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Effect of anodic oxidation on tribological behavior of 2017A alloy

Anodik oksidasyonun 2017A alaşımının tribolojik davranışına etkisi

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Highlights

- *The anodic oxidation process made a positive contribution to the hardness values of the 2017A alloy.*
- *The lowest coefficient of friction was obtained in hard anodized coatings.*
- *The highest wear resistance was measured in phosphorus-coated samples.*

Graphical Abstract

In this study, the effect of two different anodic oxidation (hard anodizing and phosphoric coating) on the wear properties of 2017A aluminum alloy was investigated.

Figure. Graphic abstract

Aim

In this study, it was aimed to improve the tribological properties of 2017A aluminum alloy by anodic oxidation.

Design & Methodology

In order to investigate the effect of 2017A aluminum alloy hard anodizing and phosphoric anodic oxidation, the microhardness, friction coefficient, wear resistance, vibration, and worn surface images of the samples were evaluated.

Originality

The effect of hard anodizing and phosphoric anodic oxidation on the tribological properties of 2017A aluminum alloy.

Findings

Anodic oxidation has improved the tribological properties of the 2017A aluminum alloy.

Conclusion

Anadic oxidation improved the wear properties of 2017 A aluminum alloy. Hard Anodizing (HAC) further increased the wear resistance of the samples.

Declaration of Ethical Standards

The author of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Effect of Anodic Oxidation on Tribological Behavior of 2017A Alloy

Araştırma Makalesi / Research Article

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ABSTRACT

Anodic oxidation is used to improve the wear resistance and surface properties of aluminum alloys. In this study, the effect of two different anodic oxidation (hard anodizing and phosphoric coating) on the wear properties of 2017A aluminum alloy used as a model aircraft engine piston was investigated. In order to determine the effect of anodic oxidation, microhardness, friction coefficient, wear resistance, vibration, and worn surface images of the samples were evaluated. It was concluded that anodic oxidation significantly improved the hardness, friction coefficient, and wear resistance of the samples.
Keywords: Anodic oxidation, wear resistance, pin on disc, 2017A aluminum alloy.

Anodik Oksidasyonun 2017A Alaşımının Tribolojik Davranışına Etkisi

ÖZ

Anodik oksidasyon, alüminyum alaşımlarının aşınma direncini ve yüzey özelliklerini iyileştirmek için kullanılır. Bu çalışmada, model uçak motoru pistonu olarak kullanılan 2017A alüminyum alaşımının, aşınma özelliklerine iki farklı anodik oksidasyonun (sert eloksal ve fosforik kaplama) etkisi incelenmiştir. Anodik oksidasyonun etkisini belirlemek için numunelerin mikrosertlikleri, sürtünme katsayıları, aşınma dirençleri, titreşim ve aşınmış yüzey görüntüleri değerlendirilmiştir. Anodik oksidasyonun numunelerin sertliğini, sürtünme katsayısını ve aşınma direncini önemli ölçüde iyileştirdiği sonucuna varılmıştır.
Anahtar Kelimeler: Anodik oksidasyon, aşınma direnci, disk üzerine iğne, 2017A alüminyum alaşımı.

1. INTRODUCTION

The anodic oxidation (Anodizing/Anodization) process is one of the methods used to improve the surface properties of aluminum alloys, such as wear resistance [1-3]. In the anodic oxidation process, the current is supplied to the system and the acid and water in the solution are separated into ions. Anodic oxidation is carried out by attracting the negatively charged oxygen ions to the anode, which is the positive pole and forming a reaction on the aluminum surface [4]. Anodic oxidation is often used to obtain oxide coatings on aluminum surfaces [5]. Different types of electrolytes and anodizing processes are used according to the place of use of aluminum and the alloy type of aluminum used.

