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The Effect of Al-Zn Composition and Immersion Time in The Galvalume Process on Low Carbon Steel Microstructure, Mechanical Properties, and Corrosion Rate

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Abstrak

Pengaruh komposisi Al-Zn dan lama masa tahan terhadap tebal, pembentukan struktur lapisan, sifat mekanik dan ketahanan korosi selama proses galvalume celup panas pada baja karbon rendah telah dilakukan. Baja karbon rendah yang digunakan dengan komposisi kimia 0,01-0,25% karbon. Parameter yang digunakan adalah Al55%-Zn45%, Al60%-Zn40%, dan Al65%-Zn35%. Variasi waktu perendaman yang digunakan adalah 10 detik, 20 detik, dan 30 detik. Sampel kemudian diuji meliputi pengujian mikro Vickers, ketebalan lapisan, metalografi dengan mikroskop optik, Scanning Electron Microscope (SEM/EDS), difraksi sinar-X (XRD), dan uji potensial dinamik. Nilai kekerasan lapisan tertinggi yang diperoleh dari hasil pengujian pada variasi komposisi Al55%-Zn45% dengan lama *holding time* 30 detik adalah 208,20 HV. Nilai kekerasan lapisan terendah yang diperoleh dari hasil pengujian pada variasi komposisi Al65%-Zn35% dengan waktu tahan tahan 10 detik adalah 172,16 HV. Nilai ketebalan lapisan terendah pada waktu tahan perendaman 10 detik adalah 342,0 μm. Nilai ketebalan lapisan tertinggi pada waktu tahan perendaman 30 detik adalah 1358,0 μm. Kisaran laju korosinya adalah 2,097-4,69 mpy.

Kata kunci: Hot Dip galvalume, Al-Zn, Low carbon steel, Thickness Hardness, Corrosion rate

Abstract

The effect of Al-Zn composition and holding time on thickness, layer structure formation, mechanical properties, and corrosion resistance during the hot dip galvalume process on low-carbon steel has been carried out. Low-carbon steel is used with a chemical composition of 0.01-0.25% Carbon. The parameters used were Al55%-Zn45%, Al60%-Zn40%, and Al65%-Zn35%. The variations in immersion time used were 10 seconds, 20 seconds, and 30 seconds. The samples were tested, including Vickers micro testing, layer thickness, metallography with an optical microscope, Scanning Electron Microscope (SEM/EDS), X-ray diffraction (XRD), and dynamic potential testing. The highest layer hardness value obtained from the test results on the Al55%-Zn45% composition variation with a holding time of 30 seconds was 208.20 HV. The lowest layer hardness value obtained from the test results on the composition variation of Al65%-Zn35% with a holding time of 10 seconds is 172.16 HV. The lowest layer thickness value at a holding time of 10 seconds is 342.0 μm. The highest layer thickness value at a holding time of 30 seconds is 1358.0 μm. The range of corrosion rates is 2.097-4.69 mpy.

Keywords: Hot Dip galvalume, Al-Zn, Low carbon steel, Thickness Hardness, Corrosion rate

1. Pendahuluan

Coated steel sheets have been widely used as steel sheet products for household appliances and building materials. In particular, since 2019, PT Alexindo has developed and commercialized highly corrosion-resistant Zn-Al coated steel sheets (Nakamura & Haruta, 2023; บรรพต & Bunphot, 2022). One of the major developments in zinc alloys with aluminium was to overcome the challenges associated with using these materials in various corrosive environments and reduce the material's weight and cost (Saarimaa et al., 2024a). Coated steels are widely used in industries for their low cost along with their higher quality and lower environmental polluting effects (Yadav et al., 2023). The use of pre-coated steel is dominant in industries and other sectors mainly due to the economic benefits and lower environment-polluting effects (Nakamura & Haruta, 2023; Saarimaa et al., 2024a; บรรพต & Bunphot, 2022). Higher corrosion resistance is required for these steels because corrosion degrades the structures and reduces their strengths with different levels of impact, starting from human safety concerns to resource and environmental degradability (Yadav et al., 2024). However, no universal system has yet emerged that can replace galvalume-coated steel in the mass production of vehicle bodies, due to its combination of corrosion resistance, toughness, and cost-effectiveness. At the same time, international automotive regulations demand increased fuel efficiency, which can be achieved by balancing the weight of the car body with the use of more resistant steel, without compromising safety standards (Bolsanello et al., 2024) Reports indicate

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that an increase in fuel efficiency of 5.5% for a reduction in car weight of about 10%. In addition, anthropogenic activities trigger significant concentrations of pollutants that can increase the aggressiveness of exposure conditions, especially in densely populated urban and industrial areas with repeated acid rain episodes. Therefore, advances in galvalume steel require the development of more durable, reliable and sustainable anticorrosive coatings, reducing the need for additional corrosion protection on coated components while reducing costs and fuel consumption in cars. Compared with galvanizing which is mostly zinc, then galvalume with 55% Al has the advantage that Aluminium corrodes more slowly than Zn in most atmospheres because its barrier layer is a very passive aluminium oxide (G. Liu et al., 2024). However, this passive layer prevents aluminium from making a significant contribution to cathodic (sacrificial) protection. Cathodic protection is the strong point of zinc coatings, so if the coating is cut or scratched, the zinc near the exposed area will corrode first. Zinc-aluminium alloys combine the strengths of zinc and aluminium, providing better passive barrier protection than ordinary galvanizing, and better sacrificial protection than alloy coatings with lower zinc compositions (Mora & Ballester, 2019; Saarimaa et al., 2024b). To improve the performance of Galvalume coating, the expected microstructure, and better properties can be obtained by adding 1~3% Magnesium into Galvalume coating (55%Al-Zn). The effect of magnesium on the corrosion resistance of 55%Al-Zn coating is that the number of surface spangles by adding 2% magnesium does not change significantly; the corrosion resistance of 55%Al-Zn-2%Mg coating becomes much better (Ding et al., 2021; Q. Liu et al., 2024). The effects of cooling rate on the phase constitution, microstructural length scale, and microhardness of the directional solidification experiments of Galvalume alloy (Zn-55Al-1.6Si) were investigated through directional solidification experiments at different drawing speeds, indicating that the microstructure of the directional solidification Galvalume alloy is composed of primary Al dendrites, Si-rich phase, and ternary eutectic (Zn-Al-Si) at drawing speeds ranging from 5 to 400 µm s-1. As the drawing speed increases, the segregation of Si elements becomes more intensive, increasing the area fraction of the Si-rich phase. In addition, the primary Al dendrites show significant refinement with the increase in drawing speed (Li et al., 2024).

