

ISSN 0970 - 6340 (PRINT), ISSN 0970 - 6358 (ONLINE)

INTERNATIONAL JOURNAL OF MECHANICAL ENGINEERING & TECHNOLOGY (IJMET)

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INVESTIGATION OF COATING THICKNESS, HARDNESS AND WEAR RESISTANCE OF ALUMINUM 6061 BY ANODIZING TREATMENT

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ABSTRACT

Aluminum 6061 has the advantages such as good formability, corrosion resistance and lightweight, but it also has weaknesses, such as its hardness and wear resistance are relatively low, thus anodizing process is conducted to increase its hardness and wear resistance. The anodizing process can also produce a more attractive appearance and texture of metal. It also can increase the resistance of surface friction. The anodizing technique is a metal plating process based on the formation of an aluminum oxide coating through controlled oxidation. The quality of the anodizing product is determined by the thicknesses of the coating formed. This study aimed to determine and analyze the mechanical properties and thicknesses of the coating on the surface of aluminum 6061 due to anodizing process. The method used in this research was a laboratory experimental method, with variations of the anodizing solution, voltage, and immersion time. The solutions used in this study were 100% 1M sulfuric acid, phosphorus acid, and nitric acid. The voltages used in this study were 15V and 30V, while the immersion time variation of the anodizing process was carried out at 10 minutes and 30 minutes. The mechanical properties of anodizing aluminum 6061 were tested using hardness and wear resistance tests. The data that had been obtained were analyzed using the descriptive analysis method. The results showed that the highest hardness rate was obtained in the treatment with the use of 100% H₂SO₄ anodizing solution, with a voltage of 15V, which was immersed for 30 minutes. The highest hardness reaching 106.47 HV was found in specimen number 2, with a wear resistance of 17153.09 m/g, and a coating thickness of 57.025 μm.

Keywords: Anodizing solution, coating thickness, hardness, wear resistance, aluminum 6061.

Cite this Article: Agus Suprpto, Pungky Eka Setyawan, Dewi Izzatus Tsamroh, Investigation of Coating Thickness, Hardness and Wear Resistance of Aluminum 6061 by Anodizing Treatment. *International Journal of Mechanical Engineering and Technology*. 11(10), 2020, pp. 1-12.

<http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=11&IType=10>

1. INTRODUCTION

Aluminum is one type of non-ferrous metal that is most widely used in the world, especially in the automotive, aircraft industry, manufacturing industry, and household appliances, this is because aluminum has several advantages such as being lightweight, resistant to corrosion, cheap, and easy to be formed [1]. However, when compared to other commercial metals, aluminum has a relatively lower hardness and wear resistance [2, 3]. Previous research about the use of anodizing treatment showed changes in hardness with variations in electrolyte solutions [4]. The value of anodizing hardness is inversely proportional to the value of the wear rate of aluminum. Meanwhile, the pore thickness on anodizing, was affected by the potential difference [5], the potential difference of 25 V resulting in an average pore thickness of 18.33 μm . Another previous research showed that the highest wear resistance were 47.33% in the degreasing composition in anodizing process: 85% Phosphorous; 15% H_2SO_4 ; 0% HNO_3 with an anodizing time for 30 minutes. Meanwhile, the lowest wear resistance was 22, 54% that found in the degreasing composition: 75% Phosphorous; 20% H_2SO_4 ; and 5% HNO_3 with an anodizing time for 10 minutes [6]. The wear rate of aluminum alloy AA 2024-T3 can be reduced from $1.66 \times 10^{-6} \text{ g/cm}$ to $9.21 \times 10^{-8} \text{ g/cm}$ by the anodizing process with a current density of 3.00 A/dm^2 and immersion time for 60 minutes [4].

Based on the above background, further research is needed to complement the results of previous researches related to the use of anodizing treatment with variations in the type of solution, voltage, and anodizing time, especially in 6061 aluminum material.

2. METHODOLOGY

The research method used in this study was a laboratory experimental study. The research was carried out in several steps, which were preparation, anodizing process and ended with testing the research specimen.

Table 1 Specimen numbering and treatment type.

