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Atmospheric Corrosion of Structural Steel and Hot Dip Galvanized Structural Steel in Saraburi, Chonburi and Songkhla, Thailand

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Abstract

The investigation of corrosion for structural steel grade SS400 and hot dip galvanized structural steel has been conducted in 3 different provinces in Thailand, Saraburi for the rural agriculture environment, Chonburi for the industrial environment, and Songkhla for the coastal environment. The exposure period of specimens was 3 months, 6 months, and 12 months from March 2020 to March 2021. Environmental conditions such as temperature, relative humidity, and rainfall were monitored monthly averaged. Pollution parameters such as chloride and sulfur dioxide were monitored 6 months averaged. The corrosion rates are calculated by the weight-loss method. The result showed that SS400 structural steel has a significantly large value of corrosion rate than hot dip galvanized structural steel in 3 provinces. The specimens in the coastal environment showed more corrosion rate than in industrial and rural agriculture environments. The life cycle cost of the steel structure constructed with these two materials was compared, and the result can be used for material consideration and service life design of steel structures.

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Keywords: atmospheric corrosion, hot-dip galvanized steel, structural steel.

1. Introduction

Structural steel design mainly considers only member strength. However, to carry the same member design strength throughout the design service life is less likely discussed. The common major problem is atmospheric corrosion which causes thickness loss of steel. Therefore, the structure that had been built for an extended period of years faced questions of structural safety.

Atmospheric corrosion is the degradation of material surfaces by physical and chemicals in a different atmospheric environment. [1] For atmospheric corrosion of carbon steel and hot-dip galvanized steel, their primary corrosion comes from several environmental parameters such as temperature, rainfall, relative humidity, Cl^- and SO_2, as proposed by several researchers.

In Thailand, environmental parameters are unique compared to other countries. Therefore, other countries' atmospheric corrosion data cannot be used to estimate the corrosion of material in Thailand.

This paper aims to investigate the corrosion magnitude of SS400 steel, and hot-dip galvanized steel in different environments in Thailand as they are common structural steel used for steel construction buildings.

4. Experimental Program

4.1. Specimen preparation

In this paper, the materials used for the study are SS400 and hot-dip galvanized steel. SS400 is the steel grade by JIS G3101 standard, which stand for general steel. Hot-dip galvanized steel in this study is SS400 hot-dip galvanized under ASTM A123/A123M standard. The chemical composition of SS400 steel shows in Table 1. The hot-dip galvanized steel coating of special high-grade zinc, chemical composition shows in Table 2, with a coating of approximately 110 μm. SS400 steel specimens were sandblasted, rubbed by sandpapers, rinsed with distilled water followed by acetone, hot-air dried, weighted, and placed inside desiccators. Hot-dip galvanized steel specimens were rubbed by sandpapers, rinsed with distilled water followed by acetone, hot-air dried, weighted, and placed inside desiccators. Both steel specimens are 100 mm x150 mm x4.5mm in size.

Table 1. Chemical composition of SS400 steel

Steel	Chemical Composition % by weight										
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Nb
SS400	0.058	0.191	0.595	0.014	0.009	0.038	0.008	0.036	0.010	0.112	0.001

Table 2. Chemical composition of hot-dip galvanized steel (HDG)

Steel	Chemical Composition % by weight					
	Zn	Pb	Cd	Fe	Cu	Sn
HDG	99.995	<0.003	<0.001	<0.001	<0.001	<0.001

4.2. Exposure Test

Specimens were distributed to exposure sites and placed on the site exposure racks in which facing south or the closest sea direction. Exposure sites are located at Saraburi, Chonburi, and Songkhla. In Saraburi, the exposure rack is placed on a ground elevation, and the surrounding environment is an agriculture area at a coordinate of 14°29'03.6", 100°53'34.4". In Chonburi, the exposure rack is placed on a ground elevation, and the surrounding environment is an industrial estate at a coordinate of 13°04'19.9", 101°05'18.3". In Songkhla, the exposure rack is placed on the 13th floor on top of the building elevation, and the surrounding environment is a sea coastline. The exposure test was conducted from March 2020 to March 2021.

Environmental parameters were collected and presented in Table 3. For Cl^-, they were collected by the dry gauze method and SO_2 by the lead cylinder method. The two methods stated are listed in ISO 9225. Other parameters were collected by the on-site weather station.

Table 3. Environmental parameters collected from each exposure sites

Exposure Site	Annual average temperature	Annual average relative humidity	Annual Cumulative rainfall	Annual Cl- deposition	Annual So2 deposition
	°C	%	mm.	mg/(m^2 day)	mg/(m^2 day)
Saraburi	28.5	76.2	927	1.68	9.30
Chonburi	27.0	83.7	1471	3.18	10.22
Songkhla	28.7	80.0	3288	10.95	8.75

5. Result and discussion

5.1. Thickness loss

Commonly, the corrosion rate of steel by atmospheric corrosion is calculated based on the weigh-loss method and put in the term of thickness loss. The equation to calculate the thickness loss is assuming uniform corrosion and show in Eq 1.

