

Thickness loss projection of bare and hot-dip galvanized steel based on a one-year atmospheric exposure test in the central region of Thailand

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1. INTRODUCTION

Corrosion deteriorates steel structures day by day. It becomes the most challenging issue for steel structures. Zinc coating is applied to protect the steel which is called Hot-Dipped Galvanized steel (HDG). Hot-dip galvanized coating has significantly contributed to improve the corrosion protection of the steel exposed to corrosive atmosphere.

The atmospheric exposure test was conducted by many researchers^{1,2)} in order to understand the corrosive behavior of bare steel and HDG steel. Usually, the atmospheric exposure test was mostly conducted in the short-term period. Even though, sometimes, some researchers already tried to conduct the atmospheric test in the long period like 3, 5, or 10 years. It is still not clear enough about the behavior for more long-term periods like 20, 30, or 50 years. The design life time for structures is mostly given in 50 years or up to 100 years.

Thickness loss of the first year of exposure is the fundamental characteristics of corrosive behavior in a specific atmosphere. Based on the first year, the thickness loss magnitude can be drawn for the further years. Thickness loss can be drawn from a suitable prediction model to predict corrosive behavior in a certain environment³⁾.

Therefore, this research aims to conduct the projection of thickness loss in the long-term period for bare steel and HDG steel in the central region of Thailand. This research will help researchers or designers to estimate the thickness loss of steel without conducting the experiment for a very long time.

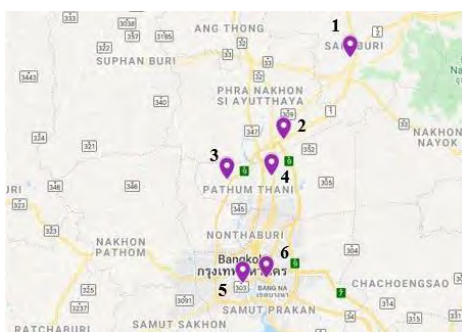


Fig. 1 Test locations



Fig. 2 Exposure rack (Sangcharoen: Pathum Thani)

2. EXPERIMENTAL METHOD

2.1 Specimens and testing procedures

Commercial SS400 and SM490A carbon steel which conformed respectively to JIS G3101⁴⁾ and JIS G3106⁵⁾ were chosen to conduct the atmospheric exposure test. The dimensions of the specimen (100 mm x 150 mm x 4.5 mm) were designed following the ASTM G92-86⁶⁾ standard. HDG steel specimen conformed to the ASTM A123⁷⁾ standard.

The specimen's surfaces of bare steel were cleaned by removing mill scale and rust. Bare and HDG steel specimen's surfaces were made to be smooth, and latterly marked the specimen's code. Subsequently, those measured specimen dimensions were recorded up to four significant figures. Next, the specimens were cleaned with DI water and acetone, dried with a hair dryer, weighed with 1 mg sensitivity digital balance, and recorded for the weight. Lastly, the dry and moisture absorption box was used to store those specimens and send to the sites.

Six locations were selected to conduct the atmospheric exposure test. The exposure started in March 2021. The exposure test followed the ASTM G50⁸⁾ standard with the 30 degree exposure angle toward the sea. The exposure periods are 3, 6, and 12 months.

Central region of Thailand consists of metropolitan areas. Atmospheric parameters and environmental pollutants were recorded and collected from Thai authority department websites.

The specimens were brought back at the determined exposure period. The rust of the exposed specimens was removed with the procedures following the ASTM G50⁸⁾ standard. Thereafter, thickness loss of both types of steel was calculated.

2.2 Thickness loss projection procedures

2.2.1 Bare steel

After getting the thickness loss results from the exposure test, thickness loss versus time of exposure was plotted. In the case of bare steel, a power law function relationship between the results at each period of exposure was observed. Therefore, the atmospheric corrosion equation with the variation in the exposure time of bare steel can be expressed as:

$$D = At^n \quad (1)$$

where D is thickness loss (μm), t is exposure time (year), A and n are constants from the fitting curve.

A logarithmic function was applied to both sides of the equation (1), then the equation became

$$\log D = n \log t + \log A \quad (2)$$

2.2.2 HDG steel

HDG steel corrosion behavior as a mathematical function was proposed by many researchers and the ASTM G16⁹⁾ standard. A linear function relationship was proposed between the magnitudes of thickness loss versus time. Another reason for using linear behavior is that after the exposure test, white powder rust was observed partially on the surfaces of the specimen. Unlike bare steel fully covered with rust, HDG steel was not fully covered with rust on all surfaces where the rust layer could not act as a barrier to slow down the corrosion rate. The thickness loss magnitude of HDG steel was found to be significantly smaller compared to bare steel. It was likely to corrode more in linear with exposure time. As a result, a linear relationship was suggested by many researchers and the ASTM G16⁹⁾ standard. The linear relationship can be expressed as:

$$D = kt \quad (3)$$

where D is thickness loss (μm), t is exposure time (year), k is a constant from the fitting curve.

