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Investigation of the Effect of Anodizing Dyes Using Purple Cabbage and Dragon Fruit Peel on Aluminum 6061alloy

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ABSTRACT

Anodizing on aluminum 6061 was carried out to improve the mechanical properties and aesthetic value of the specimen surface. Anodizing produces a thin, porous oxide layer resulting in hard surface properties and corrosion resistance. The pores resulting from the anodizing process can be used to provide various colors when filled with dyes. Coloring in the anodizing process can be done with chemical dyes or natural dyes. Anodizing using chemical solutions produces waste that can be harmful to the environment. To overcome this pollution problem, a natural dye solution is used using dyes from purple cabbage and dragon fruit peel so that it is expected to minimize the impact of environmental pollution. The purpose of this study was to investigate the effect of using natural dyes produced from purple cabbage and dragon fruit peel on anodizing aluminum 6061. The investigation is carried out through visual color testing, coating thickness testing, micro-structure testing, and micro Vickers hardness testing. From these results, it was found that the variation in the concentration of the dye solution did not affect the thickness of the resulting oxide layer. The oxide layer and pore size are influenced by temperature, electric current, voltage, solution concentration, and immersion time in the electrolyte solution during the anodizing process. So the factors that greatly influence the diffusion quality of the dye solution are the correct pore size and thickness of the oxide layer so that the dye can adhere perfectly to the surface of the specimen.

Key Words: Aluminum alloy, Anodizing, Fruit Waste, Vegetable Waste, Staining.

1. INTRODUCTION

In general, the properties of aluminum include: having a relatively lightweight with a specific gravity of 2.7 g/cm^3 or about 1/3 of the density of steel (7.86 g/cm^3). The tensile strength of pure aluminum is 90 Mpa, and its physical properties can be improved by adding alloying elements [1]. When combined with the elements, the tensile strength ranges up to 600 MPa. The advantages of Aluminum are that it is easy to bend, machine-treat, cast, draw and extrude. Aluminum 6061 is generally applied to automotive and construction tools because it has fairly good machinability, corrosion, thermal and electrical conductivity. Magnesium and Silicon form the compound Mg2Si (Magnesium Silicide) which gives high strength to aluminum alloy 6061 [2].

Anodizing is a simple electrochemical process that was developed in the 20th century by forming a protective layer of aluminum oxide on the aluminum surface. This process produces a thin porous oxide layer that is hard and corrosion-resistant. The porous layer can be used to provide various colors when filled with dyes [3]. The anodizing process can be done with chemical dyes. One method that can be used to improve physical properties includes changes in color brightness and color coating thickness on aluminum after the coloring process in the anodizing process [4], [5].

Previous research, an anodizing process using ingredients from tea leaves as coloring had been conducted [4]. The resulting color depends on the immersion time and the concentration of the tea solution used. The anodizing result using black tea dye produces a golden yellow to brownish-yellow color. If the concentration of the dye used is higher, it will produce a darker color [6].

An aluminum coloring also had been conducted by previous researcher by an anodizing process using dye from fragrant of pandan wangi leaves [7]. The color produced from fragrant pandan wangi leaves is green. The color produced from the anodizing process depends on the length of time immersing and the concentration of pandan wangi leaf solution used. According to this research, it was found that if the concentration of the dye solution used was higher, the brighter the resulting color would be [8].

Another study used extraction from mangosteen peel as a natural dye in the anodizing process [9]. The color produced from the mangosteen peel extraction ranges from light yellow to brownish-yellow. The higher the color concentration, the darker the color will be. Turmeric also was used as a natural dye in the anodizing process. This research produces colors that are not yet uniform and different. According to some of the research results above, it shows that the concentration of the dye solution used in the dyeing process greatly affects the results of the color brightness [6].

According to the several previous studies, purple cabbage and dragon fruit peel were used as alternatives to natural dyes for anodizing aluminum 6061. This study was conducted to determine the mechanical properties of the effect of dyeing on anodized aluminum 6061 using natural dyes from purple cabbage and dragon fruit peel through testing. visual color, coating thickness testing, microstructure testing, and micro Vickers hardness testing.

2. METHODOLOGY

The method used in this research is the laboratory experimental method. The research was carried out in several stages, namely preparation, anodizing process, the coloring process using vegetable waste, namely purple cabbage and fruit waste from dragon fruit peel, then tested on the research specimen. The material used in this research is aluminum alloy 6061 with dimensions of 10 mm x 33 mm x 22 mm. The research flow diagram can be shown in Figure 2.1.

