



Study on the Applicability of Oil Coating Amount for Automotive Galvanized Steel Sheets

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Abstract: The amount of oil coating on automotive galvanized steel sheets affects their rust resistance, lubrication, and degreasing performance. This study, through theoretical calculations and various experimental verifications, ultimately determined 800 mg/m² as the optimal oil coating amount, providing data support for the standardization of the oiling process and possessing certain engineering application value.

Keywords: automotive galvanized steel sheets; oil coating amount; rust resistance; lubrication performance; degreasing performance; oil retention capacity

1. Introduction

With the automotive industry continuously raising requirements for sheet metal performance, galvanized steel sheets are widely used in body manufacturing due to their excellent corrosion resistance. The appropriateness of the oil coating amount is crucial for rust prevention, lubrication, and degreasing efficiency, as both excessive and insufficient coating can affect product quality and cost [1]. Currently, the industry lacks unified standards for the oil coating amount on different galvanized sheets, and quantitative studies on the adaptability of oil coating amount based on oil retention capacity are also scarce. Therefore, investigating the applicability of oil coating amount for galvanized sheets and determining the optimal coating amount through theoretical calculations and experiments is of practical significance for process optimization, cost reduction, and quality assurance.

2. Experimental Basis and Theoretical Model

2.1 Experimental Materials and Oil Properties

In this experiment, SPCC, GA, and GI galvanized steel sheets were selected, along with RD550HN lubricating anti-rust oil. Specific details are shown in Table 1. The anti-rust oil appears reddish-brown, with a density of 0.84–0.90 g/cm³ at 15 °C and a viscosity of 28.0–32.0 mm²/s at 40 °C. Its acid value is ≤2.0 mgKOH/g, moisture content ≤0.03%, flash point ≥130 °C, and water-soluble acidity or alkalinity is neutral or slightly alkaline. The impurity content is ≤0.02%, and its lubrication performance (Pd value) reaches 315 kg, meeting the rust-prevention and lubrication requirements for galvanized steel sheets.

Table 1. Performance Indicators of RD550HN Lubricating Anti-Rust Oil

Item	Indicator	Test Method
Appearance	Reddish-brown transparent liquid	Visual inspection
Density (15°C)	0.84–0.90 g/cm ³	GB/T1884
Kinematic Viscosity (40°C)	28.0–32.0 mm ² /s	GB/T11137
Acid Value	≤2.0 mgKOH/g	GB/T264
Moisture	≤0.03 %	GB/T260
Open Flash Point	≥130°C	GB/T3536
Water-Soluble Acidity/Alkalinity	Neutral or slightly alkaline	GB/T259
Mechanical Impurities	≤0.02%	GB/T511
Lubrication Performance (Pd)	315kg	GB/T3142
Test Sheets	GI, GA, SPCC, etc.	—

2.2 Theoretical Oil Coating Amount Calculation Model

To determine the minimum oil coating amount for galvanized steel sheets with different roughness, this study estab-

lished a theoretical calculation model based on the microscopic morphology of the steel surface, proposing the following three assumptions:

Assumption 1: The theoretical oil coating amount equals the volume of the microscopic pits on the steel surface.

Assumption 2: The microscopic pits on the steel surface are identical hemispheres arranged in a lattice pattern.

Assumption 3: The radius of the microscopic pits on the steel surface is equal to the roughness value Ra.

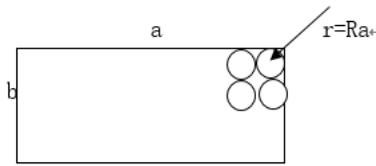


Figure 1. Schematic Diagram of the Relationship Between Surface Roughness and Theoretical Oil Coating Amount

Based on the above assumptions, the theoretical oil coating amount can be derived as follows:

Volume Calculation of a Single Microscopic Pit: Since the pit is hemispherical, according to the volume formula of a sphere, the volume V of a single pit is:

$$V = \frac{1}{2} \times \frac{4}{3} \pi R a^3 = \frac{2}{3} \pi R a^3 \quad (1)$$

In Equation (1), R is the surface roughness of the steel sheet, in meters.