Specimen Number	Treatment
1	100% H_2SO_4 , 15V, 10 min
2	100% H_2SO_4 , 15V, 30 min
3	100% H_2SO_4 , 30V, 10 min
4	100% H_3PO_4 , 15V, 10 min
5	100% H_3PO_4 , 15V, 30 min
6	100% H_3PO_4 , 30V, 10 min
7	100% HNO_3 , 15V, 10 min
8	100% HNO_3 , 15V, 30 min
9	100% HNO_3 , 30V, 10 min

The first step was specimen preparation. The material used in this research was aluminum alloy 6061 with dimensions of 10 mm x 35 mm x 25 mm. This research was conducted using several independent variables such as variations in the type of anodizing solution, the voltage used in the anodizing process, and the duration of immersion time. Table 1 showed the specimen numbering and the type of treatment performed.

The next step was the anodizing process which included three stages, which were:

1. Pre-treatment, that consisted of:
 - a. Degreasing
 - b. Etching
 - c. Desmutting

2. Anodizing Process

The anodizing process was carried out using a variety of solutions of 100% 1M Sulphuric acid (H_2SO_4), 100% 1M Phosphoric acid (H_3PO_4), and 100% 1M Nitric acid

(HNO_3), and the anode side was connected to an aluminum plate where it had role as the negative pole on the power supply. Furthermore, the voltage adjustment was carried out with a variation of 15 V and 30 V. The next process was to turn on the power supply, while the anodizing process was carried out with a variation of 10 minutes and 30 minutes.

3. Dying

Dying was the process of drying the specimen after the anodizing process took place.

The next step was the final stage, which was specimen testing which included 4 types of testing as follows:

A. Optical Microscopy

The thicknesses of oxide coating were observed by using optical microscopy.

B. Hardness Test

The surface of the specimens was tested for hardness using a micro Vickers hardness tester.

C. Wear Resistance Test

The wear test on the surface of the anodized specimen was carried out using the Ogoshi wear test equipment, the initial and final weight were weighed with a sliding distance of 171.531 m. The calculation of wear resistance was inversely proportional to the wear rate.

D. Coating Thickness Test

The last test was to collect data on the thickness of the oxide coating that was formed on the 6061 aluminum surface using a Thickness Gun.

3. RESULT AND DISCUSSION

This section presents the results of research with various tests on specimens related to the dependent variable, including the hardness of aluminum 6061, wear resistance of aluminum 6061, and the thickness of the oxide coating formed by the anodizing process. The hardness number was related to the wear resistance, as well as the resulting coating thickness on the surface of the 6061 aluminum specimen.

3.1. Oxide Coating Thickness

The following figures are the result of the optical microscopy test.



Figure 1. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_2SO_4) with a voltage variation of 15 Volt and immersion time for 10 minutes using a 100x magnification of optical microscopy

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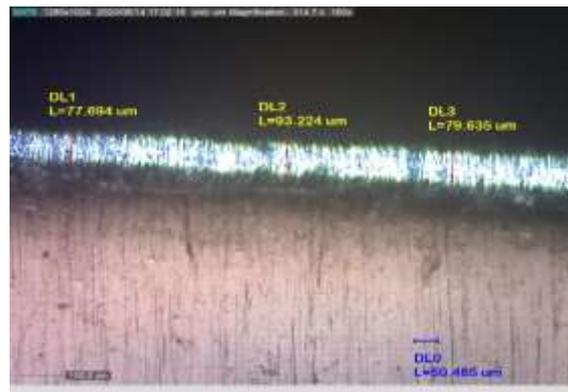


Figure 2. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_2SO_4) with a voltage variation of 15 Volt and immersion time 30 minutes using a 100 x magnification of optical microscopy



Figure 3. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_2SO_4) with a voltage variation of 30 Volt and immersion time of 10 minutes using an optical microscope 100x

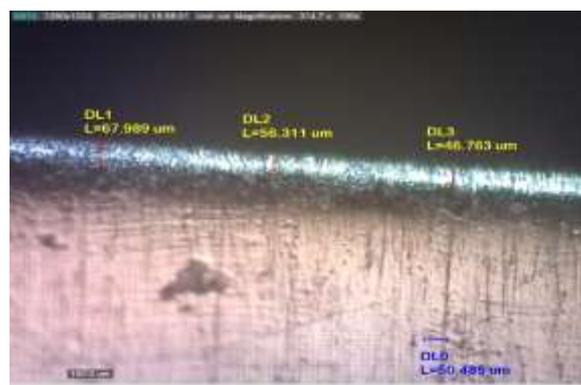


Figure 4. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_3PO_4) with a voltage variation of 15 Volt and immersion time of 10 minutes using an optical microscope 100x



