

A discussion for stabilization time of carbon steel in atmospheric corrosion

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Abstract. Stabilization time is an important parameter in long-term prediction of carbon steel corrosion in atmosphere. The range of the stabilization time of carbon steel in atmospheric corrosion has been published in many scientific literatures. However, the results may not precise because engineering experiences is dominant. This paper deals with the recalculation of stabilization time based on ISO CORRAG program, and analyzes the results and makes a comparison to the data mentioned above. In addition, a new thinking to obtain stabilization time will be proposed.

1. Introduction

Currently, the power-linear function (Fig. 1) is widely accepted to predict the long-term corrosion effects observes in tests for different periods of time in different regions of the world [1-2]:

$$K_{\tau} = K_1 \tau^n \quad (1)$$

and

$$K_{\tau} = K_0 + \alpha \tau \quad (2)$$

where K_{τ} presents the corrosion losses after the year τ , K_1 is the constant coefficient of the corrosion losses in the first year, K_0 is the intercept by extrapolation of the linear function to $\tau=0$, α is considered the corrosion rate preliminarily and n is a constant coefficient that describes the protective properties of corrosion products.

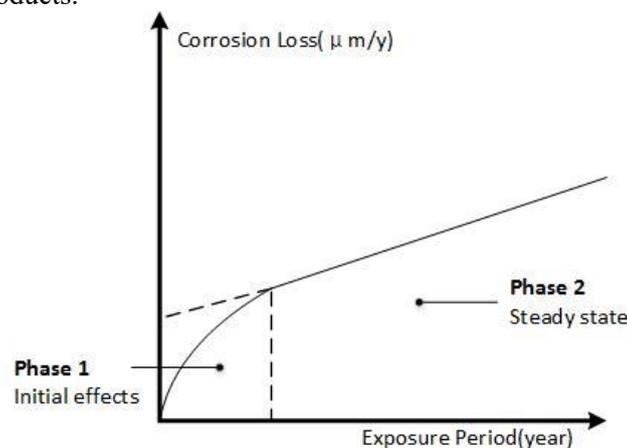


Figure 1. Power-linear model in long-term atmospheric corrosion

To estimate the service life precisely, a precise α which can be extrapolated by the stabilization time T is necessary. Commonly, if the decrease of the corrosion rate for one-year increment during exposure time $\leq 10\%$, a steady state (stabilization time) is considered to have been attained [3]. Meanwhile, the yearly variation of corrosion rate is also $\leq 10\%$.

Although the stabilization time has been discussed in the literature widely, the conclusions are quite different. Morcillo [3] considered that the stabilization time for weathering steels is 6 to 8 years in less corrosive environment and 4 to 6 years in more corrosive environment.

Another literature [4] proposed that rural and urban atmospheres have the similar stabilization time (3-5 years). And the value for industrial atmospheres is longer than rural and urban atmospheres (5-10 years). With regard to marine atmospheres, corrosion rate need in excess of 15 years to reach the steady state. Namely, rural=urban<industrial< marine.

According to [5-6], the stabilization time for low-alloy steels amounts to 6-8 years in less corrosive environments or 4-6 years in more corrosive environments. And the steady state of mild steels was observed after 4-6 years in all kinds of atmospheres [7].

This paper deals with the recalculation of stabilization time based on ISO CORRAG program, analyses the results and makes a comparison to the data mentioned above. Then, the paper will propose a new thinking to obtain the proper stabilization time.

2. Atmospheric corrosion environments

Generally, atmospheric corrosion environments are classified six categories according to corrosion rate [6]. Simply, atmospheric conditions can also be sort as rural, urban, marine and industrial atmospheres.

Rural and urban atmospheres have the similar corrosive features which contain less difference of temperature and shorter time of wetness (TOW). However, rural condition has less SO₂ concentration and less Cl deposition rate than urban condition.

On the contrary, industrial and marine environments are more severe and helpful to corrosion reaction. Although industrial atmosphere has the similar temperature and humidity with rural and urban atmospheres, the acid air which contains massive amount of SO₂ and Cl may cause destructive effect on metal and alloy materials.

