Atmospheric Corrosion of Stainless Steels in Thailand

Daopiset S.

Department of Production Engineering, Faculty of Engineering, KMUTNB, Bangkok, Thailand

Karnchanaprayut N[1]., Somsiri C[2].

[1]Corrosion technology department, Thai-French Innovation Institute, KMUTNB, Bangkok, Thailand
[2]Thainox Stainless Public Company Limited, Thailand

Abstract

Stainless steels are increasingly used outdoor. An important factor to be concerned is the appearance of stainless steel surfaces. The different appearances are produced by the different finishing processes. The stainless steel grades and surface finishes affect their corrosion resistance.

The atmospheric corrosion resistance of the different stainless steels and surface finishes which were AISI 304 HL (hairline finish), 304 MF (mirror finish), 316 HL, 316 2B, 430 HL and 430 BA (bright annealing finish) were studied. The specimens were prepared and exposed in 4 environments which were urban (Bangkok), rural (Ayuthaya), industrial (Maptaphut industrial estate, Rayong) and seaside (Kungkrabaen Bay Royal Development Study center, Chantaburi). The specimens were retrieved after 1, 3, 9, 15, 21, 27, 33 and 39 months of exposure. Pit depth, rating number (RN), weight change of the specimens were determined.

It was found that corrosion severity of seaside was 2 times higher than that of industrial, 3.3 times higher than that of urban and 10 times higher than that of rural environment. In mild environment the performance of all specimens was the same during 39 months of study. Surface finishes played a role on the corrosion resistance. MF gave the highest corrosion resistance. Rating number was a fast method to evaluate the appearance changes or atmospheric corrosion of the stainless steels. Weight change, roughness and brightness of specimens also were measured but they were insignificant different thus these parameters were not suitable for evaluating the atmospheric corrosion resistance of stainless steels.

Keywords*: Atmospheric corrosion, stainless steels, surface finishing processes, Rating Number*

1 Introduction

Stainless steels have been widely used for high resistance applications such as equipments, parts or containers in petroleum, chemical and food industries. Because of their high corrosion resistance and low maintenance cost the stainless steels have been found their way to use as architectural materials. They can be used inside and outside the buildings. For the indoor applications, the stainless steel surfaces can be made in different patterns for decorative purposes. For the outdoor applications, the different surface processes can be applied to the stainless steel surfaces. The different surface finishes not only have different appearances for the aesthetic purpose but also have an effect on corrosion resistance of stainless steels [1-3]. For the stainless steels in the architectural application the most important issue is the appearance. They should not corrode and their appearances should remain the same for many years.

Stainless steels have been used outdoor all over Thailand. They exposed to different environments. The environments can be classified into 4 catagories which are rural, urban, industrial and seaside (marine) environments. Humidity, amount of rainfall, sunshine, range of temperatures and types of pollutants in the mentioned environments certainly are different. Stainless steels behave differently in different environments.

Chromium oxide passive film on the surface of stainless steel is responsible for its corrosion resistance. The higher the chromium content is the higher corrosion resistance because of high stability of passive film [4]. The others alloying elements, Cr, Mo and Cu, also have an influence on atmospheric corrosion resistance [5]. The surface finishes also affect corrosion resistance of the stainless steels [2, 3, 6, 7].

In this study stainless steel AISI 304 HL, 304 MF, 316 HL, 316 2B, 430 HL and 430 BA were exposed in 4 sites which were rural, urban, industrial and marine environments for the maximum period of 39 months. The corrosion resistance of stainless steel coupons were determined by pit depth, weight loss and RN. The roughness, brightness, haze and gloss of all coupons were determined but these values were insignificantly different.

2 Experimental

2.1 *Specimens*

The stainless steel AISI 304 2B, 316 2B and 430 BA were provided by Thainox Stainless PCL. Their chemical compositions were shown in table 1. The surface finishing processes were performed on the stainless steels at the commercial surface treatment shop. The stainless steel grades, the surface finishes and their roughness were shown in table 2.

The steel reference coupons were also exposed in all sites and retrieved after 9, 27 and 39 months.

2.2 *The exposure sites*

The 4 exposure sites which were the representative of the rural, urban, industrial and marine environments were shown in table 3.

2.3 *The exposure periods*

The stainless steel coupons were retrieved after exposure for 1, 3, 9, 15, 21, 27, 33, and 39 months. The retrieved coupons were cleaned, dried, photographed and kept in the dry place for further evaluations.

