Study on Electrogalvanizing Technology and Chromium-Free Passivation Treatment of 08Al Plate

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Abstract. An environment-friendly electrogalvanizing technology of 08Al cold rolled steel sheet (CRS) was developed. 08Al CRS sheet was placed as cathode in the electroplating solution containing zinc salt 1-10g/L, organic acid 3-24g/L, complexing agent 0.2-0.8g/L, and Hot-dip galvanized alloyed sheet (GA) as anode. The relationship between the current density and the plating mass per unit area was studied by applying 0.15-2A direct current at room temperature, current density 0.19-2.6A/dm², and plating time 35min. The relationship between plating mass per unit area and anode thinning per unit area was linear regression by introducing current density as intermediate quantity. The effect of electric power range on the coating mass per unit area was studied under the condition of different concentration of main salt. The chromium-free passivation treatment was also carried out on the surface of electrogalvanizing layer. 08Al electrogalvanized sheet and GA sheet were placed in chromium-free passivation solution containing molybdate 1-10g/L, hydrogen peroxide 1-5g/L, fluorine ion complexing agent 1-10g/L, potassium hydroxide 1-2g/L. The temperature and reaction time of chromium-free passivation solution and the corrosion resistance of chemical conversion film were studied, and the experimental conditions of chromium-free passivation were optimized. The adhesion and corrosion resistance of the coating were tested by scratching test and neutral salt spray test (NSS). The results show that after scratching test, the adhesion of the electrogalvanizing layer on 08Al surface reaches grade 0, and the adhesion of the electrogalvanizing and chemical conversion film composite coating on 08Al surface reaches grade 0. The NSS test showed that the corrosion resistance increased with the increase of the thickness of the galvanizing layer. The corrosion resistance time of the galvanizing layer with the thickness of 15um exceeded 216h. Salt spray resistance time of electric galvanizing layer about 10um is 72-96 h; The salt spray resistance time of electrogalvanizing layer less than 5um is less than 48 h. After chromium-free passivation treatment, the corrosion resistance of GA plate is more than doubled to 192h. The salt spray corrosion resistance of the composite coating (10-11um thickness) on 08Al with electrogalvanizing and chemical conversion film can reach more than 216h.

Keywords. CRS; electric galvanizing; coating mass per unit area; linear normalization; chromium-free passivation; GA; NSS.

1. Introduction
08Al cold rolled steel sheet (CRS), as a kind of cold-rolled metal plate commonly used in commercial vehicle body and other parts, has a large amount of metal and poor corrosion resistance. It usually requires several surface treatment steps such as shot blasting (or pickling), degreasing, phosphating and cathodic electrophoresis (or powder spraying). The process is complex and the material corrosion resistance cost is high. How to use fewer steps, simple process, low cost can significantly improve the
anticorrosion performance of materials, so as to meet the use requirements of different parts on the car, is our concern. Galvanizing technology is the most basic and widely used method of steel anticorrosion in the world at present. It is widely used in various fields of national economy such as metallurgy, building materials, electric power, transportation and agriculture [1]. The methods of galvanizing steel surface include cold spraying zinc [2-3] and hot dip galvanizing [4-7]. Both of them make zinc atoms penetrate between the atomic lattices of metal materials through physical and chemical methods to form the structure of eutectic phase, thus enabling the material to have special functions, such as electrical conductivity, thermal conductivity, superhardness, wear resistance, anti-corrosion and other properties. Due to the limitation of external conditions, such as temperature, pressure and so on, the composition and structure of the coating will be affected to a certain extent, so that the process remains stable, and it is difficult to control. Electro-galvanizing process [8], as a new galvanizing technology, has its unique advantages, such as low energy consumption, independent of temperature and pressure, stable and controllable process, uniform coating, and small environmental pressure. In addition, the deposition of zinc ions on the material surface can be regulated by electrochemical method, so as to achieve the effect of improving the surface structure of the material, enabling it to have special functions and expand the application fields of the material, such as energy [9-11]. The passivating treatment on the surface of the galvanized layer produces a layer of passivating film, so that the surface of the galvanized layer has a more compact structure, which can further improve the protection ability of the substrate. The research on the passivating agent has become the focus of the field of metal surface corrosion. In this paper, a chromium-free passivation process for the surface of 08Al galvanizing layer was studied. The relationship between time, temperature and the corrosion resistance of the passivation film was investigated. The test conditions of passivation treatment were optimized. The process was simple, stable and controllable, low energy consumption, short time, uniform color passivation film, complete structure, compact, good corrosion resistance, suitable for surface sealing treatment of galvanized metal parts.

