

# The effect of immersion time to low carbon steel hardness and microstructure with hot dip galvanizing coating method

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**Abstract.** Along with developing necessities of metal materials, these rise demands of quality improvements and material protections especially the mechanical properties of the material. This research used hot dip galvanizing coating method. The objectives of this research were to find out Rockwell hardness (HRb), layer thickness, micro structure and observation with Scanning Electron Microscope (SEM) from result of coating by using Hot Dip Galvanizing coating method with immersion time of 3, 6, 9, and 12 minutes at 460°C. The result shows that Highest Rockwell hardness test (HRb) was at 3 minutes immersion time with 76.012 HRb. Highest thickness result was 217.3 µm at 12 minutes immersion. Microstructure test result showed that coating was formed at eta, zeta, delta and gamma phases, while Scanning Electron Microscope (SEM) showed Fe, Zn, Mn, Si and S elements at the specimens after coating.

## 1. Introduction

Current industry developments demand more materials for a product. Demands of metal materials in varying product components are growing. Steel is a common metal used by industries of constructions, machineries, and handcrafts. Steel uses for machinery components and constructions often demonstrate damage sooner than time use had been estimated before. Some of common causes are corrosion, metal fatigue, brittle fracture, overload, high temperature corrosion, stress corrosion cracking and wear. Effects of metal damage in a component or critical part is sometimes beyond expectation, and even it may cause disaster. Consider a steel wire for bridge drag is getting damaged because of corrosion or dynamic loads from vehicles running on the bridge that this wire receives. This may fail and this means more weight loads for other wires. This further makes the bridge fail. Continuous vibration and dynamic movement will cause metal to get fatigue. Another example is industrial pipes in mining, water pipes, oil pipes, etc. If there is no protection to these pipes, these pipes will get damaged over time caused by natural factors, chemicals, air, etc. the most common cause of metal damage is corrosion[1]. Therefore, protection and control efforts are required to prevent or minimize unexpected damage because of corrosion and other mechanical damages. Surface metal coating method is one of protection efforts. This can be done by electroplating[2], spraying or *Hot Dip Galvanizing*[3,4,5]. This research used hot dip galvanizing method and the objectives of this research were to find out the hardness value, layer thickness and microstructure of lo carbon steel material (0.02% C) after being coated with zinc.



## 2. Experimental

Steps to conduct this research were as follows:

1. Preparing equipment and research materials. They were grinding cutter, drilling machine, measuring cup, hot plate, Beaker flask, stopwatch, digital scale, Rockwell hardness tester, OES, metallurgy microscope, furnace machine, oven, polishing machine, crucible (galvanized container), low carbon steel (0.023%C), NaOH, resin, clean water/aquades, H<sub>2</sub>SO<sub>4</sub>, Zinc Ingot, Zinc Ammonium Chloride.
2. Making specimens by cutting low steel carbon material with dimension of 10 cm length, 3.5 cm wide, and 3.5 mm thickness by using grinding cutter. The specimen was drilled on each of middle tip as it is shown in Figure 1. These holes helped to facilitate specimen assembly.
- 3.



**Figure 1.** Specimen



**Figure.2** Crucible (galvanized container)

4. Making crucible (galvanized container) by using steel pipe which was cut into two pieces and then their lower back were welded. The steel pipe was cut with dimension of 35 cm length and 20 cm diameter, and it was split into two pieces by using *bluner*. After spilt, each of lower back was connected with welding, and the edges of the split pipe were closed to form a container (Figure 2)
5. Weighing before coating process to obtain weight comparison after coating.
6. Testing chemical composition to find out chemical composition contained in a particular material or percentage of each forming element; for example, C, Si, Fe, Cu, Mg, Al, or other elements.
7. Physical cleaning by sand papering and chemical cleaning by *degreasing*, *rinsing I*, *pickling*, *rinsing II*, *fluxing*. Hot dip galvanizing process was conducted with immersion time variations of 3, 6, 9 and 12 minutes at 460°C.
8. Weighing after coating to find out additional weight at the specimen and conducting Rockwell B hardness test, microstructure test by using *metallurgy microscope*, thickness test by using *Thickness Meter Gauge* and Conducting test with *Scanning Electron Microscope* (SEM)

## 3. Results and Discussions

### 3.1. Chemical Composition Test Result

The chemical compositions of basic material are listed in table 1. the specimen in this research is low carbon steel with 0.023% C.