Figure 5. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_3PO_4) with a voltage variation of 15 Volt and immersion time of 30 minutes using an optical microscope 100x



Figure 6. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (H_3PO_4) with a voltage variation of 30 Volt and immersion time of 10 minutes using an optical microscope 100x



Figure 7. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (HNO_3) with a voltage variation of 15 Volt and immersion time of 10 minutes using a 100x optical microscope

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Figure 8. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (HNO_3) with a voltage variation of 15 Volt and immersion time of 30 minutes using a 100x optical microscope

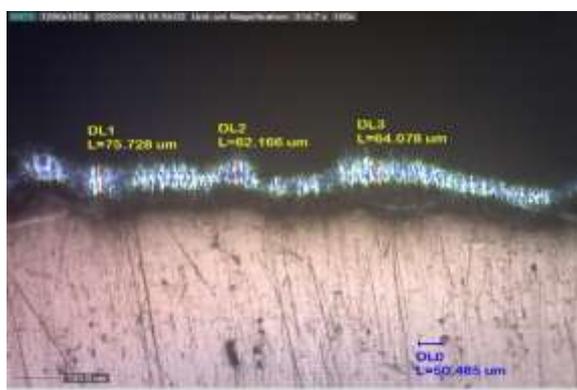


Figure 9. The oxide coating thickness resulted from the anodizing process with a 100% solution type 1M Sulfuric acid (HNO_3) with a voltage variation of 30 Volt and immersion time of 10 minutes using an optical microscope 100x

Based on Table 1, it is known that the thickest oxide coating found in specimens with treatment number 8, that is by using 100% HNO_3 solution, voltage of 10V, and immersion time of 30 minutes with a coating thickness of 88.05 μm . The results of this study are also presented in graphical form in Figure 10.

Table 2. The thickness of the anodizing oxide coating results in variations in time, voltage, and type of solution

No	Solution Type	Voltages (V)	Immersion time (minute)	Oxide Thicknesses (μm)
Base Metal				
1	100%	15	10	24.271
2	1M Sulfuric acid	15	30	53.09
3	(H_2SO_4)	30	10	57.025
4	100%	15	10	30.44
5	1M Phosphoric acid	30	10	83.52
6	(H_3PO_4)	30	30	43.37
7	100%	10	10	33.70
8	1M Nitric acid	10	30	88.05
9	(HNO_3)	30	10	67.32

Source: Primary data, processed by researchers, 2020

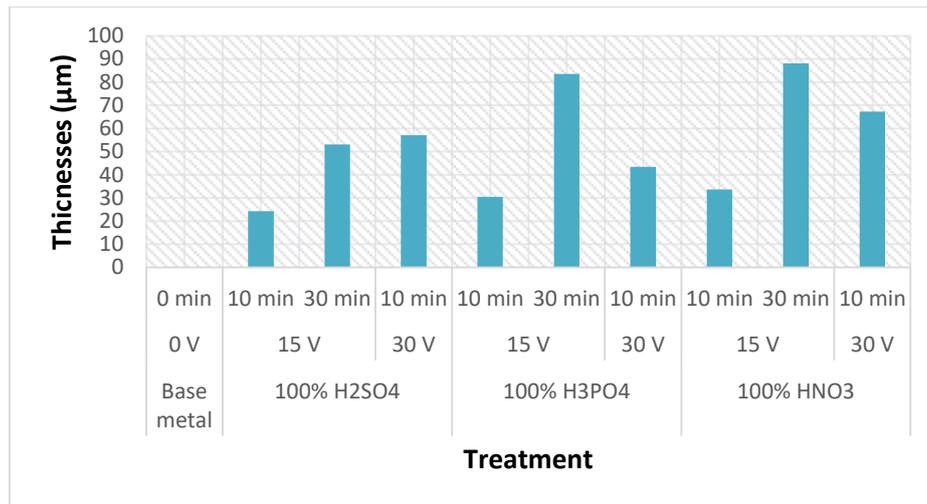


Figure 10. The graph of the thickness of the anodizing oxide coating

Previous research showed that the higher the voltage used, the thicker the resulting oxide coating [7]. The thickness of the oxide coating resulting from the anodizing process is not only affected by the voltage used, but the immersion time in the anodizing process also affects the resulting coating thickness. This is accordance with the result of previous research where the longer time used in the anodizing process will result in a thicker oxide coating [8]. Another research also shows that anodizing time with longer duration results in thicker coating thickness. This research used a variation of anodizing time of 10 minutes, 15 minutes, and 20 minutes, where the thickest coating thickness was found in specimens with an anodizing process for 20 minutes [9].