2. Method

2.1. Materials and Equipment

2.1.1. Materials

This time, the base metal material used in the galvalume process is cold rolled sheet steel with a chemical composition as shown in Table 1. The coating materials used in the galvalume process are Aluminium Ingot, Zinc Ingot, and Silicon. For the pickling and cleaning process, a solution of hydrochloric acid (HCl), Caustic Soda (NaOH), Zinc Ammonium Chloride (ZAC), and distilled water is used.

Table 1. Chemical composition of carbon steel.

Class	C (%)	Mn (%)	P (%)	S (%)	Fe (%)
SPCC	0,15 max	0.60 max	0.100 max	0,05 max	99.29 - 100

2.1.2. Equipment

2.2. Surface Preparation

The material used is low carbon steel with dimensions of 100 mm x 80 mm and a thickness of 0.8 mm.

- Physical (mechanical)

  Cleaning process Physical cleaning can be in the form of sanding using a grinding machine, which includes smoothing out uneven surfaces and removing scratches and burrs attached to the surface of the specimen. The sandpaper used is 80 mesh, 1000 mesh, and 1500 mesh.
- Chemical

  Cleaning process The Chemical cleaning process is the process of cleaning the dirt attached to the surface of the specimen using chemicals. This cleaning process is included in Figure 1.

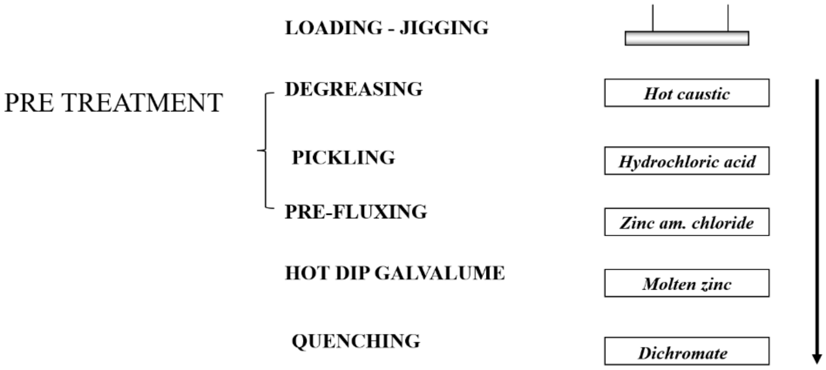


Figure 1. Hot Dip Galvalume Process Sequence

(a) Degreasing

The degreasing process is a process that aims to remove dirt, oil, grease, paint, and other solid impurities attached to the surface of the specimen. The cleaning process is carried out using a solution of NaOH (caustic soda) with a concentration of 10% at 70ºC-90ºC for approximately 10 minutes.

(b) Rinsing I

Process Rinsing aims to clean the NaOH in the degreasing which is still attached to the surface of the specimen using clean water at room temperature.

(c) Pickling

The pickling aims to remove rust attached to the surface of the specimen by immersing it in a solution of HCl (hydrochloric acid) or a solution of H_2SO_4 15% for 15-20 minutes.

(d) Rinsing II

The rinsing process aims to clean the H_2SO_4 attached to the specimen during the pickling using clean water at room temperature.

(e) Fluxing

The fluxing is an initial coating process using Zinc Ammonium Chloride (ZAC) with a concentration of 20% – 30% for 5 – 8 minutes. The fluxing process is carried out to act as a base layer to strengthen the zinc layer during the coating process, as a catalyst for the Fe-Zn coating reaction, and to prevent the oxidation process from occurring before the galvalume process. The fluxing takes place at a temperature of 60ºC-80ºC, this is intended so that the transfer of heat to the specimen takes place slowly and gradually so that no plastic deformation occurs which can interfere with the process of attaching the zinc to the workpiece during the galvalume process.

(f) Drying

The drying process is a drying and preheating process using hot gas with a temperature of around 150ºC, the aim is to remove any liquid that may be present on the surface of the specimen which can cause a steam explosion during the galvalume process

(g) The Hot Dip Galvalume Process

For specimens that have undergone the pre-treatment stage and have been cleaned of all impurities, the next step is the dipping process. During the galvalume process, molten zinc coats the steel by forming a layer of zinc steel and then a completely aluminium zinc layer is formed on the outer surface of the steel, the minimum solution used is 60% aluminium and 40% zinc with a temperature of 700 ℃. The parameters used were Al55%-Zn45%, Al60%-Zn40%, and Al65%-Zn35%. The variations in immersion time used were 10 seconds, 20 seconds, and 30 seconds. The samples, including Vickers micro testing, layer thickness, metallography with an optical microscope, Scanning Electron Microscope (SEM/EDS), X-ray diffraction (XRD), and dynamic potential testing, were tested.

(h) Corrosion testing

Potentiodynamic testing was conducted at the Chemistry and Corrosion Laboratory, Jenderal Achmad Yani University, Bandung. This test aims to determine the corrosion rate of low-carbon steel that has not been hot dip galvalume and galvalume steel. In this potentio test, the CorrTest Electrochemical Workstation tool was used using a Pt (platinum) counter electrode and an Ag/AgCl reference electrode, in the Indial configuration -0.25 V, Final +0.25 V, and Scan Rate 0.5 mV/s.

(i) Micro Vickers testing

The microhardness test of Vickers uses an indentation load of 25 grams with a measurement time of 30 seconds, the hardness measurement is carried out at 3 indentation points on all specimens. The two diagonals of the indentation marks on the surface of the specimen are measured with a microscope and entered into the formula, so that the results of the Vickers hardness are obtained.

3. Results and Discussion

3.1. Visual and Macro Examination

Observation of all specimens can be seen in Fig. 2 In the figure it is clear that there is a difference in the physical comparison of the specimens before and after coating with the hot dip galvalume method. The uncoated test object is dark gray, has sandpaper lines, and is slightly shiny.

