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Evaluation of Atmospheric Exposure Test on Structural Steel and Hot-dip Galvanized Steel in the East of Thailand

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Abstract

In today's civil engineering industry steel is one of the commonly used materials due to its versatility, high strength, and durability. However, it is highly susceptible to corrosion. Corrosion is the deterioration of steel and its critical properties due to the chemical reactions between the steel and the surrounding environment. Corrosion is unavoidable but it can be minimized by galvanizing and painting. The rate of corrosion depends on the coating and environmental conditions. This research aims to study the corrosion rate of two types of structural steel SS400 and SM490 for bare steel and Hot-dip galvanized steel, which is exposed at three locations at Chachoengsao, Rayong, and Chonburi in the Eastern part of Thailand. To determine the corrosion rate, and atmospheric exposure test is conducted. Following the ASTM G50, a test site is selected at each location and the specimens are exposed to the real environment for three months and six months, and so on. Weathering station at the test site collects and monitors environmental parameters. The exposed specimens are collected, cleaned and the data are gathered. The weight loss of the steel specimen's data is analyzed based on the ASTM standards. This analysis result shows the corrosion rate of both the bare steel and hot-dip galvanized steel, the changing appearance of steel specimen after three months and six months, and the importance of galvanizing. The result can be used for material selection and could contribute to the development of the steel corrosion manual of Thailand

Keywords

Steel corrosion, Atmospheric Corrosion Test, Structural Steel, Hot-dip Galvanized Steel, Corrosion Rate.

1. Introduction

Steel is one of the most used construction materials in the civil engineering industry. It is famous for its various properties such as strength, sustainability, and flexibility. It is also one of the most cost-effective materials and has high durability. However, steel's main shortcoming is, it is prone to corrosion. Corrosion is a natural process in which degradation of metal occurs due to the conversion of the metal to a more stable form. Corrosion of steel with or without corrosion protection is highly influenced by environmental factors. The environment has many factors which affect the rate of corrosion such as temperature, relative humidity, rainfall, presence of impurities, and presence of a suspended particle. The environment in different places differs from each other so the factors we consider for our research are different from others as well. As we know corrosion of steel cannot be avoided so the best thing, we can do to prevent corrosion is by minimizing the rate of corrosion by painting and galvanizing to improve the service life of the steel. Depending on the coating and environmental conditions, the corrosion rate varies as well. The rate of corrosion can be determined by conducting an atmospheric exposure test. The atmospheric exposure test is the test of exposing steel specimens to the environment in the desired location.

The environmental conditions in Thailand differ from those in other nations, therefore the environmental parameters we consider when determining corrosion rates vary as well. There are a variety of environmental variables that influence corrosion that we might investigate. As Thailand has a tropical climate, it’s hot and humid, with heavy rainfall. In tropical climates, the influence of high temperatures combined with high precipitation and humidity are observed, because the moisture over time is very high (Mikhailov et al., 2007). The temperature plays an important role in accelerating the corrosion rate of metals (Prawoto et al,2009). Therefore, the temperature can be considered as one of the environmental parameters. Under humid conditions, metal will corrode at a much greater rate than under dry conditions (Francis, 2002). For corrosion to occur they need moisture so that the reaction could occur if there is no moisture the corrosion ceases. Rainfall and Humidity can be taken as one of the environmental parameters for Thailand as well. The prediction of the rate of corrosion of steel plays a significant role in the steel industry of Thailand because Thailand has a very corrosive environment which tends to reduce the service life rapidly if proper maintenance is not followed. Galvanizing and painting help protect the steel service life and minimize the rate of corrosion. There is no sufficient data on atmospheric corrosion to model or predict steel corrosion to design service life of steel structures in Thailand (Permsuwan et al,2011). Therefore, this paper aims to gather more information on hot-dip galvanized steel, compare between bare steel and hot-dip galvanized steel, how the environmental parameters affect both types of steel. This could also contribute to creating a corrosion map to predict corrosion in Thailand in the future.