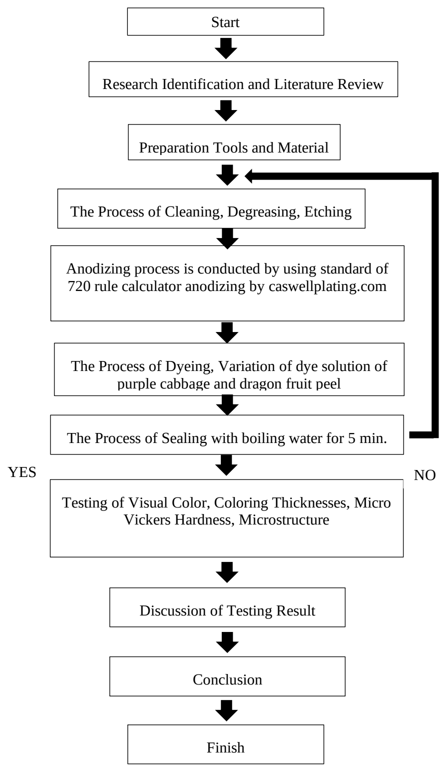

Figure 2.1: Research Flowchart

This research was conducted using several independent variables such as variations in the types of dyes, namely purple cabbage and dragon fruit peel mixed with nitric acid and aquadest then processed by distillation and food coloring with different compositions. For current, voltage, and anodizing time follow the standard 720 rule calculator anodizing by caswellplating.com. Table 2.1 below shows the specimen numbering and the type of treatment performed.

Table 2.1 Number of Specimens and Type of Treatment

No	Specimen Code	Treatment
1	2u	15 ml purple food coloring, 120 ml purple cabbage distillate, 865 ml aquadest (1000 ml dye solution)
2	3u	30 ml purple food coloring, 120 ml purple cabbage distillate, 850 ml aquadest (1000 ml dye solution)
3	5u	45 ml purple food coloring, 120 ml purple cabbage distillate,

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		835 ml aquadest (1000 ml dye solution)
4	6u	15 ml purple food coloring, 150 ml purple cabbage distillate, 835 ml aquadest (1000 ml dye solution)
5	7u	30 ml purple food coloring, 150 ml purple cabbage distillate, 820 ml aquadest (1000 ml dye solution)
6	8u	45 ml purple food coloring, 150 ml purple cabbage distillate, 805 ml aquadest (1000 ml dye solution)
7	3	15 ml red food coloring, 120 ml dragon fruit peel distillate, 865 ml aquadest (1000 ml dye solution)
8	5	45 ml purple food coloring, 120 ml dragon fruit peel distillate, 835 ml aquadest (1000 ml dye solution)
9	6	15 ml purple food coloring, 150 ml dragon fruit peel distillate, 835 ml aquadest (1000 ml dye solution)
10	7	30 ml purple food coloring, 150 ml dragon fruit peel distillate, 820 ml aquadest (1000 ml dye solution)
11	8	45 ml purple food coloring, 150 ml dragon fruit peel distillate, 805 ml aquadest (1000 ml dye solution)
12	9	45 ml purple food coloring, 120 ml dragon fruit peel distillate 835 ml aquadest (1000 ml dye solution)

2.1 Steps of Anodizing Process

The steps of the anodizing process of 6061 aluminum specimens with purple cabbage dye and dragon fruit peel include:

a. Degreasing

Degreasing is the process of cleaning the workpiece from dirt and oil attached to the specimen before etching. The solution used in the degreasing process is sulfuric acid (H_2SO_4). After that, rinsing cleaning is carried out, namely the process of rinsing the workpiece from chemicals that stick to the aluminum surface after the cleaning process using distilled water [10].

b. Etching

The etching is the process of chemically removing the oxide layer on the aluminum surface that cannot be removed from the cleaning process and aims to obtain a flatter and smoother workpiece surface. This process uses lye (NaOH). After that, rinsing etching is carried out, namely the process of rinsing the workpiece after the etching process using distilled water [11].

c. Anodizing

Anodizing is often called anodic oxidation, which is the process of forming an oxide layer (Al_2O_3). The workpiece is attached to the anode (+) and the tin sheet (Pb) is attached to the cathode (-). The solution used in this process is sulfuric acid (H_2SO_4). Next is rinsing anodizing, namely the process of rinsing the workpiece after the anodizing process using distilled water[12].

d. Dyeing/Coloring

Dyeing is the process of coloring the pores of the oxide layer which is formed after the anodizing process so that it will produce an attractive color on the aluminum surface. The dyes used are purple cabbage and dragon fruit peel mixed with aquadest, nitric acid, and food coloring [13].

e. Sealing

Sealing functions to close the pores of the oxide layer resulting from the anodizing process which is still open. Sealing also prevents the dye from escaping from the pores of the oxide layer, making it difficult for colors to fade. After the sealing process, the layer structure will be smooth and even. This process uses a solution of acetic acid or vinegar (CH_3COOH) [14].

