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Enhancement of Mechanical Properties on Aluminum 5052- H32 sheet for Automotive Panel Material using Various Coating Methods

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Abstract

Aluminum alloy 5052-H32 sheet was applied widely in automotive industries, especially for body panel, trunk lid, door, roof, fender and bonnet. It was had numerous advantages such as excellent particular strength, high density, machinability, manufacturing method, high electrical conductivity and availability in various applications. The aims of this research is to provide optimum setting laminate oxide layer on the surface of Aluminum alloy sheet 5052-H32, also to analyze the microstructure and mechanical properties of deposited coatings as well as to compare the performance of anodization and plasma electrolytic oxidation coating in Aluminum alloy 5052-H32 sheet. Factorial L 2x3 was applied as design experiment. Which is current parameter had 2 levels; 200 and 250 minutes. Parameter Coating duration had 3 levels 15, 20, 30 minutes. The oxide layer coating is seen by conducting surface characterization. The improvement of surface hardness by micro-hardness test from 35.3 VHN to 65.8 VHN for anodizing coating, and plasma electrolytic oxidation coating is in the average of 67.9 VHN. The mechanical properties for surface hardness and adhesion strength of aluminum oxide coated of Aluminum alloy sheet 5052-H32 improved.

***Keywords**: aluminum oxide, anodization, coating, plasma electrolytic oxide, surface hardness.*

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(Zhang *et al.*, 2021)

1. Introduction

Aluminum alloys have become commonplace for a number of applications since they have their unique composition of exceptional specific strength, a simple forming, better production process, high conductivity of electricity, and availability in diverse applications, in particular for automotive use (Chung *et al.*, 2017). Because of the necessity to save weight globally in order to further reduce fuel consumption, aluminum alloy has been an indicator of rising concern in recent years for automotive applications (Liyakat and Veeman, 2022)and (Jaikumar *et al.*, 2023). The application of sheets for new lightweight structural parts and body building is particularly commonplace and all major producers of aluminum alloy semi-finished products have made significant attempts to meet the primary demands. Due to its exceptional characteristics, aluminum has assumed a crucial role in engineering, making it the most produced non-ferrous metal in the metallurgical industry sectors (Muzakkir Ahamed and Natrayan, 2022)(Hägele and Sonsino, 2014).

Aluminum coated was been essential in automotive industries (Dareh *et al.*, 2019). Right coating method can increase the surface hardness of the material. It can be achieved by less cost compared with heat treatment, but not changing the grain structure and material characterization as a consequence (Yue *et al.*, 2011). In addition, metal coatings have several advantages including; corrosion prevention, frictional stress resistance, reduced surface roughness, and decorativeness (Abioye *et al.*, 2019). Aluminum 5052-H32 also easy to recycling to meet sustainable manufacturing (Dhindaw, Aditya and Mandal, 2020). Anodizing coating and plasma electrolytic oxidation (PEO) are common in industrials. An oxidation process occurs during anodizing process, aluminum is oxidized with electricity so that base material will erode and configure metal oxides which are entered by the coating substance (Aubakirova *et al.*, 2021). The chemical reactions formed during the PEO process are as follows $Al_2O_3 + H_2O \rightarrow 2AlOOH$. The coating processed by PEO have relatively superior to normal anodic oxidation (Sikdar *et al.*, 2021), this advantage including; ductile nano-ceramic oxide layer that improves mechanical properties, wear, and thermal resistance (Wang *et al.*, 2019). Beside aluminum, this process also applied to titanium, and magnesium. This chemical reaction is formed during the PEO process $Al_2O+3H_2O\rightarrow 2Al\ (OH)_3$ (Rogov and Shayapov, 2017).

