Low cycle fatigue properties of 7050-T7451 aluminum alloy under different strain ratios

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Abstract. The low cycle fatigue properties of 7050-T7451 aluminum alloy was studied. The low cycle fatigue properties of 7050-T7451 aluminum alloy at three strain ratios $R = -1$, 0.02, and 0.5 were measured by axial strain control method on MTS electro-hydraulic servo testing machine. In this research, the relationship between cyclic stress and strain at strain ratio $R = -1$ and the average stress relaxation effect of $R = -1$, 0.05 were given. The equivalent strain model was used to draw the strain-life curve for low cycle fatigue life data. The results show that under different strain ratios of 7050-T7451 aluminum alloy, the same strain amplitude in the high strain region leads to approximate fatigue life, and the effect of the strain ratio is only reflected in the low strain region.

1. Introduction

7050-T7451 aluminum alloy is used more and more in the aviation field, due to its excellent mechanical properties, it has attracted more and more attention1, 2. Thick plates’ properties requirements of aviation structure is very high, the 7050 - T7451 aluminum alloy not only to make mechanical properties meet the requirements under the condition of static load, but also to investigate the mechanics properties of dynamic load conditions, especially the research of low cycle fatigue properties3. At present, the research on the low cycle fatigue properties of 7050-T7451 aluminum alloy is often limited to the strain ratio $R = -1$, and the research on low cycle fatigue properties under different strain ratios is less. In this paper, the low cycle fatigue properties of 7050-T7451 aluminum alloy with different strain ratios $R = -1$, 0.02 and 0.5 are studied. The cyclic stress-strain curves of $R = -1$ and the average stress relaxation curves of $R = 0.02$, 0.5 are given. The equivalent strain normalization method is used to give the strain-life equations applicable to different strain ratios. The equivalent strain-life curve is given to facilitate engineering applications and improve efficiency.

2. Test procedures

2.1 Test method

The specimen design has a direct relationship with strain control and measurement. Therefore, a suitable specimen shape should be selected to ensure the reliability of the specimen data. The shape and dimensions of the specimens used in this study are shown in Figure 1. This specimen form complies with the requirements for specimens in the 《Standard Test Method for Strain-Controlled Fatigue Testing》 (ASTM E606/E606M-12)4. In order to improve the reliability of the test data, the specimen processing should be performed strictly in accordance with the shape and position tolerance requirements specified in Figure 1, and the mechanical processing or polishing method that causes the surface layer of the specimen to generate as little residual stress...
as possible is the final process, and circumferential cutting marks in machining. During the processing of the specimen, care should also be taken not to cause the specimen to cause overheating, cold hardening, and macroscopic surface damage.

Fig. 1 Low-cycle fatigue specimen

Using the axial strain control method, low cycle fatigue properties tests were performed on 7050-T7451 aluminum alloy at three strain ratios $R = -1, 0.02$ and 0.5. The strain rate is $4 \times 10^{-3}/s$, and the load waveform uses a triangular wave. The strain amplitude, maximum stress, number of cycles and strain ratio are recorded during the test. The data of the strain-cycle number test is given in symbol form in Figure 2.

2.2 Test Data Processing and Analysis of Test results

2.2.1 Cyclic Stress-strain Curve

The cyclically stable stress-strain curve is a curve obtained by smooth fitting the vertices of several cyclically stable hysteresis loops with different strain ranges. After comparing the stable cyclic stress-strain curve with the monotonic tensile stress-strain curve, you can determine whether the material is cyclically hardened or cyclically softened. The cyclic stress-strain curve provided in this study is obtained by multi-stage multi-sample method. This method is based on the constant strain range control test of multiple samples in the multi-stage multi-strain range, and the strain level of each stage is completed by a group of samples.