2. Methods and Materials

2.1 Specimen Preparation

We focus on two types of structural steel in this study: are SS400 and SM490, which are commonly utilized in Thailand. In addition, for this exposure test, we focus on two types of coating: bare steel (no coating) and hot-dip galvanized steel. The dimensions for the test specimen are 100 x 150 x 4.5 mm which follows the ASTM G92 standard.

Specimen coating	Coating material	Total coating thickness	Standard
Bare Steel (No coating)	-	0	-
Hot-dip Galvanized Steel	Zn	75μm	ASTM A123

Table 1: Details of the two types of the coating system

Steel types	Chemical Composition (% by wt)													
	C	Mn	Si	P	S	Al	Ni	Cr	Mo	V	Cu	B	Cr+Mo	Cu+Ni +Cr+Mo
SS400	0.117	0.430	0.014	0.012	0.009	0.050	0.011	0.020	0.003	0.000	0.017	0.000	0.023	0.051
SM490	0.199	1.220	0.010	0.014	0.010	0.042	0.013	0.030	0.007	0.002	0.008	0.000	0.41	0.26

Table 2: Chemical composition of bare steel

Following the specification given in the ASTM G1 and ASTM G31, the test specimen needs to be prepared. We mark the specimens with a unique appropriate specimen code with an electric engraving which allows us to identify the specimens. After we finish marking, we measure the dimensions of the specimen using the digital caliper. After measuring, we follow up with the cleaning process in deionized water and acetone. We measure the weight after the specimens have been dried by an air dryer and then store it in the desiccator.

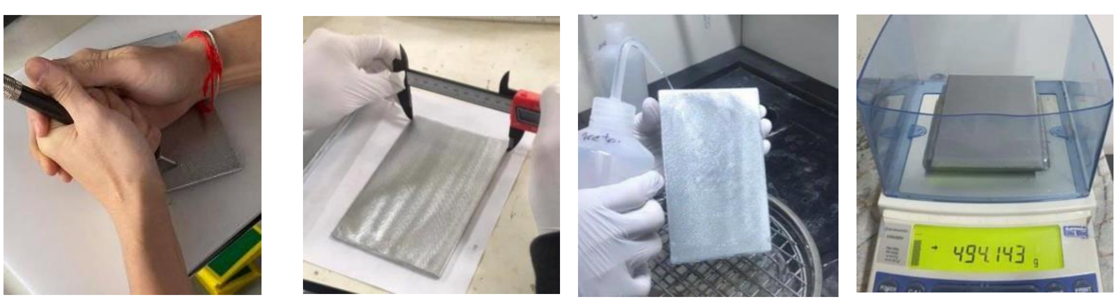


Figure 1 from left to right: Marking, measuring dimension, cleaning, and weighing

2.2 Exposure Test

Depending on the location and the environmental condition, the atmospheric corrosion rate varies significantly. The exposure sites are in three provinces: Chachoengsao, Rayong, and Chonburi in the eastern part of Thailand as shown in Fig.3. The atmospheric exposure test racks need to be installed so that we can place the prepared specimen and expose it to the real environment. The test racks are prefabricated structures made from hot-dip galvanized steel. Following the ASTM G50 standard, the test racks are installed at an angle of 30 degrees from the horizontal, facing to the south or ocean. The period of exposure for the steel specimens is 3 months, 6 months, and so on. Since environmental conditions affect corrosion, we collect the environmental data through weathering station. Based on IS0 9225, the weathering station is installed at a height higher than 1 meter so that the capture device can collect the environmental parameters such as relative humidity, temperature, and rainfall. The data are collected daily.

Station ID	Location	Province	No. of Racks and W. S
13	Union Galvanizer Company	Chachoengsao	2 racks, 1 w. s
14	Sangchareon Eastern Galvanize Co., Ltd	Chonburi	2 racks, 1 w. s
1	COTCO Metal Works Limited	Chonburi	1 rack, 0 w. s

Notes: W. S = Weathering Station

Table 3: Details of the Exposure Sites.