**Table 1.** The major chemical compositions of the sample (wt.%)

Fe	C	Ni	Mn	Si	S	Al	Cr
98.6	0.023	0.038	0.80	0.199	0.001	0.045	0.01

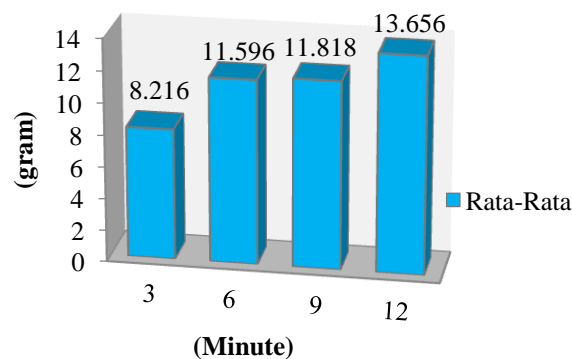
Table 2 shows that Zn content in Zinc ingot is 98.65% and it complies SNI standard number 07-135331989 where Zinc to use for coating must be G.O.B (Good Ordinary Brand) qualified and containing 98.5% Zn

**Table 2.** Chemical compositions of Zinc Ingot (wt.%)

Fe	Si	S	Ni	Zn
0.18	0.71	0.43	0.039	98.65

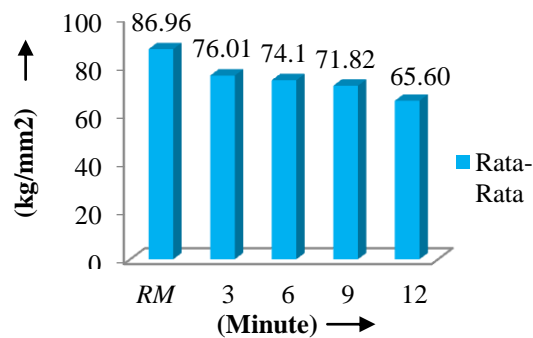
### 3.2. Difference of initial ( $W_o$ ) and final ( $W_a$ ) Weights

Figure 3 shows that specimen weighing before and after coating suggests that the longer immersion time, then, the higher is Zn ( $W_{zn}$ ) additional weight attached or coating the specimen. This can be seen from increasing specimen weight at each of time variation. 3 minutes immersion results in lowest weight difference ( $W_{zn}$ ) (8.216 gram). 6 and 9 minutes immersion result in 11.596 gram and 11.818 gram weight difference ( $W_{zn}$ ) respectively. 12 minute immersion shows significant difference by producing 13.656 gram weight difference ( $W_{zn}$ ). These are results of continuous attaching zinc into metal surface during the process. In the *hot-dipped galvanizing*, attached zinc to base metal surface is the formation and growth of inter-metallic layer. This zinc layer is principally containing of pure zinc layer which is drawn when the working material is removed from *galvanize* and produces mixing layer between zinc and base metal (Fe-Zn).

**Figure 3.** Graphic of difference of initial ( $W_o$ ) and Final ( $W_a$ ) weights of specimen based on time variations

### 3.3. Raw Material Rockwell Harness ( $HR_b$ ) test Result Before and After Coating with Immersion time Variation

Figure 4 shows that the average hardness value of the coated raw material is  $86.96 \text{ kg/mm}^2$ . After raw material is coated with zinc (Zn) by using Hot Dip Galvanizing for 3 minutes, the variations of hardness values are not significant between them. The average hardness value of 5 specimen is  $76.01 \text{ kg/mm}^2$ . The hardness value of raw material seems to decrease. It is because the raw material has been protected with Zn metal with lower hardness value ( $42.04 \text{ kg/mm}^2$ ) than raw material, so that indenter of hardness testing equipment only touches Zn layer and only a little touches base material; only on *Zeta* layer containing of 96.257% Zn and 3.743 Fe, so that hardness value becomes smaller than initial hardness value of raw material. 6, 9, and 12 minutes immersion show average hardness values of  $74.10 \text{ kg/mm}^2$ ,  $71.824 \text{ kg/mm}^2$ , and  $65.604 \text{ kg/mm}^2$  respectively. These hardness values are more decreasing compared with 3 minute immersion. This is caused by thicker Zn metal will coat base material along with longer immersion time so that indenter only touches Zn layer and presses only a little the base material. Obtained data show that the longer the immersion time, the smaller is the hardness value.

