

Effect of anode–cathode distance and anodizing time on hardcoat anodizing of AA7075

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Abstract

Fishing activities in Indramayu (a seaside city in West Java) typically use boats powered by propellers. These propellers often strike floating objects, resulting in damage such as cracked or broken blades. A survey revealed that the fractures are mainly caused by the poor quality of propellers produced using the gravity casting technique, which results in rough surfaces with pores and cracks that initiate during finishing. Therefore, surface repair is necessary, and one potential method is hardcoat anodizing. This study aims to investigate the effect of coating time and anode–cathode distance on the hardness of the oxide layer formed during the hardcoat anodizing process of AA7075 aluminum alloy. The anode–cathode distances were 5 cm, 10 cm, and 15 cm, with coating times of 40, 50, and 60 minutes. The process was conducted at 2 to 3°C, with a current of 5.12 A and a voltage of 31.5 V. The results of micro-Vickers hardness testing, conducted with a loading parameter of 200 gf and an indentation time of 15 seconds, indicated a hardness increase of 256% compared to the base material. The highest hardness value was achieved at a distance of 5 cm and a coating time of 60 minutes, measuring 322.9 VHN, with a resulting layer thickness of 67.16 μm.

Keywords:

Propeller, AA7075, heat treatment, hard coating anodize.

1 Introduction

Aluminium alloys are commonly used as drive materials alongside brass due to their ease of casting and corrosion resistance [1]. One notable application of these alloys is in propellers, which require specific characteristics such as fatigue resistance, cavitation erosion resistance, corrosion resistance, impact and crevice corrosion resistance, weld-ability, and freedom from cracks [1] [2].

To enhance the properties of alloys, surface treatments like coatings can be applied which improve safety and extend service life [3]. Anodizing is a surface treatment method that protects metal surfaces from environmental damage and enhances their decorative qualities [4] [5]. Hard anodizing, in particular, improves the surface characteristics of aluminium alloys by increasing the thickness of the anodic oxide film. This process enhances properties such as hardness, abrasion resistance, and corrosion resistance, producing a thick and durable coating in a short time. The increase in target voltage during hard anodizing positively correlates with the thickness and hardness of the oxide coating [6] [7].

The urgency of this research stems from the fact that the propeller of a certain boat is made from aluminium alloy, which is susceptible to breakage, particularly in the blade section. This breakage is primarily caused by a porous and cracked surface resulting from the gravity casting manufacturing process. This

process has several drawbacks, including a rough surface with pores and the initiation of cracks during the finishing stage.

This study aims to tackle the issue of propeller blade breakage, which disrupts fishing activities and leads to financial losses for fishermen. The objective is to improve the surface of the propeller blades by eliminating porosity and applying a protective coating to prevent corrosion and enhance service life [8].

Propellers should be lightweight, strong, and resistant to erosion and corrosion [9] [1]. One of the materials used for manufacturing propellers is aluminium alloy 7075. This alloy is known for its low density, high strength, ductility, and fatigue resistance, making it an ideal choice for propellers. Compared to other aluminium alloys, Al7075 boasts the highest strength and can further increase in hardness and tensile strength through heat treatment [10].

Complex anodizing process parameters, such as variations in voltage, produce different colors [11]. Increasing the weight concentration of oxalic acid enhances the thickness and hardness of the anodized layer. However, as the anodizing temperature rises, both the thickness and hardness of the anodized layer decrease, with the optimal anodizing temperature being below 5 degrees Celsius [12] [13]. Hard anodizing can nearly double the hardness of aluminum alloys like AA6061, and there is a direct relationship between current density and hardness increase [14]. Additionally, longer anodizing times result in a thicker aluminum oxide layer [15] [16].

In previous studies, many anodizing processes have been carried out to improve surface quality with various parameters, but not at a coating temperature of 2°C–3°C [17] [18] [19] [20].

The novelty of this study lies in its application of hard anodizing coating through a coating process treatment at a temperature of 2°C–3°C on the surface of Al7075, which forms a hard layer, smooth's the surface, and removes scratches. The purpose of this study is to determine the parameters of variation in distance and coating time to obtain an optimal hardcoat anodizing layer as needed.

2 Method

The method used to achieve the objective was to initially determine AA7075 as the material most closely resembling the propeller material in the field [10]. The stages of the hardcoat anodizing process are:

2.1 Specimen preparation

The specimens used were 24 mm in diameter and 6 mm thick. They were then sanded sequentially with 120, 240, 400, 600, 800, 1000, and 1500 grit sandpaper, followed by polishing with Autosol metal polish until the surface was smooth and uniform. The sample was then cleaned with 70% alcohol (Fig. 1).