Calculation of the Number of Pits on the Steel Surface: Assuming the steel sheet area is $a \times b$ (where a and b are the length and width of the steel sheet, in meters), and since the pits are arranged in a lattice pattern with the center-to-center distance between adjacent pits being $2Ra$, the number of pits N is:

$$N = \frac{a}{2Ra} \times \frac{b}{2Ra} = \frac{ab}{4Ra^2} \quad (2)$$

Calculation of the Total Volume of Pits on the Steel Surface: The total volume of the pits is the product of the volume of a single pit and the number of pits:

$$V_{\text{total}} = V \times N = \frac{2}{3} \pi R a^3 \times \frac{ab}{4Ra^2} = \frac{\pi R aab}{6} \quad (3)$$

Calculation of Theoretical Oil Coating Amount: The theoretical oil coating amount M (in mg/m^2) is the ratio of the oil mass to the steel sheet area. The oil mass equals the product of the oil density (in g/cm^3) and the total pit volume V_{total} . After unit conversion, it can be expressed as:

$$M = \frac{\rho_{\text{oil}} \times V_{\text{total}} \times 10^6}{ab} \quad (4)$$

Substituting into the above equation and simplifying:

$$M = 0.475 \times \rho_{\text{oil}} \times Ra \times 10^6$$

The density of RD550HN lubricating anti-rust oil was selected (taking the average value between 0.84 and 0.90), and it was substituted into the different roughness Ra values to calculate the corresponding theoretical minimum oil coating amount. Based on the calculation results and considering the uniformity requirements of surface roughness in actual production, 1.5 times the theoretical minimum oil coating amount and $800 \text{ mg}/\text{m}^2$ were set as comparative oil coating amounts. Specific parameters are shown in Table 2.

Table 2. Theoretical and Experimental Oil Coating Amounts Corresponding to Different Roughness Values

Roughness Ra (μm)	Theoretical Minimum Oil Coating (mg/m^2)	Theoretical Minimum Oil Coating $\times 1.5$ (mg/m^2)	Experimental Oil Coating of 800 mg/m^2 (mg/m^2)
0.8	323	485	800
0.9	363	545	800
1.0	404	606	800
1.1	444	666	800
1.4	565	848	800

3. Experimental Study on Rust Resistance under Different Oil Coating Amounts

3.1 Damp-Heat Test

3.1.1 Test Plan

Galvanized steel sheets with a surface roughness of $R_a=1.0\mu\text{m}$ were used, treated with three oil coating amounts: 404 mg/m^2 , 606 mg/m^2 , and 800 mg/m^2 . According to the GB/T2361 standard, a damp-heat test was conducted at $49 \pm 1^\circ\text{C}$ with a relative humidity above 95%. The proportion of rusted area was observed and recorded at 10, 20, and 30 days. Three parallel samples were set for each group, and the average value was taken.

Ra=1.0	Theoretical minimum oil application amount 404 mg/m^2	Oil application rate 606 mg/m^2	Oil application rate 800 mg/m^2
10 day	 edge rust/edge rust/edge rust	 0/0/0	 0/0/0
20 day	 10/5/0	 0/5/0	 0/0/0
30 day	 10/5/10	 0/10/20	 0/0/0

Figure 2. Test of Damp-Heat Performance Under Different Roughness and Oil Coating Conditions

3.1.2 Test Results and Analysis

As shown in Table 3, at the early stage of the test, samples with an oil coating of 404 mg/m^2 exhibited rust at the edges, and the proportion of rusted area increased day by day. In contrast, samples with oil coatings of 606 mg/m^2 and 800 mg/m^2 remained rust-free throughout the test.