2.4 *The corrosion evaluations*

2.4.1 Weight changes

The retrieved coupons were weighed before and after exposure. The weight changes of the coupons were determined.

2.4.2 Pit depth measurement

The depths of all pits were measured and averaged.

Table 1: Chemical compositions of the stainless steels

Elements	wt%		
	304	316	430
C	0.0542	0.0358	0.0509
Si	0.487	0.533	0.299
Mn	0.925	1.29	0.329
P	0.01	0.01	0.01
S	0.01	0.01	0.01
Cr	18.06	16.82	16.4
Ni	8.63	10.43	0.249
Mo	0.186	1.97	0.041
Fe	balance	balance	balance

Table 2: The stainless steel grades, surface finishes and roughness

Stainless steels	Roughness (µm)			
	HL	MF	2B	BA
304	0.21	0.02	-	-
316	0.18	-	0.07	-
430	0.19	-	-	0.03

Table 3: The exposure sites

Sites	Location
Rural	Department of Fine Art, Ministry of Education, Ayutthaya
Urban	Top of the 3 storey building of Nuclear Engineering Department, CU, Bangkok
Industry	Map Ta Phut Industrial Estate, Rayong
Marine	Kung Krabaen Bay Royal Development Study Centre, Chantaburi

2.4.3 Rating Number

RN was utilized to evaluate the degrees of surface degradation of the coupons retrieved from 15 months to the end of the exposure period since the coupons retrieved before 15 months the surfaces of the coupons were insignificant different from the original. The RN values of all coupons were obtained from comparing the test coupons to the standard pictures [7] of stainless steel with different degrees of corrosion on the surfaces. The highest value was 9 which was the original surface appearance. The lowest value was 0 which was the heavily corroded surface.

2.4.4 Visual examination

All coupons were visually examined.

3 Results

The stainless steel coupons exposed at the industrial site disappeared after 27 months. Therefore, there was no result of the industrial specimen in the last 2 retrieving.

3.1 *Weight loss*

Only the coupons exposed in marine environment for 39 months had the weight loss values greater than 0.01 %. Their weight loss values were shown in figure 1.

3.2 *Pit depth*

There was no pit on all coupons exposed for 1 month. Some of the coupons exposed for 3 and 9 months had corrosion pits. The pit depths were measured and shown in figure 2. The pit depths of the coupons exposed for 15 to 39 months were presented in figure 3.