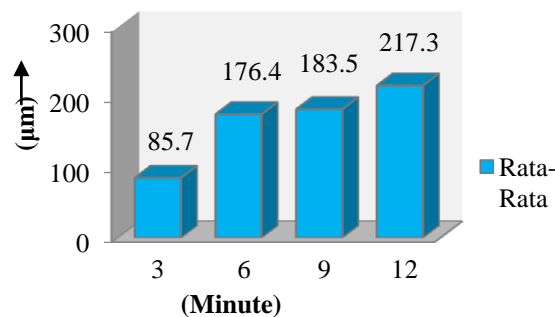


**Figure 4.** Raw material Rockwell hardness (HRb) test results before and after coating with immersion time variations

### 3.4. Layer Thickness Test Result

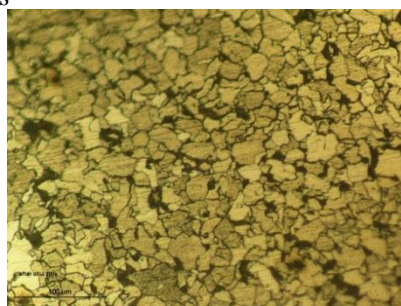
Figure 5 shows layer thickness result at each of immersion time variation. At 3 minutes, the average of layer thickness is 85.742  $\mu\text{m}$ , and this is proportional to the weighing result difference ( $W_{Zn}$ ) before and after coating and the thinnest layer is obtained with 3 minutes immersion.

6 minutes immersion produces 176.40  $\mu\text{m}$  layer thickness and this is proportional to the weighing result difference ( $W_{Zn}$ ) between 6 and 3 minutes immersion, where 6 minutes immersion produces thicker layer than 3 minutes immersion. 9 minutes immersion produces average layer thickness of 183.52  $\mu\text{m}$ . This shows a little difference with 6 minutes immersion but it is proportionally thicker compared to 6 minutes immersion. 12 minutes immersion produces average layer thickness of 217.30  $\mu\text{m}$ , and it demonstrates significant difference than lesser immersion time. This is proportional to previous weighing where 12 immersion time produce thicker layer than other less time immersion variations.



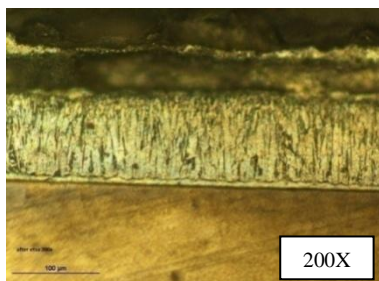
**Figure 5.** Layer thickness test result