3. RESULTS

3.1 Atmospheric exposure test results

Tables 1 and 2 are the atmospheric exposure test results for each exposure period for bare steel and HDG steel, respectively. Hot-dip galvanized coating dramatically improves the thickness loss resistance of the base steel, as shown in Table 2.

3.2 Atmospheric conditions at test location

The conditions of the atmosphere at test sites are shown in Table 3. The central region consists of metropolitan and urban areas. High temperature and high cumulative rainfall were observed in Bangkok. The SO_2 pollutant was also found to have a high cumulative value in Bangkok since it came from vehicles, while the station in Saraburi province was found to have a low SO_2 concentration. Relative humidity in the central region of Thailand ranged from 71% to 82%.

3.3 Thickness loss projection results

3.3.1 Bare steel

The constants A and n in equation (1) can be obtained by plotting the log-log of thickness loss versus time. The linear function fitting curve was used to fit the curve of the log-log plot in order to get the line slope, which equals n . The intercept in the fitting equation is $\log A$, from which A can be calculated. Station 4 (SIIT) is shown as an example for finding A and n . Figs. 3 and 4 show the log-log curve and its fitting linear equation for SS400 and SM490A, respectively.

After plotting the log-log curve for all stations for bare steel, the summary results for A and n are shown in Table 4. In order to calculate the thickness loss projection, the constant values A and n were substituted back into equation (1). The thickness loss projections of bare steel SS400 and SM490A for each station are shown in Figs. 5 and 6.

Table 1 Thickness loss of bare steel at each test site

Sta. No.	3 months (μm)		6 months (μm)		12 months (μm)	
	SS 400	SM 490A	SS 400	SM 490A	SS 400	SM 490A
1	6.26	6.79	8.91	8.81	13.46	13.48
2	3.56	3.63	7.40	7.75	11.74	13.98
3	5.64	5.24	10.53	11.64	16.55	18.98
4	5.98	6.80	9.69	9.99	13.78	14.86
5	5.69	5.67	9.76	10.03	13.94	15.52
6	4.51	4.45	8.95	9.49	13.50	14.38

Table 2 Thickness loss of HDG steel at each test site

Sta. No.	3 months (μm)		6 months (μm)		12 months (μm)	
	SS 400	SM 490A	SS 400	SM 490A	SS 400	SM 490A
1	0.12	0.12	0.22	0.22	0.33	0.38
2	0.15	0.12	0.20	0.22	0.40	0.41
3	0.17	0.13	0.27	0.26	0.63	0.69
4	0.20	0.24	0.31	0.33	0.58	0.67
5	0.15	0.13	0.27	0.27	0.53	0.43
6	0.24	0.25	0.31	0.31	0.57	0.58

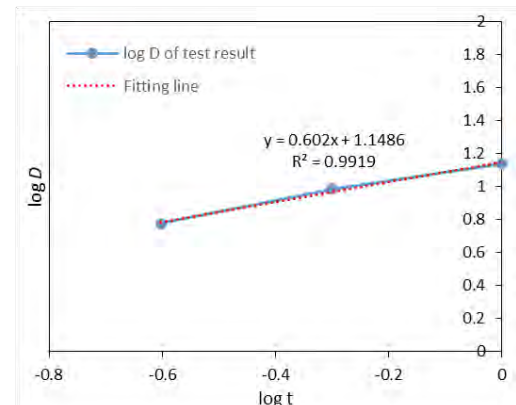


Fig. 3 Log of thickness loss for bare steel SS400 versus log of exposure time (Station 4: SIIT)

Table 3 Atmospheric parameters and environmental pollutants at the test location

Sta. No.	Location	Province	Avg. Temp. (C)	Cumulative Rainfall (mm)	Avg. RH (%)	Cumulative SO_2 ($\mu\text{g}/\text{m}^3$)
1	Saraburi province	Saraburi	28.4	905.21	77	31.44
2	Thai Metal Trade Company Limited	Ayutthaya	29.0	731.6	82	41.92
3	Sangcharoen Galvanizing Limited	Pathum Thani	29.8	1414.5	71	49.78
4	Sirindhorn International Institute of Technology	Pathum Thani	29.8	1414.5	71	49.78
5	Thai Metal Trade Company Limited	Bangkok	30.4	1786.3	76	57.64
6	Iron and Steel Institute of Thailand	Bangkok	30.4	1786.3	76	57.64