2. Experiment

2.1. Experimental Raw Materials

Reagents: sodium carbonate, sodium hydroxide, sodium dodecyl benzene sulfonate, zinc oxide, 98% sulfuric acid, 50% formic acid solution, citric acid, ammonium molybdate, sodium fluoride, hydrogen peroxide, sodium chloride, all chemicals are analytical pure (produced by domestic reagent companies), deionized water homemade (conductivity is less than 2us·cm⁻¹).

Instruments: magnetic stirrer, regulated Dc power supply (0-36V), electronic balance, magnetic thickness gauge, micro digital hardness tester, scratch tester, 3M adhesive tape, salt spray test chamber, beaker, etc.

Sample: 08Al plate, GA plate.

2.2. Preparation of Electrogalvanizing Layer

The surface of 08Al plate (15cm × 7cm × 0.8mm) was polished by 400 mesh sandpaper and removed the local rust. Iron and grease were wiped off the surface of 08Al plate with a clean gauze, then it was put into a homemade degreasing liquid. The degreasing liquid included 50g/L sodium carbonate, 25g/L sodium hydroxide, 1g/L surfactant sodium dodecyl benzene sulfonate. 08Al plate was stirred for 10min in the 3L glass beaker under 50-60°C. Then it was rinsed with tap water and dried after 30s until the surface was no water. The mass was m₀ after weighing it. GA plate performed the same operation and the mass was m₂. These two plates were put into the 1L glass plating tank, keeping electrodes parallel and 85cm apart. The electrodes were held together by two clamps with red and black color, which were immersed under the solution. The plating solution contained 1-20g/L zinc oxide, 0-32g/L sulfuric acid, 3-15g/L formic acid, 0.4-3.2g/L citric acid, and these two plates were stirred at the speed of 200-400r/min. The starting voltage Uₛ of the regulated power supply was set to a value between 0-15V. In the constant current mode, the current was set to a value between 1-2A.
Eletroplating time was 0-50min, then cleaned with tap water for 30s. Drying until there were no liquid drops on the coating surface, the coating mass was $m_1$ after weighing. In the same operation, the mass of GA plate was $m_3$.

The effective area of electrode is denoted by $S$, which is the area of the electrode under the surface of the liquid, and the unit is dm$^2$. The formula of $M_{CP}$ and $M_{AP}$ for unit area mass of electrode is as follows:

$$M_{CP} = (m_1 - m_0)/S \quad \text{(unit: g/dm}^2) \quad (1)$$

$$M_{AP} = (m_2 - m_3)/S \quad \text{(unit: g/dm}^2) \quad (2)$$

The calculation formula of electrode surface current density $I_d$ is as follows:

$$I_d = I_0/S \quad \text{(unit: A/dm}^2) \quad (3)$$

2.3. Preparation of Chromium-Free Passivation Film on Electrogalvanizing Layer

The 08Al electro-galvanized plate and GA plate were respectively placed in the chromium-free passivation solution CM-P40. The passivation solution contains ammonium molybdate 5g/L, sodium fluoride 2g/L, hydrogen peroxide 5g/L, potassium hydroxide 1g/L. The passivation solution was stirred for 10min at speed of 200-400 r·min$^{-1}$ and temperature was maintained at 35-42℃, then washed with tap water for 30s. The result of the uniform and complete chemical conversion film with black and brown surface was obtained after these two plates were dried. From left to right in figure 1, they are 08Al electro-galvanized chromium-free passivation film, 08Al electro-galvanized film, GA plate, GA chromium-free passivation film.

