Optimizing The Hot-dip Galvanizing Process Of Angle Bar Steel Product According To ISO 1461 Standard Using The Taguchi Method

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Abstract

The objectives of this research were to determine the optimal values of the dipping temperature, the length of dipping time, and the dipping tilt angle in the hot-dip galvanizing process, which influence the thickness of the galvanized angle bar steel product, in accordance with the thickness standard of ISO 1461. This research used the Taguchi technique with an experimental design. The testing and validation stages were carried out based on the average temperature value, S/N ratio, and ANOVA test. The response factor is the galvanic thickness. Control factors consist of dipping temperature, length of dipping time, and dipping tilt angle of the steel during the galvanizing process. The results showed that the main factors that influence the galvanized thickness are the length of dipping time factor (B), which contributes to the difference in the S/N ratio of 85.94118%, and the dipping tilt angle factor (C), which contributes to changes in the S/N ratio of 13.60962%. The optimal value of the dipping temperature is 448°C, the length of the dipping time is 8 minutes, and the dipping tilt angle is 45°.

Keywords
Optimization, angle bar steel, hot-dip galvanizing, Taguchi, ANOVA

1. Introduction
In Indonesia, steel is one of the most important materials for both construction and non-construction activities. Steel generally contains more than 98% iron and usually less than 2% carbon. Steel also contains other alloying elements, such as silicon, magnesium, sulfur, phosphorus, copper, chromium, and nickel, in various amounts. Steel consists of several types, one of which is profile steel. Profile steel is a specially formed steel. The most frequently used profile shapes include steel in the form of pipes, blocks, C or T channel, and angle bar. Angle bar steel has a cross section like the letter L. Angle bar steel is often chosen because it has various advantages, including being stronger and easier to form, durable, and rust resistant because it has a corrosion-preventing coating. Angle bar steel can be used as a material for iron racks, hanging racks, door frames, windows, and garlands, as well as for the construction of stairs, water tank tower structures, and others.

The strength of steel to prevent corrosion is urgently needed considering Indonesia's natural conditions, which consist of a large area of water and environmental factors that cause faster corrosion, including salinity, pH, temperature, and oxygen solubility in the media. According to the Indonesian Galvanis Association (2021), the average corrosion rate in Indonesia varies from 1-2 microns (in rural areas) to 8-15 microns (on the seafront) per year. The cost of repairing corrosion damage is a major concern, with estimates suggesting metal corrosion costs around 3% of the country's GDP. However, the cost of corrosion is greater than just financial, it can also lead to wastage of natural resources, dangerous failures, and many other indirect costs. Corrosion is a natural phenomenon that can never be completely eliminated, and implementing an adequate corrosion protection system can reduce these annual costs significantly.

To increase the ability of angle bar steel to withstand the level of damage caused by corrosion, it can be done through a galvanizing process. The galvanizing process is the process of providing a protective layer for iron and steel so it can prevent corrosion. The galvanizing process consists of two methods, namely the electroplating galvanizing method and the hot-dip galvanizing method. Hot-dip galvanizing is a steel coating process that uses a dipping technique in zinc liquid to coat the steel. The dipping method is widely used because it is a fast and easy method in the coating process.

According to Adetunji (2010), the quality of the galvanizing process is evaluated based on the appearance, luster, and uniformity of the steel thickness. According to Afandi et al. (2013), the thickness of the galvanized coating does not guarantee that the coating can protect the steel perfectly. The thicker a coating, the greater the risk of coating failure due to reduced flexibility, shrinkage, or incomplete drying. The Indonesian Galvanis Association (2021) recommends manufacturers use standard thicknesses of a galvanized coating, including Indonesian National Standards (SNI 07-1353 and SNI 07-7033), Australian Standards (AS 1214, AS 1650, AS 2312), New Zealand Standards (AS/NZS 1650), American Standards (A90, A123, A143, A153, A384, A385, and A767), and European Standards (ISO 1461). ISO 1461 regulates the specifications and test methods for coatings using hot-dip galvanizing on iron and steel. This standard specifies the minimum thickness limit of galvanized coating on various thicknesses of cast iron and steel.