Aluminum alloys are used in many different fields such as automotive and aerospace due to their superior properties [2, 6-12]. In addition to many superior properties (such as high corrosion resistance, light weight), weak tribological and interfacial mechanical properties also create some disadvantages [14]. To improve the low tribological properties of the Al alloy, anodic oxidation, which is a protective oxide coating, is one of the methods used [5, 15-17]. Studies on such coatings are carried out to improve the mechanical properties and tribological of aluminum alloys. In the studies, the effects of many different parameters of anodic oxidation on the mechanical and tribological properties of aluminum alloys were investigated. Pikas et al. [18] investigated the possibility of improving the tribological properties and corrosion resistance of hard anodized A606H-26%Al_2O_3P material. They applied the experiments of the material in pin-on disk device according to ASTM G99 standard. They observed that composite anodization had a significant beneficial effect in reducing the wear rate. Guezmil et al. [19] investigated the tribological behavior of Al5754 aluminum alloy as a result of an anodic coating. In their tests the on pin-on-disc device, the effects of sliding speed, test loads and oxide thickness on friction coefficient values were investigated. As the load and sliding speed increased, the friction coefficient increased. The increase in these two parameters caused an increase in the friction contact temperature and the heat produced accelerated the oxidation events and the transfer. According to their results, low-thickness anodic oxide layers seem to be more effective in terms of friction. Suprapto et al. [20] aimed to increase the strength of Al6061 material with an anodized coating method in their research. The method they applied in this study is to use experimental tests on solution-type sulfuric acid and phosphoric acid with variations in voltage and immersion time. According to their results, they have seen that the anodizing stress and time affect the wear rate of aluminum 6061. The higher the anodizing time and voltage, the lower the wear rate

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value, so that the wear resistance of aluminum has improved 14 times more than the wear resistance of the base metal. Polat et al. [21] coated wear resistant oxide on 2017A–T6 Al alloy with different sodium silicate concentrations. They used surface profilometry, scanning electron microscope, X-ray diffraction, and optical microscope devices to examine the coatings. Tribological tests were also applied to the samples. As a result of the experiments, it was determined that the surface hardness and wear resistance increased. Coatings were produced using three different electrolytic solutions. Ali et al. [22] In their studies, hard anodized coating was applied on AA7075-T6 alloy by PVD magnetron sputtering process. After examining the tribo-mechanical properties of the material, they compared it with the untreated alloy. After anodizing, the hardness of AA7075-T6 increased approximately 1.94 times. The results revealed that the anodized coating reduced the wear of the samples. They observed that the anodizing process nearly tripled the wear resistance of AA7075-T6 and reduced the wear rate by about 4.3 times. Pires et al. [23] In their research, they made two different coatings on SAE 305 aluminum alloy. The processes they apply are anodizing and diamond-like carbon coating, respectively. The samples were examined in terms of wear rate, hardness roughness, and coefficient of friction. Surface characterization of the samples was also done. As a result, the carbon coating increased the wear resistance of the samples. Only minor improvement was observed in the anodizing process. Kim et al. [24] investigated the tribological properties of nanostructured anodic aluminum oxide (AAO) films. The effects of AAO films with various nanopore sizes on the tribological behavior of the samples were investigated. They made the analysis in relation to contact load and pore size (pore diameter). Homogeneously arrayed nonporous aluminum oxide films were synthesized by anodizing. When the load increased 3 times, the friction coefficient value decreased by about 30%. The pore size of the AAO films made on the samples significantly affected the tribological properties of the samples. The pore size is important in the coefficient of friction at high loads but is negligible at low loads. Dejun et al. [25] 7475 aluminum alloy using anodic oxidation was coated with an oxide film layer. They investigated the friction and wear performance of the film by performing tribological tests at different loads. After anodic oxidation, the average coefficient of friction decreased, indicating improved friction performance. Guo et al. [26] coated 6061 aluminum alloy samples with an oxide film using 160 g/L sulfuric acid as the electrolyte by changing the electrolyte temperature (5, 15 and 25 °C). They evaluated the phase composition, microstructure and morphological properties of the samples. The instruments they use are the X-ray diffractometer and the field emission scanning electron microscope. Tribological properties, elastic modulus and, hardness of the films were also investigated. To obtain these values, hardness testers and rotary friction tester were used. The results showed that the oxide films turn into a loose porous structure as the temperature of the electrolyte increases. It was also observed that the thickness of the films increased. Electrolyte temperature has a significant effect on the friction performance of AAO films. Guezmil et al. [27] In their studies, anodic oxide layers were formed on Al 5754 and Al 1050A alloys under anodizing conditions (electrolyte, current density and temperature). They investigated the effects of these layers on the coefficient of friction and Vickers microhardness. The temperature at which the results were observed was 5 °C and was obtained by adding 10 g/L oxalic acid. Mohitfar et al., [28] In their research, several current densities were applied to the Al6061 alloy at different times to perform the hard anodizing process. Two types of electrolytes containing sulfuric acid or oxalic acid in various concentrations were used as a bath. They measured the microhardness of the coatings. They used sulfuric acid or oxalic acid electrolytes in the experiments. In general, hard anodizing in sulfuric acid increased the hardness more. It also increased the wear resistance. In their research, Akcan et al. [29] used sandblasted, anodized and polished Etial 171 Al alloys to determine the surface properties of the substrate material before coating. Anodizing conditions and thickness of the oxide layer, contact angle of aluminum substrates, surface roughness values, optical microscope images were examined by using AFM examinations and XRD analyzes. The end of the investigations; It was observed that the surface roughness value was high in sandblasted aluminum and it was thought that the coating would show better properties on the rough surface. Bargui et al. [30] studied the optimization of microhardness and tribological properties of anodized Al 5754 aluminum alloy. Three anodizing bath parameters, namely bath temperature, current density and sulfuric acid concentration, were used. The selected responses are: microhardness, wear rate, and growth rate of the anodic oxide layer. They used a multi-criteria optimization to microhardness and wear rate. Estimated value responses under optimal anodizing conditions were found to be 0.64 µm/min, 442 HV and 4.8% for growth rate, microhardness and wear rate, respectively.