A research observed PEO on 6061 aluminum alloy by applying a bipolar pulsed current and pulse duration. Those parameters significantly in addition of thickness and hardness (Wang *et al.*, 2022). A current research evaluating about anodized coating using sulfuric and phosphoric acid as electrode to laminate 5052 aluminum alloy. The coating thickness and deposition depend on the anodizing duration and the type of electrolyte. Thicker and harder anodic coatings were generated in sulfuric acid compared to phosphoric acid. Both electrolytes generated anodic coatings with improved friction coefficient and dimensional wear rate (Dervishi *et al.*, 2022). The resulting of combination low power and suffuse electrolyte between amorphous silicon oxide, crystalline monoclinic and tetragonal zirconia oxide on zirconia alloy was had a beneficial on produce PEO coating with high wear resistance and excellent anti-corrosion characteristic. Reported PEO deposition is three time higher than substrate (Al Afghani and Anawati, 2021). Anodizing on aluminum had less crack coating over the aluminum coating, but less suggested by SEM images (Kumar *et al.*, 2021). Other research to develop protective coating was successfully aluminum using PEO method, reported fraction of Silica Carbonate particles layer 60μm and 40μm was achieve anti corrosion against 3.5% NaCl solution . PEO aluminate-based electrolyte using trisodium phosphate, sodium dihydrogen phosphate and sodium hypophosphite on cooper to provide semiconductor was conduction. reported quick establishment of plasma discharges leading to coating formation. Deposited Copper and the subsequent formation of aluminum layer may re-passivate the copper surface [19].

Based from some research about Anodizing and PEO coating that used to laminate some materials, but so far there is lack applied to aluminum especially on aluminum alloy 5052-H32. it will give some feedback to industrial that dealing with those material. Figure out about Anodizing and PEO characteristic coating and optimum parameter on it. Those was an augmentation of this research script

2. Research Methods

Material and Method contain primary materials used in this research and methods to solving problems including methods of analysis, following to some previous research [15]. Aluminum alloy sheet 5052-H32 as the substrate which will be treated in two methods PEO and Anodization coating. Material was polishing on sand paper 800 series before coating. Hence, we can apply water and this step is designated cleaning method. Anodization coating experiment serve a handle made out of the corresponding Aluminum, it will limit the contamination of the specimen in the anodizing method, so no need to touch it. Power supply on DC, carbon graphite using to be connecting wire and cathode during anodizing and PEO coating, plastic basin is used to conduct the coating process. Dielectric containing 7.5 ml of sulfuric acid is diluted with 75ml of distilled water to make 10% concentration of sulfuric acid and it is cooled down to almost 0oC.

The aluminum component being anodized serves as the anode in a two electrodes arrangement used for anodizing. The positive lead is attached to the metal specimen. The cathode, which is made of carbon graphite, is connected to the negative lead. It is necessary to divide and align the two electrodes in parallel. Before starting the process, the anodize substrate needs to be completely submerged in the electrolyte. The porosity and thickness of this oxide layer depends on the electrical parameters, type of electrolyte H2SO4, its temperature and anodizing time. Constant parameter during PEO coating experiment on this research such as; dielectric solution containing potassium hydroxide 2 g/l, Sodium silicate 9 g/l, and distilled water 800 ml. Cathode using stainless steel based on this research. There are some parameters used in anodization process for this experiment which can be seen in table 1.

Table 1: Anodization Parameters

Parameter	Value
Concentration of sulfuric acid	10%
Voltage	25 V
Current	400mA
Temperature	4ºC
Time	25 minutes
Cathode	Carbon Graphite

Independent variable during PEO coating in this experiment showed on Table 2. Parameters of constant variable on PEO experiment showed on Table 2.

Table 2: Independent variable on PEO experiment

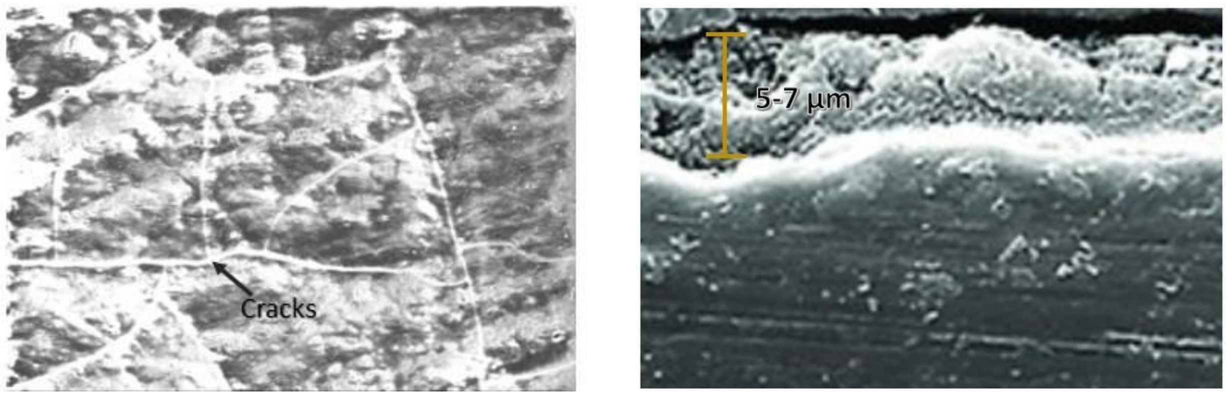
Parameters	Voltage (V)	Time (minutes)
Substrate 1	200	15
Substrate 2	200	20
Substrate 3	200	30
Substrate 4	250	15
Substrate 5	250	20
Substrate 6	250	30