Table 3. Rusted Area Proportion (%) in Damp-Heat Test for GI Galvanized Steel Sheets with $R_a=1.0\mu\text{m}$ under Different Oil Coating Amounts

Test Time (days)	Theoretical Minimum Oil Coating 404 mg/m^2	$1.5 \times$ Theoretical Minimum Oil Coating 606 (606 mg/m^2)	Oil Coating 800 mg/m^2
10	Edge rust / Edge rust / Edge rust	0/0/0	0/0/0
20	10/5/0	0/5/0	0/0/0
30	10/5/10	0/10/20	0/0/0

Analysis shows that the theoretical minimum oil coating amount can only achieve the ideal state of covering the microscopic pits on the steel surface. However, the actual surface roughness of the steel sheet is unevenly distributed. In some

areas, the pit depth exceeds the Ra value, resulting in incomplete coverage by the oil film and leading to rust formation. As the oil coating amount increases, the oil film thickness also increases, providing more comprehensive coverage of the steel surface and enhancing its rust resistance. When the oil coating reaches 800 mg/m², the oil film can fully fill the surface pits and form a uniform protective layer, effectively isolating moisture and oxygen in a damp-heat environment. Therefore, no rust appeared on the steel sheet during the 30-day test period [2].

3.2 Stacking Test

3.2.1 Test Plan

Four types of galvanized steel sheets with surface roughness of 0.9 μm, 1.0 μm, 1.1 μm, and 1.4 μm were selected. For each roughness, the sheets were treated with three oil coating amounts: the theoretical minimum, 1.5 times the theoretical minimum, and 800 mg/m². The treated sheets were cut to the same dimensions and stacked in groups of four. Stainless steel bolts were used to fasten the stacks with a tightening torque of 75 kgf/cm², and stainless steel plates were placed between the sheets in the middle of the stack for separation.

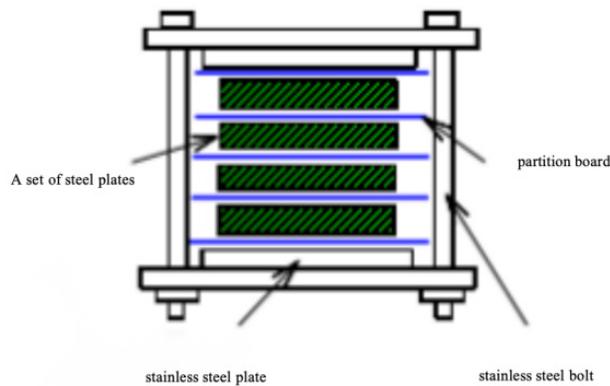


Figure 3. Schematic Diagram of Sample Stacking

The assembled samples were placed in a constant temperature and humidity chamber at 49 ± 1 °C with a relative humidity above 95%. After a 40-day test, the oil stain and rusted area proportions on the contact surfaces were observed. Three parallel samples were set for each group.

3.2.2 Test Results and Analysis

Table 4 presents the specific results of the stacking test. For samples with a surface roughness of $Ra=0.9\mu\text{m}$, the rust rate for the minimum oil coating treatment reached 6.67%, while samples treated with 1.5 times the minimum oil coating and 800 mg/m² showed no rust. For $Ra=1.0\mu\text{m}$ samples, the rust rate was 5% for both treatments, except that the 800 mg/m² treated samples did not exhibit any rust. Samples with $Ra=1.1\mu\text{m}$ and $1.4\mu\text{m}$ showed similar trends: the minimum oil coating treatment resulted in a rust rate of approximately 5%, whereas samples treated with 1.5 times the minimum and 800 mg/m² oil coatings showed no rust.

Table 4. Proportion of Rusted Area (%) After 40 Days of Stacking Test for Galvanized Steel Sheets with Different Roughness and Oil Coating Amounts

Roughness Ra (μm)	Theoretical Minimum Oil Coating	1.5 × Theoretical Minimum Oil Coating	800 mg/m ² Oil Coating
0.9	10/10/0	0/0/0	0/0/0
1.0	5/5/5	0/0/0	0/0/0
1.1	5/5/5	0/0/0	0/0/0
1.4	5/5/0	0/0/0	0/0/0

3.3 Packaging Test and Field Test

3.3.1 Packaging Test Plan and Results

GI galvanized steel sheets were selected and treated with three different oil coating amounts: 300 mg/m², 500 mg/m², and 800 mg/m². The oiled test sheets were stacked and then wrapped with anti-rust paper. The packaged samples were stored

in an indoor environment where the temperature ranged from -10 °C to 35 °C and the relative humidity ranged from 20% to 70%. The samples were unwrapped and inspected for rust after 4, 8, and 12 months. The test results showed that none of the samples treated with the three oil coating amounts exhibited any rust during the 12-month observation period, with the proportion of rusted area recorded as 0/0/0.