Union Galvanizer Company   Sangchareon Eastern Galvanize   COTCO Metal Works Limited

Figure 2: Specimens at Eastern part of Thailand

2.3 Calculation of Thickness Loss

After three months and six months of exposure to the real world, the specimens were analyzed. For each type of exposure, we gather two bare steel specimens and three hot-dip galvanized steel specimens. The thickness loss due to corrosion increases with time. To determine the thickness loss, we measure the weight of the exposed specimens before and after removing the corrosion products. We use ASTM G1 C 3.5 to remove corrosion products from bare steel, and ASTM G1 C 9.3 to remove corrosion products from hot-dip galvanized steel. The specimens are cleaned with deionized water and acetone after following the procedure for removing the corrosion product. Then we dry it and weigh it. This process is repeated several times to completely remove the rust. The data collected after cleaning the specimens are used to calculate the thickness loss.

Dip the specimen in the solution ($HCl+ H_2O$) for 10 minutes   Cleaning with Acetone   Dry it with dryer   Weighing

Fig 3: Process of removal of rust from bare steel

Following the ASTM G1 standards, we plot the graph and use the following equation used to calculate the thickness loss.

$$C = \frac{W}{\rho * A} * 10^4 \text{ (micron)} \qquad \text{Equation (1)}$$

Where C = Thickness loss (micron)
A = Exposed Area (cm^2)
W= Mass loss (g)
ρ = Density of bare steel = 7.86 g/cm^3 or ρ = Density of HDG steel = 7.13 g/cm^3

3. Results and Discussions

3. 1 Appearance of Steel Specimen

The table is given below shows the changing appearance of the bare steel specimens for the two types at the three stations.

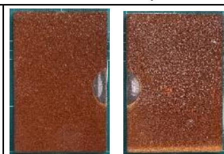
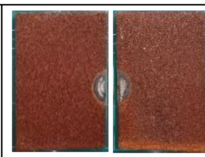
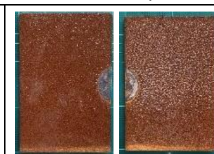
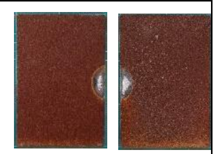
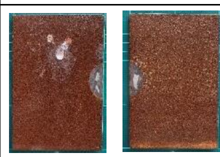
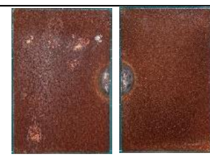
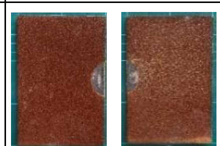
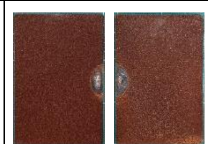
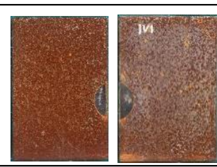
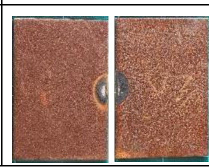
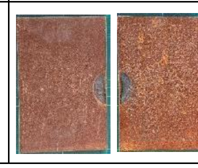
Station Name	Unexposed	Exposed for 3 months	Exposed for 6 months	Unexposed	Exposed for 3 months	Exposed for 6 months
	SS400 Specimen			*SM490 Specimen*		
Union Galvanizer Company						
Sangchareon Eastern Galvanize Co., Ltd						
COTCO Metal Works Limited						

Table 4: the changing appearance of the bare steel specimens (front and back)

The table is given below shows the changing appearance of the hot-dip galvanized specimens for the two types at the three stations.

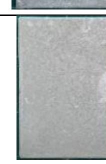
Station Name	Unexposed	Exposed for 3 months		Exposed for 6 months	
Types of Steel		SS400	SM490	SS400	SM490
Union Galvanizer Company					
Sangchareon Eastern Galvanize Co., Ltd					
COTCO Metal Works Limited					

Table 5: the changing appearance of the HDG specimens (front view)

In table 3, Both SS400 and SM490 bare steel specimens have corroded. From the images, we can see that Station 1 (COTCO Metal Works Limited) has lesser corrosion compared to the other two stations. The specimens that were collected after three months have a uniform red-orange rust color while the ones collected after six months have a more uniform brownish-orange rust color. From table 4, Both SS400 and SM490 hot-dip galvanized steel did not have any corrosion product. Though the color from the unexposed changed to gray, there was no corrosion taking place on the hot-dip galvanized specimen. The specimen collected after 6 months has a little bit of white rust on the specimens. From the comparison of the two tables, Hot-dip galvanized steel can withstand corrosion and uncoated steel is easily corroded within a few months. This shows how important galvanizing steel can be.