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f. Rinsing Sealing

The rinsing sealing process is the process of cleaning the aluminum workpiece after the sealing process using distilled water from chemicals that stick to the aluminum surface, thus no chemical residue sticks to the aluminum surface [14].

2.2 Specimen Testing

Testing of the material resulting from anodizing staining with purple cabbage and dragon fruit peel includes 4 types of tests, namely as follows:

a. Color Visual Testing

Color visual testing through image analysis involves a lot of visual perception. This process has input data and output data in the form of images. Digital images can be obtained automatically from a digital image capture system that performs image browsing and forms a matrix, where the matrix elements represent the value of light intensity at a discrete set of image points. Calculation of the color index parameters R, G, and B is obtained from each pixel in the image. Generating characteristics from images can also be based on the color index value of RGB (Red, Green, Blue) using color analysis software.

b. Coloring Thickness Testing

This test is a data collection of the thickness of the oxide layer that is formed on the surface of aluminum 6061 using a Thickness Gun. Where the thickness value is taken at 3 surface points then averaged.

c. Micro Structure Testing

Microstructure testing was carried out on the surface of the specimens stained with purple cabbage and anodized dragon fruit peel using a Nikon optical microscope with a 200x magnification.

d. Hardness Testing

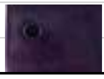
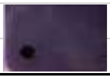
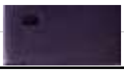
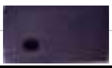
Hardness testing was carried out on the surface of the stained specimens with purple cabbage and anodized dragon fruit peel using the Vickers micro-test. The micro Vickers test was chosen because this test is compatible with testing the hardness of small or complex areas.

3. RESULT AND DISCUSSION

3.1 Color Visual Test Results

Following are the results of testing color brightness with color brightness (RGB) using color analysis software.

Table 3.1 Visual anodizing test results with purple cabbage dye

No	Specimen	Red	Green	Blue	Percent	Colour group
1	Specimen 2u 	73	74	92	60.59003	Cyan-Blue
2	Specimen 3u 	41	28	48	64.49565	Green-Cyan
3	Specimen 5u 	63	43	68	68.82746	Cyan-Blue
4	Specimen 6u 	73	74	95	53.08397	Cyan-Blue
5	Specimen 7u 	74	56	78	38.18713	Cyan-Blue
6	Specimen 8u 	68	55	72	59.63992	Cyan-Blue

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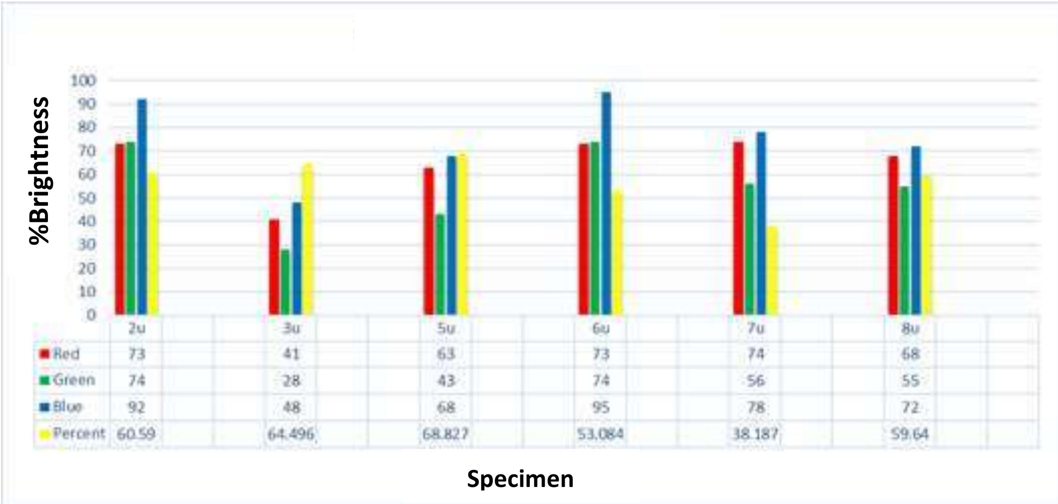
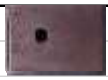
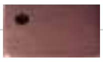
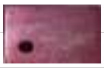
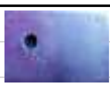


Figure 3.1 Graph of Visual Testing Results Color Anodizing Process Using Purple Cabbage Dye

