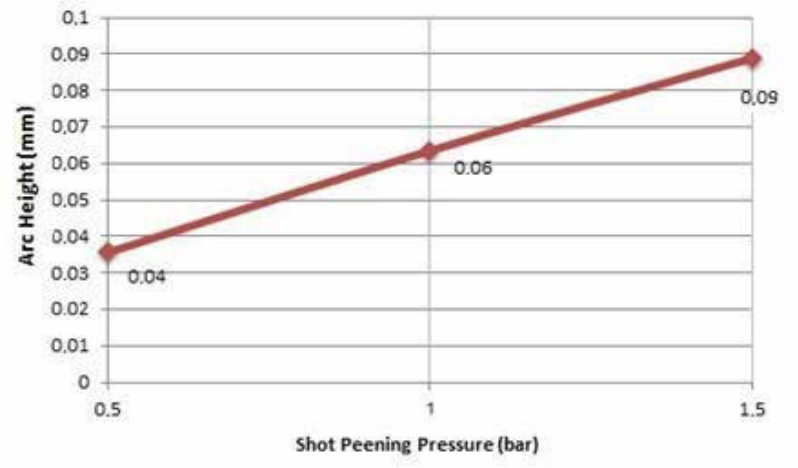


Figure 3. Correlation between the arc height and shot peening pressure.

The optical microscope images of the samples shot peened at different pressures (0.5;1;1.5 bar) were given in Figure 4. As the shot peening pressure increased, the intensity increased and also the deformation amount increased on the surfaces.

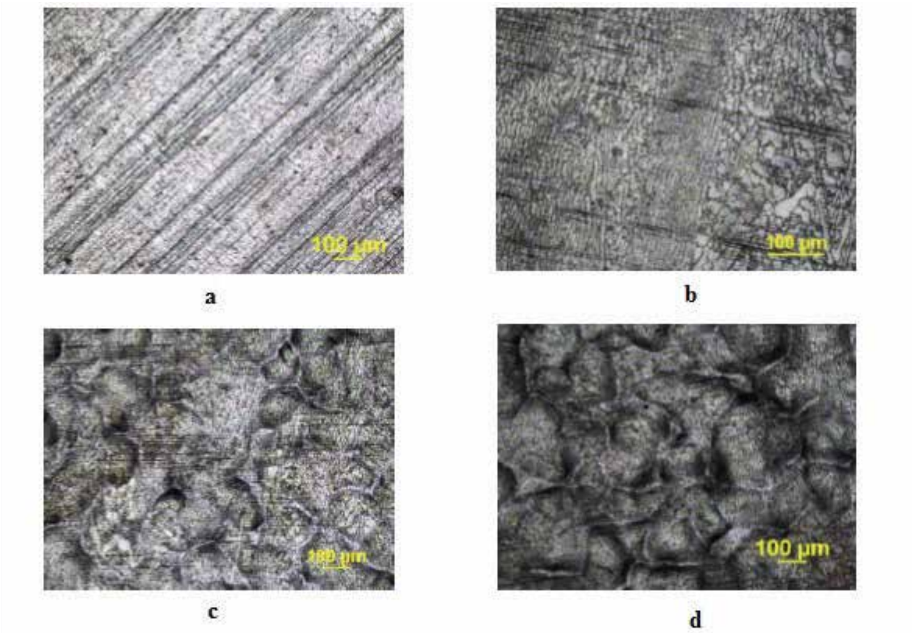


Figure 4. Optical microscope images of the samples shot peened at different pressure a) reference sample (untreated sample) b) 0.5 bar c) 1 bar d) 1.5 bar.

Morphological changes (Figure 5) on the sample surfaces and counter surfaces were analyzed via an optical microscope to explore wear scar widths, wear radius. When considering at the width of the wear scars, the widest scar was measured for the sample shot peened with 0.5 bar-worn under 5 N as 1733.04 µm. When looking the counter surfaces, wear diameter of the sample shot peened with 0.5 bar, worn under 5 N was 871.94 µm.

