Corrosion Damage Assessment of AerMet100 Steel Based on Image Analysis

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Abstract. This paper aims to evaluate the corrosion damage of AerMet100 steel based on image analysis technology. Through the accelerated corrosion test of AerMet100 steel, the corrosion morphology under different corrosion ages was obtained. Based on MATLAB software, median image filtering, grayscale transformation and fuzzy enhancement are used to preprocess the corrosion image. Then the fractal theory was used to determine the optimal grayscale threshold for the corrosion image of AerMet100 steel. Then the binary image processing technology was used to extract the features and calculate the corresponding degree of corrosion damage. In the accelerated corrosion of 3a and 6a, the corrosion morphology of AerMet100 steel was pitting corrosion, and the corrosion damage was lighter; thereafter, it gradually developed into uniform corrosion, and the corrosion damage was aggravated. For the specimens with different corrosion ages, the fractal theory can be used to obtain the corresponding optimal grayscale threshold and the corresponding fractal dimension. In the initial stage of corrosion, the corrosion damage degree of the specimen increases rapidly with the increase of the corrosion time. In the later period of corrosion, the increase of the corrosion damage tends to be gentle. Based on image analysis technology, it can provide reference for corrosion damage characterization and evaluation of AerMet100 steel.

1. Introduction
Corrosion images contain a lot of corrosion information and are one of the important sources of corrosion data. The corrosion image visually records corrosion information such as the area, distribution, corrosion morphology, etc. Corrosion morphology is used to qualitatively and quantitatively describe the change process of corrosion damage, which is important for studying corrosion damage rules and corrosion damage assessment [1-5]. Zhang Xin-xin et al [6] studied the corrosion behavior of Q235 steel in atmospheric corrosion environment, obtained information of rust layer composition through image processing, combined electrochemical monitoring and image analysis, extracted image feature parameters, and compared with electrochemical information to study the correlation between corrosion behavior and image information of Q235 steel under thin liquid films. Yin Wen-bo et al [7] calculated the three-dimensional fractal dimension of the corrosion steel structure image after rust removal based on the fractal theory. The study found that there is a nonlinear relationship between the fractal dimension and its rust corrosion rate, and the fractal dimension decreases with the increase of the corrosion rate. After the rust removal of the corrosion specimen, the image's texture characteristics can describe its corrosion characteristics well. Kong De-ying et al [8] used image scanning to obtain images of corrosion morphology of carbon steel and low-alloy steel real
sea specimens and analyzed the image. Grey-scale correlation and typical correlation techniques were used to analyze the relationship between gray-scale distributions of the image, the average weight loss per unit area of the sample and the average depth of local corrosion.

Corrosion morphology image is an important basis for judging the type of corrosion, analyzing the corrosion, and studying the law and characteristics of corrosion. It extracts the topographical parameters from the surface corrosion topography image to quantitatively describe the corrosion morphology and thoroughly studies the corrosion law. It is of great significance. This article will be combined with AerMet100 steel accelerated corrosion test, using image processing technology to assess the corrosion damage of AerMet100 steel.

2. Test Materials and Methods

2.1. Test Specimen
The test material is aerospace new type ultra high strength steel AerMet100 (23Co14Ni12Cr3Mo). The chemical composition is shown in Table 1. The test specimen is in the form of a unilateral semi-circular notch specimen (SENT) with a thickness of 5 mm and a notch radius of 4 mm. The specific dimensions are shown in Figure 1.

| C  | Ni | Co  | Cr  | Mo | Si  | Mn  | Fe   |
|----|----|-----|-----|----|-----|-----|------|
| 0.23 | 11.73 | 13.85 | 3.13 | 1.25 | 0.10 | 0.10 | Bal  |

Table 1. Chemical component of AerMet100 (w/%).

![Figure 1. Single-edge-notch specimen (mm).](image1)

2.2. Accelerated Corrosion Test
Simulate the field service environment of the aircraft, compile an accelerated test spectrum, and carry out periodic infiltration accelerated corrosion tests. The test equipment is a ZJF-75G periodic infiltration test chamber; the test conditions are: 5% NaCl solution, pH 4.0±0.2, temperature 40±0.5°C; There are four sets of test specimens, each with 6 specimens. The accelerated corrosion tests were carried out for equivalent corrosion for 3 years, 6 years, 9 years and 12 years (3a, 6a, 9a, 12a). The accelerated corrosion test is shown in Figure 2.