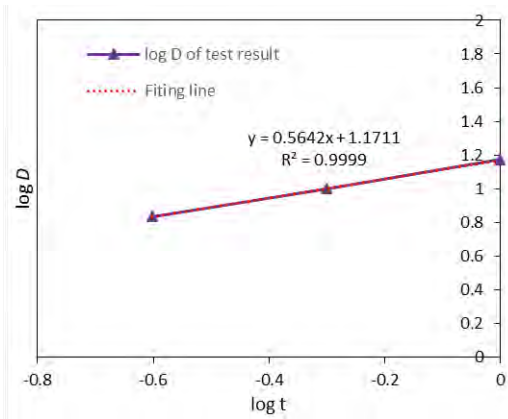


Fig. 4 Log of thickness loss for bare steel SM490A versus log of exposure time (Station 4: SIIT)

Table 4 The value of constants A and n obtained from the fitting curve for bare steel

Sta. No.	SS400		SM490A	
	A	n	A	n
1	13.326	0.5526	13.113	0.4943
2	12.282	0.8612	14.38	0.9727
3	17.028	0.7761	19.976	0.9278
4	14.08	0.602	14.828	0.5642
5	14.367	0.6457	15.863	0.7257
6	14.127	0.7907	15.217	0.8459

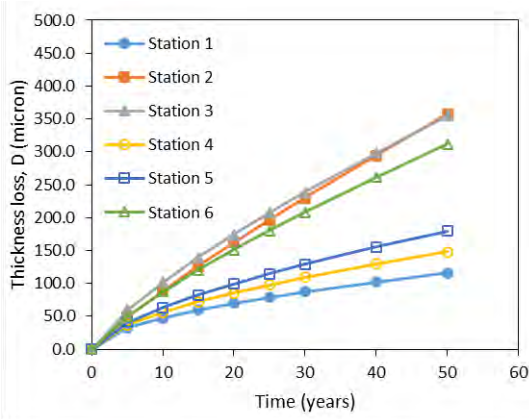


Fig. 5 Thickness loss projection of bare steel SS400 for each station

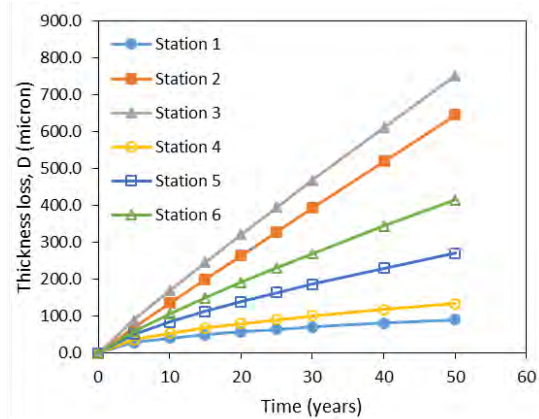


Fig. 6 Thickness loss projection of bare steel SM490A for each station

3.3.2 HDG steel

The constant k in equation (3) can be obtained by plotting the thickness loss of HDG steel versus time. The linear function fitting curve was used to fit the curve. The slope of the fitting curve equation is the constant k . Station 4 (SIIT) is shown as an example for finding the value of k . **Figs. 7 and 8** show the plot of thickness loss of HDG steel versus exposure time and their fitting linear equations for SS400 and SM490A, respectively.

After fitting the curve for all stations for HDG steel, the summary results of the constant k value are shown in **Table 5**. To calculate the projection thickness loss, the constant value k was substituted back into the equation (3). The thickness loss projections of HDG steel SS400 and SM490A for each station are shown in **Figs. 9 and 10**.

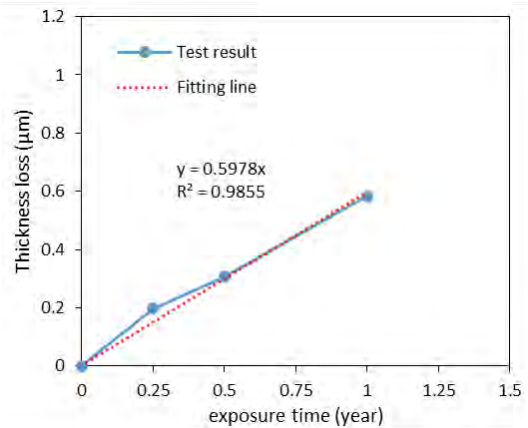


Fig. 7 Thickness loss of HDG steel SS400 versus exposure time with a linear function fitting curve (Station 4: SIIT)