Figure 3.1.Shows the results of color brightness (RGB) in the anodizing process using purple cabbage dye specimens 2u R 73%, G 74%, B 92%, 3u R 41%, G 28%, B 48% specimens, 5u R 63% specimens, G 43%, B 68%, specimen 6u R 73%, G 74%, B 95%, specimen 7u R 74%, G 56%, B 78%, specimen 8u R 68%, G 55%, B 72% The graph explains that the dominant color composition is Blue due to the pores of the oxide layer which are filled with a dye solution based on purple cabbage used in this study. Then, for the highest brightness in the 6u specimen with 53.08397% (table 3.1), the color is dominated by cyan-blue with R 73%, G 74%, B 95%, and indeed the resulting color is better and evenly distributed compared to other specimens. Thus, a composition of 15 ml of purple food coloring, 150 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) produces the best color. It is thought that there is a residue from the composition of the purple cabbage solution which diffuses on the aluminum surface. This is proven empirically. The resulting lighter color on aluminum is due to differences in the composition of the solution mixture.

Table 3.2 Visual Anodizing Test Results with Dragon Fruit peel Coloring

No	Specimen	Red	Green	Blue	Percent	Colour group
1	 Specimen 3	97	65	68	24.76971	Magenta-Pink
2	 Specimen 5	114	68	68	43.02376	Red-Orange
3	 Specimen 6	156	92	119	27.73526	Red-Orange
4	 Specimen 7	81	40	56	20.15753	Orange And Brown
5	 Specimen 8	92	53	58	17.75888	Orange And Brown
6	 Specimen 9	91	109	168	51.70290	Dark Pastel Blue

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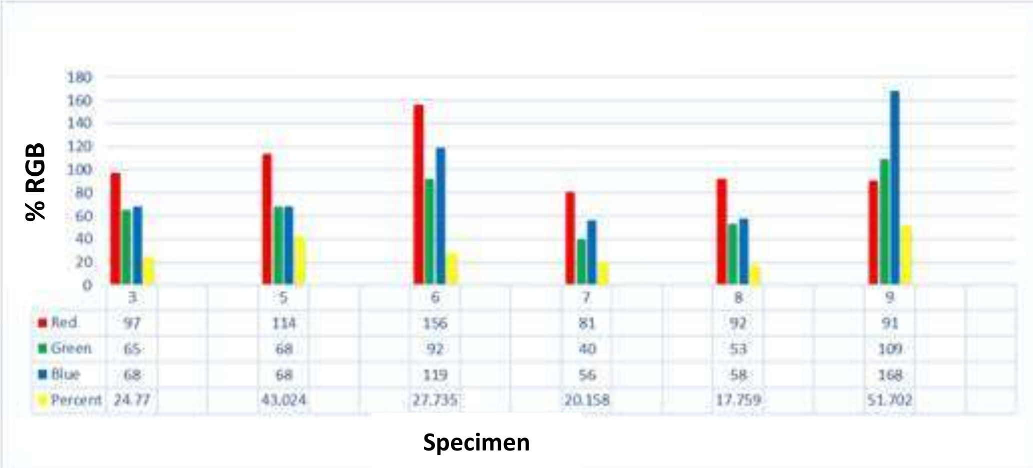

Figure 3.2. Graph of Visual Testing Results Color Anodizing Process Using Dragon Fruit peel Dyes

Figure 3.2.shows the results of color brightness (RGB) in the anodizing process using dragon fruit peel dye. Specimen 3 R 97%, G 65%, B 68%, 5 R 11%, G 68%, B 43% specimen, 6 R specimen 156%, G 92%, B 119%, specimen 7 R 81%, G 40%, B 56%, specimen 8 R 92%, G 53%, B 58%, specimen 9 R 91%, G 109%, B 168% The graph explains that the dominant color composition is Red due to the pores of the oxide layer which are filled with a dye solution made from dragon fruit peel as the base ingredient of this research. Then, for the highest brightness in specimen 6 with 27.7353% (table 3.2), it is dominated by Red - Orange color with R 156%, G 92%, B 119%, and indeed the resulting color is more by the dragon fruit peel color compared to another specimen. So with a composition of 15 ml of red food coloring, 150 ml of dragon fruit peel distillate, 835 ml of aquadest (1000 ml of dye solution) produces the best color. It is thought that there is a residue from the composition of the dragon fruit peel solution which diffuses on the aluminum surface. This is proven empirically. The resulting lighter color on aluminum is due to differences in the composition of the solution mixture [11], [13].

3.2 Coating Thickness Test Results

The average thickness of the oxide layer formed on the surface of aluminum 6061 which has been anodized with a variety of purple cabbage coloring solution and dragon fruit peel using Thickness Gun can be seen in table 3.3.