$$Thickness\ loss\ (\mu m)\ = \frac{w}{\rho \cdot A} \times 10^4 \qquad (1)$$

Where w = mass loss (g), ρ = density of steel (7.86 g/cm3) / hot dip galvanize coating (7.14 g/cm3), and A = specimen exposure areas. Fig 1 and Fig 2 show the thickness loss of SS400 and HDG from 3, 6, and 12 months at different exposure sites. Thickness loss of SS400 steel at different exposure sites from 3 months, 6 months, and 12 months is shown as follows: Saraburi: 6.26, 8.91, and 13.46 μm, Chonburi: 7.85, 11.80, and 19.77 μm, Songkhla: 6.75, 12.53, and 23.76 μm. Thickness loss of HDG steel at different exposure sites from 3 months, 6 months, and 12 months is shown as follows: Saraburi: 0.12, 0.22, and 0.33 μm, Chonburi: 0.26, 0.42, and 0.68 μm, Songkhla: 0.36, 0.46, and 1.17 μm. From the thickness loss at 12 months, HDG steel shows better performance than SS400, about 40 times in Saraburi, 29 times in Chonburi, and 20 times in Songkhla.

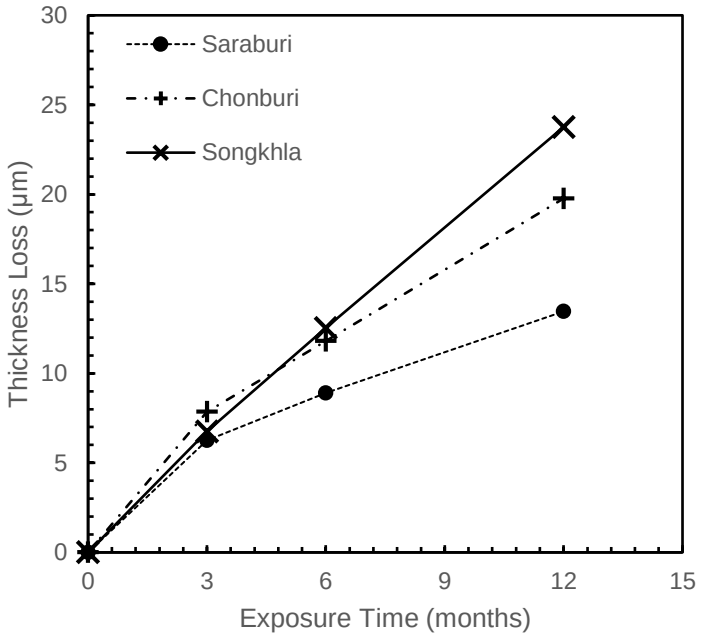

Fig. 1. Thickness loss of SS400 at different exposure sites

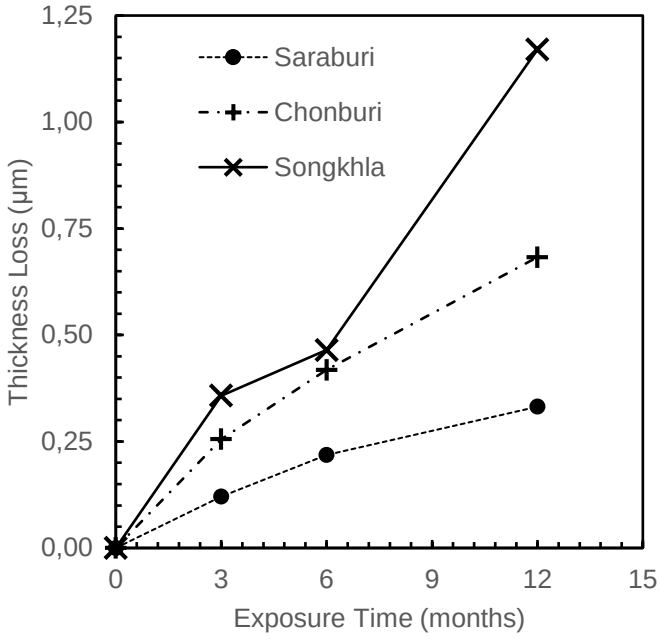

Fig. 2. Thickness loss of SS400 at different exposure sites

5.2. Project thickness loss

Thickness loss prediction equation due to atmospheric corrosion, which several researchers proposed. [2,3,4]

$$Project\ thickness\ loss\ (\mu m)\ = At^{b} \qquad (2)$$

Where A and b are constants obtained in fitting curve analysis, t = extended exposure time (months). The b value is considered a growth rate of corrosion product on steel surface related to environmental corrosion effect of different locations to different steels and usually < 1. When b < 0.5, it is considered that corrosion products had formed some rust protection layers, which become compacted and reduce corrosion rate in longer exposure time. For b > 0.5, It is believed that corrosion products had formed some rust protection layers which become compacted but did not significantly protect steels or did not become compacted at all [5]. The constant value of each steel is presented in Table 4. For SS400 and HDG, the b value at Songkhla is the highest, representing the harsh corrosive environment due to high present of Cl^- and rainfall. Therefore, the corrosion activity is high in Songkhla than in Saraburi and Chonburi.