Marine atmosphere has the longest TOW which may be the most influential factors in atmospheric corrosion because the moist air provides sufficient reaction medium. The moist air also contains substantial Cl so that marine air has extreme corrosivity. Furthermore, wider difference of temperature for marine condition may influence the corrosion rate to some degree.

Therefore, the corrosivity of these four atmospheric corrosion environments has the sequence: rural<urban<industrial< marine.

3. Results and analysis

According to the data of flat steel specimens from ISO CORRAG program TABLE 22 and Eqs. (1), the constant coefficient K_1 and n can be obtained. And the instantaneous corrosion rate is expressed as:

$$\alpha = nK_1\tau^{n-1} \quad (3)$$

so the steady-state start time T can be calculated by:

$$\frac{|nK_1T_2^{n-1} - nK_1T_1^{n-1}|}{nK_1T_1^{n-1}} \leq 10\% \quad (4)$$

where $T_2=T_1+1$ and T_1 is the stabilization time.

Table 1. Test locations within ISO CORRAG program, stabilization time T (y), T_{5%} (y), values of K₁ (μm), α ($\mu\text{m} \cdot \text{y}^{-1}$), $\alpha_{5\%}$ ($\mu\text{m} \cdot \text{y}^{-1}$) and n for flat carbon steel specimens

| Location | Designation | K1 | n | α | T | $\alpha_{5\%}$ | T _{5%} |
|--------------------------|-------------|---------|-------|----------|-------|----------------|-----------------|
| <i>Rural Atmosphere</i> | | | | | | | |
| Bergen | N5 | 30.880 | 0.363 | 3.758 | 5.560 | 2.311 | 11.925 |
| Iguazu | ARG1 | 6.651 | 0.406 | 1.020 | 5.153 | 0.647 | 11.088 |
| Pardo | E2 | 19.123 | 0.408 | 2.962 | 5.134 | 1.882 | 11.049 |
| Stockholm-Vanadis | S1 | 28.592 | 0.420 | 4.711 | 5.020 | 3.018 | 10.815 |
| Picherande | F3 | 18.818 | 0.431 | 3.277 | 4.916 | 2.117 | 10.601 |
| Birkenes | N3 | 25.762 | 0.437 | 4.623 | 4.859 | 2.999 | 10.484 |
| Ahtari | SF3 | 16.128 | 0.506 | 4.013 | 4.206 | 2.735 | 9.140 |
| Los Angeles, California | US6 | 18.928 | 0.532 | 5.288 | 3.961 | 3.672 | 8.633 |
| Ojmjakon | SU4 | 0.948 | 1.045 | - | - | - | - |
| <i>Urban Atmosphere</i> | | | | | | | |
| Madrid | E1 | 31.465 | 0.260 | 2.039 | 6.535 | 1.165 | 13.933 |
| Oslo | N1 | 29.562 | 0.336 | 3.086 | 5.815 | 1.861 | 12.452 |
| Kopisty | CS3 | 73.675 | 0.379 | 9.789 | 5.408 | 6.090 | 11.614 |
| Svanwik | N6 | 24.101 | 0.413 | 3.831 | 5.086 | 2.442 | 10.951 |
| Batumi | SU2 | 29.742 | 0.422 | 4.950 | 5.001 | 3.176 | 10.776 |
| Kasperske | CS1 | 26.752 | 0.439 | 4.849 | 4.840 | 3.149 | 10.445 |
| Otaniemi | SF2 | 30.122 | 0.443 | 5.568 | 4.802 | 3.627 | 10.367 |
| Praha-Be | CS2 | 50.366 | 0.456 | 9.920 | 4.679 | 6.523 | 10.114 |
| Helsinki | SF1 | 40.376 | 0.466 | 8.344 | 4.585 | 5.526 | 9.919 |
| Crowthorne, Berkshire | UK2 | 40.750 | 0.495 | 9.645 | 4.310 | 6.522 | 9.354 |
| Saint Remy | F4 | 51.841 | 0.504 | 12.784 | 4.225 | 8.701 | 9.178 |
| Paris | F7 | 45.256 | 0.663 | 21.404 | 2.725 | 16.329 | 6.083 |
| Bergisch Gladbach | D1 | 31.520 | 0.799 | 23.368 | 1.451 | 19.647 | 3.440 |
| Choshi | JAP1 | 40.851 | 0.801 | 30.462 | 1.433 | 25.647 | 3.401 |
| <i>Marine Atmosphere</i> | | | | | | | |
| Boucherville | CND1 | 22.203 | 0.408 | 3.440 | 5.134 | 2.185 | 11.049 |
| Biarritz | F9 | 88.594 | 0.419 | 14.522 | 5.030 | 9.298 | 10.834 |
| Tannanger | N4 | 63.544 | 0.419 | 10.416 | 5.030 | 6.669 | 10.834 |
| Bohus Malmon, Kvarnvik | S3 | 60.203 | 0.432 | 10.538 | 4.906 | 6.810 | 10.581 |
| Rye, East Sussex | UK3 | 62.386 | 0.448 | 11.819 | 4.755 | 7.727 | 10.269 |
| Tokyo | JAP2 | 41.409 | 0.542 | 12.082 | 3.866 | 8.450 | 8.438 |
| Bohus Malmon, Kattesand | S2 | 36.536 | 0.555 | 11.270 | 3.743 | 7.956 | 8.185 |
| Point Reyes, California | US5 | 36.541 | 0.597 | 13.407 | 3.347 | 9.755 | 7.367 |
| Murmansk | SU1 | 28.527 | 0.742 | 17.741 | 1.983 | 14.321 | 4.546 |
| Ostende, Belgium | F6 | 105.503 | 0.768 | 71.259 | 1.740 | 58.602 | 4.041 |
| Vladivostok | SU3 | 26.847 | 0.812 | 20.659 | 1.331 | 17.530 | 3.188 |
| Camet | ARG2 | 30.832 | 0.977 | 33.462 | 0.010 | 31.625 | 0.120 |

