Effects of the specimen form on high cycle fatigue properties of 7050-T7451 and 2524-T3 aluminum alloys

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Abstract. High cycle fatigue properties of 7050-T7451 and 2524-T3 aluminum alloys at three stress ratios R=-1, 0.06, and 0.5 were experimentally studied, in which the axial stress control method was used to measure the funnel-shaped and iso-section specimens, with a MTS electro-hydraulic test system. Stress-life data were obtained and equivalent stress-life curves were plotted based on the equivalent stress model. Results showed that as for 7050-T7451 and 2524-T3 aluminum alloys, stress-life curves obtained with two kinds of specimens basically agreed, and effects of the specimen form on high cycle fatigue properties of these two aluminum alloys can be neglected.

1. Introduction

The 7050-T7451[1] and 2524-T3[2] aluminum alloys are increasingly used in the aerospace engineering due to their excellent mechanical performances, and thus have been drawn high attention in the past decades. High performances and reliability are basically required in primary and secondary structures in aviation, which demands that the 7050-T7451 and 2524-T3 aluminum alloys should satisfy the requirements of mechanical properties not only under static load conditions, but also under dynamic load conditions, especially high cycle fatigue issues. Up to now, high cycle fatigue properties of the 7050-T7451 and 2524-T3 aluminum alloys have been systematically investigated under various of stress ratios. However, effects of specimen forms on the high cycle fatigue properties of aluminum alloys have been barely studied. In this work, as for the 7050-T7451 and 2524-T3 aluminum alloys, two forms including the funnel-shaped and iso-section specimens have been manufactured and tested under different stress ratios $R=1$, 0.06, and 0.5. Based on the experimental outcomes and with the Processing method of equivalent stress normalization [3], equivalent stress-life equations were presented for different specimen forms under various of stress ratios. It is shown that effects of the specimen form on high cycle fatigue properties of these two aluminum alloys can be neglected, and the equivalent stress-life curves can be further applied in engineering practices.
2. Test procedures

2.1 Test method

The accuracy of experimental results are closely related to the specimen design and the control method of stress during the tests, which demands for a careful and appropriate design of the specimen shapes. In this work, the funnel-shaped and iso-section specimens were designed according to the ASTM E466-15\cite{4}, as shown in Fig. 1. In order to improve the reliability of experimental outcomes, geometric tolerance requirements in Fig. 1 were strictly followed in the manufacture process, during which the overheating and hardening of material were simultaneously avoided to minimize the residual stress on the sample surface and ensure that the surface condition of the sample is consistent. The surface of the sample should not be scratched or corroded, and the plate sample is not allowed to bend and warp.
In accordance with the axial stress control method, tests on the funnel-shaped and iso-section rod specimens of 7050-T7451, and the funnel-shaped and iso-section plate specimens of 2524-T3 have been conducted under three stress ratios $R = -1, 0.06, \text{ and } 0.5$, respectively. The experimental frequency was set as 90–150 Hz, and triangular waveform has been chosen. During the experimental procedure, the maximum stresses, cycle numbers, and stress ratios have been recorded, and the stress-cycle data been presented in Fig. 2 in symbolic forms.

2.2 Test Data Processing and Analysis of Test results

2.2.1 Fatigue limit

The fatigue limit is commonly determined with the up-and-down test. The stress increment (or reduction) between each two adjacent stress levels should be within 5% of the estimated fatigue limit. Besides, the stress level of the first specimen should be slightly higher than the expected fatigue limit. The test result (failure or not) of the root specimen determines the stress level (lower or higher) of the next sample until all tests are completed. The fatigue limit can be calculated with Eq. (1) below,

$$\sigma_f = \frac{1}{n} \sum_{i=1}^{m} V_i \sigma_i$$

In which $n$ is the number of valid tests, $m$ is the total number of stress levels, $\sigma_i$ is the $i^{th}$ stress level, and $V_i$ is the number of tests under the $i^{th}$ stress level.
2.2.2 Stress-life curves

At least four stress levels were used to obtain stress-life (S-N) curves of different specimens. The fatigue limits obtained with up-and-down test were used as the lowest stress level, and other stress levels were determined with group test. The total number of specimens in each test was determined in accordance with the requirements of the confidence level.

2.2.3 Equivalent stress-life curves

Combining the experimental results at three stress ratios on the basis of equivalent stress, the equivalent stress-life curves can be given as Eq. (2) below,

$$\log_{10}(N_f) = A_1 + A_2 \log_{10}(\sigma_{eq} - \sigma_t)$$  \hspace{1cm} (2)

where:

$$\sigma_{eq} = \sigma_{max}(1 - R)^{K_t}$$  \hspace{1cm} (3)

Substituting the experimental data at stress ratios of $R=1$, 0.06 and 0.5 into Eq. (2), the equivalent stress-life curves of 7050-T7451 and 2524-T3 aluminum alloys can be obtained, as shown in Fig. 2, and the related parameters are given in Table. 1.
(c) 2524-T3 aluminum alloy (funnel-shaped plate specimen)  
(d) 2524-T3 aluminum alloy (iso-section plate specimen)

Fig. 2 Equivalent stress-life curves of the 7050-T7451 and 2524-T3 aluminum alloys

Table 1 Parameters of equivalent stress-life curves of the 7050-T7451 and 2524-T3 aluminum alloys

| Parameters       | 7050-T7451 | 2524-T3 |
|------------------|------------|---------|
|                  | iso-section rod specimen | funnel-shaped rod specimen | funnel-shaped plate specimen | iso-section plate specimen |
| $A_1$            | 11.3622    | 10.6441 | 12.8      | 12.3156     |
| $A_2$            | -2.9223    | -2.5788 | -3.3533   | -3.1196     |
| $A_3$            | 0.57567    | 0.54922 | 0.60525   | 0.66584     |
| $A_4$            | 211.4487   | 213.1551| 66.0549   | 58.849      |

Equivalent stress-life curves of the 7050-T7451 and 2524-T3 aluminum alloys with different specimen forms were systematically compared and given in Fig. 3, in which it can be clearly seen that, specimen forms including the funnel-shaped and iso-section specimen have little effect on the equivalent stress-life curves.
3. Conclusions
High cycle fatigue properties of 7050-T7451 and 2524-T3 aluminum alloys at three stress ratios $R=-1$, 0.06, and 0.5 were experimentally studied with funnel-shaped and iso-section specimens. Stress-life data were obtained and equivalent stress-life curves were plotted based on the equivalent stress model. Results showed that as for 7050-T7451 and 2524-T3 aluminum alloys, specimen forms including the funnel-shaped and iso-section specimen have little effect on the equivalent stress-life curves. Further, equivalent stress-life equations were presented for different specimen forms under various stress ratios, which can be further applied in engineering practices.

References
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