3.2 Thickness Loss

The corrosion rate is calculated in terms of thickness loss generally and the equation used to calculate the thickness loss is shown in equation (1)

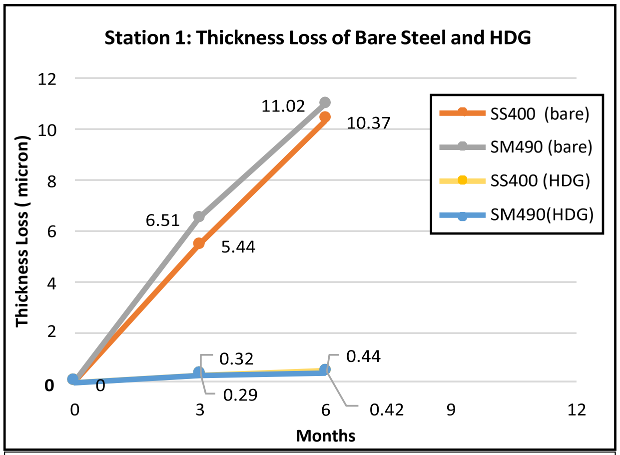


Fig 4: Thickness loss of specimen versus exposure time (Station 1)

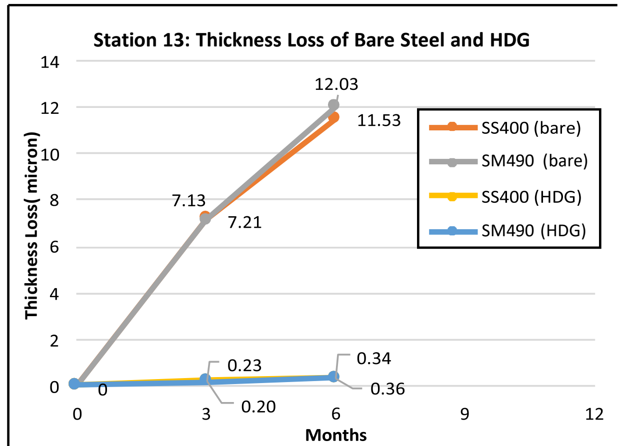


Fig 5: Thickness loss of specimen versus exposure time (Station 13)

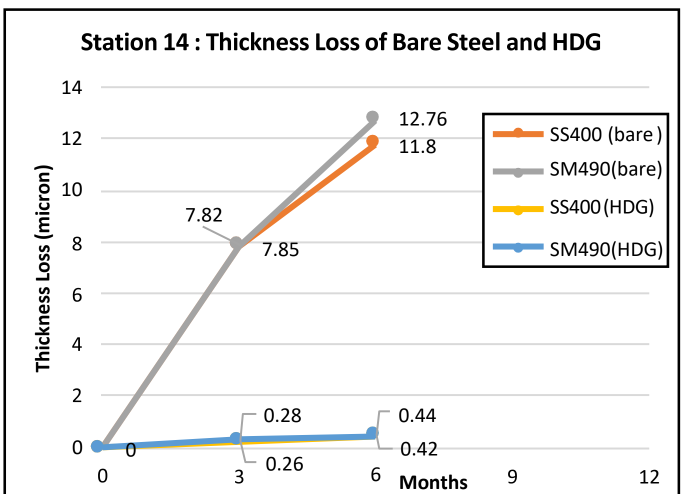


Fig 6: Thickness loss of specimen versus exposure time (Station 14)

