Fracture Retro Estimation of Friction Plate Made of 30CrMnSiA in Laboratory Condition

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Abstract. Fatigue life and fatigue stress range of the friction plate which is made of 30CrMnSiA were studied under laboratory environment. By using Scanning Electron Microscopy (SEM) to observe the fracture striation, the width of the fatigue striation can be obtained. Fatigue life and fatigue stress range can be studied with the combination of Paris law and fatigue striation width. The method is simple and mature, and the relative error of estimation is within expected values.

1. Introduction

30CrMnSiA is a high strength alloy, which is widely used in many fields such as aeronautics field [¹]. Friction plate is an important component in the brake systems of special vehicles. The friction plate which is manufactured by 30CrMnSiA gets fractured after being subjected to constant amplitude load in laboratory environment. The fracture of the friction plate of special vehicle brake system is shown in Fig 1. At present, some scholars have studied the mechanical properties of 30CrMnSiA materials. However, the research on the fracture retro estimation about actual mechanical components which were made of 30CrMnSiA has not been reported. In this paper, the fracture striation width was obtained with the help of Scanning Electron Microscopy (SEM). By using Paris law, fatigue life and fatigue stress range were estimated.
2. Method of Fracture Retro estimation
The width of fatigue striation during the stage of stable crack growth represents and numerically equals the fatigue crack growth rate. After observing the fracture of the friction plate and obtaining the fatigue striation width, the fatigue crack growth rate and the range of the fatigue life can be estimated by Paris law. According to Paris law, fatigue crack growth rate and fatigue crack length have a power exponential relationship. Paris laws can be written as followed \([2,3]\):

\[
\frac{da}{dN} = c (\Delta K)^n = c \left( \frac{Y \cdot \Delta \sigma \cdot \sqrt{\pi \cdot a}}{c_0} \right)^n
\]  

(1)

Where: \(c\) and \(n\) are the material parameters to be fitted, \(da/dN\) is fatigue crack growth rate, \(\Delta K\) is the stress intensity factor, \(Y\) is the form factor of the friction plate, \(\Delta \sigma\) is the difference between the maximum stress and the minimum stress, and \(a\) is the crack length.

By transforming the formula (1), the fatigue crack growth life and the fatigue stress range can be calculated. The expression of the fatigue crack growth life is as follows:

\[
N_p = \int_{a_0}^{a_c} \frac{da}{c_0 a^{n/2}} = \frac{2}{(2-n)c_0} \left[ a_c^{1-n/2} - a_0^{1-n/2} \right]
\]  

(2)

Where: \(N_p\) is the fatigue crack growth life, \(c_0\) and \(n\) can be determined by taking the logarithm of formula (2) and then make algebraic fitting.

The expression of the fatigue stress range is as follows:

\[
\Delta \sigma = \frac{S}{c_0^{1/2}} \left( \frac{Y \cdot \sqrt{\pi \cdot a}}{c_0} \right)^{-1}
\]  

(3)

Where: \(\Delta \sigma\) is the fatigue stress range, \(S\) is the width of the fatigue striation which equals to the fatigue crack growth rate \(da/dN\). \(c\) and \(n\) are material-related constants that can be determined by experiments.

3. experiments
By using constant amplitude to load the friction plate, test conditions of the friction plate are shown in Tab.1. The maximum stress of the test is 30MPa and the minimum stress is 30MPa. The fatigue life obtained by experiments is 9687, which contains crack initiation life and crack growth life.

|                  |                  | Force Ratio R | Fatigue Life |
|------------------|------------------|---------------|--------------|
| \(F_{\text{max}}/\text{MPa}\) | \(F_{\text{min}}/\text{MPa}\) |               |              |
| 300              | 30               | 0.1           | 9687         |

Before testing, friction plate needs to be cut. Cutting based on the two gears above and below the crack. While testing, During the test, a metallographic microscope was used to observe and record the
crack length. A certain size of load needs to be applied to the friction plate to allow the crack fully opened to be observed.