Figure 2. Specimens Before The Immersion Process (Magnification)

In contrast to the hot-dipped test specimens, the surface is bright grey. The color of this coating is due to the coating of the aluminium-zinc alloy. Figure 3, this chemical composition is based on the standard operating procedure at the Galvalume factory of PT Alexindo, namely with a composition of Al 55% and Zn 45% with varying times of 10 seconds, 20 seconds, and 30 seconds, it shows that at 10 seconds there are still bubbles on the surface of the sample, currently the nucleation of the Al-Zn Alloy is occurring, before the nucleation develops, it has been cooled directly by being dipped in water. In the image with a time of 20 seconds, the bubbles of the nucleation have decreased, some have formed grains, but the spangles are not yet visible, and the grains are still in a flat shape. With a time of 30 seconds, grains have formed and there are still some nuclei although in very small amounts. The grains that are formed have not formed spangles, because the time to form spangles is not enough. Compared with 60% Al-40% Zn Alloy, Figure 4 shows significant differences. At 10 seconds of immersion time, there are uncoating areas, and bubbles are still found in the coating. At 20 seconds of immersion time, the coating is good, only a few areas still have bubbles. At 30 seconds immersion time, the coating is relatively better, better than 55% Al-45% Zn Alloy. The results of the galvalume process with a chemical composition of 65% aluminium with 35% Zinc are shown in Figure 5. The number of bubbles on the coating is visible, sequentially seen at hot dip times of 10 seconds, 20 seconds, and 30 seconds there is no significant change, whereas in the three samples, many bubbles were found on the coating. Commercial coatings with an appearance like this cannot be accepted by the market, where the market is more accepting of coating surfaces with a chemical composition of 55% Aluminium and 60% Aluminium, namely, there are no bubbles that can reduce the beauty of the appearance of the coating surface. With coating surface, Zn-rich dendritic areas, and Al-rich dendritic areas, the surface of the galvalume coating exhibits an even more intricate pattern. For galvalume, the Al-rich areas between the depressions had very finely distributed Zn phases, while the biggest continuous Zn phases were found within the surface depressions. According to XPS studies, each coating's outermost few nanometers were made up of (i) a layer rich in Al and O, (ii) some carbon impurities, and (iii) very little Zn. Si made up around 5% of the galvalume surface. As a result, the topmost layer of all substrates is comparable and primarily made of aluminium oxide, which covers the Al- and Zn-rich phases equally (Saarimaa et al., 2024a).

Figure 3. The Results of The Galvalume Process with a Composition of 55% Aluminium and 45% Zinc, with a Hot Dip Time of 10 Seconds, 20 Seconds, and 30 Seconds.

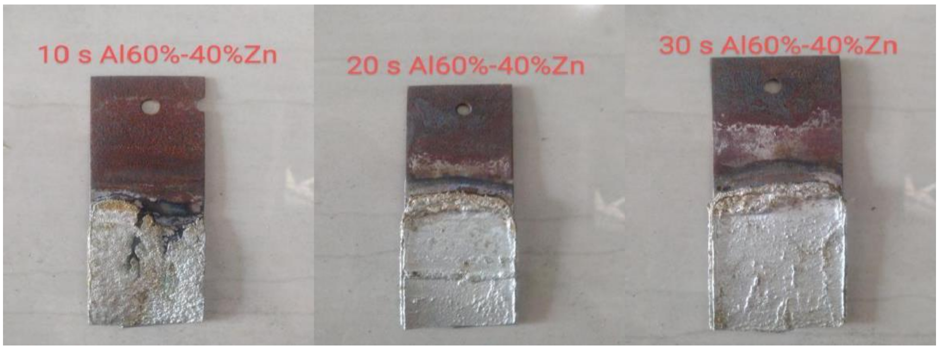
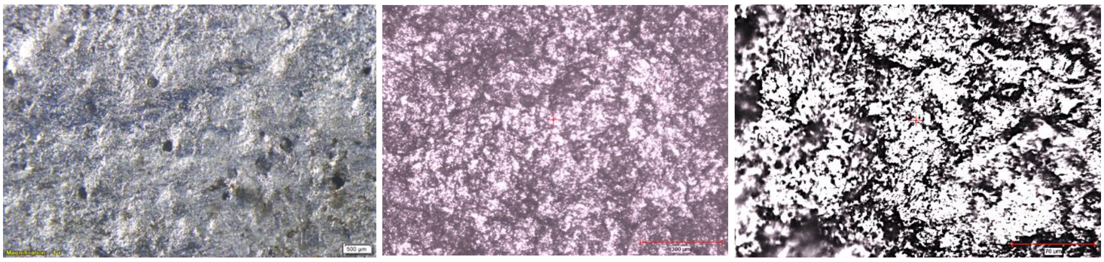


Figure 4. The Results of The Galvalume Process With a Composition of 60 % Aluminium and 40% Zinc, With a Hot Dip Time of 10 Seconds, 20 Seconds, and 30 Seconds.

Figure 5. The Results of The Galvalume Process with a Composition of 55% Aluminium and 45% Zinc, with a Hot Dip Time of 10 Seconds, 20 Seconds, and 30 Seconds.