![Figure 2. Accelerated corrosion test.](image2)
3. Test Results and Discussion

3.1. Corrosion Damage Morphology
The KH-7700 digital microscope was used to observe and collect the corrosion damage on a fixed area of the test specimen surface, as shown in Figure 3. It can be seen from the figure that the corrosion behavior of A100 steel begins with pitting and gradually develops uniform corrosion. In equivalent accelerated corrosion 3a, the corrosion damage on the surface of the test specimen is lighter, a small amount of corrosion pit appears, the size of the corrosion pit is small, the rolling line on the surface of the test specimen is continuous and clear; For equivalent corrosion of 6a, the number of corrosion pits on the surface of the test specimen increased, the size of a few corrosion pits increased, the surface color of the test specimen deepened, and the rolling line gradually disappeared; For the equivalent corrosion of 9a, the size of the corrosion pits increases significantly and they are interconnected. Only a small part of the corrosion damage is lighter; when the equivalent corrosion is 12 years, the corrosion damage on the surface of the test specimen covers the entire observation area.

![Corrosion morphology of specimen under different corrosion years.](image)

3.2. Degree of Corrosion Damage
After corrosion damage of the test specimen, the corrosion pit on the surface is unevenly distributed and the morphology is complex, as shown in Fig 4. If it is simply simplified as a circle, an ellipse, etc., and then evaluated for corrosion damage, it cannot truly and effectively reflect the corrosion damage on the surface of the test specimen. Therefore, a more reasonable and effective method is needed to quantitatively evaluate the corrosion damage of the test specimen. Corrosion pit is a prominent feature of the surface corrosion damage of the test specimen. Corrosion damage degree is often used as a parameter to describe its distribution on the surface of the test specimen [9-10].
The degree of corrosion damage is defined as follows:

\[ \alpha = \frac{1}{A} \sum_{i=1}^{n} A_i \times 100\% \]  

(1)

In the formula: \( n \) is the total number of corrosion pits in the observation area; \( A \) is the total projected area of the observation area; \( A_i \) is the projection area of the \( i \)-th corrosion pit in the observation area.

Due to the complex and large number of corrosion pits, the amount of corrosion damage obtained by directly measuring the area of the pit is a huge workload. Therefore, the corrosion image is processed by the image analysis method to calculate the corrosion damage degree.

### 3.3. Corrosion Image Preprocessing

In the process of collection and conversion of the corrosion image, due to the lighting conditions, acquisition and conversion equipment accuracy and other reasons, it will cause information loss and noise interference and reduce the image quality, thereby affecting the binary erosion image feature extraction and corrosion rating assessment [11-13]. Therefore, after the original corrosion image is initially converted to the corrupted grayscale image, it is necessary to use MATLAB software to perform image preprocessing such as median filtering, grayscale transformation, and fuzzy enhancement.

1. **Image Median Filter**

The median filter uses a non-linear method to preprocess the corrosion image to remove the interference signals such as pulses and noise in the corrosion image. The median filtered image is shown in Fig 5.

![Figure 4. Corrosion pit projection area measurement.](image)

![Figure 5. Median filter image.](image)
(2) Image Grayscale Conversion
Because the brightness distribution in the corrosion image collected by the microscope is not uniform and the contrast is insufficient, a good visual observation effect cannot be formed. Therefore, it is necessary to perform gradation conversion on the image so as to better display the detailed information in the eroded image. The grayscale image is shown in Figure 6.

![Figure 6. Grayscale transformation image.](image)

(3) Image Blur Enhancement
Due to the uneven distribution of corrosion pits and complex morphology, the contours and edges of the pits are difficult to identify and may be similar to the background in the corrosion image. Therefore, blur enhancement is required to detect the contours and edges in the corrosion image. The fuzzy enhanced image is shown in Figure 7.

