Investigation of Zinc Coating Thickness and Mass on Galvanized Steel: Bridging Classical and Modern Non-Invasive Techniques

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Abstract: ***Galvanized steel, protected by a layer of zinc, is widely used across industries for its superior corrosion resistance and structural durability. Accurate assessment of the zinc coating mass is essential for ensuring product performance, longevity, and compliance with international standards. This study investigates the quality and coating characteristics of imported galvanized steel sheets using both destructive (chemical stripping) and non-destructive techniques. Samples were evaluated according to IS 6745 and ASTM B499 standards. The research highlights the benefits and limitations of each method while emphasizing the growing need for non-invasive, environmentally sustainable alternatives. Results demonstrate that non-destructive methods, when properly calibrated, can reliably complement traditional techniques, supporting quality assurance practices across the galvanized steel industry.***

Keywords: Zinc Coating, Mass of Coating, Galvanized Steel, Coating Thickness Measurement, Gravimetric Method, Non-Destructive Testing (NDT), etc.,

1. Introduction

Steel is the most commonly used metal material in outdoor buildings and is used for a wide range of equipment and metal structures because it is cheap and reliable in mechanical properties. In order to avoid corrosion, steel pipes are coated with protective layers of zinc or zinc alloy using hot-dip coating [1]. It's vulnerability to corrosion has long been mitigated by zinc coating, with galvanization offering a highly effective barrier against environmental degradation. Zinc coatings protect by providing both a physical barrier and cathodic protection to the underlying steel [2]. Among various galvanizing methods such as hot-dip galvanization, electrogalvanic, galvalume, galvannealed, hot-dip galvanizing remains the most prevalent, whereby steel is immersed in molten zinc to create a robust, metallurgically bonded layer. It has been used in industrial fields such as automobile, electrical home applications or construction due to their excellent corrosion performance [3,4]. This process not only enhances corrosion resistance but also imparts sacrificial protection, where zinc preferentially corrodes before the base metal does.

However, the evaluation of imported galvanized steel sheets poses a significant challenge. Conventional testing methods such as chemical stripping, magnetic analysis, and eddy current testing are often invasive, labor-intensive, and environmentally unfriendly. As industries move toward more sustainable and efficient quality control systems, the demand for accurate, non-destructive evaluation (NDE) methods becomes increasingly urgent.

A total of twelve GI sheet samples, designated sample numbers 1 to 12, are presented in this investigation. (Fig 1) illustrates the representation of 12 samples.

Figure 1: Visual representation of 12 individual samples

This study undertakes a comprehensive evaluation of galvanized steel sheet coatings through a combination of standard gravimetric analysis and non-destructive coating thickness measurements, with the aim of improving coating assessment techniques without compromising sample integrity.

2. Methodology

2.1 Sample Preparation

Twelve samples, each measuring 50 mm × 50 mm length and width respectively, were taken from different galvanized sheets and labeled for further analysis and testing.

Sample No.	Surface Pattern Observation
1	Smooth surface, no visible spangle
2	Large, well-defined spangle
3	Large, prominent spangle
4	Medium to large spangle
5	Fine, compact spangle
6	Medium spangle with surface blemishes
7	Dull surface, minimal spangle
8	Dark matte surface, no visible spangle
9	Fine spangle, low reflectivity
10	Very fine, uniform spangle
11	Small, consistent spangle
12	Smooth surface, no visible spangle

Remark: The surface pattern was visually examined and noted for correlation.

2.2 Non-Destructive Method

Non-destructive measurements were carried out using the MiniTest 650 FN coating thickness gauge. The instrument measures the thickness of non-magnetic coatings (e.g., zinc) on ferromagnetic substrates (e.g., steel) based on magnetic induction and eddy current principles. Measurements were taken at five locations on both sides (A and B) of each sample. The Total Coating Thickness (TCT) was calculated by summing the average thickness values of both sides.