**Figure 1.** 08Al electrogalvanizing chromium-free passivation film, 08Al electrogalvanizing film, GA plate and GA chromium-free passivation film from left to right.

2.4. Corrosion Resistance

2.4.1. Corrosion Resistance of Electrogalvanizing Layer. The prepared 08Al electro-galvanized sheets with different thicknesses, named EZ-1, EZ-2, EZ-3, EZ-4, EZ-5, were placed in a salt spray box at an angle of 15 degrees from the vertical direction. The salt spray test conditions were in accordance with GB/T 10125-1997. From table 1, comparison of corrosion resistance performance of prepared 5 kinds of electro-galvanized sheets with different thickness after neutral salt spray test.
Table 1. Salt spray resistance test of electro-galvanized sheets with different thickness.

| The name of sample | EZ-1 | EZ-2 | EZ-3 | EZ-4 | EZ-5 |
|--------------------|------|------|------|------|------|
| The thickness of the coating (um) | 5    | 8    | 11   | 12   | 15   |
| 72 h salt spray results | A lot of red rust | No red rust | No red rust | No red rust | No red rust |
| 96 h salt spray results | /    | Red rust | No red rust | No red rust | No red rust |
| 144 h salt spray results | /    | /     | Red rust | No red rust | No red rust |
| 168 h salt spray results | /    | /     | /     | Red rust | No red rust |
| 216 h salt spray results | /    | /     | /     | /     | No red rust |

2.4.2. Corrosion Resistance of Chromium-Free Passivation Film on 08Al Electrogalvanizing Layer. 08Al electro-galvanized chromium-free passivation sheet was compared in a salt spray test chamber. The salt spray test conditions were in accord with GB/T 10125-1997. The result of corrosion test was shown in figure 2.

Figure 2. 192h salt spray test (08Al electro-galvanized chromium-free passivation).

2.4.3. Corrosion Resistance of GA Plate and GA Chromium-Free Passivation Film. The corrosion resistance of GA plate and GA chromium-free passivation plate was compared under the same conditions in a salt spray test chamber. The salt spray test conditions were in accord with GB/T 10125-1997. From figures 3 and 4, the result of corrosion test of GA chromium-free passivation film could reach 168h, the corrosion resistance of GA plate could only reach 120h.

Figure 3. 168h salt spray test results of GA chromium-free passivation film.

Figure 4. 120h salt spray test results of GA plate (left 1).
3. Results and Discussion

3.1. Influence of Zinc Oxide Concentration on Electroplating

Adding zinc oxide as main salt into plating solution can increase concentration of zinc ions in solution, improve conductivity of solution, increase polarization current, and have a positive effect on thickness of coating. When zinc oxide concentration is 1g/L, voltage is 5-15V, current is 0.15-0.5A, the result of coating thickness is 1-5um and area is 77cm², cathode mass increase 0.09-0.26g, anode reduction is 0.11-0.36g. When zinc oxide concentration is 3g/L, voltage is 10-14V, current is 0.75-1.2A, the result of coating thickness is 7-19um and cathode mass increase 0.42-0.83g, anode reduction is 0.56-1.03g. When zinc oxide concentration is 5g/L, voltage is 7.2-9.2V, current is 1A, the result of coating thickness is 5-12um and cathode mass increase 0.35-0.76g, anode reduction is 0.42-0.82g. The calculation formulas of power and electrical work are shown in equations (4) and (5).

\[ P = U \times I \] (unit: W) (4)
\[ W = P \times t = U \times I \times t \] (unit: J) (5)

Table 2. Influence of zinc oxide concentration on initial current and electroplating thickness.