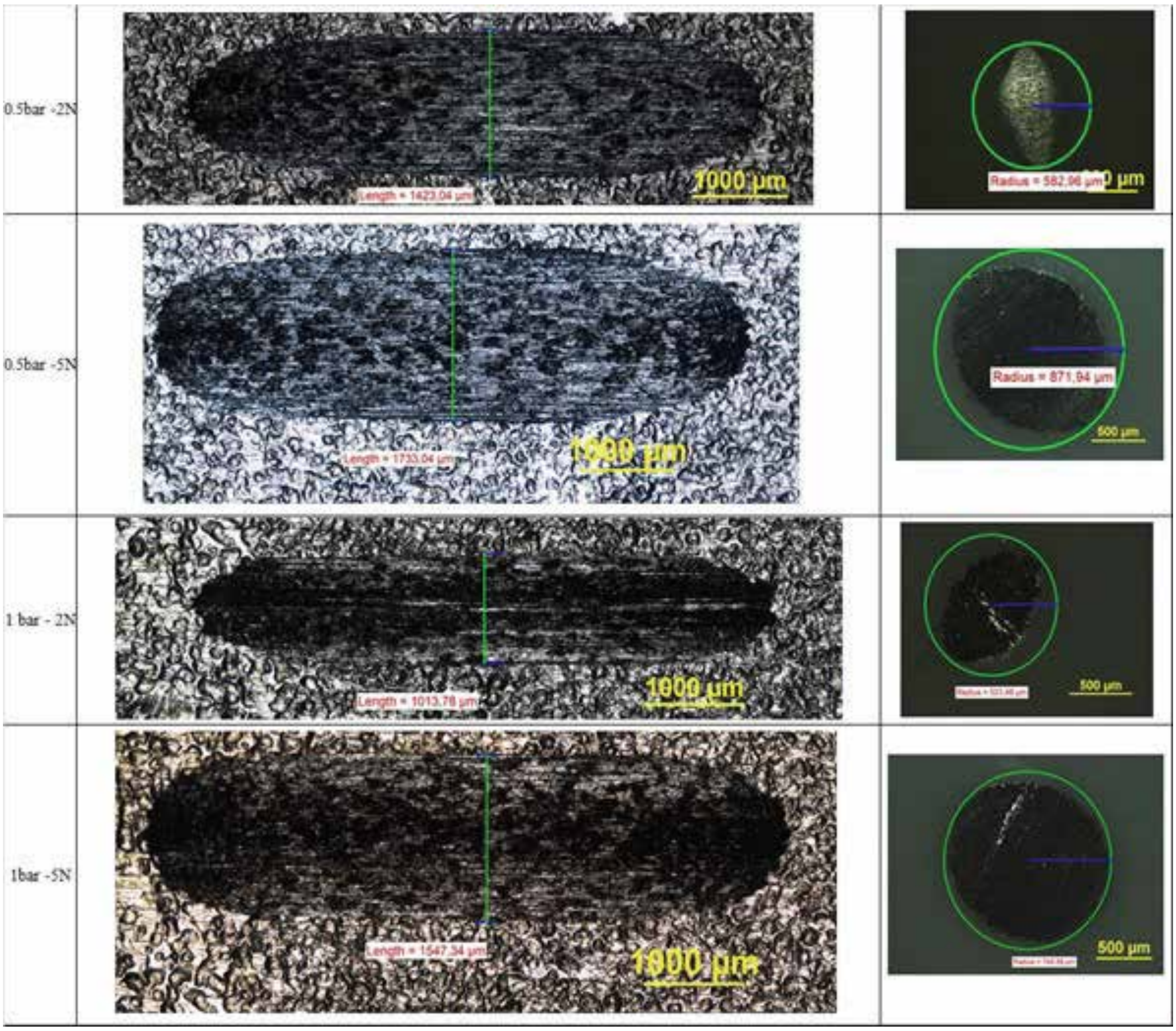
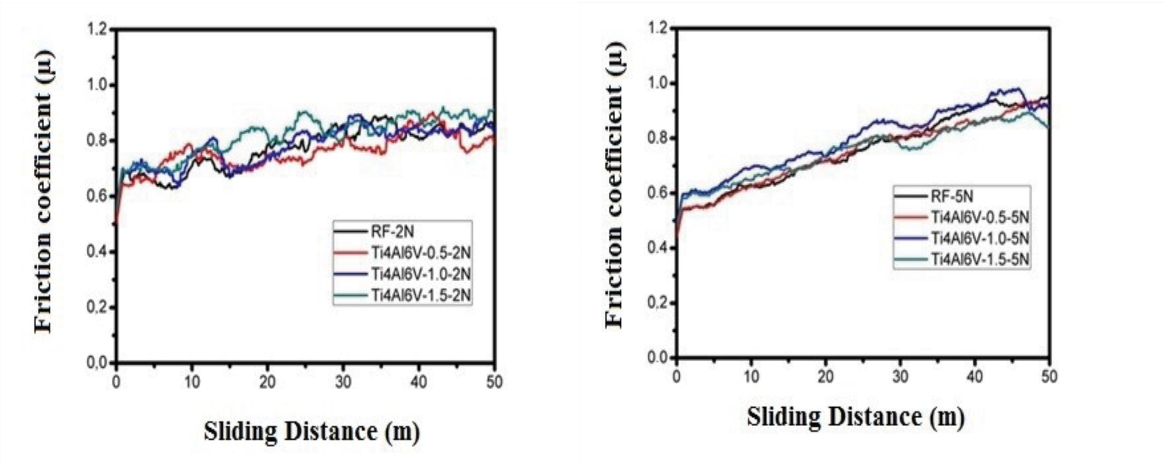


Figure 5. Optical microscope analysis of wear scars of the samples (with 0.5 bar-1 bar shot peening pressure), counter surfaces under 2 N-5 N load.