Fig. 1. Initial specimen.

2.2 Hardcoat anodizing preparation

Before commencing the hardcoat anodizing process, preparations must be made for the chemical mixture used in the pre-hardcoat anodizing steps [5] (Fig. 2 and Table 1).

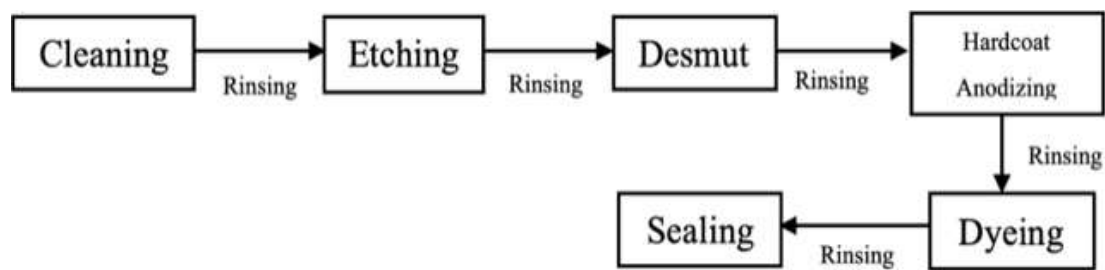


Fig. 2. Pre-hardcoating anodizing steps.

Table 1. Chemical materials

| Process | Chemical solution | Concentration |
|--------------------|---|----------------------------|
| Cleaning | Natrium carbonat (Na_2CO_3) | 50 grams/litre Aquadex |
| Etching | Baking soda (NaOH) | 100 grams/litre Aquadex |
| Desmut | Phosphoric acid (H_3PO_4) | 750 ml |
| | Sulphuric acid (H_2SO_4) | 200 ml |
| | Nitric acid (HNO_3) | 100 ml |
| Hardcoat anodizing | Sulphuric acid (H_2SO_4) | 500 ml/litre Aquadex |
| Dyeing | Anodize Diex | 150 ml/litre Aquadex |
| Sealing | Acetic acid (CH_3COOH) | 5 grams/litre Aquadex |
| Rinsing | Aquadex | 100% |

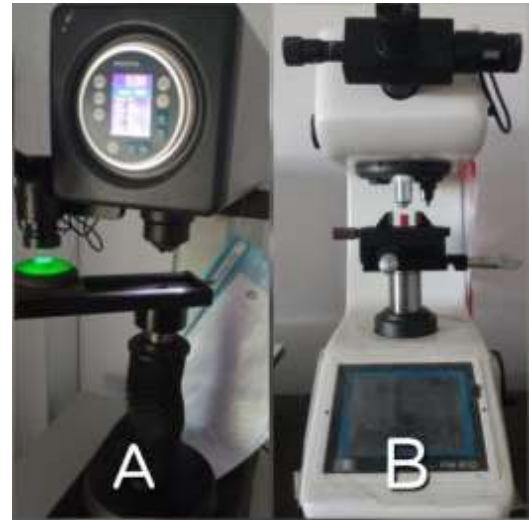


Fig. 4. A. Innovatest, B. Microhardness tester FM-810.

2.3 Equipment

2.3.1 Coating equipment

The coating equipment is equipped with a cooling medium to condition the coating solution, which maintains a stable temperature of between 2°C and 3°C inside the tank. This equipment is designed to cool the acid liquid inside the cabin for the purpose of performing the hardcoat anodizing process (Fig. 3).



Fig. 3. Hardcoat anodizing coating media.

2.3.2 Hardness testing equipment

Data collection on material hardness in this study used an Innovatest hardness tester (Fig. 4(A)) to test hardness before coating the material, i.e. to test the initial hardness of the material, while a Microhardness tester FM-810 (Fig. 4(B)) was used to test hardness after the hardcoat anodizing coating process.

2.3.3 Microstructure testing equipment

The microstructure testing equipment utilises an Olympus BX3M microscope to determine the thickness of the layer formed by the hard coat anodizing process. Specimen preparation for imaging is carried out by cutting a cross-section, which is then sanded sequentially from P120 to P1500 and polished using Autosol (Fig. 5).



Fig. 5. Olympus BX3M microscope.