Many different Al alloys were used as substrate in the coating studies. In addition, mechanical, tribological etc. of different process parameters related to the anodic oxidation process effects on the properties were investigated. In this study, anodic oxidation process was applied to the samples in order to improve the wear properties of the 2017A (AlCu4MgS) alloy, which is the piston material used in model aircraft engines. Hard Anodized and Phosphorus coating process was applied to the samples. In order to investigate the effect of the two oxidation processes on the tribological properties of the samples, wear tests were carried out on a pin-on-disc tester. With this research, it is desired to increase the wear resistance of 2017A alloy pistons, which are subject to intense wear.

2. MATERIAL METHOD

2.1. Material

Aluminum 2017A (AlCu4MgS) alloy with dimensions of Ø10 x 20 mm was used in experimental studies. Its density is 2.79 g/cm³. 2017A aluminum alloys are Al-Cu based alloys. The main alloying element is copper. Other alloying elements, especially magnesium, can also be found, and it is widely used in the aviation industry where high strength is required. The chemical composition according to the manufacturer's certificate of the aluminum 2017A alloy used in the experiments is given in Table 1.

Table 1. Elemental composition of Aluminum 2017 A (AlCu4MgS) alloy

Si	Fe	Cu	Mn	Zn	Ag	Li	Zr	Al
0.13	0.14	4.1	0.85	0.2	0.15	0.9	0.015	Rem

2.2. Coating

In order to improve the tribological properties of aluminum materials, it is subjected to processes such as anodizing. Anodizing process was applied to increase the wear resistance, hardness etc. of aluminum 2017A samples. Anodizing process type and anodizing application parameters were determined according to literature studies. Test samples were subjected to Hard Anodizing / Anodization (Sample: HAC) and Phosphorus coating (Sample: PC). The results of the coated samples were compared with the uncoated samples (Sample: UC). Hard anodized coating process was applied in 10 minutes for 8 µm at a concentration of 160 gr/lt in an environment of 14 Volts and 18 °C. Phosphorus coating was carried out at a concentration of 240 gr/lt at a concentration of 50 volts and at 25 °C in 8 µm thickness in 10 minutes. At the end of the process, the test samples were thoroughly cleaned from acid by four rinses. Coated test samples are given in Figure 1.