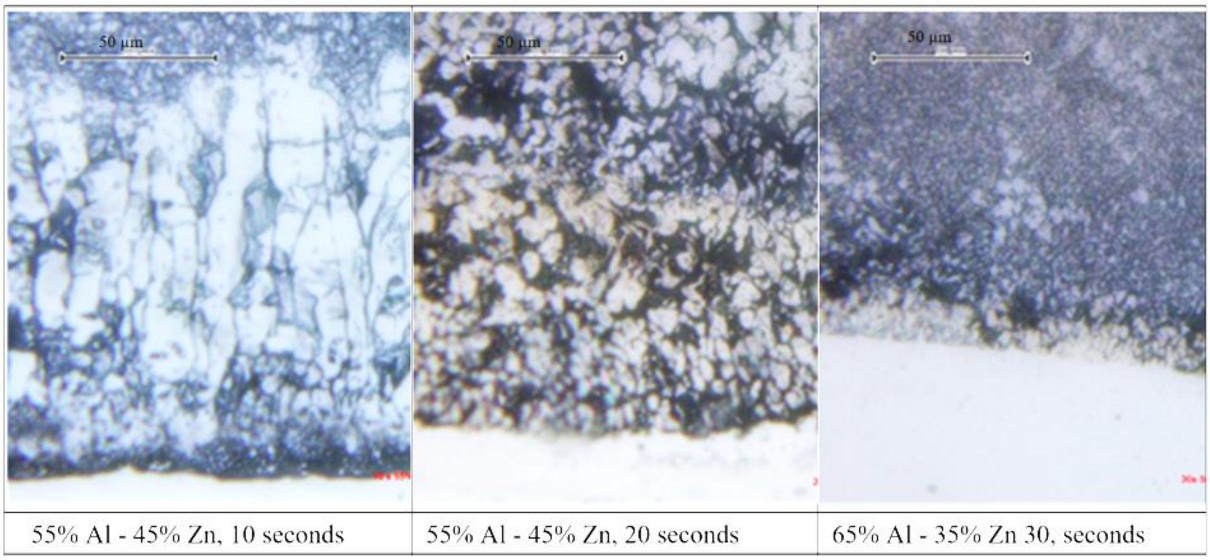
a b c

Figure 6. Taking Photos of The Galvalume Surface, (a) Surface Macro with Alloy Composition 60% Al and 40% Zn, Magnification 4 X, (b) Surface Macro with Alloy Composition 60% Al and 40% Zn, Magnification 50 X and (c) Surface Micro with Alloy Composition 60% Al and 40% Zn, Magnification 200 X.

Figure 6 a. shows a macro photo with a magnification of 4 X, it can be seen that there is a coating surface with a very smooth spangle, this is due to the very fast nucleation process because the cold rolled sheet plate that is hot dip galvalume has a temperature that is not too high because it is not possible to get a high temperature, different from the continuous galvalume line process before entering the hot dip galvalume, the temperature is kept high at around 700 °C in the Snout in Hot Dip Galvalume process. Small spangles or hot dip galvalume without spangles are usually found in electric pole steel whose pre-heating process of hot dip galvalume is not too high. Wet storage spots are a feature that closely resembles the black patches that were seen. The protective oxide that forms in the air on the surface of galvalume gives it exceptional resilience to atmospheric conditions. However, a more rapid form of corrosion occurs through the development of hydrated aluminium oxide in the presence of water or moisture and the absence of unrestricted access to dry air. Under these circumstances, the Galvalume sheet's surface look may deteriorate in as short as 24 to 48 hours because no barrier oxide layer is present. Like "wet storage spots," these tiny pores, particularly at the crystal surfaces, permit moisture to enter the air and cause black oxidation. At a magnification of 50 X as seen in Figure 6 b, only grain boundaries with a 10-70 µm diameter are visible. So with the naked eye, the spangles will not be visible, like continuous galvalume line products. Figure 6 c with a magnification of 200 X, inside the grains there are small grains again, with a size of 100 µm. The main parameter in hot dip galvalume that must also be considered is the temperature before the hot dip galvalume process, in addition to the chemical composition also plays a crucial role, in getting a good coating.

3.2. Examination by Optical Microscope

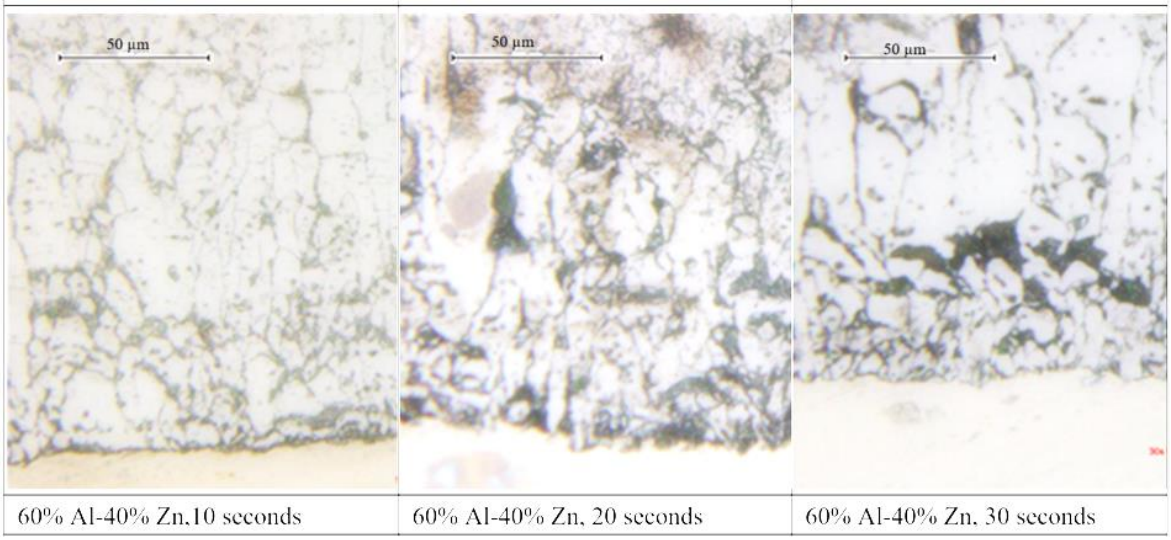
The results of the microstructure examination using an optical microscope on the cross-section of hot dip galvalume are shown in Figure 7, which shows the Al-Zn alloy layer, which consists of cold rolled sheet steel, intermetallic layer, and top layer.



55% Al - 45% Zn, 10 seconds | 55% Al - 45% Zn, 20 seconds | 65% Al - 35% Zn 30, seconds

Figure 7. Cross-Section Microstructure Image of Aluminium 55% and 45% Zinc.