3.3.2 Field Test Plan and Results

According to the actual production, packaging, and storage processes of automotive manufacturing enterprises, GI galvanized steel sheets treated with oil coating amounts of 300 mg/m², 500 mg/m², and 800 mg/m² were packaged and placed in the Zhanjiang Iron and Steel storage area. The environmental temperature of the storage area ranged from 14 °C to 37 °C, and the relative humidity ranged from 30% to 90%. The samples were inspected for rust after 4, 8, and 12 months. The inspection results showed that all samples treated with the three oil coating amounts exhibited no rust during the 12-month storage period and remained in good condition.

3.3.3 Result Analysis

In both the sealed package test and the field test, no rust was observed on samples with different oil coating amounts. The primary reason is that the anti-rust packaging materials effectively isolated the samples from external moisture, oxygen, and impurities, thereby reducing the risk of corrosion. However, combined with the results of the damp-heat test and the stacking test, it can be concluded that in the absence of packaging or when the packaging is damaged, insufficient oil coating will still lead to corrosion. When protected by packaging, a coating amount of 800 mg/m² can further enhance storage safety. Even if minor packaging damage occurs, the sufficient oil film can delay the onset of corrosion, providing dual protection for actual production, storage, and transportation processes [3].

3.4 Summary of Anti-Rust Performance Tests

Based on the results of the damp-heat test, stacking test, sealed packaging test, and field test, the following conclusions can be drawn:

(1) Theoretically, the minimum oil coating amount can only meet anti-rust requirements under ideal conditions. In practical applications, due to uneven surface roughness of the steel sheets, incomplete oil film coverage may occur, resulting in a higher risk of corrosion.

(2) Applying 1.5 times the theoretical minimum oil coating amount can improve the oil film coverage and achieve a generally acceptable level of anti-rust performance. However, under prolonged exposure to hot and humid environments or stacking pressure, some samples may still exhibit slight corrosion.

(3) Samples treated with an oil coating amount of 800 mg/m² demonstrated optimal anti-rust performance across different surface roughness levels and test environments, fully meeting the anti-rust requirements of automotive galvanized sheets during storage, transportation, and pre-processing stages.

(4) Anti-rust packaging plays an important supporting role in enhancing corrosion resistance. Proper packaging can mitigate the risks associated with insufficient oil coating, while the combination of optimal coating amount and effective packaging can achieve the best overall anti-rust performance.

4. Study on Lubrication Performance under Different Oil Coating Amounts

4.1 Test Scheme

GI galvanized sheets with different oil coating amounts were selected to conduct simulated stamping and deep drawing tests. During testing, the drawing depth was set to 76 mm, and the clamping force was 50 kN. A force sensor was used to record the pressure variations during the stamping process. Based on the recorded data, torque (force–displacement) curves were plotted, and the peak value of the curve was used to evaluate the lubrication performance of the galvanized sheet — a lower forming force indicates better lubrication performance. Each oil coating condition was tested three times, and the average forming force was calculated to ensure the reliability and accuracy of the results.

4.2 Test Results and Analysis

As shown in Table 5, the relationship between oil coating amount and maximum stamping force is as follows: when the oil coating amount is 300 mg/m², the maximum stamping force reaches 10.91 kN; in the 500–800 mg/m² range, it decreases to 10.14–10.48 kN; in the 1000–1200 mg/m² range, it remains stable at 10.05–10.11 kN; and when the coating increases to 1600–1800 mg/m², it further decreases to 9.66–9.88 kN. Overall, the variation amplitude of the forming force is relatively small.