The mass of the zinc coating (g/m²) was computed using the ASTM A653 standard correlation, where 1 µm of zinc thickness corresponds to 7.14 g/m², the density of zinc. [5] The following formula was then used to determine the coating mass per unit area:

Mass of coating (g/m²) = Total coating thickness (µm) × Density of zinc (g/cm^3)

2.3 Destructive Method

The classical gravimetric method was employed as per IS 6745. Each sample was cleaned, weighed (M1), and then immersed in a stripping solution made from 100 ml of strong hydrochloric acid with 5 ml of antimony-HCl stock solution (derived from SbO_3 or $SbCl_3$). to remove the zinc coating [7]. Upon cessation of hydrogen evolution, the sample was removed, rinsed, dried, and reweighed (M2). The coating mass per unit area was then calculated using the formula:

Coating Mass (g/m²) = ((M1 - M2) / Area in mm²) × 10^6

3. Results and Discussion

A galvanized steel sheet was cut into samples measuring 50 mm × 50 mm each. Every sample was labelled from 1 to 12, with the two faces identified as Side A and Side B. The thickness of the zinc coating was measured using a MiniTest 650 FN coating thickness gauge. To ensure accuracy, the probe was carefully calibrated with a standard specimen without any foil, the reading returned a zero value, confirming proper zero calibration (Figure 1). Subsequently, calibration with a standard 25 µm foil (tolerance ±1 µm) was performed, yielding an accurate measurement of 25 µm (Figure 2), which verified the instrument is calibrated.

Figure 1: abc

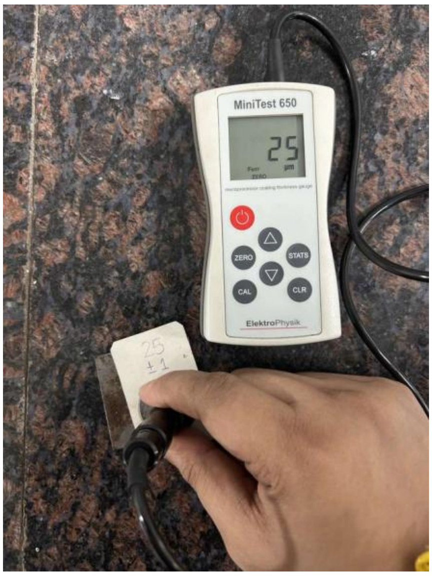

Figure 2: xyz

After calibration, five readings were taken on both Side A and Side B of each sample to ensure accuracy, single spot tests were conducted by taking measurements from both sides of the sample. The mean value of these readings was then recorded as the final coating thickness for each respective side. An example of the results obtained for Sample 3 is illustrated in Figures 3 and 4.

Figure 3

Figure 4

Following the thickness measurements, the mass of coating for Side A and Side B was calculated using the equation provided in Section 2.2. The total coating thickness (µm) was computed by summing the average thicknesses of Side A and Side B. Similarly, the total mass of coating (g/m²) was determined for each sample using the same formula. The compiled data for all 12 samples is presented in Table 2.

Before initiating the chemical dipping procedure, the total coating thickness (µm) of each sample was recorded using a digital micrometer. This measurement represented the overall thickness of the coated sheet in its initial state, the corresponding measurements are illustrated in Figure 5.

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Figure 5

To validate the non-invasive coating thickness measurement method, a classical method was also performed using the same sample specimens. Initially, the mass of each sample before dipping (m1) was recorded, with the values provided in Table 3.

The samples were then immersed in a stripping solution, following the procedure detailed in Section 2.3. After dipping, a visual inspection was carried out to identify any signs of blisters or bulges on the specimen surfaces. During the visual inspection conducted after dipping, it was observed that once the zinc coating was removed, the specimen surface began to show signs of corrosion. Subsequently, the coating thickness was measured again using the MiniTest 650 FN gauge to verify whether any coating remained as shown in Figure 6.

Figure 6

Finally, the mass of each sample after dipping (m2) was measured. Using the initial and final masses along with the equation described in Section 2.3, the coating mass was calculated.

Once the chemical treatment was completed and the coating was removed, the base metal thickness (µm) was measured again using the digital micrometer as shown in Figure 7.

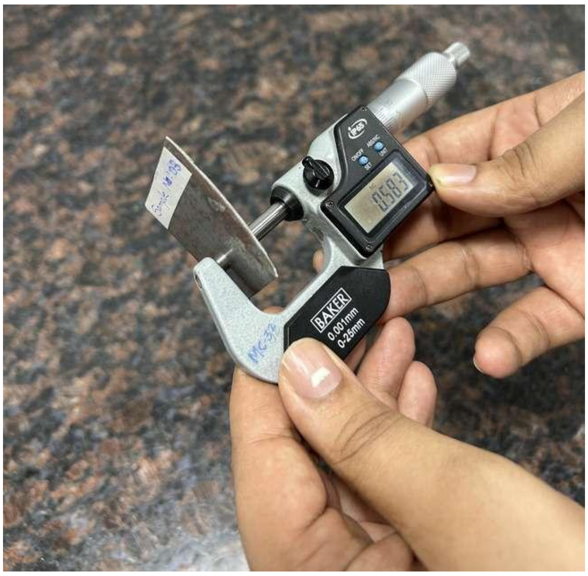

Figure 7

By calculating the difference between the initial total thickness and the final base metal thickness, the actual coating thickness was obtained. This method offered a direct and effective way to quantify the coating layer and the comprehensive results for all samples are summarized in Table 5.