In order to produce a standard thickness for the galvanized process, it is necessary to control the influencing variables. The thickness of the zinc layer on the coating using the hot-dip galvanizing method is influenced by surface conditions, length of dipping time and dipping temperature (Eliana et al. (2019). Another factor that affects the quality of the results of the galvanization process is the angle of inclination when hanging the steel on the jig during the dyeing process. This is to ensure the liquid zinc flows efficiently and prevent uneven or rough layers from forming due to the uneven flow of the molten zinc, causing some of the molten zinc to solidify on the way and allowing hot steam to escape through the highest point. In addition, the tilted position also aims to prevent explosions caused by hot steam in the galvanization process.

In Indonesia, numerous study of surface condition dan length of dipping time in the steel galvanizing process have been conducted. Research on the effect of surface roughness on the thickness of the hot-dip galvanizing has been carried out by Alamsyah et al. (2012). Based on the research, it was concluded that a rough steel surface will cause thicker galvanization results. Research on the length of dipping time in the hot-dip galvanizing process in Indonesia, was carried out by Eliana et al. (2019), which concluded that too fast a dipping time produces a bad coating, but too long a dipping time will produce a thick layer that tends to be dull. In addition, Indarto (2007) and Ridluwan (2007) concluded that a fast dipping time produces a bad coating, but if it takes too long, a thick and dull coating will be obtained. Prameswari (2008) and Pattireuw et al. (2013) found that an appropriate dipping process would produce an appropriate thickness so that it has good corrosion resistance.

Galvanizing temperature is one of the factors that affects the quality of the coating (Keenan and Kleinfelter 1996). The quality of the steel produced from this galvanizing process is durable, resistant to corrosion, and resistant to bumps (Eliana et al. 2019). According to the Indonesian Galvanis Association (2021), the thickness of the galvanized layer is measured from the surface distance to the steel surface below. Galvanizing temperature has an effect on reducing the stress relieving effect, so it can increase corrosion resistance (Wijayanto and Ilman 2008). Santosa et al. (2022) conducted research on the effect of temperature on the quality of the galvanizing process on steel pipes for ships. The research shows the optimum temperature for the galvanizing process of AISI 1020 steel is between 440°C and 455°C. In addition, Eliana et al. (2019) establish the optimal temperature of 460°C in the galvanization process for steel with a thickness of 107 μm.

The object of this research is the guardrail post angle bar steel, which has a thickness of 4 mm. In order to produce high-quality angle bar steel, according to ISO 1461, the minimum thickness of the galvanized layer is 70 µm. The coating stage is carried out by dipping the base metal into a molten zinc solution at a temperature of 440 - 480°C.

1.1 Objectives

The objectives of this research were to determine the optimal values of the dipping temperature, the length of dipping time, and the dipping tilt angle in the hot-dip galvanizing process, which influence the thickness of the galvanized angle bar steel product, in accordance with the thickness standard of galvanized angle bar steel in Indonesia.

2. Literature Review

According to ASM International (2006), the environment is an explicit element in all corrosion processes. There are two main ways to mitigate corrosion. The first is adding a chemical inhibitor to change the chemistry of the water to reduce corrosion. The second method is to physically coat the metal surface so that water and dissolved oxygen (or other electron acceptors) cannot reach the metal surface. Metal surface coatings are often used to increase hardness, abrasion resistance, and prevent corrosion. This coating can be done with other metals as long as they have better properties than the metal. Coating methods are divided into 2 types: (a) surface treatment, including electroplating, painting, hot-dipping, and (b) case hardening, including carburizing, cyaniding, and nitriding.