| Zinc oxide concentration (g/L) | 1  | 3  | 5  | 8  | 10 |
|--------------------------------|----|----|----|----|----|
| Initial current I₀ at 10V startup voltage (A) | 0.3 | 0.75 | 1.0 | 1.5 | 1.7 |
| Coating thickness after electrification for 35min (um) | 2  | 8  | 11 | 13 | 15 |
| Electrical work (J) | 1.75 | 4.38 | 5.83 | 8.75 | 9.92 |
| Coating mass per unit area (g/m²) | 22.08 | 54.55 | 83.12 | 128.57 | 155.84 |
| Value of plating mass per unit area proportion to electric work value (times) | 12.62 | 12.45 | 14.24 | 14.69 | 15.71 |

As shown in table 2, at 10V startup voltage, the coating thickness increases with the increase of zinc oxide concentration and current density. When initial current is 0.3A and current time is 35min, only a coating of 2um thickness can be obtained from solution containing 1g/L of zinc oxide. Under 3g/L zinc oxide condition, the initial current at 10V constant voltage starts up to 0.75A, electrification for 35min, the coating thickness can reach 8um. When 5g/L zinc oxide, 10V constant voltage starts, the initial current reaches 1A, after electrification for 35min, the coating thickness can reach 11um; When 8g/L zinc oxide, 10V constant voltage starts, the initial current reaches 1.5A, after electrification for 35min, coating thickness can reach 13um; When 10g/L zinc oxide, 10V constant voltage starts, the initial current reaches 1.7A, after electrification for 35min, electrical work is 9.92J, coating thickness can reach 15um and coating mass per unit area is 155.84g/m².

Figure 5. The relationship between zinc oxide concentration with W, coating mass per unit area, coating thickness.
3.2. Effect of Electrical Work on Coating Mass per Unit Area under Different Main Salt Concentrations

As can be seen from table 3, with increase of electrical work, coating mass per unit area also increases. With increase of main salt concentration, coating mass per unit area increases significantly.

Table 3. Relationship between electrical work and coating mass per unit area at different main salt concentrations.

| The lord salt concentration (g/L) | 1   | 3   | 5   |
|-----------------------------------|-----|-----|-----|
| Electrical work W (J)            | 0.44| 1.75| 4.38|
| Coating mass per unit area (g/m²)| 11.69| 22.08| 33.77|
| Main salt concentration (g/L)    | 8   | 10  |
| Electric work W (J)             | 4.88| 5.18| 5.86|
| Coating mass per unit area (g/m²)| 96.10| 102.60| 103.90|

From figure 6, it can be included that low concentration of main salt has low electrolyte concentration, the solution conductivity is low, so it need start at low voltage and current, and the electrical work range is narrow, so only the coating with lower thickness can be obtained. To get a better coating, low electric work can only be used. On the contrary, under high concentration electrolyte, the coating has a wider mass per unit area because of wide range of electrical work.

Table 4. Different concentrations of salt in roughly the same electric work under the coating thickness.

| The lord salt concentration (g/L) | 1 | 3 | 5 | 8 | 10 |
|-----------------------------------|---|---|---|---|----|
| 4-5J of coating thickness (g/m²)  | 30-35 | 50-60 | 70-90 | 90-100 | 100-120 |
When concentration of electrolyte is low, the conductivity of solution is also low. It is suitable to start with low voltage and current, at the same time, the electric power is also at a low value. The thickness of coating under 4-5J electric work is taken as research object, and the results are shown in table 4. Under the electric work of 4-5J, if the coating with a mass of 50-60g/m² per unit area is to be selected, the concentration of main salt is 3g/L; if the coating with a mass per unit area of 100-120g/m² is to be selected, the concentration of main salt is 10 g/L.

3.3. Effect of Electroplating Time on Anode Mass Reduction per Unit Area
The effect of 5g/L zinc oxide, 15g/L formic acid, 1.3A/dm² current density, 20min, 30min, 35min, 40min on electroplating thickness and mass reduction per unit area of anode MAP was studied. The contact area between electrode and bath is 77cm², and the distance between electrodes is 85cm.

| Time (min) | 20  | 30  | 35  | 40  |
|------------|-----|-----|-----|-----|
| Electric work W (J) | 2.97  | 4.19  | 4.73  | 5.28  |
| Anode mass reduction per unit area Map (g/dm²) | 0.55  | 0.79  | 0.95  | 1.06  |