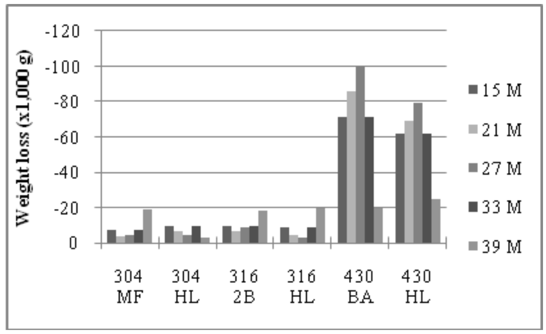


Figure 1: the loss of the coupons exposed in marine environment

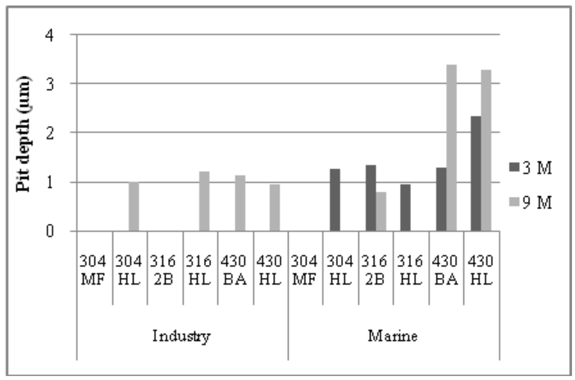


Figure 2: Pit depths of the specimens exposed for 3 and 9 months

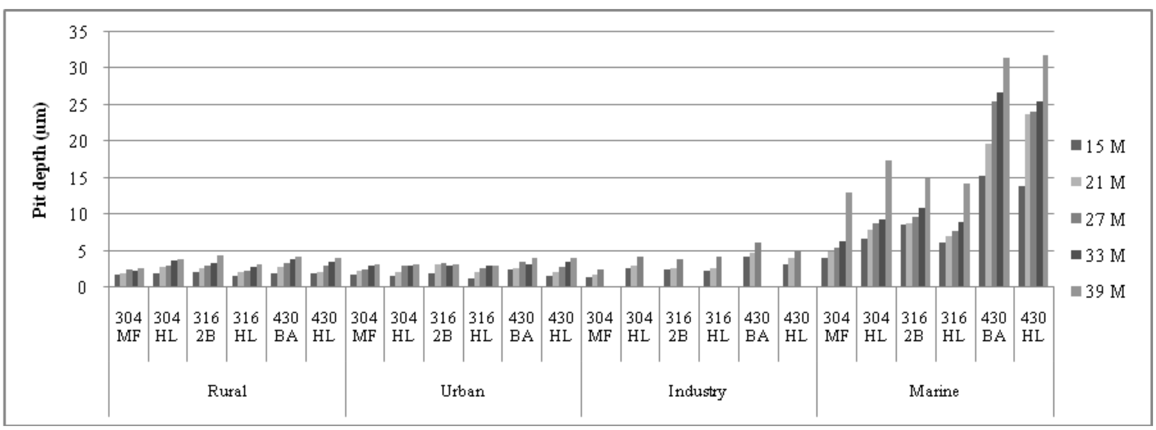


Figure 3: The pit depths of the stainless steel coupons exposed from 15 months to 39 months

3.3 *Rating numbers*

The average rating number was calculated from 5 values obtained from 5 personnel of corrosion technology department. Degradation of the coupons became obvious with longer exposure periods. RN's of the stainless steel coupons were shown in figure 4.

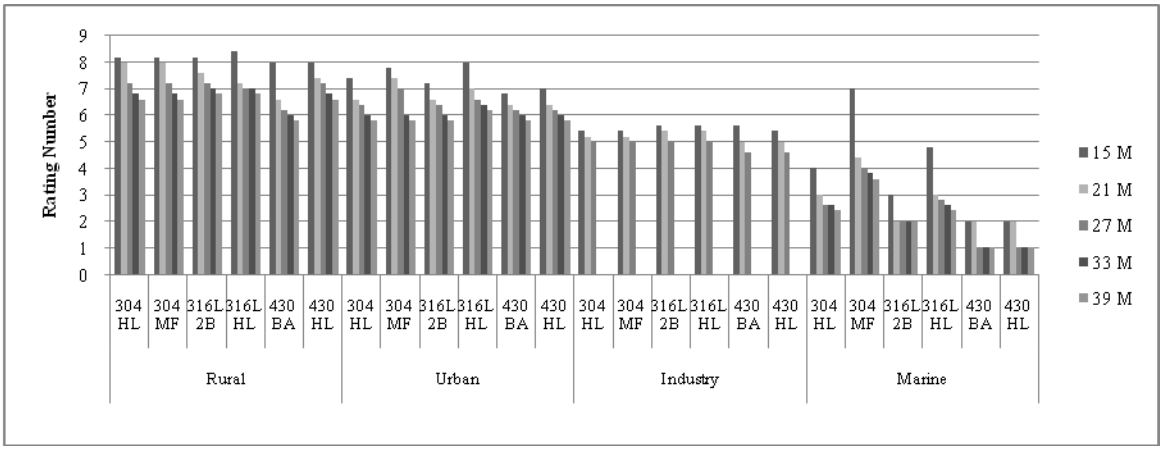
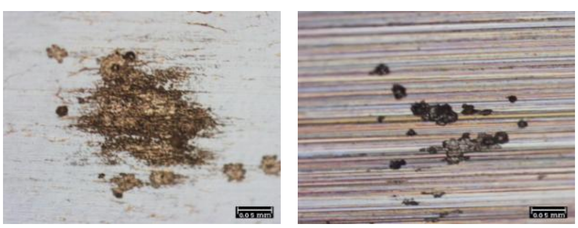


Figure 4: Rating numbers of the specimens

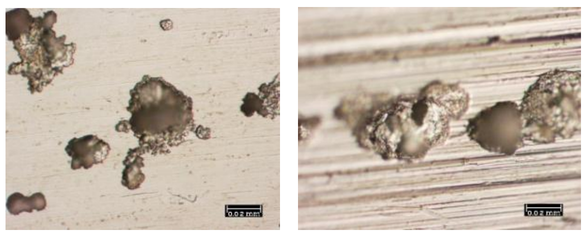
3.4 *Visual examination*

After 1 month of exposure, 430 BA and 430 HL in the marine atmosphere had corrosion pits and 316 2B had the corrosion stain. The pictures of the corroded stainless steel coupons after 3 and 9 months were shown in figure 5, 6 and 7. A water droplet which stayed on the stainless steel surface for long period could cause corrosion as shown in figure 8. After 39 months in marine environment, 430 corroded severely. All coupons corroded heavily at the edges as shown in figure 9.