![Figure 7. Blur enhanced image.](image)

3.4. Feature Extraction Based on Binary Corrosion Images
After the grayscale image is preprocessed, the parameters such as corrosion damage degree cannot be obtained directly, and it needs to be further transformed into a binary image. There are only two black and white pixels in the binary image, which are 0 and 1 respectively. A point with a pixel value of 0 represents corrosion damage and a point with a pixel value of 1 represents the substrate. The ratio of the number of pixels with a pixel value of 0 to the total number of image pixels is the degree of corrosion damage of the image. However, the key problem of the binarization processing is the selection of the threshold $k$. Different $k$ will calculate different degrees of corrosion damage, too large or too small will lead to distortion of the calculation result. Therefore, in order to select a suitable threshold $k$, fractal theory needs to be applied.
3.5. Calculate Gray Threshold Based on Fractal Theory

Fractal theory is a new discipline born in the 1970s. It uses “fractal dimension” to describe complex geometric shapes in nature. Fractals are characterized by strict or statistical self-similarity in whole and in locality. The quantitative parameters that describe the self-similarity of fractals are the fractal dimension, or abbreviation fractal dimension. The methods for calculating fractal dimensions include similar dimensions, box-counting dimensions, topological dimensions, and rulers [14-16].

This paper uses the box-counting method to calculate the fractal dimension D. The specific method is to cover the original specimen corrosion image and the binarized corrosion image respectively with a square box of size $\delta \times \delta$ [17-19], where $\delta$ is a variable. Given a certain value of $\delta$, the corresponding number of boxes N is calculated by MATLAB programming. Then use the following formula to fit the relationship between $\delta$ and N:

$$N = \alpha \cdot \delta^{-D}$$  \hspace{1cm} (2)

Logarithmic transformation of equation (2):

$$\lg N = -D \cdot \lg \delta + \lg \alpha$$ \hspace{1cm} (3)

According to formula (3), the linear fitting of $\delta$-N is performed in double logarithmic coordinates. As shown in Fig 9, the scoreable dimension D is 1.8809.

For a grayscale image, given a grayscale threshold k, a binary image can be obtained. According to formula (3), the corresponding fractal dimension can be obtained. It can be seen that there is a functional relationship between the fractal dimension D and the gray level threshold k.
Figure 10 shows the variation curve of the fractal dimension of the image of the corrosion 6a specimen with the gray level threshold. The fitting relationship is:

$$D = 1.8809 + \frac{-0.0381 - 1.8809}{1 + (k / 69.0905)^{2.9639}}$$  \hspace{1cm} (4)$$

The optimal gray level threshold is determined by the following formula:

$$\begin{align*}
&\frac{dD}{dk} = 0 \\
&\frac{d^2D}{dk^2}
\end{align*}  \hspace{1cm} (5)$$

Solving formula (5), the optimal gray scale threshold is 175, and the corresponding fractal dimension is 1.88. Corresponding optimal grayscale thresholds and corresponding fractal dimensions can be obtained for different corrosion age specimens. Corrosion damage parameters under different corrosion ages were obtained. The results are shown in Figure 11. The GaussAmp function in the Origin software is used to fit the calculation result and equation (6) is obtained. In the formula, \( t \) is the calendar year of corrosion.

$$\alpha = 0.116 + 0.734 \times e^{\frac{(t-11.754)^2}{2 \times 3.295^2}}$$  \hspace{1cm} (6)$$

Figure 10. The relationship between the fractal dimension D and the gray level threshold k of the image after 6 years of corrosion.

Figure 11. Corrosion damage degree under different corrosion years.
4. Conclusion

(1) For the equivalent corrosion of 3a and 6a, the corrosion morphology of AerMet100 steel shows pitting corrosion, and the corrosion damage is lighter. After equivalent corrosion of 9a, the corrosion morphology of AerMet100 steel shows uniform corrosion and the corrosion damage increases.

(2) There is a functional relationship between the fractal dimension D and the gray-level threshold k. Corresponding optimal gray-scale thresholds and corresponding fractal dimensions can be obtained for different corrosion age test specimens.

(3) In the initial stage of corrosion, the degree of corrosion damage of the specimen increases rapidly with the increase of the age of corrosion. In the later period of corrosion, the increase of the degree of corrosion damage tends to be gradual and gradually reaches a platform.

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