Based on the results of research that have been carried out and the results of previous studies, the thickness of the oxide coating is significantly affected by the immersion time and the anodizing voltage.

3.2. Surface Hardness

Table 2 below shows the hardness value resulting from the anodizing process with variations in the type of solution, voltage, and immersion time. Based on the table above, it's found that the highest hardness number is 106.47 HV resulting from treatment number 2, which is treatment by using 100% H₂SO₄ solution, voltage of 15V, and immersion time of 30 minutes. The results of this study indicate that using different solutions will affect the hardness of the specimen after receiving anodizing treatment [3].The following figures are the result of the optical microscopy test.

Table 3. The hardness of anodizing results with variations in time, voltage, and type of solution

No	Solution Type	Voltages (V)	Immersion time (minutes)	Hardness (HV)
Base Metal				95.80
1	100%	15	10	91.24
2	1M Sulphuric acid	15	30	101.88
3	(H ₂ SO ₄)	30	10	94.05
4	100%	15	10	99.20
5	1M Phosphoric acid	30	10	103
6	(H ₃ PO ₄)	30	30	95.20
7	100%	10	10	85
8	1M Nitric acid	10	30	90.20
9	(HNO ₃)	30	10	94

Source: Primary data, processed by researchers, 2020

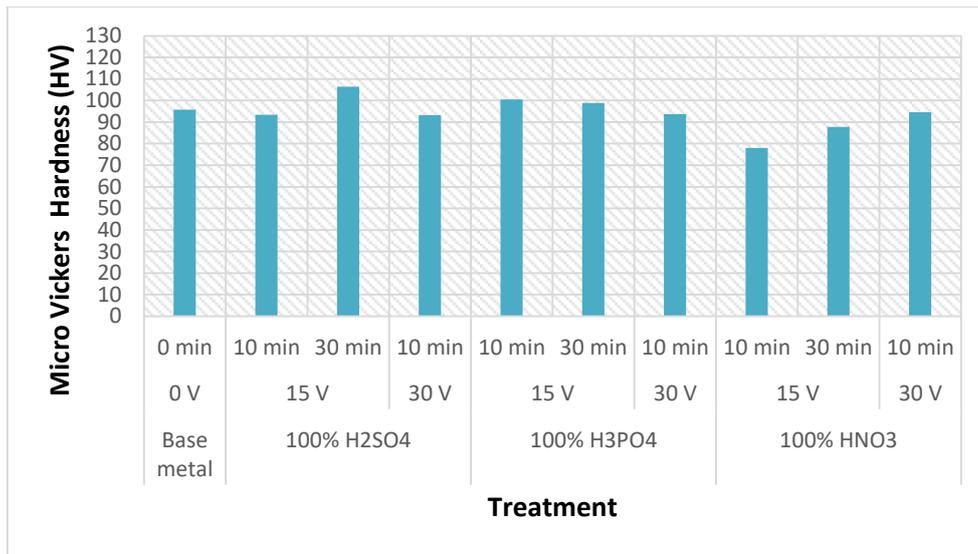


Figure 11. Graph of anodizing hardness on aluminum 6061

The duration of immersing specimens into the anodizing solution has a significant effect on the hardness of aluminum, which is also the case in previous research, which showed that the longer the immersion time of the anodizing process, the specimen's hardness will increase [7]. In this study, the highest hardness was obtained by specimens with an immersion time of 30 minutes, where when compared to the base metal, the hardness of this specimen increased by 13.5%.