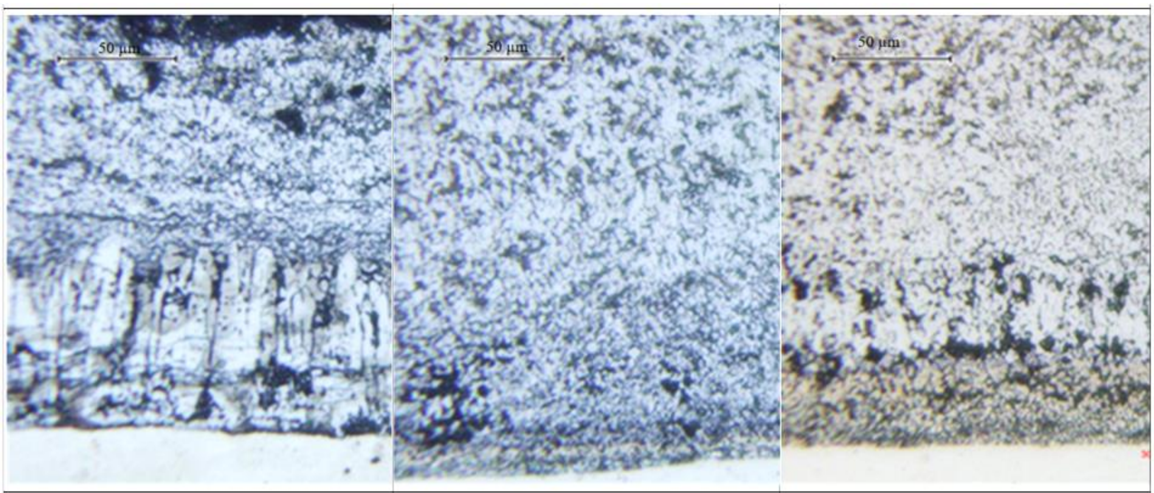
In Figure 7. With 55% Al, a hot dip galvalume time of 10 seconds, shows the topmost spangled coating surface, consisting of an excellent dendritic network, so that when viewed from Figure 6 a, no spangles are visible, because the grains are excellent. The bottom of the spangle grain is Al-rich dendritic and below it is Zn-rich dendritic. At the bottom, the grains become smaller again because they are rich in alloy with the steel. With a hot dip time of 20 seconds, the grains that form the spangle on the surface of the galvalume remain small, so that they do not produce spangles that can be seen with the naked eye. The dendritic structure in the middle area begins to form equiaxial grains, and the area's microstructure bordering the steel as the base material is relatively smooth. At a hot dip time of 30 seconds, the grains produced are relatively the same between the surface of the galvalume, the middle of the galvalume, and the base part compounded with the raw material plate in the form of low-carbon steel.



60% Al-40% Zn.10 seconds | 60% Al-40% Zn, 20 seconds | 60% Al-40% Zn, 30 seconds

Figure 8. Cross-Section Microstructure Image of Aluminium 60% and 40% Zinc.

In Figure 8 with a composition of 60% Aluminium and 40% zinc, a hot dip time of 10 seconds, dendritic structures are still found on the entire cross-section of galvalume. The grains are still relatively small on the galvalume surface, so no spangles are found when viewed in macro at 4X magnification. At a dip time of 20 seconds and 30 seconds, dendritic microstructures are still found. In the part between Al-Zn and steel, relatively small grains are found.



65% Al - 35% Zn, 10 seconds | 65% Al - 35% Zn, 20 seconds | 65% Al - 35% Zn, 30 seconds

Figure 9. Cross-Section Microstructure Image of Aluminium 65% and 35% Zinc.

In Figure 9. It has a chemical composition of 65% aluminium and 35% zinc. At the time of hot dip 10 seconds, dendritic microstructure is still found, but the surface is still with excellent grains so what is seen on the surface from above, no spangles are found because the grain size on the surface is too small. For hot dip times of 20 and 30 seconds, the microstructure is relatively the same and the size is relatively the same, so that when viewed from the surface of galvalume, no spangles occur on the surface of galvalume.

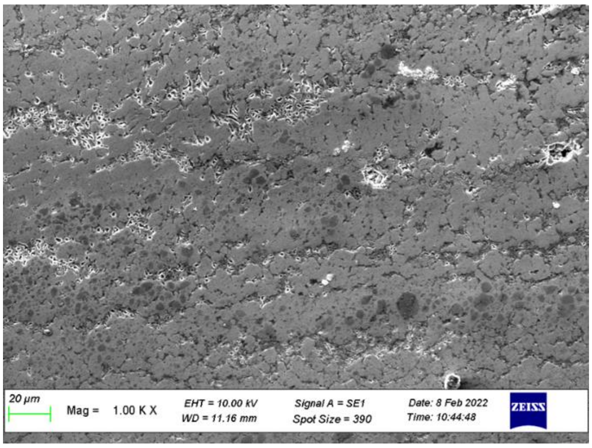


Figure 10. Cross-Section Microstructure Image of Aluminium 60% and 40% Zinc,
Using a Scanning Electron Microscope Magnification 1000 times.

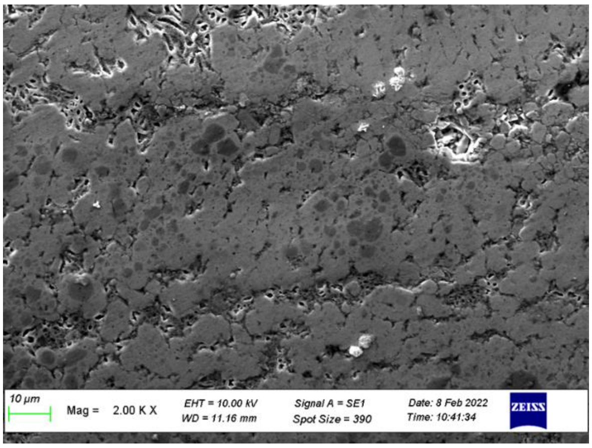


Figure 11. Cross-Section Microstructure Image of Aluminium 60% and 40% Zinc,
Using a Scanning Electron Microscope Magnification 2000 times.

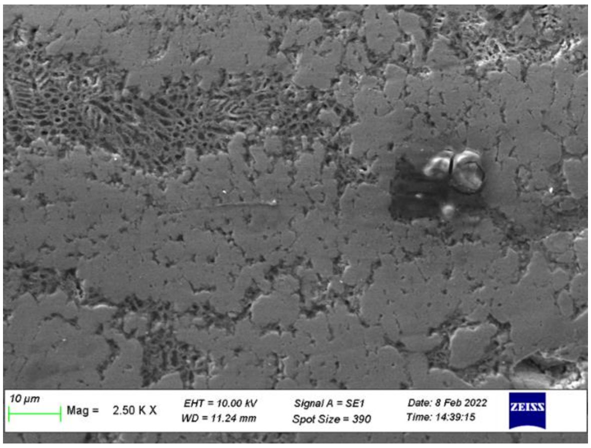


Figure 12. Cross-Section Microstructure Image of Aluminium 60% and 40% Zinc, Using a Scanning Electron Microscope Magnification 2500 times.

Identification of the microstructure of the galvalume cross-section can be seen in Figure 10 with a magnification of 1000 times, Figure 11 with a magnification of 2000 times, and Figure 12, using a magnification of 2500 times. The results show that the eutectic region is a Zn2Mg/Zn/Al compound, while the black phase is FCC Al, the grey phase is Zn2Mg and the white phase as a matrix is HCP Zn.