It can be seen from figure 7 that under the current density of 1.30A/dm², the reduction of anode plate per unit area increases from 0.55g/dm² at 20min to 1.06g/dm² at 40min, and the mass reduction of anode has a linear relationship with the power on time.

| Time (min) | 0  | 10  | 20  | 30  | 40  |
|------------|----|-----|-----|-----|-----|
| Anode mass reduction per unit area (g/dm²) | 0  | 0.2  | 0.4  | 0.6  | 0.8  | 1.0  | 1.2  |
| Time (min) | 0  | 10  | 20  | 30  | 40  |

**Figure 7.** The relationship between time with anode mass reduction per unit area.

| The plating time (min) | 20  | 30  | 35  | 40  |
|------------------------|-----|-----|-----|-----|
| The thickness of coating (um) | 5  | 8  | 11 | 12 |

As can be seen from table 6, when plating time is between 0 and 35min, the coating thickness increases significantly. After 35min, the coating thickness increases slowly. The anode reduction increases linearly with the prolongation of electroplating time. When the electrode is more than 40min, the electrode loss is serious, and the electrode slag will be precipitated in the anode area, which affects the stability of the plating solution, and the surface uniformity of coating is poor, and there is blackening phenomenon. Therefore, in order to ensure the thickness of coating, the uniformity of coating surface, the reducing of anode loss, and stability of plating solution, the appropriate plating time is 35min.
3.4. Effect of Complexing Agent Concentration on Electroplating

The complexing agent is used for complexing with metal ions, reducing the formation of electrode slag and improving the stability of the bath. By adding citric acid and complexing ferrous ions in the bath, the effect of ferrous ions on zinc coating was reduced, and the surface mass of the coating was improved positively.

Figure 8. Influence of complexing agent on the surface of coating (left: 0.8g/L, middle: 2.0g/L, right: 3.2g/L).

Because of bath plating for a long time, there is some precipitation of impurities at the anode. Producing excess ferrous ions increased difficulty of complexing agent. This side reaction has a competitive effect with the reduction of zinc by gaining electrons from zinc ions. At the same time, the increase of current density and electrification time accelerates the hydrogen evolution reaction. The most direct impact on the cathode coating is that the coating surface weak areas first appear coating peeling phenomenon, such as sharp edge area. The coating integrity is poor, and there is blackening at the edges, this is shown on the left of figure 8. Increasing the concentration of complexing agent can enhance complexing ability of ferrous ions and improve the integrity of coating. The surface mass of coating is improved with increase of the concentration of complexing agent. This is shown on the right in figure 8. The initial conditions of plating solution in figure 6 are: zinc oxide 20g/L, sulfuric acid 22g/L, formic acid 30g/L, citric acid 0.4g/L, current density 0.91A/dm², plating time 35min.

3.5. The Derivation of Relationship between the Mass of Cathode Coating and the Amount of Anode Coating

It can be seen from figure 9, the mass per unit area of anode increases linearly with the increase of current density. The relationship between these two factors satisfies the following formula:

\[ Y(\text{Map}) = 0.7541X(\text{Id}) + 0.0096 \quad (6) \]

This can be inferred from figure 10, the coating mass per unit area increases linearly with the increase of current density. As shown in the following formula:

\[ Y'(\text{Mcp}) = 69.698X(\text{Id}) - 6.2732 \quad (7) \]

By combining equation (3) with equation (4), it can get:

\[ Y'(\text{Mcp}) = 92.4254Y(\text{Map}) - 7.1605 \quad (8) \]

There is a linear relationship between the mass increase of cathode coating Map and the mass decrease of anode Mcp, as shown in equation (8).
Table 7. The influence of current density $I_d$ on the anode unit area reduction $M_{ap}$.