Parameters that affect the quality of the hot-dip galvanizing are the quality of zinc, chemical composition of the substrate, liquid zinc temperature, and length of the dipping time. The zinc used must be of G.O.B (good ordinary brand) quality, which contains a minimum of 98.5% Zn and 1.65% total of a mixture of lead, iron, and cadmium. Lead contents of greater than 1% can be used because the excess lead will separate and precipitate under the molten zinc (Saragih 2008). The contents of elements in the substrate, such as carbon, silicon, manganese, and phosphorus, will determine the characteristics of the resulting galvanic coating, such as thickness, appearance, and coating brittleness. C < 0.35%, P < 0.05%, Mn < 1.35%, Si < 0.05% are the recommended chemical composition for hot-dip galvanizing substrates.

The temperature commonly used in the galvanization process generally ranges from 445-465°C. The maximum temperature for the hot-dip galvanizing process is not recommended to exceed 480°C. At temperatures above 480°C the resulting FeZn inter-metallic alloy layer becomes a non-adherent crystal and allows the continuous diffusion process to penetrate the base metal. High temperatures also accelerate the breakdown of the galvanized bath in addition to wasting energy (Saragih 2008, Bicao 2007).

The length of dipping time is generally between 1-5 minutes. In the initial minutes, the thickness of the layer increases rapidly, then the rate of layer growth decreases very slowly. In addition to the dipping time, the thickness of the inter-metallic layer in the galvanized coating is also influenced by the silicon content of the steel to be galvanized. The dipping time of the steels with a high silicon content must be limited. This is to prevent excessive growth of the inter-metallic layer. For long steels, the dipping time must be arranged so that the gradient of dipping time between the initial and final is not significant.

3. Methods

This research used the Taguchi technique with an experimental design that consisted of data collection, data processing, and data analysis. Data collection consists of determining the quality of the response, and identifying critical factors of various stages. Data processing consists of determining the level and degrees of freedom, determining the orthogonal matrix, and determining the optimum value of the control factor.

The analysis was carried out based on testing and validation of the factor effect test on the average of galvanized thickness, the factor effect test on the variability of galvanized thickness, and the critical factor test. The test was carried out based on the average temperature value, S/N ratio, and ANOVA test. Based on this methodology, the optimum combination of zinc liquid temperature, length of dipping time, and tilt angle of steel during the galvanization process will be determined to meet the standard for galvanized angle bar steel thickness.

4. Data Collection

This research used primary and secondary data. Primary data consists of experimental data of control factors, consisting of dipping temperature, length of dipping time, and dipping tilt angle during the galvanization process. Secondary data consists of the production process of angle bar steel and specifications of the existing value for setting control factors during the galvanization process.

4.1 Determination of Quality Response

In this research, the quality response was the galvanized thickness of the 4 mm post guardrail product according to ISO 1461 standards, with a minimum thickness value of 70 μm. The process of measuring the thickness of galvanized steel using the Elcometer tool and the quality characteristics are "thicker is better".

4.2 Identification of Critical Factors

The thickness of galvanized steel is influenced by three main factors: the machine factor, the material and the galvanization method. From these factors were derived control factors such as temperature, length of time, and the dipping tilt angle of the steel during the galvanization process.

4.3 Factor Levels and Degrees of Freedom Values

The determination of the orthogonal array is based on the number of levels used. The number of levels used for each factor is three, as shown in Table 1.

Table 1. Control Factors and Level

No	Control Factor	Level 1	Level 2
1	Dipping Temperature	453 °C	448 °C
2	Length of Dipping time	4 minutes	8 minutes
3	Dipping Tilt Angle	90°	45°

The determination of degrees of freedom is obtained based on the number of levels resulting in a total combination, as shown in Table 2 below.

Table 2. Degrees Of Freedom

Control Factor	Initial	Degrees Of Freedom
Dipping Temperature	A	(2 – 1) =1
Length of Dipping time	B	(2 – 1) = 1
Dipping Tilt Angle	C	(2 – 1) = 1
Total Degree Of Freedom		3

4.4 Orthogonal Matrix

The orthogonal matrix is determined based on the number of degrees of freedom of all factors and their interactions. Since it is known that the total degrees of freedom are 3 with each factor consisting of two levels, an orthogonal matrix is produced as shown in Table 3.