Table 2: Non-Destructive Measurement Results

Sample No.	Side A (µm)	Mass of coating (Side A) (g/m^2)	Side B (µm)	Mass of coating (Side B) (g/m^2)	TCT (µm)	Mass (g/m^2)
1	16.0	114.24	13.8	98.532	29.8	212.772
2	10.8	77.112	20.0	142.8	30.8	219.912
3	18.2	129.948	11.8	84.252	30.0	214.200
4	13.6	97.104	21.8	155.652	35.4	252.756
5	12.4	88.536	17.4	124.236	29.8	212.772
6	13.4	95.676	18.2	129.948	31.6	225.624
7	16.2	115.668	10.8	77.112	27.0	192.780
8	13.2	94.248	13.4	95.676	26.6	189.924
9	10.6	75.684	17.6	125.664	28.2	201.348
10	14.6	104.244	15.6	111.384	30.2	215.628
11	16.2	115.668	15.0	107.1	31.2	222.768
12	13.4	95.676	11.4	81.396	24.8	177.072

Table 3: Destructive (Gravimetric) Method Results

Sample No.	M1 (g)	M2 (g)	Area (mm^2)	Mass (g/m^2)
1	11.9403	11.4016	2548	211.421
2	11.8794	11.3390	2474.5	218.388
3	11.8662	11.3280	2525	213.149
4	12.3238	11.6729	2587.875	251.519
5	11.9164	11.3764	2550.25	211.744
6	13.0015	12.3826	2729.0625	226.781
7	12.0460	11.5543	2562.875	191.855
8	15.7195	15.2187	2623.5	190.890
9	14.0227	13.5522	2340	201.068
10	14.159	13.6333	2450	214.571
11	14.5843	14.0303	2499	221.689
12	15.216	14.7666	2550.25	176.218

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Table 4: Comparison of Non-Destructive and Destructive Results

Sample No.	Non-Destructive (g/m²)	Destructive (g/m²)
1	212.772	211.421
2	219.912	218.388
3	214.200	213.149
4	252.756	251.519
5	212.772	211.744
6	225.624	226.781
7	192.780	191.855
8	189.924	190.890
9	201.348	201.068
10	215.628	214.571
11	222.768	221.689
12	177.072	176.218

Table 5: Thickness Measured on Micrometer Results

Sample No.	Total Coating Thickness (mm)	Base Metal Thickness (mm)	Thickness of coating (µm)
1	0.6064	0.5768	29.6
2	0.6192	0.5887	30.5
3	0.6136	0.5838	29.8
4	0.6224	0.5872	35.2
5	0.6052	0.5756	29.6
6	0.6160	0.5843	31.7
7	0.6044	0.5776	26.8
8	0.7752	0.7485	26.7
9	0.7750	0.7469	28.1
10	0.7710	0.7410	30.0
11	0.7728	0.7418	31.0
12	0.7722	0.7476	24.6

4. Conclusion

In conclusion, the study demonstrates that accurate determination of zinc coating mass—an essential requirement under various international standards for ensuring corrosion resistance and durability of galvanized steel sheets—can be effectively achieved using both traditional and modern approaches. The strong correlation observed between the classical gravimetric method and the non-destructive coating thickness gauge confirms the validity and practical applicability of the latter.

While minor deviations were noted in certain samples, these variations can be reasonably attributed to surface irregularities and underlying chemical influences rather than inherent limitations of the methods. Importantly, the non-destructive technique offers significant advantages, including preservation of sample integrity, reduced environmental impact, and improved efficiency in routine inspection processes.

Furthermore, the study provides a useful perspective for future applications: when the coating thickness is known, it becomes possible to estimate the density of the coating material using classical relationships such as mass divided by volume, and conversely, to estimate coating mass when density and thickness are known. This interrelationship opens avenues for more flexible and integrated evaluation techniques in industrial practice.

Future work may focus on enhancing the precision of non-destructive measurements under varying surface conditions, integrating digital calibration systems, and expanding the methodology to different coating materials and alloy compositions. Such advancements would further strengthen the reliability and versatility of non-invasive inspection techniques in modern manufacturing and quality assurance environments.

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