| | | | | | | | |
|-------------------------------------|------|---------|-------|--------|-------|--------|--------|
| Okinawa | JAP3 | 91.292 | 1.028 | - | - | - | - |
| <i>Industrial-marine Atmosphere</i> | | | | | | | |
| Baracaldo | E4 | 47.318 | 0.374 | 6.118 | 5.456 | 3.793 | 11.711 |
| Borregaard | N2 | 71.083 | 0.431 | 12.380 | 4.916 | 7.995 | 10.601 |
| Saint Denis | F1 | 40.923 | 0.465 | 8.417 | 4.594 | 5.570 | 9.938 |
| Stratford, East London | UK1 | 41.382 | 0.507 | 10.345 | 4.197 | 7.056 | 9.120 |
| Auby | F8 | 106.529 | 0.529 | 29.371 | 3.989 | 20.352 | 8.692 |
| Lagoas-Vigo | E3 | 31.293 | 0.542 | 9.130 | 3.866 | 6.386 | 8.438 |
| Fleet Hall | UK4 | 41.522 | 0.576 | 13.985 | 3.545 | 10.023 | 7.776 |
| Salins de Giraud | F5 | 83.123 | 0.615 | 32.759 | 3.177 | 24.145 | 7.017 |
| Ponteau Martigues | F2 | 74.911 | 0.640 | 32.513 | 2.941 | 24.398 | 6.530 |

Table 2. The average values of T (y), $T_{5\%}(y)$, α ($\mu\text{m} \cdot \text{y}^{-1}$) and $\alpha_{5\%}$ ($\mu\text{m} \cdot \text{y}^{-1}$)

| Location | α | T | $\alpha_{5\%}$ | $T_{5\%}$ |
|-------------------------------------|----------|-------|----------------|-----------|
| <i>Rural Atmosphere</i> | 3.707 | 4.851 | 2.432 | 10.467 |
| <i>Urban Atmosphere</i> | 10.717 | 4.350 | 7.886 | 9.430 |
| <i>Marine Atmosphere</i> | 19.218 | 3.406 | 15.077 | 7.455 |
| <i>Industrial-marine Atmosphere</i> | 17.224 | 4.076 | 12.191 | 8.869 |

Generally, according to the Table 1 and 2, it is obvious that the stabilization times are less than the engineering experiences mentioned above. The most steady-state start times are less than 6th year. Meanwhile, the trend of stabilization time is not very consistent with [4]. But the trend of average corrosion rate when exposure time reached the stabilization corresponded to the common sense.