According to the cyclic stress-strain curve, the cyclic strain hardening index $n'$ and cyclic strength coefficient $K'$ can be obtained. According to the relationship proposed by Morrow et al. [5], it is expressed as follows:

$$\frac{\Delta \sigma}{2} = K' \left( \frac{\Delta \varepsilon}{2} \right)^{\frac{n'}{2}}$$

(1)

where: $\Delta \sigma/2$ is the stress amplitude; $\Delta \varepsilon/2$ is the plastic strain amplitude. Eq. (1) can also be written as the function of $\Delta \varepsilon/2$ and $S_{\text{max}}$:

$$\log_{10}(S_{\text{max}}) = \log_{10}(K') + n' \cdot \log_{10}(\Delta \varepsilon/2 - S_{\text{max}}/E)$$

(2)

The cyclic stress-strain curve is obtained by substituting the experimental data of strain ratio $R = -1$ into Eq. (2), as shown in Figure 2. In the process of data processing, the stress is treated as an independent variable and a least squares regression fit is performed, and the cut-off value of cyclic plastic strain is given. The cut-off value of the plastic strain amplitude used in this paper is about 0.0001. Through the above analysis can get 7050 - T7451 aluminum alloy thick plate circulation intensity coefficient $K' = 506.9394$, cyclic strain hardening index $n' = 0.0227$.

Assuming that the strain amplitude is independent of the strain ratio, and the estimated value of cyclic strain hardening index $n'$ is greater than zero, the average value of strain amplitude $S_a$ can be defined as a function of the strain range, as shown in Eq. (3):

$$S_a/E + (S_a/K')^{n'/2} = \Delta \varepsilon/2$$

(3)
2.2.2 Average Stress Relaxation Effect

Generally speaking, the strain amplitude at the place where the average stress relaxation occurs decreases with the increase of the strain ratio. The average stress value predicted by the elastic response is much higher than the actual measured value, indicating that there is an average stress relaxation [6]. The average relaxation stress $S_m$ can be obtained from data of all strain ratios except $R=\pm1$, see Eq. (4):

$$S_m = \alpha + \beta(\Delta\varepsilon/2)$$

(4)

The average stress relaxation curve of 7050-T7451 aluminum alloy plate can be obtained by substituting the experimental data $R=0.02$ and $R=0.5$ into Eq. (4), as shown in Figure 3.

2.2.3 Equivalent Strain - life Curve

Unified data on the basis of equivalent strain, the data set includes three strain ratios, which is expressed by the following equivalent strain equation:

$$\log_{10}(N_r) = A_1 + A_2 \log_{10}(\varepsilon_{eq} - A_3)$$

(5)

where:

$$\varepsilon_{eq} = (\Delta\varepsilon)^{A_4} (S_{max}/E)^{1-A_5}$$

(6)

The test data of $R=\pm1$, 0.02, 0.5 were substituted into Eq. (5) to obtain the equivalent strain-life curve of 7050-T7451 aluminum alloy thick plate, as shown in Fig. 4. $A_1 = -5.2093, A_2 = -3.9230, A_3 = 0.6178, A_4 = 0.0032$. The maximum stress value $S_{max}=S_a+S_m$ under a given $\Delta\varepsilon$ was obtained by adding the $S_a$ and $S_m$ in Eq. (3) and (4), and the corresponding number of cycles $N_r$ could be obtained by substituting them into Eq. (5).

It can be seen from the Figure. 4, 7050 - T7451 aluminum alloy under different strain ratio, within the scope of high strain area, strain amplitude will have little impact on the low cycle fatigue life, and only in low strain range area, the influence of strain amplitude of fatigue life to appear, and the material has entered the linear elastic stress control in the stage of fatigue life.

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**Fig. 2** Cyclic stress-strain curve of 7050-T7451 aluminum alloy $R=-1$

**Fig. 3** Average stress relaxation curve of 7050-T7451 aluminum alloy $R=0.02$ and 0.5
Fig. 4 Equivalent strain - life curve of $R = -1, 0.02$ and $0.5$ of 7050-T7451 aluminum alloy

3. Conclusions

The low cycle fatigue properties of 7050-T7451 aluminum alloy was studied, the thorough analysis of cyclic stress-strain curve when $R = -1$, and the average stress relaxation effect when $R = 0.02, 0.5$, and the processing method based on equivalent strain, the strain of different strain-life data processing has become the normalized equivalent strain-life curve. Different strain ratio and strain amplitude in the equivalent strain-life curve can be convenient to get the corresponding fatigue life, equivalent strain-life curve is convenient for engineering application is given, to improve the efficiency.

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