The friction force (2N and 5N) - sliding distance diagrams of reference Ti6Al4V and shot peened Ti6Al4V samples were given in Figure 6. The friction coefficient increased proportionally as the sliding distance of the applied force increased. The reference sample had low surface roughness, it had low surface hardness. A decrease in wear rates due to increasing surface hardness with shot peening treatments was observed. It was determined that wear rates were decreased by increasing shot peening pressure. It also increased the surface roughness values. Therefore, the effects of both hardness and surface roughness on surface resistance should be taken into consideration as reported by Kovacı, et al. The deterioration layers began to form on the surfaces. The graphics came out with variability because of the roughness that occurred on the surface after shot peening.



(a) (b)

Figure 6. Correlation between the friction coefficient and sliding distance of the samples worn under a) 2 N b) 5 N load.

The microstructural changes (Figure 7 and Figure 8) could be seen with the increase of the shot peening pressure. The increase in pressure caused the formation of microcracks, also deep and large pits occurred. As the shot peening pressure increased, wear tracks were formed as large scratches (Figure 7c and 8c). The scratches caused high wear depth. Severe adhesive wear traces were seen in wear scar as also reported by Kovacı, et al.

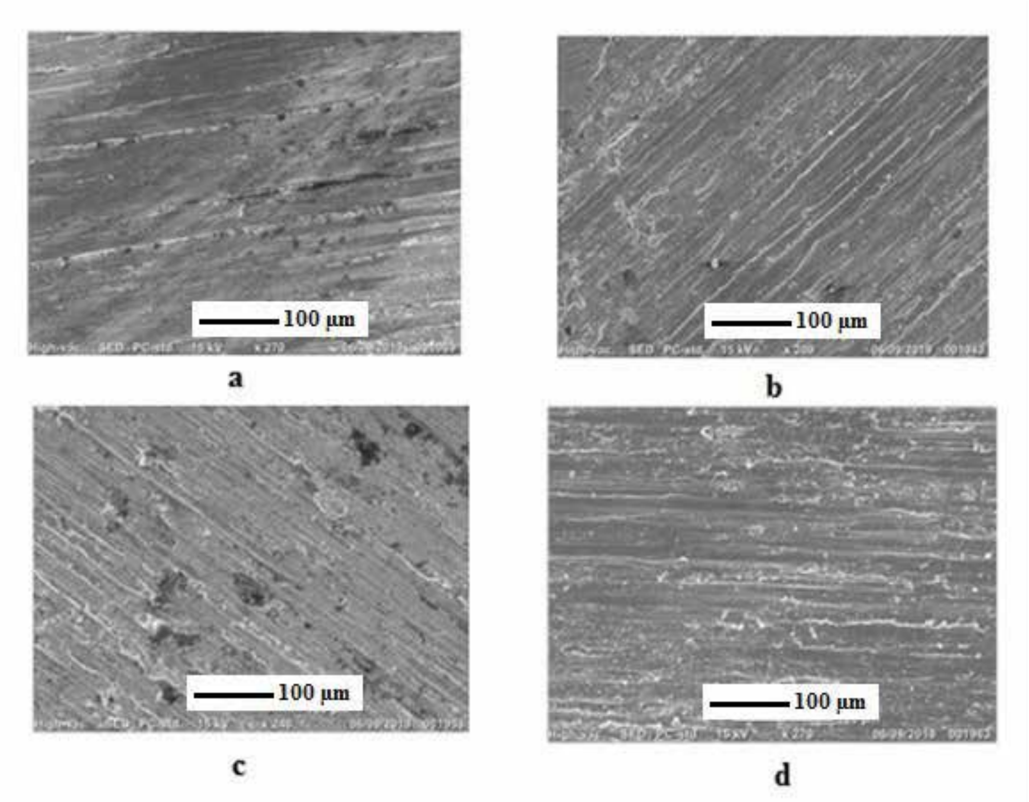


Figure 7. SEM photos of wear surfaces of the samples under 2 N, shot peened at different pressure a) reference sample (untreated sample) b) 0.5 bar c) 1 bar d) 1.5 bar.