2.3.4 Supporting equipment

The supporting equipment are: (1) a grinding and polishing machine to perform the sanding process on the surface of the test specimen to make it flatter and smoother; (2) DC power supply functions to conduct electrical current during the coating process with a capacity of 0–5 amps and 0–30 volts; (3) SF-400 digital scales are used to weigh chemical measurements in the hardcoat anodizing process. These scales have a capacity of 0–5000 grams and an accuracy of 0.1; (4) measuring cups is used to measure chemical dosages for use in the hardcoat anodizing process. Measuring cups are available in various capacities, including 50 ml, 100 ml, and 250 ml; (5) gloves are used to protect hands from hazardous chemicals when mixing chemicals for the hardcoat anodizing process; (6) a portable stove is used to heat the sealing solution (acetic acid and distilled water) to a temperature of 100°C .

2.3.5 Additional material

The additional material are: (1) autosol is used to clean test specimens mechanically. Autosol serves to smooth the surface of the specimen, making it appear shiny and smooth; (2) aluminium wire is used to attach the test specimen to the shaft during the hardcoat anodizing process. Aluminium wire is also used to conduct electricity from the power supply to the specimen; (3) lead plates are used as the cathode material, which serves to conduct electricity from the anode to the cathode during the hardcoat anodizing process.

2.4 Hardcoat anodizing process

The hardcoat anodizing process involves immersing test specimens, as shown in Fig. 2. The selected specimens are those that achieved the best hardness test results. These specimens undergo the hardcoat anodizing coating process with varying distances between the anode and cathode set at 5, 10, and 15 cm. Additionally, coating times are set at 40, 50, and 60 minutes, using a current density of 5.12 amperes and a voltage of 31.5 volts. The steps in the hardcoat anodizing process are:

2.4.1 Cleaning

The test specimens were first cleaned by soaking them in a pure detergent solution (Na_2CO_3) for 10 minutes. During this process, the Na_2CO_3 solution was heated to a temperature of 50°C to 70°C .

2.4.2 Rinsing

The rinsing process is the procedure of cleaning test specimens that have been previously cleaned by dipping them in a distilled water solution. The purpose of this process is to clean the test specimens so that any remaining chemicals attached to the surface of the specimens are removed and to prevent other chemical mixtures from being damaged in the following dipping process.

2.4.3 Etching

Etching is the process of removing the natural oxide layer on the surface of aluminium that cannot be removed by previous processes, such as cleaning or rinsing. The etching process is designed to clean the surface of the workpiece. The etching process is carried out with a dipping time of 1 minute.

2.4.4 Desmut

Desmut aims to clean black spots caused by the etching process. This process is carried out with a dipping time of 2 minutes.

2.4.5 Hardcoat anodizing

Hardcoat anodizing is an electrochemical coating process that forms an oxide layer on the surface of aluminium. The aluminium metal to be anodised is immersed in an electrolyte solution of sulphuric acid (H_2SO_4) with a concentration ratio of 1:1 (1 litre of H_2SO_4 and 1 litre of distilled water). The solution is then cooled to a temperature of 2°C to 3°C . The coating process involves passing a direct current of 5.12 amperes and a voltage of 31.5 volts. The aluminium (test specimen) is connected to a positive current (+), which acts as an anode, while the cathode is lead. The variations used in this study are the immersion times of 40, 50, and 60 minutes, with an anode-cathode distance of 5, 10, and 15 cm.

2.4.6 Sealing

The sealing process serves to close the pores of the oxide layer produced by the anodizing process that are still open. The layer that has been sealed can increase the surface hardness of the aluminium. This process is carried out at a boiling water temperature of 100°C , and the immersion time is 5 minutes.

2.5 Specimen testing

2.5.1 Hardness test

The Vickers hardness test refers to the ASTM E92 standard, which is divided into two parts: using an Innovatest device to test

the initial hardness of the material with a load parameter of 3 kg and an indentation time of 15 seconds, while to test the hardness of the hardcoat anodizing coating, a Microhardness tester FM-810 is used with a load of 300 grams and an indentation time of 20 seconds, and each specimen is tested 5 times. Before the testing process, the hardness testing equipment is calibrated and tested using standard specimens.

2.5.2 Roughness test

This roughness test is used to evaluate the surface roughness of the hard coat anodizing results using a surface roughness tester, brand Mitutoyo SJ310, based on the Ra value standard (μm).

2.5.3 Coating thickness test

Photo microstructure testing is used to measure the thickness of the specimen coating according to the ASTM B487-2013 standard after the hardcoat anodizing coating process. Thickness measurements are taken using an Olympus BX3M microscope with $200\times$ magnification. Samples for thickness testing are taken from specimens with the highest hardness and lowest roughness values.