Table. 3.3 Thickness data of anodizing results with purple cabbage dye and dragon fruit peel

Coloring Coating Thicknesses									
No	Coloring Type	Code	Thicknesses						Average
			Top Surface			Bottom Surface			
1	Purple Cabbage	2u	22.500	6.100	7.400	27.500	8.600	23.800	15.983
2		3u	11.100	8.600	35.500	20.000	17.500	32.700	20.900
3		5u	9.900	21.300	8.600	34.200	16.200	13.600	17.300
4		6u	6.100	11.100	46.000	17.500	4.900	23.800	18.233
5		7u	13.600	17.500	22.600	11.100	8.600	37.100	18.417
6		8u	9.900	7.400	16.200	18.800	6.100	12.300	11.783
7	Dragon Fruit Peel	3	8.600	16.200	22.600	4.900	13.600	14.900	13.467
8		5	3.600	4.900	9.800	8.600	11.100	14.900	8.817
9		6	11.100	13.600	12.300	8.600	16.200	23.800	14.267
10		7	17.500	20.000	14.900	12.300	16.200	21.300	17.033
11		8	16.200	21.300	14.900	18.800	17.500	23.800	18.750
12		9	12.300	11.100	13.600	14.900	7.400	22.500	13.633

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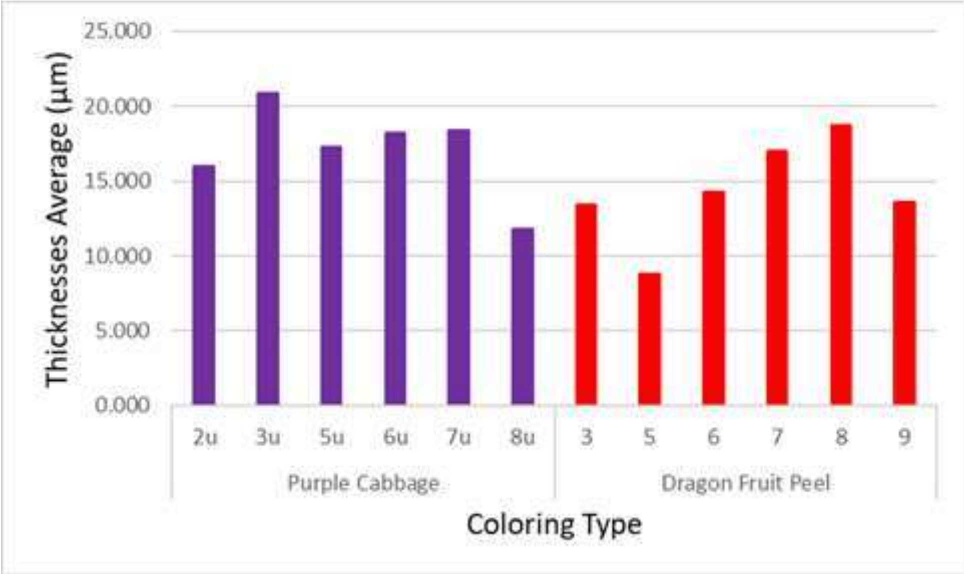

Figure 3.3. Graph of Thickness Value of the coloring layer with variations of the purple cabbage and dragon fruit peel dye solution

Figure 3.3 shows that the highest layer thickness is the result of anodizing using a purple cabbage dye solution, namely in the 2u1 specimen with 30 ml of purple food coloring, 100 ml of purple cabbage distillate, 870 ml of aquadest (1000 ml of dye solution) with a thickness value of 29.550 µm but the color the resulting less evenly. While the highest layer thickness resulted from anodizing using dragon fruit peel dye solution, namely specimen 8 with 45 ml red food coloring, 150 ml dragon fruit peel distillate, 805 ml aquadest (1000 ml dye solution) with a thickness value of 18,750 µm. The variation in the concentration of the dye solution does not affect the thickness of the resulting oxide layer. The oxide layer and pore size are influenced by temperature, electric current, voltage, solution concentration, and immersion time in the electrolyte solution during the anodizing process. So the factors that greatly affect the quality of the dye solution diffusion are the correct pore size and thickness of the oxide layer so that the dye can adhere perfectly to the surface of the specimen [15], [16].

3.3 Micro Structure Testing Results

Microstructure testing was carried out on the surface of the stained specimens with purple cabbage and anodized dragon fruit peel using a Nikon optical microscope with a 200x magnification. The data from the microstructure observations on the 6061 aluminum surface that had been anodized with a variety of purple cabbage dye and dragon fruit peel using a Nikon optical microscope with a magnification of 200x can be seen in table 3.4.