The hardness test results are also shown in the graph in Figure 11. Based on Figure 11, the highest hardness is indeed achieved by specimen number 2, however, a significant increase in hardness is achieved in specimens number 7, 8, and 9, which used 100% HNO₃ solution. However, using this type of solution produces a rough surface, which is not a good result for the following processing. The increase in hardness in the anodizing treatment is influenced by the immersion time and the amount of voltage used [10].

3.3. Wear Resistance

Table 4 shows the results of the calculation of wear resistance using the Ogoshi method. The highest wear resistance is shown in specimen number 2, while the lowest wear resistance is shown in specimen number 7. This shows that the wear resistance of 6061 aluminum as a result of the anodizing process is influenced by the type of solution, the voltage used, and the anodizing time.

Table 4. Wear resistance of anodizing specimens with variations in time, voltage, and type of solution

No	Solution Types	Voltages (V)	Immersion time (minutes)	Wear Resistance (m/g)
Base Metal				1732,63594
1	100%	15	10	15593,72354
2	1M Sulphuric acid (H ₂ SO ₄)	15	30	17153,09589
3		30	10	17153,09589
4	100%	15	10	3009,31506
5	1M Phosphoric acid (H ₃ PO ₄)	15	30	10090,0564
6		30	10	12252,2113
7	100%	15	10	5045,02820
8	1M Nitric acid (HNO ₃)	15	30	2766,62836
9		30	10	2450,44227

Source: Primary data, processed by researchers, 2020

Wear resistance is also related to the hardness of the material, where the higher the hardness of the material, the higher the wear resistance. This is following the results of this study, specimen number 2 has the highest hardness number and has the highest wear resistance, thus, the lowest wear rate is found in specimen number 2. Anodizing treatment on specimen number 2 has increased the wear resistance of aluminum 6061 by 10 times higher than the base metal.

The wear resistance of the anodized specimen is influenced by the voltage and immersion time. The previous research showed that wear resistance increases with the increasing voltage used [11], while another research shows that an increase in specimen hardness was found in the anodizing process for 30 minutes [10].