Table 5. Maximum Forming Force (kN) in Simulated Stamping of GI Galvanized Sheets with Different Oil Coating Amounts

Oil Coating Amount (mg/m ²)	300	500	800	1000	1200	1600	1800
Maximum Force 1	10.92	10.51	10.13	10.08	10.09	9.88	9.68
Maximum Force 2	10.88	10.41	10.18	10.13	10.01	9.91	9.72
Maximum Force 3	10.93	10.52	10.11	10.12	10.05	9.85	9.58
Average	10.91	10.48	10.14	10.11	10.05	9.88	9.66

Observing Figure 5, it can be seen that the curve near an oil coating amount of 800 mg/m² is the most stable. When the oil coating is too low, friction increases, causing the forming force to rise; when the oil coating is too high, the force decreases slowly. Therefore, considering both the lubrication requirements of GI galvanized sheets in automotive stamping and cost factors, 800 mg/m² is identified as the optimal oil coating amount.



Figure 4. Erichsen Universal Sheet Metal Tester

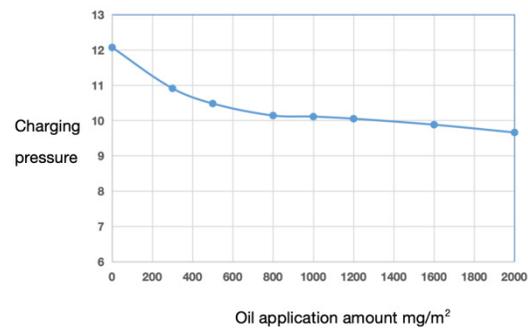


Figure 5. Variation of Lubrication Characteristics under Different Oil Coating Amounts

5. Study on Degreasing Performance under Different Oil Coating Amounts

5.1 Test Scheme

GI galvanized sheets were selected and treated with different oil coating amounts of 300, 500, 800, and 1000 mg/m². After stacking the sheets for 7–10 days at 49 ± 1 °C and relative humidity RH > 95%, degreasing was carried out using a 55 °C immersion oscillating wash, with an oscillation speed of 1 cycle per second. The time required for the sheet to become fully wetted was used as the evaluation criterion. Each condition was tested in three parallel trials, and the average value was calculated. A sheet achieving ≥95% wetted area within 180 seconds was considered acceptable, verifying the feasibility of the process.

5.2 Test Results and Analysis

Table 6 shows the degreasing times corresponding to different oil coating amounts. For all tested oil coating conditions, the wetted area reached ≥95% within 180 seconds, meeting the standards of the automotive manufacturer. An oil coating amount of 800 mg/m² provided the best balance between degreasing effectiveness and efficiency.

Table 6. Degreasing Time (s) of GI Galvanized Sheets with Different Oil Coating Amounts

Oil Coating Amount (mg/m ²)	300	500	800	1000	1200	1600	2000
Degreasing Time 1	60	90	90	120	120	150	150
Degreasing Time 2	65	95	85	115	120	140	160
Degreasing Time 3	55	90	80	120	130	155	165
Average	60	91.7	85	118.3	123.3	148.3	158.3

The study shows that the oil coating amount is positively correlated with degreasing time. When the oil coating increases from 300 mg/m² to 800 mg/m², the degreasing time rises gradually, whereas increasing from 1000 mg/m² to 2000 mg/m² leads to a substantial increase in degreasing time. Comprehensive analysis indicates that an oil coating amount of 800 mg/m²

m² is the optimal choice, as it satisfies degreasing time requirements, ensures operational efficiency, and provides strong protection for rust resistance.

6. Conclusion

This study explored the relationship between oil coating amount and the anti-rust, lubrication, and degreasing performance of galvanized sheets using a theoretical model combined with experimental analysis. The results indicate that an oil coating amount of 800 mg/m² provides the best overall performance. This coating amount is suitable for various types of galvanized sheets. The findings provide data support for the standardization of the oiling process, help reduce quality issues and production costs of galvanized sheets, and offer a foundation for future research on environmental factors and new types of anti-rust oils.

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