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Table 3.4. Anodizing 200x micro-test results with purple cabbage

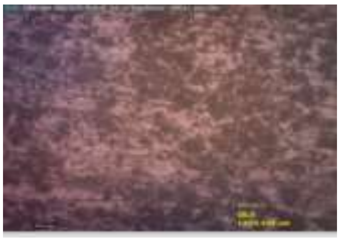
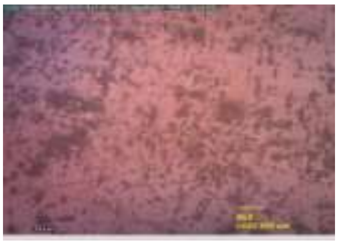
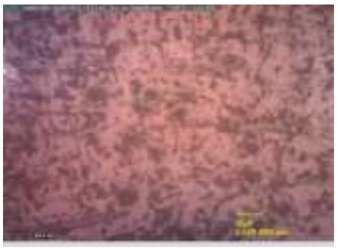
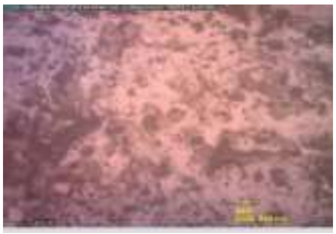
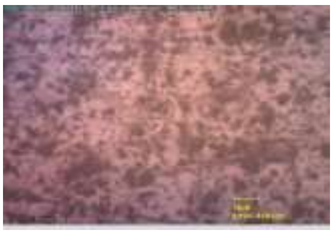
No	Specimen	Microstructure Test 200x
1	Specimen 2u 	
2	Specimen 3u 	
3	Specimen 5u 	
4	Specimen 6u 	
5	Specimen 7u 	
6	Specimen 8u 	

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Table 3.5. Anodizing 200x micro-test results with dragon fruit peel

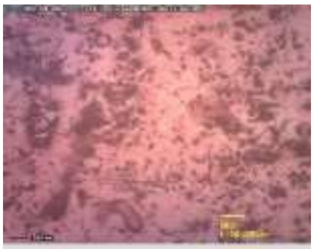
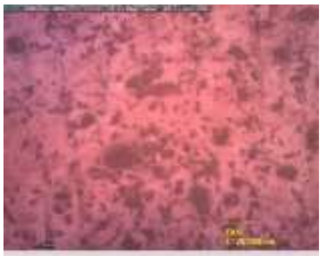
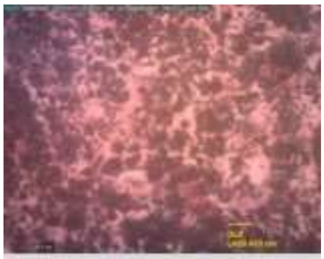
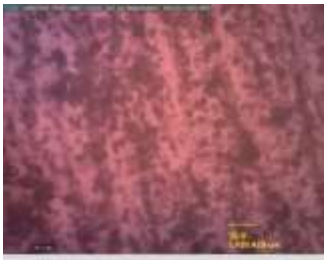
No	Specimen	Microstructure Test 200x
1	Specimen 3 	
2	Specimen 5 	
3	Specimen 6 	
4	Specimen 7 	
5	Specimen 8 	
6	Specimen 9 	

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Table 3.4 shows that there is a correlation between% pores and color brightness. The more uniform the pores and the greater the%, the higher the absorption of the specimen for the dye and the lighter the color. In the 6u anodizing specimen using purple cabbage dye with a composition of 15 ml of purple food coloring, 150 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) has a homogeneous% pore, this affects the absorption of the specimen to the dye. Maximum absorption will produce a cyan-blue color that is evenly distributed on the specimen surface. According to table 3.5 shows the 6 anodizing specimens using dragon fruit peel dye with a composition of 15 ml red food coloring, 150 ml dragon fruit peel distillate, 835 ml aquadest (1000 ml dye solution) also has a homogeneous pore%, this has an effect on absorption specimens against dyes. The maximum absorption will produce a red-orange color that is evenly distributed on the specimen surface [15], [17].

3.4 Micro Vickers Hardness Testing Results

The specimens were tested for hardness on the surface using the micro Vickers hardness test.