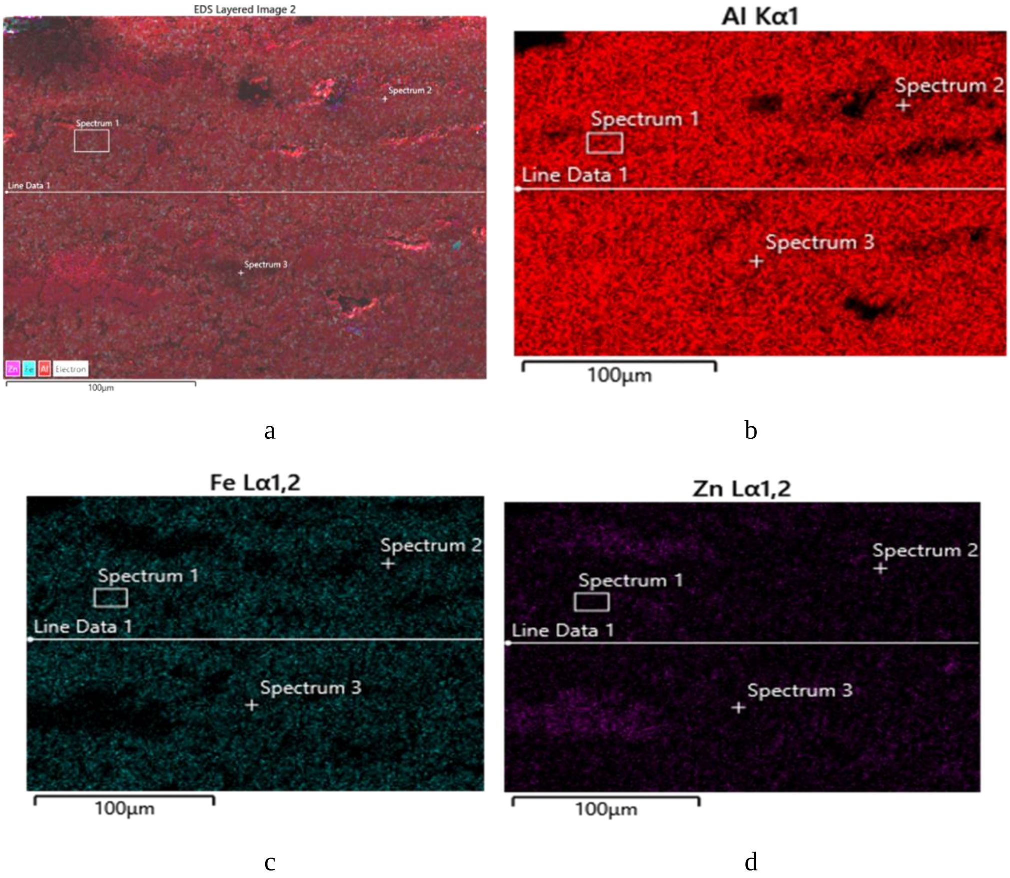


Figure 13. Results of X-Ray Mapping on The Cross-Section Galvalume Using a Scanning Electron Microscope (SEM). (a) Secondary Electron Image of Galvalume; (b) 52 % - 95 % of The Aluminium Element's Surface in a Steel X-Ray image; (c) 28%-43% of The Ferrum Element's Surface in a Galvalume X-Ray Image; (d) 3 % - 10 % of The Zinc Element's Surface in a Galvalume X-Ray Image.

3.3. Examination by Using X-Ray Diffraction on Galvalume Cross-Section.

X-ray diffraction testing on hot dip Galvalume with Aluminium 55% and 45% Zinc coating specimens conducted at Metallurgy Laboratory Unjani. This test was conducted to determine the phase formed in the composition layer of

55% Aluminium and 45% zinc, so observations were made on the surface of the hot dip galvalume coating specimen. From Figure 13, it can be seen that. The following phases can be seen in all ternary phase diagrams of all elements used in the Aluminium 55% and 45% Zinc alloy. Table 1. above shows the presence of Al, Zn, Al-Fe, and Fe-Zn. The existence of Al-Fe compounds is intermetallic and Al rice dendritic, Zn rice dendritic is a coating alloy. The description of Al_3Fe and $Al_{5.4}Fe_2$ shows that the intermetallic compounds formed in the galvalume coating cannot be predicted well in each process, but what is certain is the formation of Fe-Al compounds as the intermetallic area.

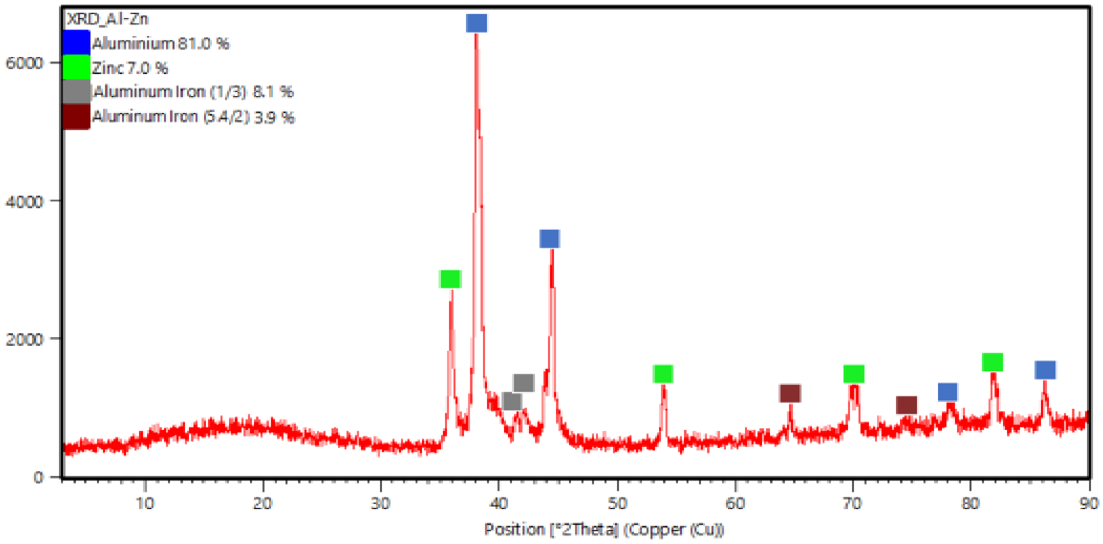


Figure 14. X-Ray Diffraction Results on The Cross-Section Galvalume Aluminium 55% and 45% Zinc

The results of processing with Highscore software, show the phases in the galvalume layer, namely Al-Fe compounds are intermetallic, namely Aluminium Iron (Al_3Fe), Aluminium Iron ($Al_{5.4}Fe_2$), and Al rice dendritic, Zn rice dendritic. Al rice dendritic and Zn rice dendritic validation is very strong, namely appearing in 4 peaks, followed by Aluminium Iron (Al_3Fe) and Aluminium Iron ($Al_{5.4}Fe_2$).