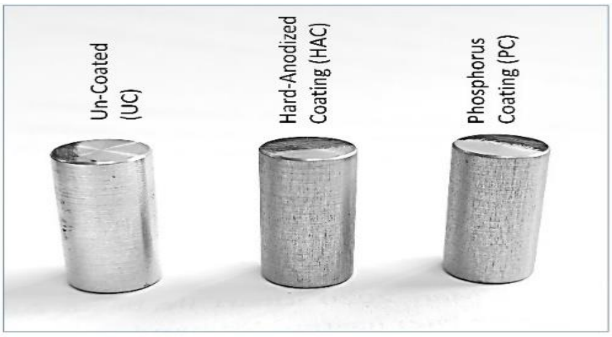


Figure 1. Test samples

2.3. Micro Hardness measurements

The hardness of the anodic oxide is very important for the protection of the aluminum substrate in industrial applications. Hard anodic coatings enable long-lasting aluminum products and the expansion of their applications [31]. The anodizing process affects the hardness of the samples. The applied anodizing process affects the hardness values with the type and parameter. Therefore, the microhardness of the samples was measured after anodizing. The hardness values of the samples affect the tribological properties. In order to investigate the effect on the hardness of the anodizing, the hardness of the samples was measured according to the ASTM E384-17 standard. Hardness measurements the average of five measurements was taken using the Metkon Duroline micro hardness tester. The accuracy of the instrument was ensured with a standard test block before each measurement. 20 sec waiting time and 500 gf load were kept constant for all measurements. For the reliability of the hardness test results, measurements were taken from 12 different parts of the sample. The lowest and highest values were subtracted. The remaining 10 values were averaged and the standard deviation was calculated.

2.4. Optical microscope examinations

Dino Lite brand AM7915MZT model digital microscope was used for the images of the worn surfaces of the samples subjected to different Anodic Oxidation processes. As a result of the wear tests, it was desired to determine the effect on the wear behavior of different anodized coated samples. Before the measurements, the digital microscope was calibrated with a calibration gauge to ensure the accuracy of the measurements.

2.5. Friction wear tests

The coatings applied to the samples affect the tribological properties of the materials. Coatings are widely used to improve the wear resistance of materials. It was desired to increase the wear resistance with different anodized coatings applied to the 2017A samples. Turkyus brand Pin-on-Disc wear test device was used to examine the effect of different coating types on the coefficient of friction and wear resistance. It is desired to increase the abrasion resistance of the samples with different types of anodized coating. Ck45 disc with 60 HRC hardness was used in the experiments. The results of the friction tests performed on the Pin On Disc tester were evaluated according to the ASTM G99-05 standard. Experiments were carried out at room temperature (22 °C), a fixed track diameter of 50 mm, a load of 7 N, a sampling frequency of 5 Hz and a rotation speed of 400 RPM. Each test was repeated 5 times for the reliability of the results. The lowest and highest values were subtracted. The average of the remaining 3 values was taken and the standard deviation was calculated. Before and after the test, the samples were cleaned with a cleaning solution (ethyl alcohol) and dried. The weight loss was calculated to define the wear resistance of the samples. Weight loss was realized on Radwag brand precision balance.