Table 3. Orthogonal Mtrix L_4 (2^3)

Eks.	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

5. Results and Discussion

5.1 Experimental Implementation

The purpose of the experiment was to determine the thickness of the galvanized layer on angle bar steel products using Elcometer, as shown in Figure 1.

Figure 1. Thickness Test and Measurement Specimens

The measurement resulting from four specimens at three control factors is used to determine the average galvanic thickness. Calculation of the average value of galvanized thickness through a combination of factors is shown in Table 4.

Table 4. Average Of Galvanic Thickness

Orthogonal Matrix L_4 (2^3)									
Experiment No	**Factor Control**			**Trial(µm)**				**Total**	**Average**
	A	**B**	**C**	**1**	**2**	**3**	**4**		
1	1	1	1	72,4	72,2	71,8	73,6	290	72,5
2	1	2	2	143,8	146,1	143,7	144,8	578,4	144,6
3	2	1	2	89,8	91,8	89,5	92,1	363,2	90,8
4	2	2	1	122,6	121,9	122,4	121,9	488,8	122,2
Total								1720,4	430,1
Average								430,1	107,525

Based on the average value of galvanized thickness at each factor level, the average response value of galvanized thickness was obtained to determine the most influential factor between dipping temperature, length of dipping time and dipping tilt angle.

Table 5. Average Response Of Galvanic Thickness

Level	Dipping Temperature (A)	Length of Dipping Time (B)	Dipping Tilt Angle (C)
1	108,55	81,65	97,35
2	106,5	133,4	117,7
Delta	2,05	51,75	20,35
Rank	3	1	2

Based on Table 5 it is known that the most influential factor is the length of dipping time, with an average difference up to 51.75, and the dipping tilt angle, with an average difference of up to 20.35. The weakest effect is the temperature factor, with an average difference up to 2.05. The optimal combination, according to the average response, is a dipping temperature of 453°C, 8 minutes of dipping time and a dipping tilt angle of 45°. The main effect of the length of dipping time factor can be seen from the main effect plot for the mean of galvanic thickness value, as shown in Figure 2.

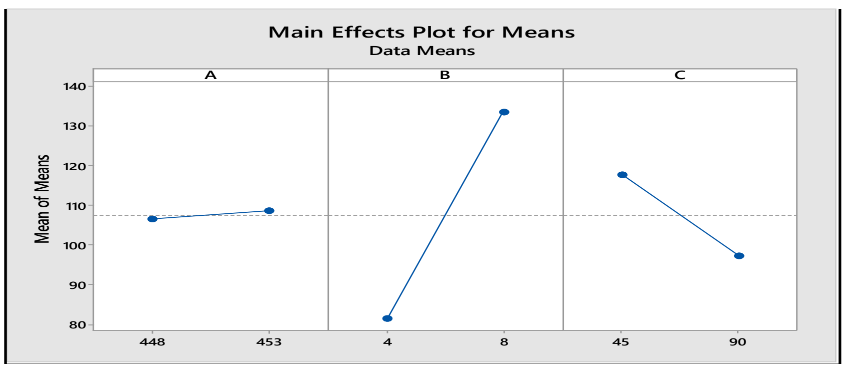

Figure 2. Main Effects Plot For Means

5.2 Variability of Factors on Galvanized Thickness Variability

Signal to Noise Ratio (S/N Ratio) is used as a parameter selection criterion that minimizes "error variance" caused by uncontrollable factors, as shown in Table 6.

Table 6. Signal To Noise Ratio For Each Factor

Orthogonal Matrix $L_4(2^3)$										
Eks.	Factor			Tria(µm)				Total	Average	S/N Ratio
	A	B	C	1	2	3	4			
1	1	1	1	72,4	72,2	71,8	73,6	290	72,5	37,206
2	1	2	2	143,8	146,1	143,7	144,8	578,4	144,6	43,203
3	2	1	2	89,8	91,8	89,5	92,1	363,2	90,8	39,161
4	2	2	1	122,6	121,9	122,4	121,9	488,8	122,2	41,741
Total								645,248		161,312
Mean								161,312		40,328

The variability of the S/N ratio of galvanic thickness generated from the combination of each factor. The normalization of the S/N ratio is used to obtain the response value of the S/N ratio for all factors, as shown in Table 7.