3. Results and Discussion

These are instances of anodization and PEO coating; the variances between them will depend on the supplied parameters. Figure 1(a). shows the sample's alternative coating clearly. The plan view of the anodization coating is depicted in Figure 2. SEM is used to get the picture at a 500x magnification. Figure 1 (b) shows the surface morphology of the anodization coating. Aluminum oxide is immediately produced by the aluminum in response to the oxygen. When the process is finished, the oxide remains firmly bound to the surface, creating an impenetrable coating. Some fissures in the oxide layer can be seen in the morphology presentation. The ingredients for this anodization coating include 10% sulfuric acid, 25 V of DC power, 400 mA of current, 4ºC of temperature, and 25 minute duration of deposition, and cathode is carbon graphite.

(a) (b)

Figure 1. aluminum substrate coated sample by (a) Anodization, (b) PEO coating,



(a) (b)

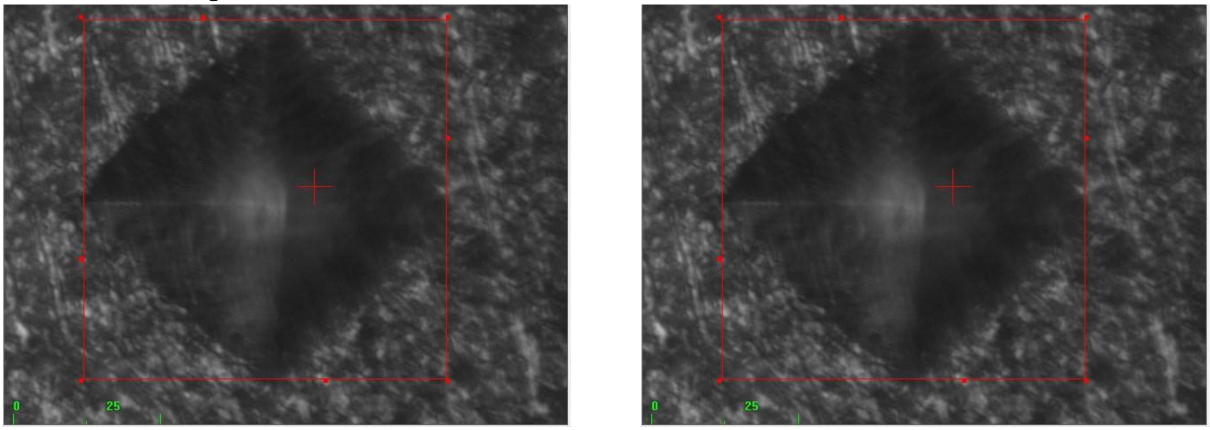
Figure 2. Result of Anodizing (a) Surface Morphology on Anodization Coating (b) Thickness of anodization coating VOS Network Visualization for Bibliometric

