A Study of Pitting Depth of 30CrMnSiA Steel in Airport Atmospheric Environment

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Abstract: In order to investigate the corrosion damage of aviation steel material in the atmospheric environment, the present study used the 30CrMnSiA steel specimen to carry out the accelerated corrosion test simulated aviation steel material under the airport environment. The pitting depth was measured in different corrosion years. The results shown that the Weibull function model could be more precise to predict development of 30CrMnSiA steel pitting depth and represent a better pitting development process.

Introduction

Corrosion in the atmosphere will cause damage and failure of aviation steel components, which can bring about catastrophic major disaster. Corrosion wastage would decay the ultimate strength of components within the life cycle of aviation steel components. It will be improper to analyze the structure reliability without considering the influence of components ultimate strength which caused by corrosion. In the traditional analysis of structure reliability, it is generally reported that the general corrosion of well maintained structure is the main factor of reduce of structure ultimate strength [1]. In most studies on metal components reliability impacted by corrosion, the linear or non-linear models have been used to represent the thickness of the metal components decreasing with time [2].

The pitting corrosion has been rarely considered as an important factor in the aviation steel ultimate strength design. However, in the recent observations of steel corrosion test, a large number of pits can be found after one year exposure in the atmosphere [3]. In addition, some studies have indicated that pitting corrosion and general corrosion both can significantly reduce the ultimate strength of the steel members [4]. Therefore, we should also pay attention to the localized corrosion, especially pitting corrosion, when we involve the reliability assessment of aviation steel members in the atmosphere environment.

The pitting corrosion model which is applied to predict statistical properties of corrosion damage is essential. Therefore, we designed the 30CrMnSiA steel specimen and carried out the accelerated corrosion test, and obtained the pitting depth data. Then the corrosion damage property of 30CrMnSiA steel was analyzed under airport atmospheric environment.

Accelerated Corrosion Test

The atmospheric corrosion of metallic materials in the natural environment is a very long process. It is difficult to operate the material placed in the natural environment which is researched within limited time. So we chose accelerated corrosion test method for the 30CrMnSiA steel corrosion in this study.

Preparation of Test Specimen. The 30CrMnSiA steel has been selected as the test material, whose chemical composition was shown in Table 1. The specimen dimension was shown in Fig. 1. The specimen thickness is 3mm. Before the test, the specimens were cleaned in order to remove surface oil. After cleaning with ethanol, they were placed in a drying oven.

Table 1 Chemical composition of 30CrMnSiA steel (mass percent)



Fig. 1 Dimensions of specimen

Experimental Method. In order to obtain the most similar corrosion damage from the accelerated corrosion test compared with that from the natural environment corrosion damage process, we applied the environmental spectrum equivalent relationship principle in this article. According to the reported researches from Z. T. Mu [5, 6], we used the same experimental method of accelerated corrosion environment spectrum to prepare an equivalent environment spectrum of a coastal airport in our country. Then we used this accelerated environmental spectrum for 30CrMnSiA steel specimens in the accelerated corrosion tests.

The equipment used for accelerated corrosion test is ZJF-75G environmental chamber. In order to simulate the alternation of rain and wet coastal environment and sun exposure environment, the chamber use fluorescent light to heat. The temperature was set at $40 \pm 2^{\circ}$ C. The corrosion solution in the chamber was a mass fraction of 5% NaCl solution, and the pH of the solution was adjusted to pH=4.0±0.2 via H₂SO₄. All the specimens were periodically soaking and baking. Each cycle contained soaking for 3.5min, baking for 16.4min. Alternating wet and dry was 402 times. The total test time is 133.33h, which is equivalent to one year corrosion damage in the natural environment.

After 1, 2, 4, 8, 16 years of accelerated corrosion, we used KH-7700 microscope to observe the surface image and corrosion pits image of all specimens, and measured the depth of corrosion pits. The average pitting depths of 5 pits on every specimen in different corrosion years are shown in Table 2. The surface image, pitting depth and three-dimensional image of corrosion pits which were belonged to equivalent corrosion 2 years specimen were shown in Fig. 2.



Table 2 The data of average pitting depth in different corrosion years

(a) Surface image (b) Three-dimensional image (c) The depth of pitting corrosion Fig. 2 Pitting corrosion image of equivalent corrosion 2 years specimen enlarged 160 times

Test Data Fitting and Analysis

Power Function Model. According to the reported research from Y. D. Xiao [7], there is a popular belief that the corrosion rule of steel material from the result of corrosion test in atmospheric environment is represented by the power function. The depth of pitting corrosion with time is described as below,

$$D(t) = A \cdot t^n \tag{1}$$

Where D(t) is the depth of pitting corrosion, t is the exposure time, A and n are constants which are obtained from curve fitting of corrosion test data.

Weibull Function Model. According to the reported research from S. P. Qin [8], on the foundation of current corrosion model summed up, they have brought up a kind of non-linear model about metal corrosion, and that model uses the equation of Weibull function to represent the corrosion rate. Compared with different models which are applied corrosion data, it is shown that

the Weibull model has good ability of fitting and higher precision. That model also can simulate the corrosion damage process of steel structure in corrosion environment. The depth of pitting corrosion with time is described as below,

$$D(t) = d_m \left\{ 1 - \exp\left[-\left(\alpha t\right)^m \right] \right\}$$
(2)

Where D(t) is the depth of pitting corrosion, t is the exposure time, d_m , m and α are constants which are obtained from curve fitting of corrosion test data.

Data Fitting and Analysis. Using the least-squares method, the data of pitting depth accelerated corrosion 16 years about 30CrMnSiA steel was fitted with equation (1) and equation (2), then the relation curve about corrosion depth and corrosion years is shown in Fig. 3. The fitting parameters are shown in Table 3.



Fig. 3 The fitting curve of pitting depth Table 3 The fitting parameter

Power function		Weibull function		
Α	n	d_{m}	m	α
0.06748	0.70012	0.46829	0.14954	1.38328

From the result of data fitting, the corresponding correlation coefficient R^2 of the power function model and Weibull function model are $R_{Power}^2 = 0.95399$ and $R_{Weibull}^2 = 0.99136$ respectively. Compared with R^2 , the correlative degree of Weibull function model is higher than that of power function model. From chi-square test of fitting goodness, the value of power function model is 0.00132, and the value of Weibull function model is 0.00027, the result shows that the Weibull function model could be more precise.

The corrosion rate curves of 30CrMnSiA steel are shown in Fig. 4. From the current of curves, we can get the conclusion that the corrosion rate curve of power function model is monotonously reduced, and that of Weibull function model is decreased after an initial increase. The result of Weibull function model is consistent with the reported research from M. Liu [9]. The time of maximum corrosion rate is 2.644 year, and the extreme value of corrosion rate is 0.052mm/yr.

Summary

We carried out accelerated corrosion test using 30CrMnSiA steel with accelerated environment spectrum. The depths of pitting corrosion were obtained in different corrosion years. We get the conclusions as below:

(1) Compared to the power function model, the Weibull function model has a higher precision on the prediction of 30CrMnSiA steel pitting depth.

(2) The Weibull function model can reflect the development process of 30CrMnSiA steel corrosion rate, which decreased after an initial increase.

(3) With pitting depth representing corrosion damage of high strength steel material, it is the foundation to study on the corrosion damage dynamic regulation of high strength steel material.

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