Table 7 . Response Value Of Signal To Noise Ratio

Level	Dipping Temperature	Length of Dipping Time	Dipping Tilt Angle
1	40,204	38,183	39,473
2	40,450	42,472	41,181
Delta	0,246	4,289	1,708
Rank	3	1	2

Based on table 7 it is known that the most influential factor is the length of dipping time, with the optimal temperature according to the average response being 448°C, the length of dipping time being 8 minutes, and the dipping tilt angle being 45°. The main effect of the length of dipping time factor can be seen from the main effect plot for the value of the S/N ratio of galvanic thickness, as shown in Figure 3.

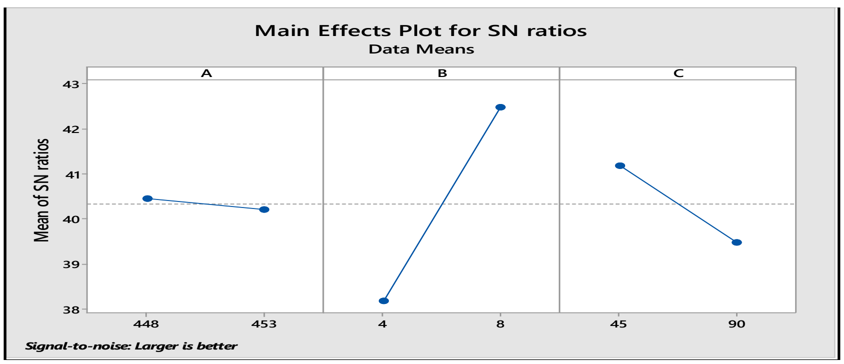

Figure 3. Main Effects Plot for Signal To Noise Ratio

5.3 Testing and Validation

5.3.1 Analysis Of Variance For Means

An Analysis Of Variance is used to determine the factors that significantly influence the average value of galvanized thickness or the average of the adjustment factor. This test is also to ensure the validity of the calculation of factors that significantly influence the thickness of the galvanized steel based on the response ratio.

Table 8. Analysis Of Variance For Means

Source	SS	DF	Average of SS	F value	SS'	ρ %	F Table
A	16,81	1	16,81	17,851	15,868	0,128	4,75
B	10712,25	1	10712,25	11375,841	10711,308	86,476	4,75
C	1656,49	1	1656,49	1759,104	1655,548	13,366	4,75
e	11,3	12	0,942	1	3,767	0,030	

St	12396,85	15	12386,492		12386,492	100	
Average	184986,01	1					
Total	197382,86	16					

Based on table 8, the factors that have a significant influence on the average galvanized thickness are the dipping temperature factor (A), the length of dipping time factor (B), and the dipping tilt angle factor (C). This experiment uses an orthogonal matrix L4(23), so only one influential factor is taken. The A factor with the smallest F-ratio value is pooled into the error in this pooling.

Table 9 . *Pooling* Analysis Of Variance For Means

Source	SS	DF	Average of SS	F-value	SS'	ρ %	F-Table
A	*Pooling*						
B	10712,25	1	10712,25	4954,082	10710,088	86,575	4,67
C	1656,49	1	1656,49	766,075	1654,328	13,373	4,67
Pool e	28,11	13	2,1623077	1	6,487	0,052	
St	12396,85	15	12370,902		12370,902	100	
Average	184986,01	1					
Total	197382,86	16					

Based on table 9, the parameters that affect the average of galvanic thickness are the length of dipping time factor (B), which has an 86.57% contribution to the average of difference, and the dipping tilt angle factor (C), which has 13.373% contribution to the average of the difference.