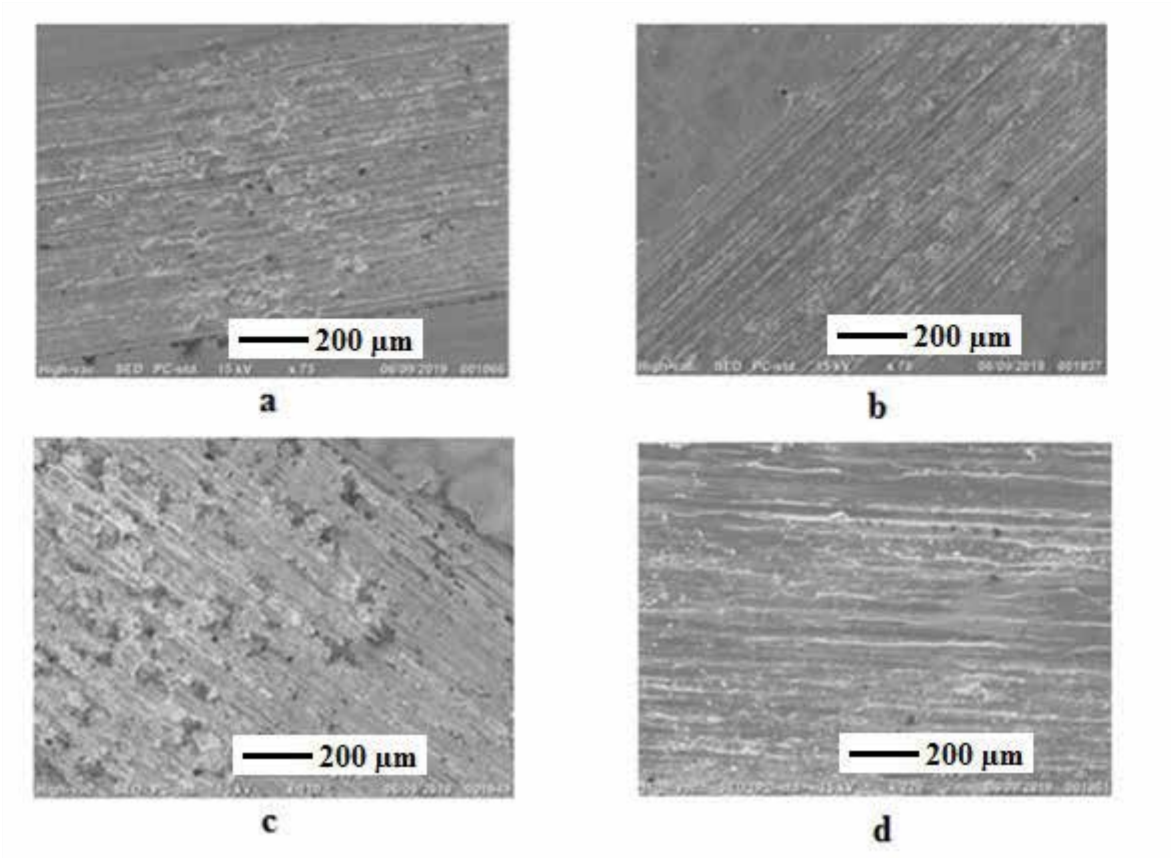


Figure 8. SEM photos of wear surfaces of the samples under 5 N, shot peened at different pressure a) reference sample (untreated sample) b) 0.5 bar c) 1 bar d) 1.5 bar.

4. Conclusions

In this study, the shot peening process was applied to Ti6Al4V alloy. Microstructural and hardness characterization of the samples were performed to investigate the effects of shot peening on the mechanical properties and microstructure of Ti6Al4V alloy. It had been shown that shot peening pressure played an important role in surface properties. It was seen that there was an increase in the surface roughness in the images taken as a result of different shot peening pressures. This situation had been associated with a more severe shot peening operation as a result of the increased pressure and the increase of kinetic energy of the balls. As the shot peening pressure increased, the microstructure changed severely. It had been observed that plastic deformations occurred on the surface after shot peening operations performed at high pressure. It was also understood from the microstructures that in the samples subjected to the wear test after the shot peening process, the current strength applied in the shot peening and the wear marks increased as the applied load increased. The increase in the values of the traces paralleled the surfaces deteriorated with the shot peening, and the radius values also increased. Shot peening increased the surface roughness values of titatinum alloys and consequently, they increased friction coefficient values. And also, shot peening improved the wear resistance of the samples. The results presented in this study were expected to provide a resource for understanding the changes in microstructural and tribological properties that affect the wear behavior depending on the shot peening parameters of titanium alloys used in aviation.

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