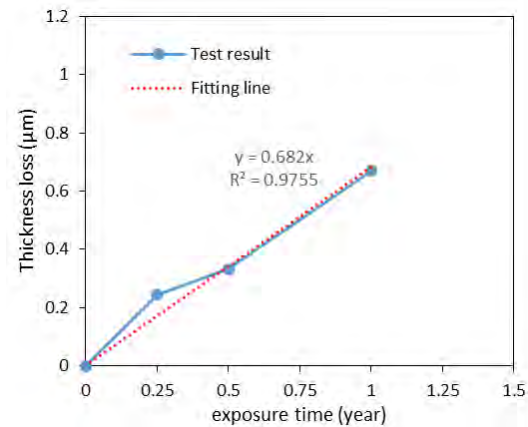


Fig. 8 Thickness loss of HDG steel SM490A versus exposure time with a linear function fitting curve (Station 4: SIIT)

Table 5 The value of constant k obtained from the fitting curve for HDG steel

Sta. No.	SS400	SM490A
	k	k
1	0.3589	0.3924
2	0.4115	0.4188
3	0.6143	0.6455
4	0.5978	0.682
5	0.5355	0.4585
6	0.5988	0.6118

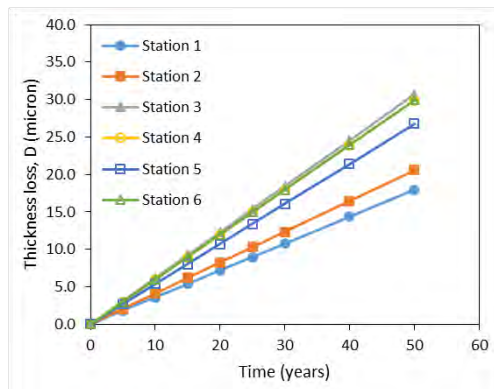


Fig. 9 Thickness loss projection of HDG steel SS400 for each station

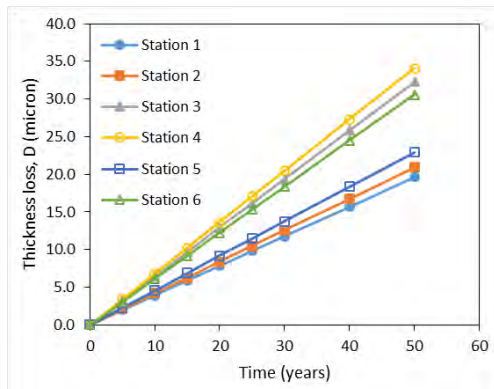


Fig. 10 Thickness loss projection of HDG steel SM490A for each station

4. DISCUSSION

The first year thickness loss is an essential data not only for determining the corrosivity of the atmosphere, but also for long-term thickness loss forecasting¹⁰⁾. The value of the constant n in equation (1) indicated a parabolic growth of the thickness loss of the bare steel during the exposure time. Its value can represent the degree to which the corrosion product layer acts as a barrier, slowing down corrosion speed. The value of the constant n is in a range from 0 to 1. When $n < 0.5$, the corrosion product dramatically decelerated the corrosion rate of bare steel. When $n > 0.5$, the corrosion product slightly decelerated the corrosion rate of bare steel. Based on the results in Table 4, it can be observed that all the values of the constant n are higher than 0.5 for both grades of bare steel except station 1 for SM490A. It means that the corrosion products of bare steel for both grades were slightly affected. When the value n is close to 1, it means that the magnitude of the thickness loss grows linearly with time. Each station has its own value of A and n , which has its own thickness loss projection for each grade of steel, as shown in Figs. 5 and 6.

For HDG steel, the linear growth relationship between thickness loss and exposure time was observed and suggested. The value of the constant k depends on the regression fitting curve. As the results of the thickness loss projection value of HDG steel in Figs. 9 and 10, the thickness losses of HDG steel were found to be significantly smaller compared to the thickness loss projection for bare steel at the same test location, even though the behavior of bare steel is parabolic growth. It

can be explained that hot-dip galvanized coating could be a durable coating for steel to withstand corrosion not only in the short-term exposure but also in the long-term exposure.

5. CONCLUSIONS

In this paper, the long-term thickness loss projection for bare steel and HDG steel based on a one-year exposure test in the central part of Thailand was studied and illustrated. The power law function fitting curve method was used to perform the thickness loss projection of bare steel. Whereas, the linear fitting curve method with the plot of thickness loss and exposure time was used to do the thickness loss projection for HDG steel. The results of the thickness loss projection of HDG steel at each station were found to be significantly smaller compared to bare steel, even though the behavior of HDG steel is a linear growth with time. Those results are essential data or significant information for designers or researchers without conducting a very long exposure test.

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