5.3.2 Analysis Of Variance For Signal To Noise Ratio Values

An Analysis Of Variance is used to determine the factors that significantly influence the value of the S/N ratio of galvanized thickness or the S/N ratio adjusting factor. This test is also carried out to ensure the validity of the calculation of factors that significantly influence the thickness of the galvanized steel based on the response ratio value, as shown in Table 10.

Table 10. Analysis Of Variance For Signal To Noise Ratio

Source	SS	DF	Average of SS	F-value	SS'	ρ %	F-Table
A	0,2428939	1	0,2428939	32,29695	0,23537	0,27506	4,75
B	73,567847	1	73,567847	9782,121	73,560327	85,96234	4,75
C	11,671748	1	11,671748	1551,961	11,664	13,63077	4,75
e	0,0902477	12	0,00752	1	0,113	0,13183	
St	21,38143191	15	21,38143191		21,35570427	100	
Average	26021,55076	1					
Total	26107,12349	16					

Based on the Analysis of Variance, the parameters that significantly contribute to the value of the S/N ratio of galvanized thickness are the temperature factor (A), the long dipping factor (B), and the slope factor (C). To avoid overestimation, half of the degrees of freedom of the orthogonal matrices is used. This experiment uses the orthogonal matrix L4(23), so one influential factor is considered. The factor with the smallest F-ratio value is pooled into the error (factor A) and combined into the columns in row e.

Table 11. *Pooling* Analysis Of Variance For Signal To Noise Ratio

Source	SS	DF	Average of SS	F-value	SS'	ρ %	F-Table
A	*Pooling*						
B	73,567847	1	73,567847	2870,797	73,542221	85,94118	4,67
C	11,671748	1	11,671748	455,460	11,646	13,60962	4,67
Pool e	0,3331416	13	0,02563	1	0,384	0,44920	
St	85,572737	15	85,265		85,57274	100	
Average	26021,55076	1					
Total	26107,12349	16					

According to Table 11, the length of the dipping time factor (B), which contributes 85.94118% to the difference in the S/N ratio, and the dipping tilt angle factor (C), which contributes 13.6096% to the difference in the S/N ratio, are the parameters that influence the S/N ratio of galvanized thickness.

5.4 Optimization Result

Based on the Analysis of Variance, the distribution of controlled factors is carried out, as shown in Table 12.

Table 12. Distribution of Controlled Factors

Controlled Factors		
Significant to Means	**Significant to Signal To Noise ratio**	**Not Significant**
Length Of Dipping Time	Length of dipping Time	Dipping Temperature
Dipping Tilt Angle	Dipping Tilt Angle	

Based on the Analysis of Variance in Table 10, it is known that the parameters influencing the S/N ratio of galvanized thickness are the length of the dipping time factor (B), which has contributed to difference in the S/N ratio of 85.94118%, and the dipping tilt angle factor (C), which has contributed to the difference in the S/N ratio of 13.60962%. The results of the proposed design for setting all parameters can be seen in table 13.

Table 13. Optimization Result

	Factors	Level	Setting
A	Dipping Temperature	2	448 ^{o}C
B	Length of Dipping time	2	8 minutes
C	Dipping Tilt Angle	2	45^{o}

Based on the optimization results, the proposed parameter adjustments for the dipping process in hot-dip galvanizing are the dipping temperature of 448 °C, the length of dipping time of 8 minutes, and the dipping tilt angle of 45 °.

6. Conclusion

Based on the results of the research, it can be concluded as follows:

1. The response factor is the galvanized thickness of the 4 mm post guardrail product according to ISO 1461 standards, with a minimum thickness value of 70 m. The control factors consist of dipping temperature, length of dipping time, and dipping tilt angle during galvanizing operations.

2. The main factors that influence the galvanized thickness are the length of dipping time factor (B), which contributes to the difference in the S/N ratio of 85.94118%, and the dipping tilt angle factor (C), which contributes to changes in the S/N ratio of 13.60962%.

3. The optimal value of the dipping temperature is 448 oC, the dipping time is 8 minutes, and the dipping tilt angle is 45°.

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Biography

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