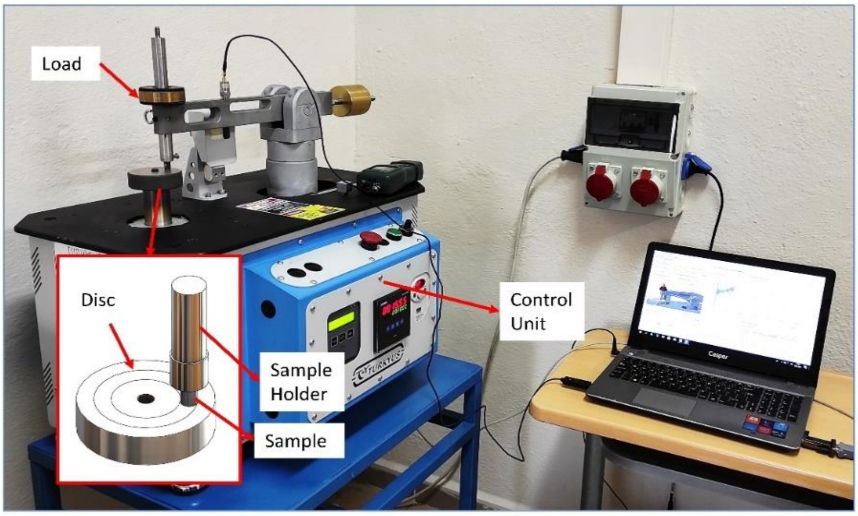
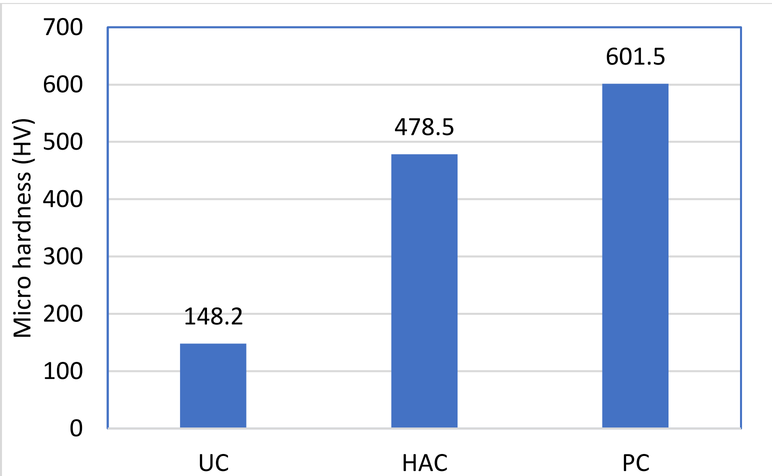


Figure 2. *Experiment setup*

3. RESULT AND DISCUSSIONS

3.1. Micro hardness

Microhardness values of UC, HAC and PC samples are given in Figure 3. The hardness values of the samples were 148.2±2.9, 478.5±5.7 and 601.5±6.8, respectively. The hardness of the samples has increased thanks to the coatings made on the 2017A alloy. The highest microhardness value was reached in PC samples. The hardness increases of PC and HAC samples compared to UC samples is 222.87% and 305.87%, respectively. There is also a significant difference in hardness between coating types. This shows the effect of coating types on hardness. In many studies, it has been stated that anodized coating increases the hardness of the samples [32]. Coatings with oxides and phosphates are said to improve some properties of metallic surfaces such as hardness, wear resistance, electro-insulation properties [33]. The morphology, oxide growth rate, structure and composition of the anodic film affect the mechanical properties of the anodic film [34]. Since these parameters differ in different anodizing processes, the hardness of the coatings differ. The pores of the hard anodized layer are smaller than normal anodizing. therefore the anodized film layer is very hard, resistant to wear [35].



3.2. Coefficient of friction

The effect of hard anodizing and phosphate coating on the friction coefficient of aluminum 2017A alloy was investigated. The variation of the friction coefficient obtained in the pin-on test device with respect to the distance is given in Figure 4. The average friction coefficients of Uncoated (UC), Phosphorus Coating (PC) and Hard-Anodized Coating (HAC) samples were defined as 0.55±0.01, 0.43±0.04, and 0.41±0.05 respectively. According to the graphs, it is seen that the coated samples have similar coefficient of friction. After half of the friction test period, the friction coefficients started to increase. This increase showed itself with a sudden increase in uncoated samples. The differences observed in the friction coefficient values can be considered to be related to the changes in the wear morphology [19]. These increases in the friction coefficient can be clarified by the increase in the actual contact area after the running-in phase. Since the test load and the distance are kept constant, this change in the friction coefficient shows the effect of the coating process. According to these results, the lowest average friction coefficient occurred in hard anodized coated samples. Similar values were also obtained in phosphorus-coated samples.