Table 4. Constants values from fitting curve of SS400 and HDG steel

Steel type	Exposure site	A	b
SS400	Saraburi	3.37	0.55
	Chonburi	3.71	0.66
	Songkhla	2.48	0.90
HDG	Saraburi	0.056	0.73
	Chonburi	0.117	0.71
	Songkhla	0.135	0.85

5.3. Life cycle cost

Life cycle cost is the estimated cost for feasibility analysis of the project. The main parameters are starting cost and service cost that may occur. In this paper, SS400 and HDG steel were analysed as construction

materials. The life cycle cost for a steel structure service life of 20 years, according to data analysed from Eq. 2 and Table 4 is shown in Table 5. This calculation was only performed in Songkhla as the location had the highest corrosion rate in this paper. The calculation is based on a commonly used steel section, WF150x150x7x13x31.5 kg/m, for an outdoor low-rise steel building column of 3.00 meters. The unit cost of materials was observed in Thailand in 2020. The cost was converted from THB to USD using 34 THB to 1 USD. The result shows the total cost over 20 years of HDG is very high compared to SS400 about 74%. This is because the starting cost of HDG is very expensive. However, if the starting cost is neglected, HDG steel shows a lesser cost than SS400 steel about 39% at 20 years of service life due to the very low corrosion rate of the materials.

Table 5. Life cycle cost of SS400 and HDG steel in in Songkhla for 20 years of service life design.

Steel type	Starting cost	Service life cost = w x A x Unit cost				Total cost
		Weight loss	Exposure area	Unit Cost	Service life cost	
		w	A			
	USD	kg / m^2.	m^2.	USD	USD	USD
SS400	**84**	2.85	2.65	0.89	**6.72**	**91**
HDG	**153**	0.96	2.65	1.62	**4.07**	**158**

5.4. Durability of design strength

Durability design is the design of a structural member to maintain structural design strength throughout the expected service life of a structure. After the life cycle cost of the material was analyzed, the durability of strength also must be verified throughout the expected service life of a structure. The durability problems are usually ignored as the construction industry is very competitive. Most of the steel members are very optimized in design strength to achieve the lowest price in a construction project bidding possible. The steel column made of SS400 and HDG steel as analyzed in Table 5 were used to compute a structural design strength in Fig. 3 when considered an effect of thickness loss due to atmospheric corrosion for 20 years of service life design. The standard to determine the column strength is based on Allowable Strength Design (ASD) 1986 code with effective length factor, k =1.20. At 20 years, the results show SS400 steel loses the structural design strength about 15% compared to its original design strength value at the beginning. This is due to a high project thickness loss of 362 μm in which the gross section area of the steel column is reduced during service life period. For HDG steel, it does not lose structural design strength throughout the service life as it has hot-dip galvanized coating as a corrosion protection in which the project thickness loss is only 13.4 μm out of the initial coating thickness of 110 μm. In term of maintaining a structural design strength, HDG steel show a better performance than SS400 steel.

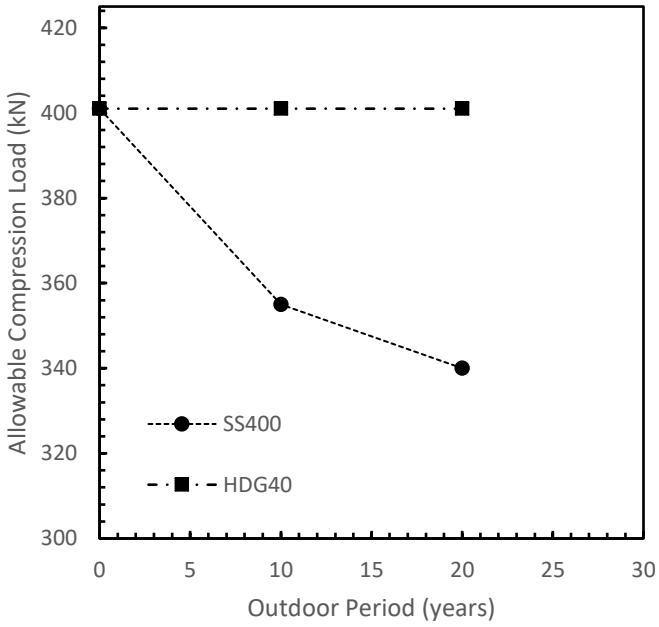

Fig. 3. Allowable compression load of SS400 and HDG steel in Songkhla.

6. Conclusion

Atmospheric corrosion cause steel to lose thickness. Saraburi, HDG Steel, shows better corrosion resistance about 40 times than SS400 Steel for the lowest corrosive environment in this study. Songkhla, HDG steel shows better corrosion resistance about 20 times for the highest corrosive environment in this study. In terms of project life cycle cost of 20 years, SS400 steel shows a cheaper cost than HDG steel. However, when it comes to the durability of design strength, HDG steel shows better in maintaining design strength throughout 20 years, while SS400 steel loses 15% from the initial design strength. Only not the cost must be concerned, but the safety of a structure should be considered as well, whether it is still capable of resisting the design load or not. This led to more considering of choosing materials for construction when atmospheric corrosion factors are considered.

Acknowledgements

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