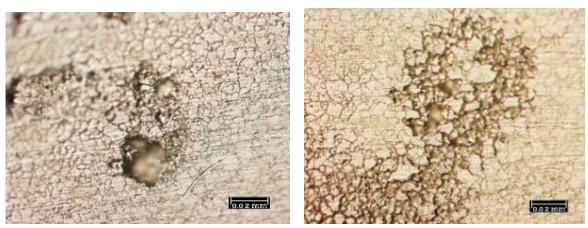
a) 430 BA b) 430 HL

Figure 5: Appearance after 1 month exposure



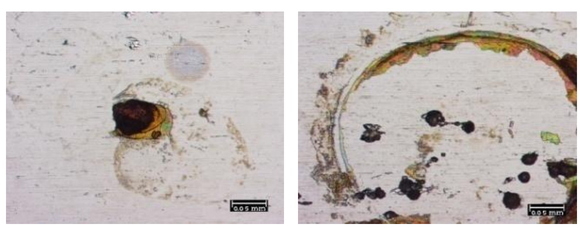
a) 430 BA b) 430 HL

Figure 6: Appearance after 3 months exposure



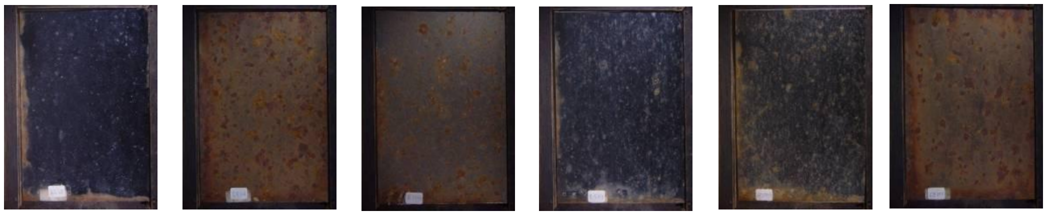
a) 3 months b) 9 months

Figure 7: 316 2B with different exposure periods



a) Industrial environment b) Marine environment

Figure 8: 430 BA exposed for 9 months, 200x



304 MF 304 HL 316 2B 316 HL 430 BA 430 HL

Figure 9: The coupons in marine environment after 39 months of exposure

3.5 *The steel reference coupons*

The weight loss values of the steel reference coupons were presented in figure 10.

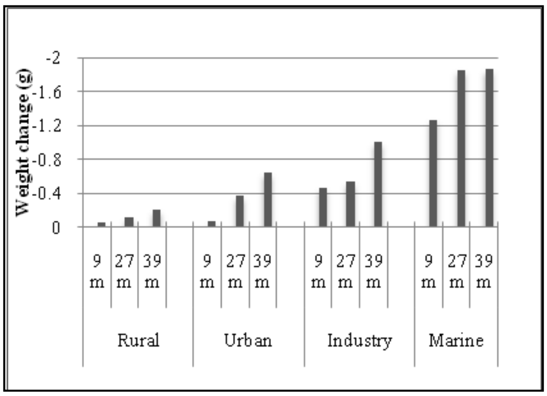


Figure 10: Weight loss of the reference coupons

4 Discussion

All of the stainless steel coupons had the weight loss less than 0.01% except the coupons exposed in marine environment for 39 months. The corroded areas of the coupons concentrated at the edges. The weight loss of the whole coupon was dominated by corrosion at the edge. But the area 1 cm. from the edge of the coupon was disregarded. Therefore, weight loss value might not be a good parameter for atmospheric corrosion of stainless steel.

Pit depth

The first year: 1, 3 and 9 months

After 9 months all coupons in rural and urban sites were intact. In industrial site, 304 MF and 316 2B did not corrode but the others had small pits. These pits were difficult to resolve with the naked eyes. The coupons in marine site, only 304 MF had no corrosion. The others had small pits.