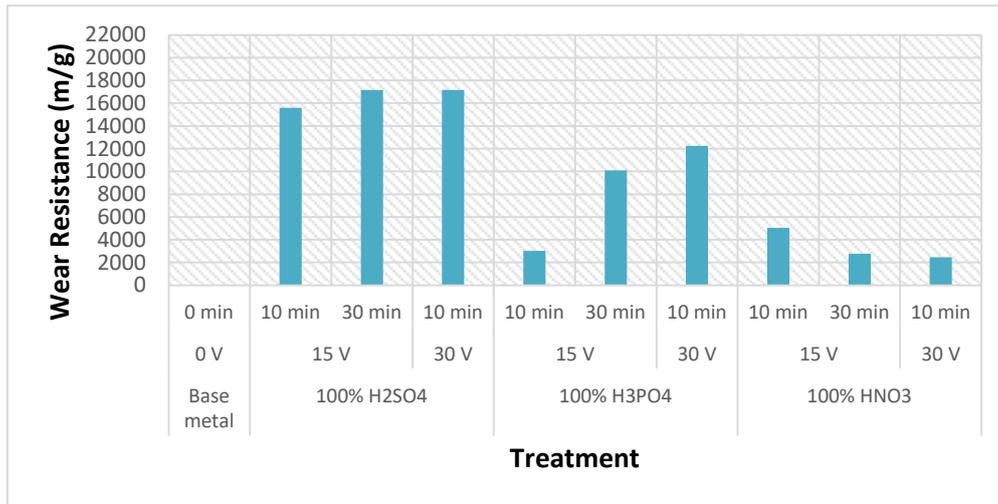


Figure 12. Anodizing wear resistance graph on aluminum 6061

3.4. Relationship between Coating Thickness and Hardness

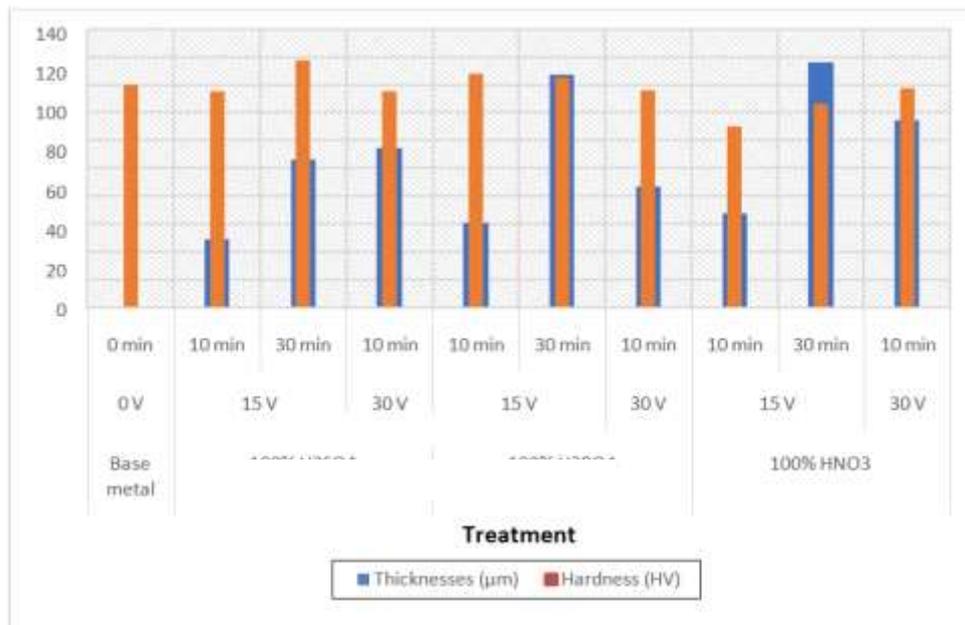


Figure 13. Graph of coating thickness against the surface hardness

The thickness of the oxide coating resulting from the anodizing process has a significant effect on the surface hardness of the specimen. The thicker the resulting coating, the higher

the hardness rate on the surface. In previous research conducted, it's shown that the increase in the thickness of the anodizing oxide coating is directly proportional to the increase in hardness in aluminum alloys [12]. However, the phenomenon that appears in this study is slightly different, where the thickness of the oxide coating on the surface of aluminum 6061 is the thickest found in specimen number 8, but the highest hardness is found in specimen number 2. This is presumably because the oxide coating formed on the surface of aluminum 6061 uneven.