Table 1. Processing of X-Ray Diffraction Data Using Highscore Software.

No	Symbol (Color)	Position (2Theta)	Aluminium (Al)	Zinc (Zn)	Aluminium Iron (Al_3Fe)	Aluminium Iron ($Al_{5.4}Fe_2$)
1	🟩	35.961		√		
2	🟦	38.108	√			
3	⬛	42.796			√	
4	⬛	43.928			√	
5	🟦	44.480	√			
6	🟩	53.974		√		
7	🟫	64.00				√
8	🟩	64.60		√		
9	🟫	70.24				√
10	🟦	78.22	√			
11	🟩	81.834		√		
12	🟦	86.231	√			

3.4. Results of Micro Vickers Hardness Testing on Galvalume Cross-Section

From Figure 15 it can be seen that the longer the hot dip galvalume time, the harder the galvalume layer will be. This can be seen from the microstructure in Figure 7, Figure 8, and Figure 9, there is a grain shrinkage in the microstructure of hot dip time of 10 seconds, 20 seconds, and 30, this is because the fast hot dip time of 10 seconds does not allow the formation of many grain cores so that the grains become large, while the time of 20 and 30 seconds will cause nucleation so that the results of the microstructure. In addition, a matrix is formed with a rich aluminium dendritic and a rich zinc dendritic which forms intermetallic compound precipitates such as Al_3F_e and $Al_{5.4}Fe_2$. This precipitation functions as precipitation hardening with hot dip galvalume samples of 20 seconds and 30 seconds.

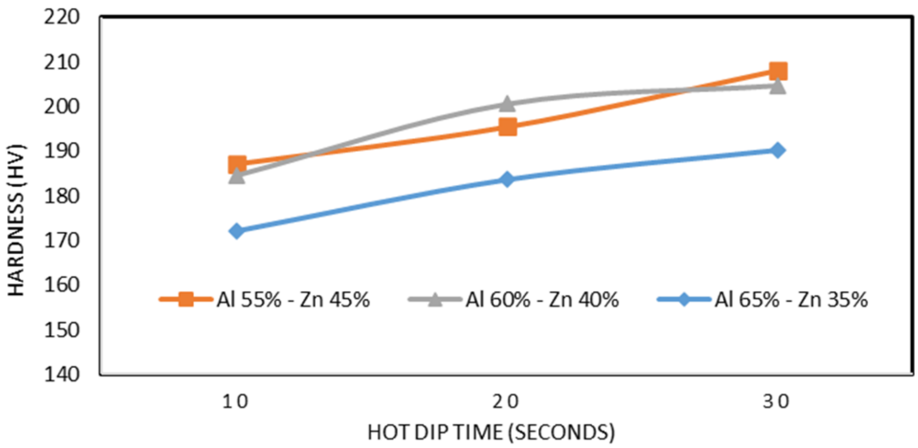


Figure 15. Effect of Hot Dip Galvalume Time on Hardness in the Galvalume Coating Area.

3.5. Test Results of Thickness Inspection on The Galvalume

From Figure 16 it can be seen that the longer the hot dip galvalume time is directly proportional to the influence of the layer thickness, namely the longer the thicker. This is because the liquid metal has a longer time to stick to its first coating sequentially. In this case, it is known that the longer hot dip galvalume time can make the Al-Zn base metal layer thicker so that it can be deposited well and perfectly on the steel surface which results in the expansion of the interdendritic area rich in Zn, and rich in Al and provides the ability of the Al Zn composition to grow so that the size of the Al, Zn dendrites grows increasingly larger, followed by the formation of intermetallic precipitar which makes the grains increasingly have to. The effect of variations in immersion time on the hot dip galvalume coating process has a significant impact on the thickness value of the resulting specimen. From the thickness test data, a graph of the average thickness of the hot dip galvalume coating results is obtained for each variation of the specimen composition and different immersion time variations, namely 10 seconds, 20 seconds, and 30 seconds at a temperature of 700 °C. It can be seen in Figure 16, where the average thickness data obtained is the lowest layer thickness with a holding time of 10 seconds of 342.0 µm and the highest thickness value with a holding time of 30 seconds of 1358.0 µm. The holding time of hot dip galvalume is directly proportional to the thickness of the layer which gets thicker over time.

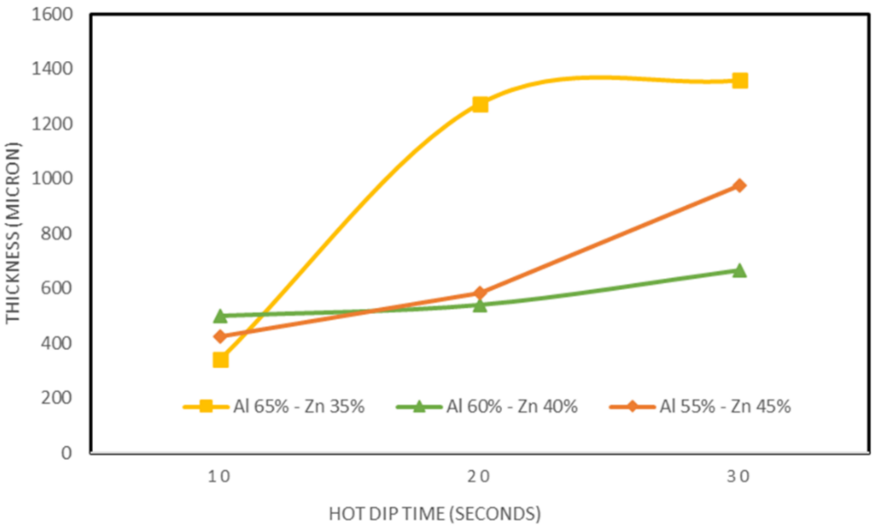


Figure 16. Effect of Hot Dip Galvalume Time on The Thickness of The Galvalume Layer