4. results and discussion

4.1. Fracture Observation

The results of fracture observation are shown in Fig 2. Fig 2(a) shows the source area of the crack. Fig 2(b) shows the instantaneous break zone. Fig 2(c) and Fig 2(d) show the fatigue striation observation results at 2mm crack growth and 3.5mm crack growth respectively. Clear fatigue striation can be seen in the stable crack growth zone.

Fig 2. Results of The Fracture Observation
4.2. Fitting Results of Shape Factor Y

The parameters of the friction plate geometry were input into the NASGRO software, and the graph of the relationship between shape factor of the friction plate and crack length can be obtained [4]. Export data points on the graph and then comply a polynomial fitting, the functional expression of shape factor and crack length can be get [4,5]. The functional expression is determined:

\[
Y = -0.0009984a^5 + 0.02996a^4 - 0.338a^3 + 1.808a^2 - 4.67a + 7.839 \tag{4}
\]

Where: Y is the shape factor, a is the crack length.

The relationship curve and fitting curve of shape factor and crack length are shown in Fig 3.

4.3. Results of Fatigue Life Retro Estimation

Take logarithm of crack propagation rate \(\frac{da}{dN}\) and the crack length a. Then plot the trends of \(\lg \frac{da}{dN}\) and \(\lg a\). Observe the image, the curve is divided into three stages of change and raise in S-shaped. So consider piecewise fitting. The data points are divided into three sections to be fitted, and the fitting coefficients \(c_i\) and \(n_i\) are obtained [6]. The values of \(c_i\) and \(n_i\) are shown in Tab.2.

| \(c_1\)  | \(c_2\)  | \(c_3\)  | \(n_1\)  | \(n_2\)  | \(n_3\)  |
|--------|--------|--------|--------|--------|--------|
| 3.03e-4 | 1.04e-4 | 3.02e-4 | 0.1321 | 2.5106 | 0.8032 |

The curve of fitted data is shown in Fig 4.

Substitute \(c_i\) and \(n_i\) into the formula (2), and then obtain the fatigue growth life \(N_i\) of different sections. \(N_1 = 4777.97\), \(N_2 = 2447.03\), \(N_3 = 2783.19\), \(N = N_1 + N_2 + N_3 = 10008.19\). Curves between estimated fatigue growth life N and crack length a are shown in Fig 5.
4.4. Results of Fatigue Stress Range Retro Estimation

The width of fatigue striation $S$ is equal to fatigue crack growth rate $da/dN$ [7], so it’s feasible to substitute $da/dN$ as $S$ into the formula (3). According to Paris law, material-related constants $c$ and $n$ can be tested in collecting the length of fatigue crack and the cycle during experiments. In order to estimate the fatigue stress range, take the material-related constants $c$ as $1.0614 \times 10^{-10}$, $n$ as 3.474. Then substitute $Y$, $c$, $n$ and $da/dN$ into the formula (3), fatigue stress range can be obtained. The curves of estimated fatigue stress range $\Delta \sigma$ and crack length $a$ are shown in Fig 6(a).

Real fatigue stress of the friction plate is 270MPa and amplitude is constant, which can be calculated from Tab.1. The relative error of fatigue stress range can be calculated by formula (5).

$$\delta = \frac{\Delta \sigma_i - 270}{270} \times 100\%$$

Where: $\delta$ is the relative error of fatigue stress range, $\Delta \sigma_i$ is the relative error of fatigue stress range at stage $i$.

The curve of the change in fatigue stress range is shown in Fig 6(b), and the average error of fatigue stress range is 7.84%.
5. Conclusions
(1) The estimated fatigue growth life of the friction plate is 10008.19, while the real fatigue life is 9687.
(2) The relative error of estimated fatigue stress range is 7.84%. The estimation error is within the allowable range.
(3) The error mainly comes from the following two reasons:
   a. The observation of fatigue striation remains several errors.
   b. The friction plate was subjected to bending moment during the test, but the size of the bending moment is difficult to obtain. Therefore, there might remain some errors when using NASGRO software to calculate the shape factor $Y$.

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