3 Results and discussion

3.1 Hardness test

Fig. 6 shows that the average initial hardness value of Al7075 material is 93.3 HV. Meanwhile, for the hardcoat anodizing coating hardness test with a variation in the anode-cathode distance of 5 cm and a time of 40 minutes, there was a 204% increase in hardness with an average hardness value of 283.1 HV. At 50 minutes, there was a 225% increase with an average hardness of 303.4 HV. At 60 minutes, there was a 256% increase in hardness, with an average hardness value of 322.9 HV.

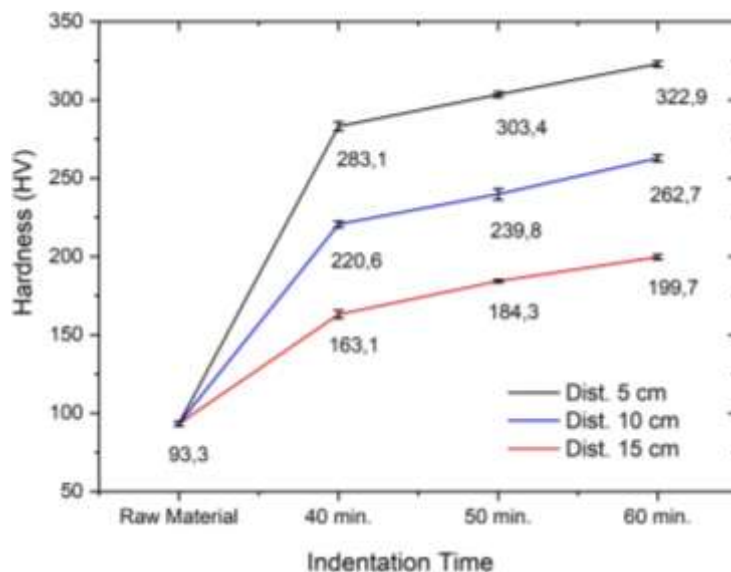


Fig. 6. Hardness value against indentation time.

In the hardcoat anodizing coating hardness test, a variation in the anode-cathode distance of 10 cm with a time of 40 minutes resulted in a 137% increase in hardness with an average hardness value of 220.6 HV, while a time of 50 minutes resulted in a 157% increase with an average hardness value of 239.8 HV. At 60 minutes, there was a 182% increase in hardness, with an average hardness value of 262.7 HV.

In the hardcoat anodizing coating hardness test, a 15 cm variation in the anode-cathode distance over 40 minutes resulted in a 75% increase in hardness, with an average value of 163.1 HV. Extending the time to 50 minutes led to a 96% increase, yielding an average hardness of 184.3 HV. At 60 minutes, the increase reached 118%, with an average hardness of 199.7 HV.

Fig. 7 illustrates the hardness testing results, showing that a closer anode-cathode distance and a longer coating time both contribute to higher hardness values in the coated material. The

highest hardness value observed in this study was 322.9 HV, achieved with a 5 cm distance and a 60-minute coating time, representing a 256% increase compared to the initial material.

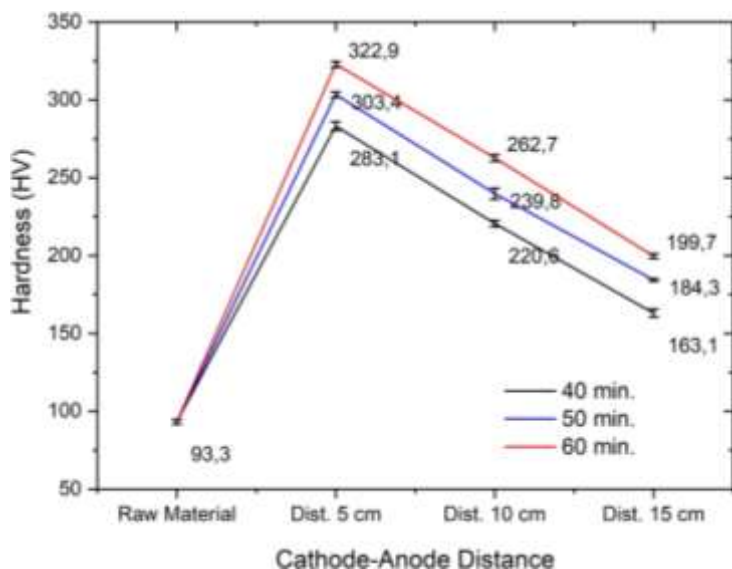


Fig. 7. Hardness value against cathode-anode distance.