3.6. Results of Potentiodynamic Testing on The Galvalume

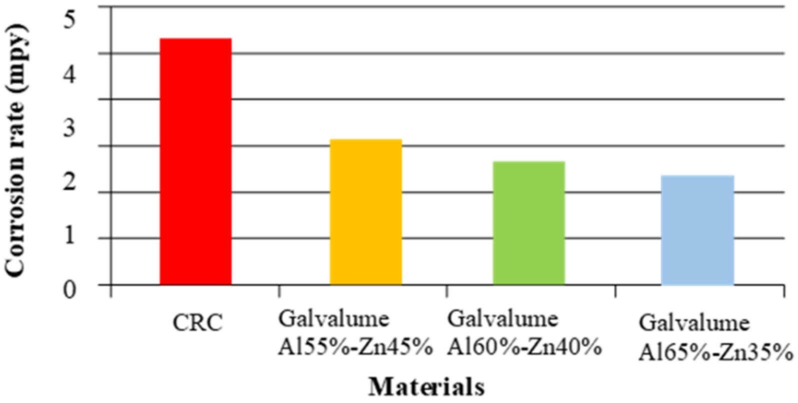


Figure 17. Effect of Corrosion Rate on Low Carbon Steel and Galvalume Coating Alloy Materials.

The test aims to determine the corrosion rate of the test object by comparing low carbon steel (CRC) before hot dip galvalume as the base metal and low carbon steel that has been hot dip galvalume with variations in the composition of Al55%-Zn45, Al60%-Zn40%, and Al65%-Zn35%, the test was carried out using the Corrtest Electrochemical Tool and processed with the Corrtest V5 software.

The potentio dynamic test result data is in the form of ICORR which is then converted into mills per year (mpy). The lower the mpy value, the lower the corrosion rate value, and can be analogized to better corrosion resistance. If the mpy value is higher, the corrosion rate value is higher and is analogized to the decreasing/worse corrosion resistance. The corrosion rate value of low carbon steel with a simulation of 1M NaCl electrolyte solution has the highest value of 4.69 mpy, which can be converted to 0.11 mm/year. The corrosion rate value of Al55%-Zn45% alloy steel has a corrosion rate value of 2.759 mpy or 0.070 mm/year. The corrosion rate value Al60%-Zn40% alloy steel has a corrosion rate value of 2.255 mpy or 0.057 mm/year. The corrosion rate value of Al65%-Zn35% alloy steel has the lowest corrosion rate value of 2.097 mpy or 0.053 mm/year. From these data, it can be seen that sequentially the corrosion rate values of low-carbon steel that has not been hot-dip galvalume and low-carbon steel that has been hot-dip galvalume show a tendency that the corrosion rate value has decreased quite significantly, although in comparison between various compositions of galvalume steel values, it is not too significant, the corrosion rate value continues to decrease according to the variation in the composition of %wt Al contained which is greater than %wt Zn. This is because the higher Al content in the coating composition can reduce the corrosion rate and improve corrosion resistance to be better. Aluminium will form aluminium oxide compounds on the surface of the coating.

Conclusion

The results of visual and macro examinations on the surface of galvalume did not find spangles, this is due to the very fine grain size, cooling for 10 seconds, 20 seconds and 30 seconds is still fast when the layer is dried on the outside air again.

The microstructure of aluminuim-rich phases, zinc-rich phases in the form of a matrix, and intermetallic compounds Al_3Fe and $Al_{5.4}Fe_2$ in the form of precipitates that spread over the galvalume layer were discovered by metallographic investigations conducted using an optical microscope. The liquid metal did not have enough time to form a core with a galvalume hot dip time of 10 seconds, and a dendritic structure was formed. A hot dip time of 20 seconds produced multiple cores, and the grains were rather small. The grains became smoother at 30 minutes, when the hot dip time was smoother than at 20 seconds, and the coarsest grains were hot dip at 10 seconds.

The metallographic results of the galvalume cross-section under the scanning electron microscope show that the colored phase is rich in FCC aluminium and the white matrix is rich in HCP Zn. The results of the scanning electron microscope (SEM) X-ray mapping of the galvalume cross-section, there are 52% to 95% of the aluminium element surface in the steel X-ray image; there are 28% to 43% of the iron element surface in the galvalume X-ray image; and 3% to 10% of the zinc element surface in the galvalume X-ray image.

The coating's thickness is impacted by variations in the hot dip coating procedure. The coating will be thicker the longer the hot dip time, which is directly correlated with the immersion time. There was a range of thickness values from 342.0 µm to 1358.0 µm.

Variations in composition and hot dip time significantly affect the hardness of the coating. The longer the hot dip galvalume time, the higher the hardness value obtained, because the grains become finer, due to the formation of more nucleation at longer hot dip galvalume times. The effect of the composition variation is the composition of the Zn element in the Al-Zn alloy layer, where the characteristic of Zn is to increase the hardness value. The test object with the highest hardness value is 55% Aluminium and 45% zinc with a 30-second hot dip galvalume time of 208.20 HV.

For the test object with the lowest hardness value, namely with a composition of 65% Aluminium and 35% zinc with a 10-second hot dip galvalume time of 172.16 HV.

The variation of Al-Zn composition affects the corrosion rate results, sequentially the corrosion rate values of low carbon steel that has not been hot-dipped galvalume and low carbon steel that has been hot-dipped galvalume show a trend that the corrosion rate value has decreased significantly, although the comparison between the variations in the composition of galvalume steel is not too significant, the corrosion rate value continues to decrease according to the variation in the composition of %wt Al contained is greater than %wt Zn. This is because the higher Al content in the coating composition can suppress the corrosion rate and increase corrosion resistance to be better. Al forms a more rust-resistant $Al2O3$ compound. The corrosion rate value of low carbon steel with a simulation of 1 M NaCl electrolyte solution has the highest value of 4.69 mpy, which can then be converted to 0.11 mm/year. The corrosion rate value of galvalume, with a coating content of 55% Aluminum-45% Zinc has a corrosion rate value of 2.759 mpy or 0.070 mm/year. The corrosion rate value of galvalume with a chemical composition of 60% Aluminum-40% Zinc has a corrosion rate value of 2.255 mpy or 0.057 mm/year. The corrosion rate value of galvalume with a chemical composition of 65% Aluminum-35% Zinc coating has the lowest corrosion rate value of 2.097 mpy or 0.053 mm/year.

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