3.5. Relationship between Coating Thickness and Wear Resistance

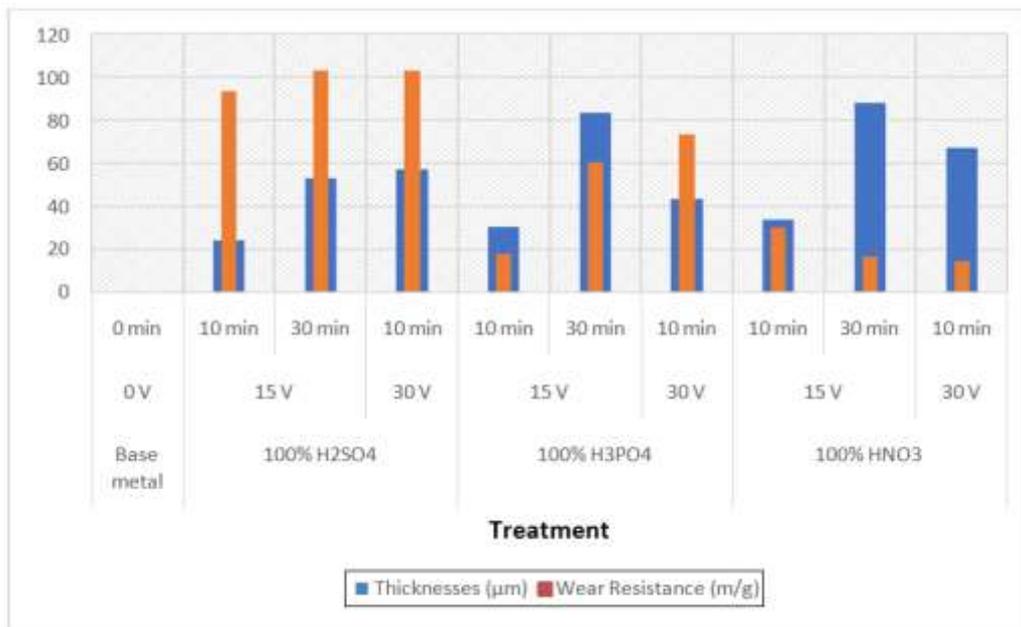


Figure 14. Graph of coating thickness against wear resistance

Figure 14. shows the relationship between the thickness of the oxide coating resulting from the anodizing process and the wear resistance of aluminum 6061. The thicker the oxide coating is produced, the higher the hardness number of aluminum 6061. Thus, the lower the wear rate, this shows the wear resistance of aluminum 6061. the higher it is. The highest wear resistance was achieved by specimens with treatment number 2, but the thickest thickness of the oxide coating was found in specimens with treatment number 8. This was presumably because the oxide coating formed during the anodizing process was uneven. Previous research stated that the hardness of the material increases with increasing anodizing time, which means that the longer the anodizing time is used, the thicker the oxide coating is. Thus, the thicker the resulting oxide coating will increase the wear resistance of the material [13].

3.5. Relationship between Surface Hardness and Wear Resistance

Figure 15. shows that the surface hardness against the wear resistance of aluminum 6061 anodizing results. The highest wear resistance was found in the specimen with the highest hardness number, namely specimen number 2. The increase in surface hardness was directly related to the increase in wear resistance of the material. Wear resistance is influenced by various aspects, one of which is the voltage on anodizing. Previous research also showed that the higher the voltage used, the higher the wear resistance obtained by the specimen [11]. Thus, the higher the wear resistance of the specimen, the higher the surface hardness obtained.

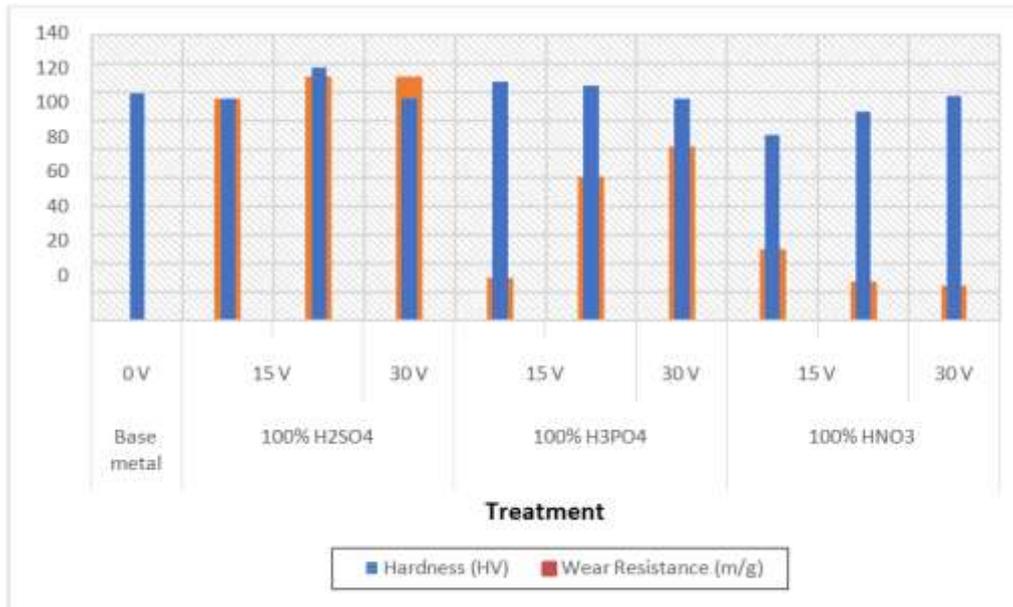


Figure 15. Graph of surface hardness against wear resistance

4. CONCLUSION

According to the result and discussion above, thus the following were the conclusions of this study.

1. The highest hardness figure was obtained in the treatment using 100% H₂SO₄ anodizing media, with a voltage of 15V, which was immersed for 30 minutes. The highest hardness number reaching 106.47 HV was found in specimen number 2, with a coating thickness of 57.025 μm and wear resistance of 17153.09 m/g.
2. The thicker the oxide coating, the higher the surface hardness figure of aluminum 6061.
3. The higher the hardness number of aluminum 6061, the higher the wear resistance obtained by aluminum 6061.
4. The increased hardness and wear resistance of 6061 aluminum is significantly affected by voltage and anodizing time.

ACKNOWLEDGEMENTS

The author would like to thank the Ministry of Research, Technology, and Higher Education of Republic Indonesia for PDUPT Research Grant 2020.

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