| Current density $I_d$ (A/dm$^2$) | 0.19 | 0.38 | 0.65 | 0.97 | 1.25 | 1.30 | 1.30 |
|----------------------------------|------|------|------|------|------|------|------|
| Anode reduction per unit area $M_{ap}$ (g/dm$^2$) | 0.14 | 0.30 | 0.47 | 0.73 | 1.00 | 0.95 | 1.06 |
| Coating mass per unit area (g/m$^2$) | 11.69 | 22.08 | 33.77 | 54.55 | 77.92 | 83.12 | 98.70 |
| The process parameters | 1g/L zinc oxide + 3g/L formic acid + 0.2g/L citric acid, 35min | 1g/L zinc oxide + 3g/L formic acid + 0.2g/L citric acid, 35min | 1g/L zinc oxide + 3g/L formic acid + 0.2g/L citric acid, 35min | 3g/L zinc oxide + 9g/L formic acid + 0.4g/L citric acid, 35min | 3g/L zinc oxide + 9g/L formic acid + 0.4g/L citric acid, 35min | 5g/L zinc oxide + 15g/L formic acid + 0.4g/L citric acid, 35min | 5g/L zinc oxide + 15g/L formic acid + 0.4g/L citric acid, 35min |
| Current density $I_d$ (A/dm$^2$) | 1.69 | 1.95 | 2.60 | 1.01 | 1.56 | 2.21 | 2.60 |
| Time (min) | 33 | 20 | 17 | 35 | 35 | 35 | 35 |
| Anode reduction per unit area $M_{ap}$ (g/dm$^2$) | 1.19 | 0.83 | 0.91 | 0.83 | 1.16 | 1.58 | 2.06 |
| Coating mass per unit area (g/m$^2$) | 103.90 | 71.43 | 83.12 | 70.13 | 107.79 | 155.84 | 172.73 |
| The process parameters | 8g/L zinc oxide + 24g/L formic acid + 0.8g/L citric acid | 8g/L zinc oxide + 24g/L formic acid + 0.8g/L citric acid | 8g/L zinc oxide + 24g/L formic acid + 0.8g/L citric acid | 10/L zinc oxide + 24/L formic acid + 0.8/L citric acid | 10/L zinc oxide + 24/L formic acid + 0.8/L citric acid | 10/L zinc oxide + 24/L formic acid + 0.8/L citric acid | 10/L zinc oxide + 24/L formic acid + 0.8/L citric acid |

Figure 9. The relationship between current density and anode mass reduction per unit area.
3.6. Preparation of Chemical Conversion Membrane

The purchased GA plate and the self-made 08Al electrogalvanized plate were placed in the prepared chromium-free passivation solution. The test conditions for the passivation solution are as follows. It contains ammonium molybdate 1-10g/L, sodium fluoride 1-10g/L, hydrogen peroxide 1-5g/L, potassium hydroxide 1-2g/L. The passivation solution was put into a 1L beaker. These two plates were performed with magnetic stirring at a speed of 100-400r/min, and soaked for a period of time, then the plates were taken out to rinse and dry. A uniform and complete black-brown chemical conversion film was obtained.

3.6.1. Influence of Temperature on Corrosion Resistance of Chromium-Free Passivation Film on GA Plate Surface. The corrosion resistance of chromium-free passivation film on GA plate surface at 15℃, 25℃, 30℃, 35℃, 40℃ and 45℃ was investigated.

It can be seen from table 8, with the increase of reaction temperature, the resistance of chemical conversion film to salt spray corrosion is improved. When the temperature of passivation solution is 35-40℃, the corrosion performance of chemical conversion film is the best.

| Temperature (℃) | 15 | 25 | 30 | 35 | 40 | 45 |
|-----------------|----|----|----|----|----|----|
| Salt spray corrosion condition | Less than 96 h red rust corrosion | The red rust corrosion of 96 h | The red rust corrosion of 120 h | The red rust corrosion of 168 h | The red rust corrosion of 168 h | Passivation film is not complete, and there are shrinkage holes, no salt spray test |

3.6.2. Effect of Reaction Time on Corrosion Resistance of Chromium-Free Passivation Film. The corrosion resistance of chromium-free passivation film on GA plate surface was investigated at 35-40℃ for 3min, 5min, 10min, 15min and 20min.
### Table 9. Corrosion resistance of chromium-free passivation film at different time.

| Reaction time (min) | 3 | 5 | 10 | 15 | 20 |
|---------------------|---|---|----|----|----|
| Salt spray corrosion condition | The red rust corrosion of 120h | The red rust corrosion of 168h | The red rust corrosion of 168h | The red rust corrosion of 120h | The red rust corrosion of 120h |

It can be seen from table 9, the corrosion resistance of chemical conversion film increases first and then decreases when the reaction time ranges from 3 to 20min, and the optimal reaction time is 5-10min.