The anodic layer thickness increases as the anodizing time increases, as seen in Figure 2 (a). However, a number of variables, including treatment time, electrolyte type, and current density, also affect thickness. The original thickness initially increases quickly and steadily. This is followed for a long enough time by anodization, which causes a slight contraction but results in an increase in thickness as a result of continuous current. The anodic film thickness continuously increases during the anodization process, and chemically induced disintegration also takes place. The general thickness less the dissolved oxide layer is the original thickness. The theoretical value is nonetheless equal to processing time. The Faraday law, which requires that the oxide formed is proportional to the electrical charge transferred, defines the continuous current density. Micro-hardness findings reveal a noticeable rise in surface hardness. 5 minutes are spent pressing, with a constant force of 980.7 Nm. As a result, the result increased to 65.8 VHN. As shown in table 5, a constant force of 980.7 Nm was applied for a period of time of 5 minutes. In doing so, a result of 35.3 VHN for this material's hardness was obtained. When conducting a micro-hardness test, this indication caused thickness anodization on anodized aluminum contributed a vital part in holding the intender. Table 3 displayed the microhardness test results.

Table 2: Independent variable on PEO experiment

Parameter	Bare Aluminum	Anodizing Coating
H Length (μm)	61.72	43.4
V length (μm)	83.25	62.75
Average length (μm)	72.49	53.08
Hardness (VHN)	35.3	65.8

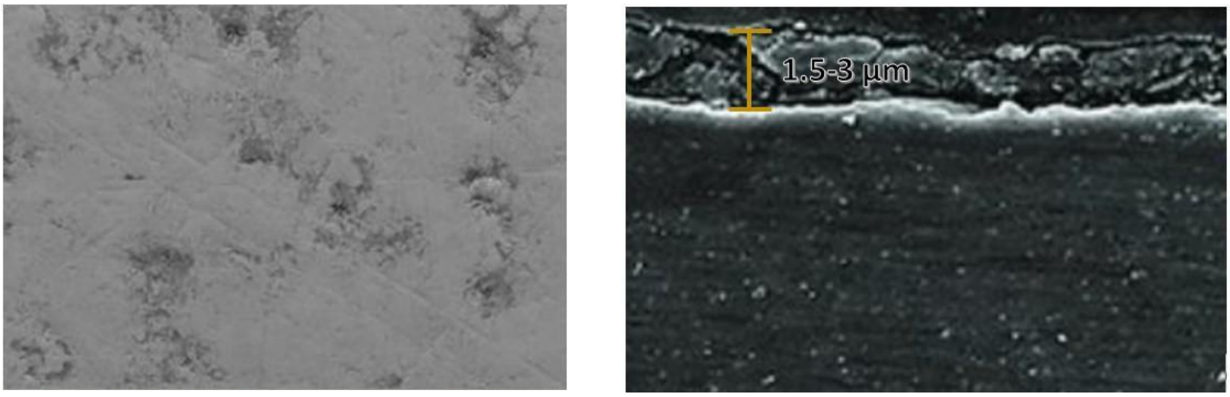
Based on table 3 bare aluminum had wider intender area than anodized substrate. Bare aluminum had 72.49μm and anodizing cutting had 62.75μm. that because the longer duration substrate dipping on sulfuric acid, the more carbon graphite been erode from cathode. This might come oxide layer forming like in this research(Al Afghani and Anawati, 2021), so aluminum had high density aluminum oxide layer. This layer not found in bare aluminum, so intender hit base metal easily. This lack lead to wider intender area (Jiang *et al.*, 2019). The picture of intender on bare and anodized substrate showed on figure 3.



(a) (b)

Figure 3. Pre-anodized (left) and Anodized (right) sample conducted micro-hardness test

The PEO Coating's morphological and elemental analysis. In the PEO process, the voltage has a vital effect on the growth of the oxide film. Voltage and dielectric analyses take place in the crack across the oxide layer. Sparks additionally operate as a good example of the PEO approach and are very important in the creation of the coating. Figure 4(a) illustrates the PEO coating's surface morphology. The surface morphology of the substrate coated with PEO appears to be smoother and brighter than the substrate coated with anodization. However, there are some superficial cracks now. This PEO coating contains 800 mL of distilled water, 2 g/L of potassium hydroxide, 9 g/L of sodium silicate, and a DC supply voltage of 250 volts. The deposition time is 30 minutes. The high electrolyte temperature generated during the PEO process affects the PEO coating's thickness. A thicker coating is formed by an electrolyte at a higher temperature. High temperatures during the procedure had an impact on coating production, but in addition accelerated electrolyte dissolution. Consequently, the coating was generally thinner in some places of the substrate. The thickness of the PEO coating is visible in Figure 4(b).