Table 3.6. The results of the hardness test used purple cabbage

HARDNESS TEST					
Methods :		○ Brinell	● Vickers		○ Rockwell : -(convertion)
Indenter : ○ Ball Ø2.5mm			○ Ball Ø5mm		Load : 1 kgf
	○ Ball Ø10mm		● Diamond pyramid 1		Time : 15 second
No.	Specimen	Location	Hardness Value	Average	Information
1	2uA	BM	134.5		
2	2uB	BM	125.5	130.2667	
3	2uC	BM	130.8		
4	3uA	BM	127.1		
5	3uB	BM	122.3	122.2333	
6	3uC	BM	117.3		
7	5uA	BM	144.5		
8	5uB	BM	129.7	132.7	
9	5uC	BM	123.9		
10	6uA	BM	129.7		
11	6uB	BM	120.5	127.5	
12	6uC	BM	132.3		
13	7uA	BM	127.3		
14	7uB	BM	131.6	130.8333	
15	7uC	BM	133.6		
16	8uA	BM	121.1		
17	8uB	BM	114.1	118.5	
18	8uC	BM	120.3		

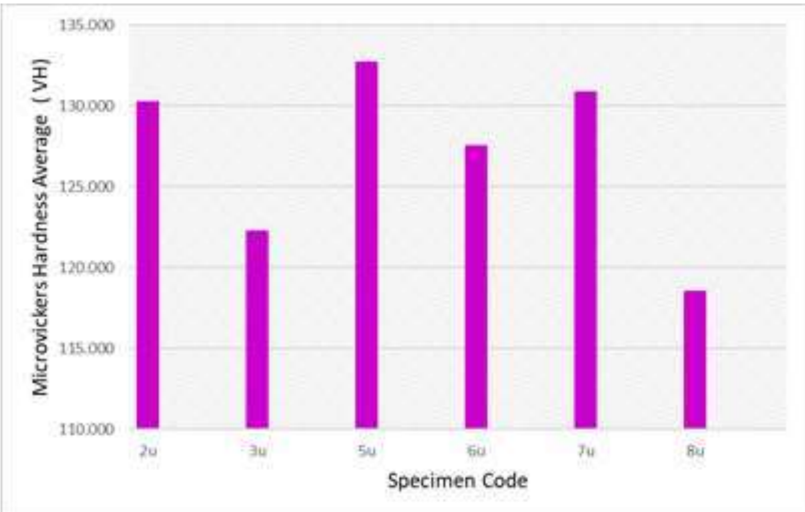

Figure 3.4. Micro Vickers Hardness Value of staining coating

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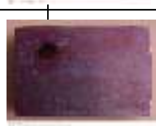
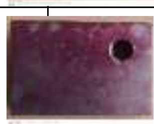
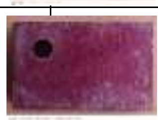
Table 3.7 Hardness test results using dragon fruit peel

HARDNESS TEST					
Methods:	○ Brinell		● Vickers	○ Rockwell : -(convertion)	
Indenter :	○ Ball Ø2.5mm		○ Ball Ø5mm		Load : 1 kgf
	○ Ball Ø10mm		● Diamond pyramid		Time : 15 second
No.	Specimen	Location	Hardness Value	Average	Information
1	3A	BM	120.2	140.2667	
2	3B	BM	150.8		
3	3C	BM	149.8		
4	4A	BM	137.8	132.5	
5	4B	BM	127.4		
6	4C	BM	132.3		
7	5A	BM	122.9	132.7667	
8	5B	BM	135.7		
9	5C	BM	139.7		
10	6A	BM	136.4	132.1333	
11	6B	BM	133.1		
12	6C	BM	126.9		
13	7A	BM	139.6	136.3333	
14	7B	BM	130.3		
15	7C	BM	139.1		
16	8A	BM	159.4	159.4667	
17	8B	BM	162.6		
18	8C	BM	156.4		