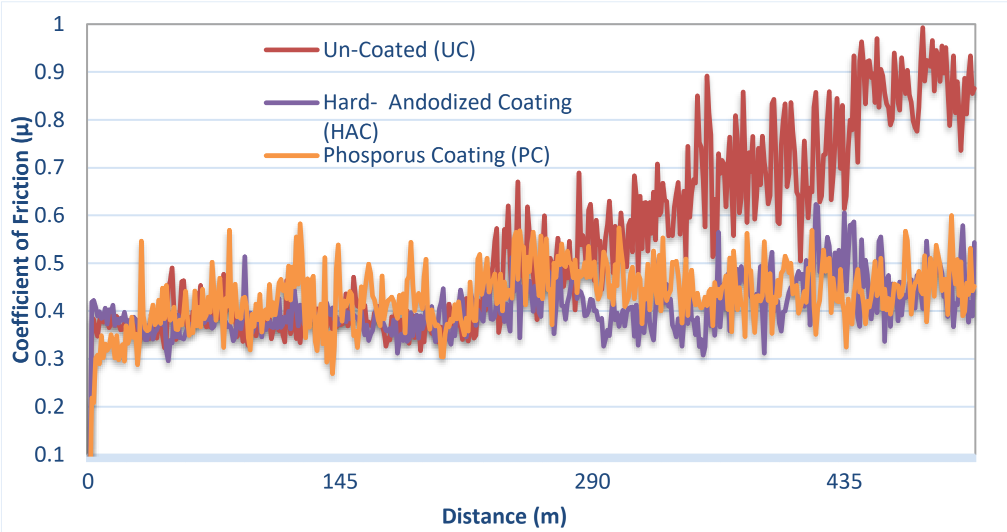


Figure 4. Variation of friction coefficient of UC, HAC and PC samples with respect to time

3.3. Wear resistance

The effect of hard anodizing and phosphor coating on the wear resistance of aluminum 2017A alloy was investigated. The wear resistance values of the samples are given in Figure 5. It is seen that the hard anodized coated samples have the highest wear resistance. Phosphor-coated samples, on the other hand, seem to have higher wear resistance than uncoated samples. In the studies, it has been stated that anodizing processes increase the wear resistance of the materials used as the substrate [3, 23, 36]. In the studies, the way of application of the anodic coating process, voltage application temperature, etc. parameters, the type of backing material affects the wear resistance of the coating. In this study, the substrate material and anodizing parameters were kept constant. The effect of hard anodizing and phosphate coating as variables was evaluated. Different wear resistances differed according to coating types.

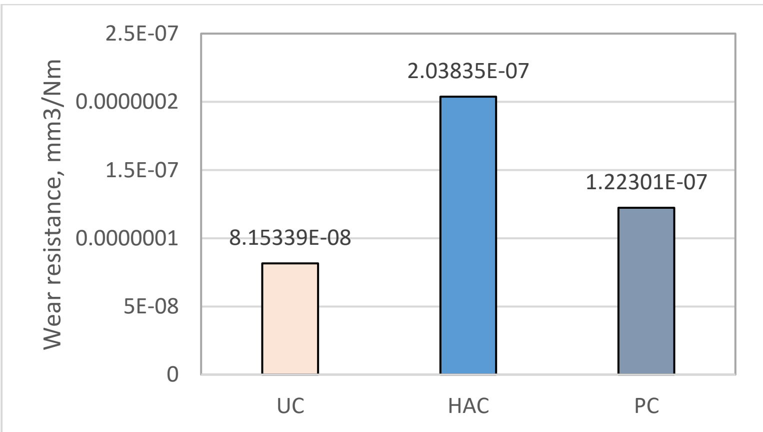


Figure 5. Wear resistance values of UC, HAC and PC samples

3.4. Vibration

Vibrations during the pin-on disc test were measured. The effect of obtained vibration values on wear and friction coefficient was investigated. The graph showing the average vibration values measured during the friction test is given in Figure 6. The mean vibration values measured during the friction test of the UC, HAC and PC samples were 10.73±0.82 mm/sec^2, 7.11±1.09 mm/sec^2 and 7.92±0.93 mm/sec^2, respectively. It is seen that there is a parallelism between the average friction coefficient