(a) (b)

Figure 4. Pre-anodized (left) and Anodized (right) sample conducted microhardness test

Table 4 displays the hardness data, and Figure 7 illustrates the standard deviation of hardness for all substrates deposited using the PEO technique at various voltages and durations. In this experiment, PEO coatings are created using an electrolyte with constant parameters, including 800 mL of distilled water, 2 g/L of potassium hydroxide, and 9 g/L of sodium silicate. Stainless steel serves as the cathode. Voltage under DC power supply and time elapsed are the variables modified. Table 4 displays the results of the Vickers micro-hardness test on PEO-coated samples.

Table 4: Independent variable on PEO experiment

Parameters	Voltage (V)	Time (minutes)	Average Hardness (VHN)	Standard Deviation
Substrate 1	200	15	49.2	2.6
Substrate 2	200	20	50.0	2.5
Substrate 3	200	30	63.4	3.5
Substrate 4	250	15	50.2	3.7
Substrate 5	250	20	63.6	4.4
Substrate 6	250	30	67.9	7.4

According to Table 4, Substrate 6 (in hydroxide 2 g/l, sodium silicate 9 g/l, voltage 250 v, time 30 minutes, distilled water 800 ml, cathode stainless steel) exhibits the highest hardness at an average of 67.9 VHN under the conditions of 980.7 Nm of test force and a duration time of 5 seconds. Higher porosity coatings are less hard, hence a sample's coating hardness is highly correlated with the coating compactness. The harder the covering, the more compact it is. In order to enhance the hardness coating of a sample, it is crucial to manage porosity levels. By adjusting the process variables, including voltage and deposition time, these can be accomplished. additional elements that influence the hardness of process parameters such as voltage and deposition time (Du et al., 2021).

The crystalline and amorphous phases, which are a result of the high temperatures that the coating locally achieved, are additional elements that affect a coating's hardness. These phases can result in coatings with a high hardness and resistance to wear (Jiang *et al.*, 2019). To demonstrate how much variance there is from the mean, utilize the standard deviation. The definition of a low standard deviation is a set of data points that are relatively near to the mean. Data points that are dispersed over a wide range of values are what is referred to as having a high standard deviation. The structural uniformity of PEO layers correlates with the standard deviation of coating hardness.

According to the results in Figure 3(a) and (b), the standard deviation values for Substrates 1, 2, and 3 are similar, whereas Substrate 6 has the highest standard deviation, which may be related to the uniformity of the PEO coating on the surface. According to table 3, the substrate number 6 at 67,9 VHN, which is a mixture of 2 g/L of potassium hydroxide, 9 g/L of sodium silicate, and 800 mL of distilled water, has the highest number of the hardness of PEO coating. The modifying parameters have been DC supply power at 250 V and 30 minutes of deposition time, respectively. The second-highest values are contributed by substrates 3 (63.4 VHN) and 5 (63.6 VHN), respectively. comparable lowest hardness values in each of the three.

4. CONCLUSSION

This research study focuses on finding optimal parameters for anodizing and plasma electrolytic oxidation coating methods to achieve the highest hardness value. The anodizing method resulted in a hardness value of 65.8 VHN with a voltage setting of 25V, current of 400mA, temperature of 4oC, and a deposition time of 25 minutes. On the other hand, the plasma electrolytic oxidation method achieved a hardness value of 67.9 VHN with a voltage setting of 250V and a deposition time of 30 minutes. The anodizing method produced an oxide layer ranging from 5μm to 7μm, while the plasma electrolytic oxidation method produced an oxide layer ranging from 1μm to 3μm. The oxide layer in the plasma electrolytic oxidation method resulted in a significantly higher hardness value compared to anodizing, as observed through scanning electron measurements which showed micro cracks in the oxide layer produced by anodizing. The micro cracks formed are elongated and hairy. The micro cracks produced by this method in addition to stretching are also formed into the oxide layer. Based on the S/N Ratio, increasing the duration of immersion in plasma electrolytic oxidation can also increase the amount of oxide layer and surface hardness value of the aluminum alloy. Overall, both coating methods significantly increased the hardness value of the aluminum plate.

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