From Figures 4,5 and 6, we can see the thickness loss of the bare steel and hot-dip galvanized steel at the three stations over 3 months and 6 months. While comparing the two types of bare steel SS400 and SM490, we discover that SM490 has a little higher thickness loss compared to SS400. This is due to the chemical composition of steel as shown in table 2, the percentage of carbon (C) for SM490 is higher but the percentage of Copper (Cu) is lower than SS400. Higher carbon also reduces air corrosion resistance, which causes rusting. (Dalton et al., 2020). Copper, on the other hand, boosts the steel's corrosion resistance and protects it from corrosion. Station 1 has the lowest thickness loss for bare steel, ranging from 10 microns to 11 microns when compared to the other stations. Even though stations 1 and 14 are in close proximity in terms of location, station 14 has a somewhat higher thickness loss due to the difference in specimen exposure duration. Stations 14 and 1 were exposed in March and June, respectively. As a result of the diverse environmental conditions that the specimens were exposed to, the thickness loss is also different. The thickness loss of bare steel is lower for station 13 compared to 14 because of the distance of the station to the sea. Thus, we can see that the corrosion rate is affected by location and environmental conditions. When we compare the corrosion rate of bare steel from 3 months to 6 months, the rate of corrosion of 6 months is less compared to 3 months. The formation of protective rust layers reduces the rate of corrosion in the long term (Permsuwan et al,2011). Therefore, the rust layer formed acts as a barrier layer and prevents the transport of moisture, oxygen, and other impurities.

When compared to bare steel, the thickness loss of hot-dip galvanized steel is very low. Just like bare steel, Station 13 has a lower thickness loss of HDG compared to stations 1 and 14. It is consistent with the behavior that the rate of corrosion is affected by location and environmental conditions. The thickness loss between the two types of grades is minimal since the exposed layer is zinc, so the bare steel is protected. This proves how effectively galvanized steel can prevent corrosion of steel. The rate of corrosion of hot dip galvanized is very less compared to the rate of corrosion of bare steel.

3.3 Environmental Data

From the weathering stations, we collected the environmental parameters such as temperature, rainfall, and relative humidity. Figures 7,8 and 9 are the data collected from the weathering station. Station 13 and Station 14 were exposed in March 2021, while station 1 was exposed only in June 2021, due to the different exposure of timing the best comparative result can be found between stations 13 and 14. The average temperature from March to September in station 13 (Chachoengsao) was not consistent, as indicated in figure 7, the relative humidity was around 76 percent, and the rainfall was 174 mm. The temperature was constant at station 14, which is in Chonburi, and the humidity was more than 85%, however, the rainfall was around 137 mm. Climatic conditions interact to cause corrosion, an environment with a consistently high temperature, high relative humidity, and little rainfall becomes a more suitable corrosive environment. Therefore, Station 14 has a little higher thickness loss.

Station 1 thickness loss was lesser compared to the other two stations because the temperature was low compared to other stations, the relative humidity was not consistent, and rainfall was not so heavy as well. Corrosion is affected directly by temperature and humidity, therefore station 1 has less thickness loss compared to the other two stations.