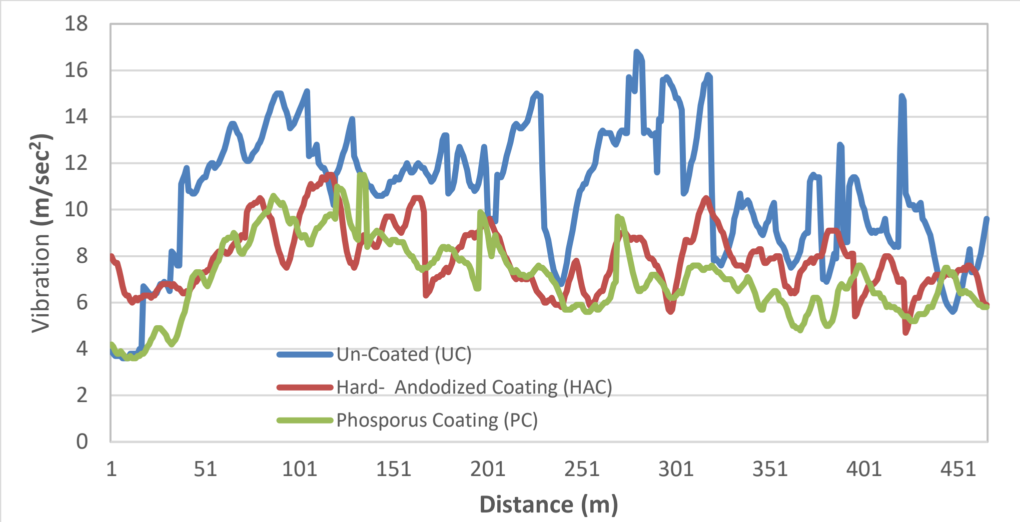


Figure 6. Average vibration values measured during friction test of UC, HAC and PC samples

and the vibration values. In the tests, it is seen that the friction coefficient increases with the increase in vibration. The highest vibrations occurred in UC samples with the lowest vibrations in HAC samples. It can be said that the hard anodized coating contributes positively to the friction coefficient by reducing the vibration during friction.

3.5. Surface morphology of the worn surface

After the friction tests, the worn surface images formed on the contact surfaces of the samples were examined. The effect of coating types on the worn surface has been tried to be determined. The worn surface images of the samples are given in Figure 7.

Figure 7a shows the eroded surface images of the UC samples. It is seen that grooves and plough wear type are formed on the worn surface of UC samples. It can be said that the low surface hardness of these samples also increases the deformations that occur during wear. It is seen that the surface deformations are reduced on the coated surfaces (Figure 7b and 7c).

It is seen that the wear is less and superficial in HAC test samples (Figure 7b). In this case, it can be said that the hard-anodized coating improves the wear properties of the sample. It can be said that the surface images obtained and the wear resistance are also compatible. The highest wear resistance was obtained in phosphor coated samples. The high wear resistance is also evident from the worn surface images. Ali et al. [22] stated that the oxide layer produced by hard anodizing coating process of AA7075-T6 aluminum alloy is very dense and harder than natural oxidation. They also found that the coating layers increased the substrate surface melting point from about 650 °C to about 2000 °C. This improved the mechanical properties at high temperature.