With the n increases, the stabilization time T decreases. When n approaches to 1, the corrosion losses curves approximate a linear model. As a result, the corrosion rate (slope) can be regarded as a constant so that the corrosion process has reached steady state rapidly, although it has the higher corrosion rate. Similarly, when the value of n becomes small, the yearly increment increases and the stabilization time is later.

In response to these phenomena, a reasonable explanation is that a thicker rust layer is formed easily and rapidly in more corrosive environments like industrial and marine atmospheres. The thicker rust layer may restrict corrosion reaction via preventing from contacting with oxygen and water. On the contrary, a thinner rust layer usually appears in less corrosive environments like rural and urban atmospheres. The thinner rust layer may absorb more oxygen and water because of the loose structure and corrosion rate may rise. Therefore, corrosion rate in more corrosive conditions is higher than in less corrosive conditions and corrosion reaction achieves stabilization early in more corrosive environments.

4. Results of new thinking

In addition, the loose calculation condition may cause the results above. The loose calculation means that the corrosion rate still fluctuates in a larger range. Thus, when the constraint condition become severe, the state may be steadier. For instance, if the yearly variation of corrosion rate reduces 5%, namely, the Eqs. (4) rewrites as:

$$\frac{|nK_1T_2^{n-1} - nK_1T_1^{n-1}|}{nK_1T_1^{n-1}} \leq 5\% \quad (5)$$

The recalculation is on the Table 1 and the average values is on the Table 2.

Obviously, according to the Table 1 and 2, the stabilization time has the same variation tendency but becomes higher. Meanwhile, the values are close to the engineering experiences and conclusion in other literature.

5. Conclusion

The conventional calculation method for stabilization time by considering the variation of corrosion rate may obtain the inaccurate results. And the results are lower than the experiences and the literature commonly.

The steady-state corrosion rate rises in sequence of rural, urban, industrial and marine atmospheres and the start time of steady state observes the contrary sequence.

If the yearly corrosion rate decrease is changed into 5%, the stabilization time calculated by Eqs. (5) has the similar result with the usual hypotheses

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References

- [1] Yu. M. Panchenko, A. I. Marshakov, Long-term prediction of metal corrosion losses in atmosphere using a power-linear function, *Corrosion Science* 109 (2016) 217-229.
- [2] Yu. M. Panchenko, A. I. Marshakov, T. N. Igonin, V. V. Kovtanyuk, L. A. Nikolaeva, Long-term forecast of corrosion mass losses of technically important metals in various world regions using a power function, *Corrosion Science* 88 (2014) 306-316.
- [3] M. Morcillo, B. Chico, I. Diaz, H. Cano, D. de la Fuente, Atmospheric corrosion data of weathering steels. A review, *Corrosion Science* 77 (2013) 6-24.
- [4] I. Diaz, H. Cano, B. Chico, D. de la Fuente, M. Morcillo, Some clarifications regarding literature on atmospheric corrosion of weathering steels, *International Journal of Corrosion* (2012) 1-9.
- [5] BS EN ISO 9224. Corrosion of metals and alloys – corrosivity of atmospheres-guiding values for the corrosivity categories, 2012.
- [6] BS ISO 9223. Corrosion of metals and alloys. Corrosivity of atmospheres. Classification, determination and estimation, 2012.
- [7] D. de la Fuente, I. Diaz, J. Simancas, B. Chico, M. Morcillo, Long-term atmospheric corrosion of steel, *Br. Corros. J.* 28 (1993) 50-52.