### 3.5. Microstructure Test Results

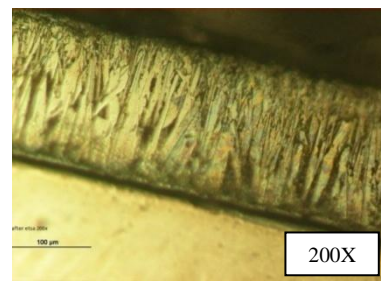


**Figure 6.** Microstructure of base material

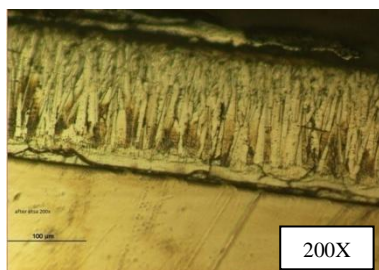
Figure 6 demonstrates microstructure image of raw material where domination of *ferrite* crystal appears in white bright color toward dark color *pearlite* crystal. *Ferrite* phase is called as alpha ( $\alpha$ ). Inter atom space is small and dense so that it will accommodate lesser Carbon atom. The maximum carbon dissolve is 0.025% at 723<sup>0</sup>C and its crystal structure is BCC (body center cubic). At room temperature, its carbon degree is 0.008% so that it is considered as a pure iron. Ferrite is magnetic until 768<sup>0</sup>C and it has low toughness, high tenacity, medium corrosion resistance and it has most smooth structure amongst Fe<sub>3</sub>C diagram. Meanwhile *pearlite* phase is mechanical mixture containing of two phases; *ferrite* with 0.025% carbon content and *cementite* in form of *lamellar* (layer) with 6.67% carbon content with interstitial forms. Thus *perlite* is the microstructure of *eutectoid lamellar* reaction. This domination shows that the raw material is a metal which is not too hard and it is in fact a low carbon steel



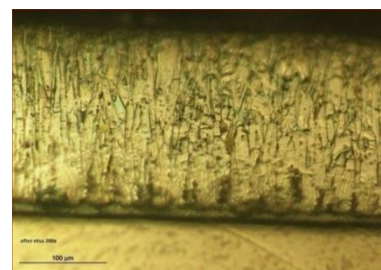
**Figure 7.** Micro structure with 3 minute time variation



**Figure 8.** Micro structure with 6 minute time variation



**Figure 9.** Micro structure with 9 minute time variation



**Figure 10.** Micro structure with 12 minute time variation

The microstructures of the images above demonstrate result of Zinc (Zn) coating to low steel carbon surface and it is shown that the zinc coating is not evenly distributed. Specimen having pre-treatment is immersed into a container with liquid zinc at 460<sup>0</sup>C temperature for 3 (Figure 7), 6 (Figure 8), 9 (Figure 9) and 12 minutes (Figure 10) so that mixture Fe-Zn layer is formed. The formed Fe-Zn mixture in the outer layer is Eta ( $\eta$ ) phase, Zeta ( $\zeta$ ) phase and Delta ( $\delta$ ) phase, while layer in steel interface is Gamma ( $\gamma$ ) phase. The raw material does not undergo microstructure change. Eta ( $\eta$ ) phase is the outer layer which is composed from pure 100% of zinc (Zn) with hexagonal structure and it has soft and ductile mechanical characteristics. Zeta ( $\zeta$ ) phase is the second outer layer after Eta ( $\eta$ ) phase which is composed of 94% Zn and 6% Fe (FeZn<sub>13</sub>), and it has monoclinic structure with hard and brittle mechanical characteristics. The next layer is Delta ( $\delta$ ) layer composed of 90% Zn and 10% Fe (FeZn<sub>7</sub>) with hexagonal structure and it has ductile mechanical characteristic. The last layer is



Gamma ( $\gamma$ ) layer composed of 75% Zn and 25% Fe ( $\text{Fe}_3\text{Zn}_{10}$ ) with BBC structure and it has thin, hard and brittle mechanical characteristics.

#### 4. Conclusions

- a) The longer immersion time, the smaller is the hardness value. Highest hardness value obtained after *hot dip galvanizing* process at 3 minutes immersion time produces 76.012  $\text{kg/mm}^2$  Rockwell hardness (HRb).
- b) The longer time immersion, the longer is layer thickness. The highest layer thickness value after *hot dip galvanizing* process obtained after 12 minutes immersion is 217.3  $\mu\text{m}$ .
- c) Microstructure testing result shows that raw material composed of *pearlite* and *ferrite*, where *ferrite* crystal dominates more than *pearlite* crystal. Specimen of *hot dip galvanizing* at 3 minutes immersion shows that Zn coating is not evenly distributed and it is formed in stratifying form. Zn layer will be thicker along with longer time immersion until 12 minutes immersion time variation.
- d) 3, 6, 9, and 12 immersion time do not change microstructure of specimen after *hot dip galvanizing* process.

#### Acknowledgements

This work was financially supported by Research Unit for Mineral Processing Technology and Department of Mechanical Engineering, Faculty of Engineering, University of Malahayati

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