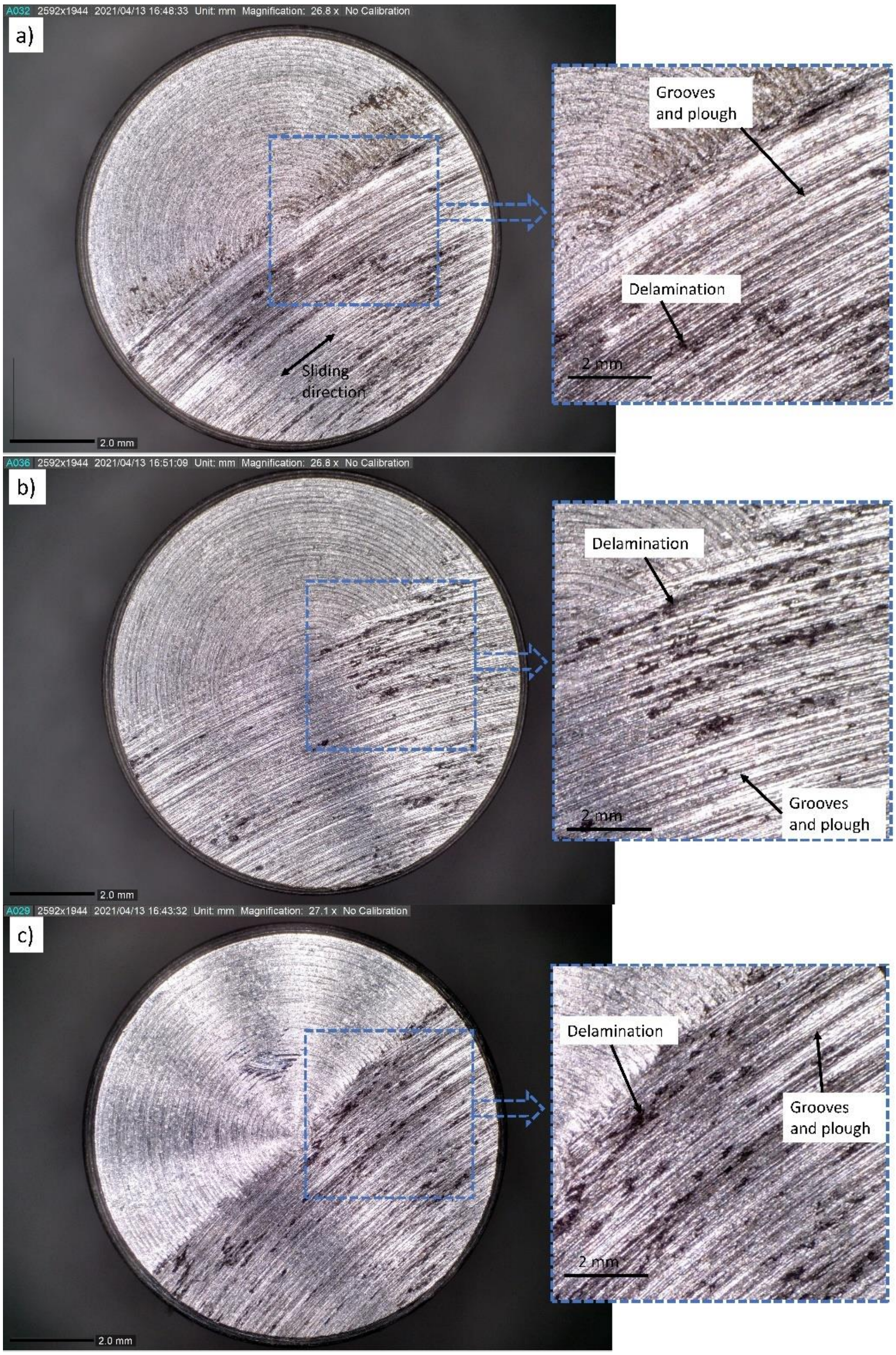


Figure 7. Worn surface of the samples in friction tests, a) UC, b) HAC and c) PC

4. CONCLUSIONS

The results obtained in my study, which investigated the effect of hard anodizing and phosphoric coating on the wear properties of a 2017A aluminum alloy, are listed.

- The coating types had a positive contribution to the hardness values of the samples. The highest hardness was obtained in hard anodized coated samples. Phosphor coating can be preferred in applications where high hardness value is desired.
- Coating types also contributed positively to the coefficients of friction. The friction coefficients decreased according to the coating types. The lowest coefficient of friction was achieved in hard anodized coatings.
- The highest wear resistance was measured in phosphorus-coated samples. It has been found that the wear resistance is markedly high. The hard anodized coating also increased the wear resistance.

- Vibrations measured during wear tests vary. It was observed that the vibrations were also reduced compared to the coatings made. Thanks to the coatings, the improvements on the surfaces positively affected the wear and vibration in the contact area.
- Compared to the worn surface images, wear is less in phosphorus coated samples with higher abrasion resistance. The highest surface deformation was obtained in uncoated (UC) samples.
- In future studies, the effect of coating parameters affecting the coating properties on the wear properties can be investigated.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTION

Gülşah Akıncıoğlu: Conceptualization, Writing-original draft, Visualization, Supervision, Project administration, Validation.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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