The second year: 15, 21 and 27 months

All coupons in all sites had corrosion pits. The coupons in rural and urban sites had the pit depths less than 5 µm. Pit depths of all coupons in the industrial were between 5-10 µm. Marine site, only 304 and 316 had pit depths less than 10 µm and pit depths of 430 were 2.5 times greater than those of 304.

RN's of all coupons in rural and urban sites were greater than 6. RN's of the coupons in industrial site were between 4-6. Marine site, 304 MF had high RN of 7 and RN 2 for 430.

The third year: 33 and 39 months

Pit depths of all coupons in rural and urban sites were still less than 5 µm. Among all sites, coupons of the same grade and surface finish in marine site had the highest pit depths. 304 MF had the lowest pit depth of 13 µm and 430 had the highest pit depth of 32 µm.

Rating numbers of all coupons in rural site were between 6 and 7. The coupons in marine had the lowest RN.

The grades

In mild environment, the performance of 304, 316 and 430 was the same. In aggressive environment such as marine environment 430 corroded more than 304 and 316. Pits propagated slowly in mild environment but in aggressive environment pits grew fast. Degradation rate was high.

Surface finishes

MF gave the highest resistance. HL with machine marks in the vertical direction performed better than in the horizontal one.

During 39 months of study, 304 MF performed better than 316 2B and 316 HL. The chemical composition was important for corrosion resistance but surface finishes also played an important role on the resistance as well.

The severity of the sites was determined from the weight loss of the steel reference coupons. The marine site was the most aggressive environment. The severity of marine site was 2.0 times higher than that of industrial site, 3.3 times higher than that of urban site and 10.0 times higher than that of rural site.

The surface examination by light microscope

There were very small grooves along the grain boundaries on the 2B finished surface. If the water droplets stayed on the surface long enough, corrosion could initiate at the groove (figure 7). The machine lines on HL surface provided the way for water droplets to run off. The surface could dry up fast. If water stayed on the surface, the pits occurred along the machined lines (figure 5b and 6b). BA surface was very smooth. Water droplets could easily run off from the clean surface. But for long exposure period the surface became dirty and decreased tendency of water droplets to run off. Then corrosion occurred (figure 8).

The surface finishes had the effects on the atmospheric corrosion resistance (1, 2, 6). From Asami and Hashimoto (1) found that surface finishes affected the amount of Cr^{ox} and Fe^{ox} in passive film. 2B and HL finishes enriched Fe^{ox} in the film but MF and BA caused deficient of Fe^{ox} regardless of stainless steel type. Ni containing stainless steel would have less Fe^{ox} in the film than Ni-free or low Ni stainless steels. Cr^{ox} in the film of 304 MF was higher than that of 304 HL.

Corrosion resistance, either pit depth or RN value, depended on Cr^{ox} content in the film. All surface finishes increased Cr^{ox} in the film but not to the same extent. Therefore, in mild atmosphere, all stainless steel coupons, 304, 316 and 430 of all surface finishes, performed almost the same. But in the severe environment, industrial and marine, the coupons with lower Cr in bulk and Cr^{ox} in the film would corrode faster. In the environment with Cl^-, Cl^- destabilized the film and attacked the metal under the film. Once passive film breakdown locally, pit formed and propagated. If Cr content in the bulk was low and environment was severe, the reproduction of the film might not be possible or as good as the initial state. Pits grew bigger and deeper. Then corrosion product or rust would spread out and stain the surface around the pits. Rust-stain could be very large comparing to the size of the pit. RN value was the way to identify rusted area and to quantify degradation of stainless steel in the atmosphere. Therefore, information from the pit depth and RN would be supportive to each other.

5 Conclusions

Corrosion resistance of stainless steels depended on Cr^{ox} content in the film. Cr content in the film depended on,

- Bulk composition of stainless steels, the higher the Cr in the bulk was the higher Cr^{ox} in the film.
- Surface finishes, MF had the higher Cr^{ox} in the film.

RN and pit depth measurement yield the supportive information to each other. Deterioration of stainless steel surface could be quickly determined by RN.

Weight change can be negative or positive. Weight changes of the coupons were very small. For the long exposure period, this might not be the good method to determine the corrosion resistance because the edges of the coupons would corrode heavily comparing to the other area. The surface area 1 cm. from the edges was disregarded. But the corrosion of the disregarded area could affect the weight change of the whole specimen. Roughness and brightness of the coupons were insignificantly different. Therefore, these parameters were also not suitable for this purpose.

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