This finding supports previous research. Study [21] indicated that the weight of the coating increases as the anode-cathode distance decreases. Similarly, research [22] demonstrated that longer coating times result in higher material hardness. Furthermore, [23] found that lower temperatures during the hardcoat anodizing process correlate with increased hardness.

3.2 Roughness test

Based on Fig. 8, the lowest roughness value was achieved at a distance parameter of 5 cm with a coating time of 60 minutes, resulting in a surface roughness of 0.094 μm . An increase in the distance between the anode and cathode will result in a rougher surface, which is consistent with previous studies [24][25].

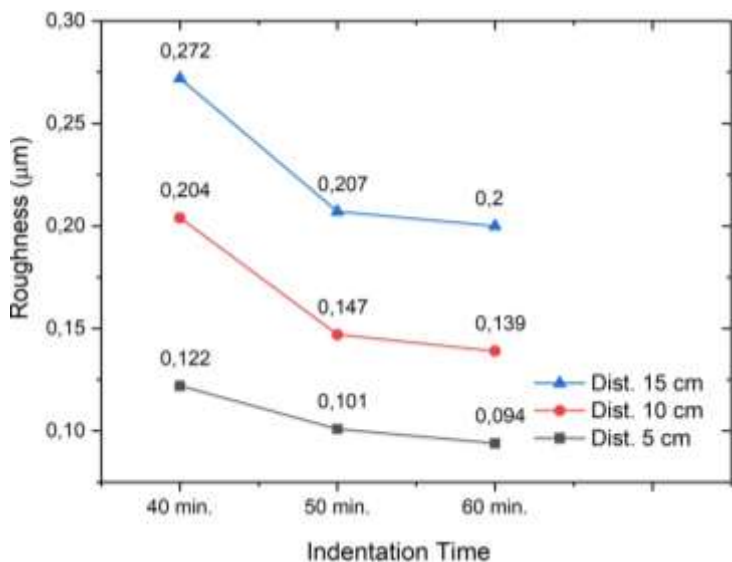


Fig. 8. Roughness value against indentation time.

3.3 Coating thickness test

Based on Fig. 9, the thickness testing of the 7075 aluminum alloy coating during the hardcoat anodizing process involved test specimens with a 5 cm variation in the distance between the anode and cathode, and a dipping time of 60 minutes. These parameters were chosen because they produced the highest average hardness and the lowest roughness values, resulting in an average thickness of 67.16 μm . This result indicates that a longer anodizing time significantly increases the coating thickness.

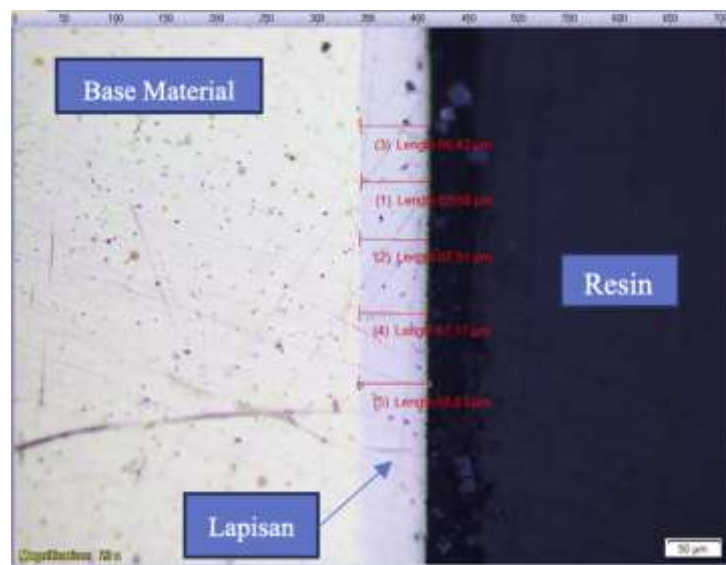


Fig. 9. Layer thickness.

4 Conclusions

This study demonstrates that variations in anode-cathode distance and coating time significantly influence the hardness and oxide layer thickness of hardcoat-anodized AA7075. The results of hardcoat anodizing coating with variations in time and distance can increase the hardness of the 7075 series aluminium alloy by 256% compared to the base material, with the highest hardness value of 322.9 VHN. The smaller the anode-cathode distance, the greater the thickness of the oxide layer, which in turn affects the material's corrosion resistance and hardness. The thickness of the layer produced from the hardcoat anodizing process was highest at a variation of 5 cm between the anode and cathode and a dipping time of 60 minutes, obtaining the highest average thickness value of 67.16 μm .

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