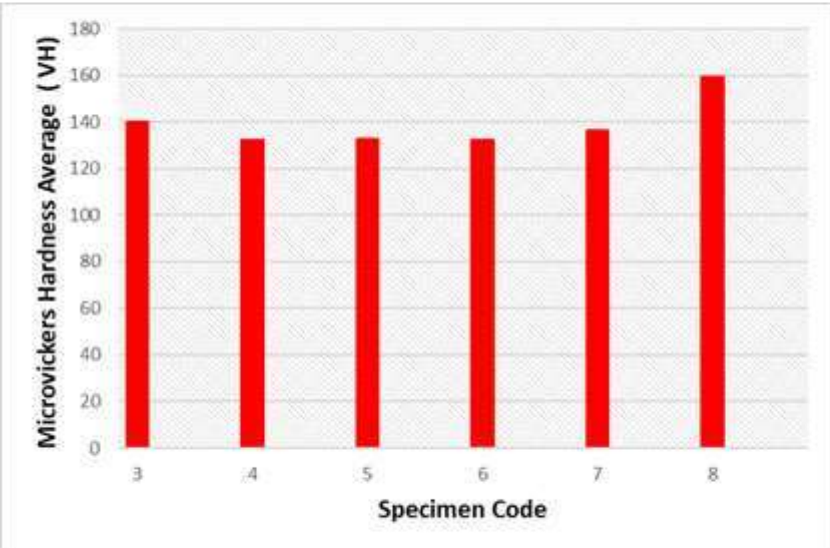


Figure 5. Thickness value of the coloring layer

Figure 5 shows that the highest anodizing hardness test uses a purple cabbage dye solution, namely the 5u specimen with 45 ml of purple food coloring, 120 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) with an average hardness value of 132.700 HV. however, the resulting color is not evenly distributed. While the highest layer thickness resulted from anodizing using dragon fruit peel dye solution, namely specimen 8 with 45 ml of red food coloring, 150 ml of dragon fruit peel distillate, 805 ml of aquadest (1000 ml of dye solution) with an average hardness value of 159.467 HV. The variation in the concentration of the dye solution does not affect the hardness of the resulting oxide layer. The oxide layer and pore size are influenced by temperature, electric current, voltage, solution concentration, and immersion time in the electrolyte solution during the anodizing process. Thus, the factors that greatly influence the diffusion quality of the dye solution are the correct pore size and thickness of the oxide layer, then the dye can adhere perfectly to the surface of the specimen [13], [17].

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4. CONCLUSION

According to the results and discussion of the research, it could be concluded as follows:

1. The highest color brightness (RGB) was anodizing using purple cabbage dye, namely in the 6u specimen with 53.08397% dominated by cyan - blue colors with R 73%, G 74%, B 95%, thus, a composition of 15 ml of food coloring purple, 150 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) produces the best colors. It is thought that there is a residue from the composition of the purple cabbage solution which diffuses on the aluminum surface.

2. The highest brightness of the color (RGB) was anodizing using purple cabbage dye, namely at the highest brightness in specimen 6 with 27.7353% dominated by Red - Orange with R 156%, G 92%, B 119%, and indeed the colors produced more by the color of the dragon fruit peel than the other specimens. Thus, a composition of 15 ml of red food coloring, 150 ml of dragon fruit peel distillate, 835 ml of aquadest (1000 ml of dye solution) produces the best color. It is thought that there is a residue from the composition of the dragon fruit peel solution which diffuses on the aluminum surface.

3. The highest layer thickness was the result of anodizing using a purple cabbage dye solution, namely in 2u1 specimens with 30 ml of purple food coloring, 100 ml of purple cabbage distillate, 870 ml of aquadest (1000 ml of dye solution) with a thickness value of 29.550 μm but the resulting color was uneven.

4. The highest layer thickness resulted from anodizing using dragon fruit peel dye solution, namely specimen 8 with 45 ml of red food coloring, 150 ml of dragon fruit peel distillate, 805 ml of aquadest (1000 ml of dye solution) with a thickness value of 18,750 μm.

5. The highest anodizing hardness test used a purple cabbage dye solution, namely the 5u specimen with 45 ml of purple food coloring, 120 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) with an average hardness value of 132.700 HV but the resulting color was less equally.

6. The highest hardness test resulted from anodizing using dragon fruit peel dye solution was specimen 8 with 45 ml of red food coloring, 150 ml of dragon fruit peel distillate, 805 ml of aquadest (1000 ml of dye solution) with an average hardness value of 159.467 HV.

7. The more uniform the pores and the greater the%, the higher the absorption of the specimen for the dye and the lighter the color. In the 6u anodizing specimen using purple cabbage dye with a composition of 15 ml of purple food coloring, 150 ml of purple cabbage distillate, 835 ml of aquadest (1000 ml of dye solution) has a homogeneous% pore, this affects the absorption of the specimen on purple cabbage dye. Maximum absorption will produce a cyan-blue color that is evenly distributed on the specimen surface.

8. In the anodizing specimen 6 using dragon fruit peel dye with a composition of 15 ml red food coloring, 150 ml dragon fruit peel distillate, 835 ml aquadest (1000 ml dye solution) also has a homogeneous% pore, this affects the absorption of the specimen on peel dye. Dragon fruit. The maximum absorption will produce a red-orange color that is evenly distributed on the specimen surface.

9. The variation in the concentration of the dye solution does not affect the thickness of the resulting oxide layer. The oxide layer and pore size are influenced by temperature, electric current, voltage, solution concentration, and immersion time in the electrolyte solution during the anodizing process. So the factors that greatly influence the diffusion quality of the dye solution are the correct pore size and thickness of the oxide layer so that the dye can adhere perfectly to the surface of the specimen.

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