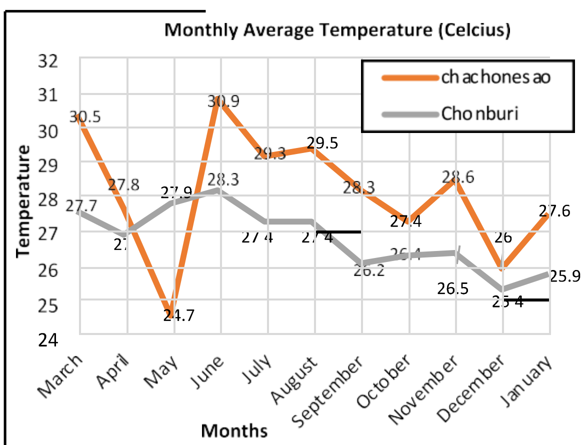


Fig 7: Monthly average temperature

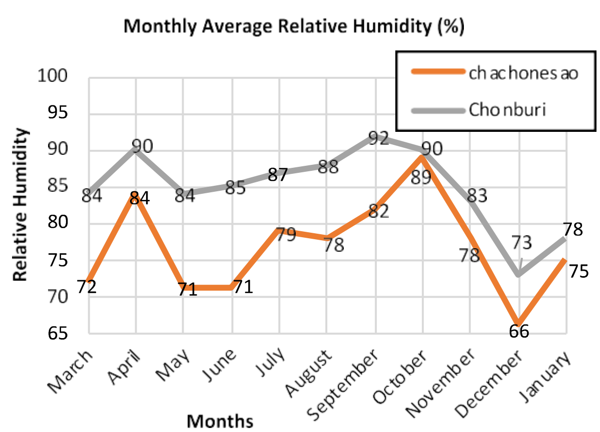


Fig 8: Monthly average relative humidity

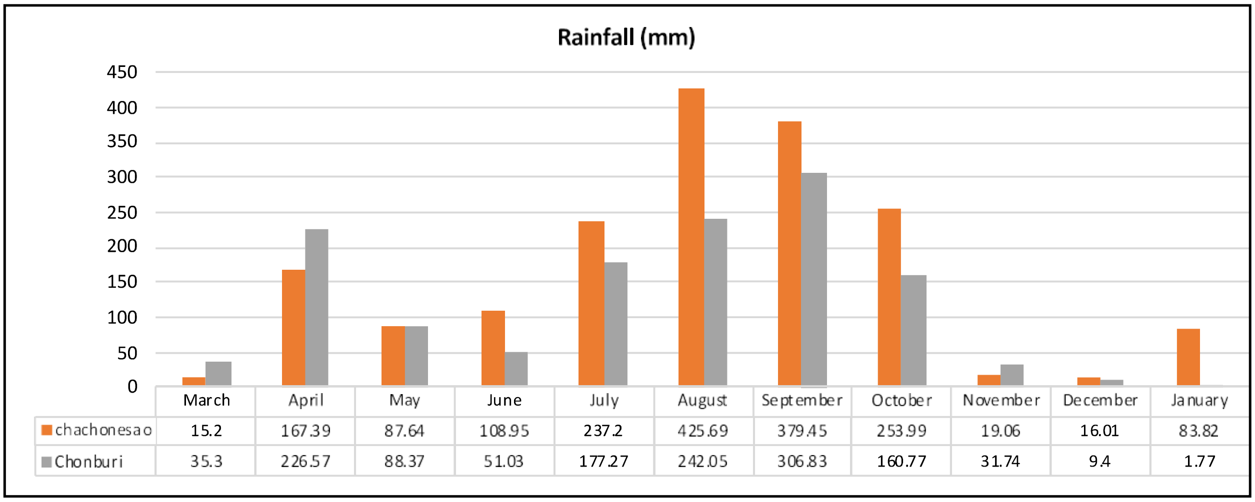


Fig 9: Monthly Rainfall

4. Conclusions

Steel corrosion is heavily influenced by environmental factors as well as the distance from the sea. Galvanizing can be highly effective in extending the service lif matic condition. All the three stations were in the eastern part of Thailand, the small difference in the environmental factors between the locations have caused changes in the corrosion rate as well. After 6 months of exposure in the eastern part of Thailand, thickness loss of bare steel ranges between 10 to 13 microns, and the thickness loss of hot-dip galvanized steel ranges between 0.3 to 0.4 microns which shows that the rate of corrosion can be lowered around 30 times. Therefore, the service life of the steel is now increased around 30 times. For a climatic condition like Thailand, the best option to reduce steel corrosion is by galvanizing. The thickness loss from the HDG specimens let us know that corrosion is unavoidable, and the only way is to reduce the rate of corrosion. Uncoated steel specimens are easily corroded by the atmospheric factors and though the rate of corrosion is reduced by the formation of rust layer, the rate of corrosion reduction is very less compared to the rate of corrosion reduced by galvanizing. The changes of the uncoated steel show how the rust formation color changes within months. The changes in galvanized steel show us how galvanizing can reduce the rate of corrosion and no corrosion product is being formed on the galvanized steel. From this research, we can understand the importance of galvanizing steel and how the environment affected steel corrosion. The limitation of this paper is that we have not considered the chloride and Sulphur dioxide present in the environmental factors as the eastern part of Thailand is close to the marine area and the stations selected are in the industrialized area as well so these two parameters could have affected the rate of corrosion as well.

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