### 3.7. Effect of Oxidant Content on Corrosion Resistance of Chromium-Free Passivation Film

The corrosion resistance of chromium-free passivation film on GA plate surface was investigated under different oxidant content, 5-9g/L conditions. It can be seen from table 10, the passivation capacity of newly configured solution is different from that of the old solution. The corrosion resistance of GA plate can reach 168h after being passivated by 5g/L newly equipped passivating solution. The concentration of oxidizer in solution must be greater than 5g/L and less than 7g/L and the corrosion resistance is only 120h. As it is consumed, the oxidant concentration drops below 5g/L at this time. After adding 2g/L oxidant to former old chromium-free passivation solution, the corrosion resistance can reach 192h, so the concentration of oxidizer in solution must be greater than 5g/L and less than 7g/L. After use, the concentration of oxidizer decreases, and the corrosion resistance of passivation plate also decreases. The salt spray resistance is 144h. It can be inferred that the concentration of oxidizer is lower than 5g/L at this time. After adding 1g/L oxidant to this old chromium-free passivation solution, the salt spray resistance time of sample can reach 168h again, so the concentration of oxidizer in solution must be 5g/L. After adding 1g/L oxidant to former old chromium-free passivation solution, the corrosion resistance of passivation film can reach 192h, so the concentration of oxidizer is 6g/L. Based on the above data, it can be inferred that the salt spray time of 144h corresponds to the oxidant concentration of 4-5g/L.

### Table 10. Corrosion resistance of different oxidants on chromium-free passivation film.

| Oxidant content (g/L) | 5 | <7 | <8 | <9 |
|-----------------------|---|----|----|----|
| Salt spray corrosion condition | The red rust corrosion of 168h (New chromium-free passivation solution) | The red rust corrosion of 192h (Adding 2g/L oxidant to former old chromium-free passivation solution) | The red rust corrosion of 168h (Adding 1g/L oxidant to former old chromium-free passivation solution) | The red rust corrosion of 192h above |
| | The red rust corrosion of 120h (Old chromium-free passivation solution, Leaving at room temperature for five days) | The red rust corrosion of 144h (Old chromium-free passivation solution, with less than 7g/L oxidant, Leaving at room temperature for six days) | The red rust corrosion of 120h (Old chromium-free passivation solution, Leaving at room temperature for one day) |  |
| Determine the concentration of oxidant and the corresponding corrosion resistance time | 5g/L, 168h | 6g/L, 192h | 5g/L, 168h | 6g/L, 192h |
4. Conclusion

1) A linear relationship between current density and plating mass per unit area of cathode was found. A linear relationship also existed between the mass increase of cathode coating Map and the mass decrease of anode Mcp.

2) The conditions of chromium-free passivation treatment and salt spray corrosion resistance of zinc coating are studied. The optimum temperature is 35-40°C and the reaction time is 5-10min. When the oxidant concentration ammonium molybdate is 5-6g/L, the corrosion resistance of chromium-free passivation film on the surface of galvanized layer reaches 168-192h. Galvanized sheet (thickness 11um) without passivation can resist salt spray corrosion for no more than 120h. Chromium-free passivation can be used as the surface of galvanized sheet enclosed. It can significantly improve the corrosion resistant ability of galvanized layer surface.

3) The salt spray resistance time of 08Al steel plate after electrogalvanizing (thickness 11um) and chromium-free passivation is more than 216h. Electrogalvanizing and chromium-free passivation combined surface treatment is a good anti-corrosion measure for steel plates.

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