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Influence of Low Load Truncation Level on Crack Growth for Al 2324-T39 and Al 7050-T7451

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Abstract

Tests with middle-crack tension (M(T)) specimens made of Al 2324-T39 and Al 7050-T7451 are conducted to investigate the influence of low load truncation level on fatigue crack growth. The six different truncated spectra are obtained by removing the small cycles of which amplitudes are less than the specified percentages of the maximum amplitude in the basic flight-by-flight loading spectrum and the remainder of the spectrum is untouched. The tests indicate that the mean level of fatigue crack growth life (FCGL) increases as the load truncation level is enhanced. Considering both the time saving and the influence on FCGL, there is an applicable choice (i.e. spectrum S2 or spectrum S3 in this investigation) for full scale fatigue test. The scatter of FCGL becomes much larger than that under the basic spectrum when the load truncation level is increased to a specified high level, mainly due to the occurrence of crack slanting and branching under the high level truncated loading spectra.

Keywords: fatigue crack growth; aluminum alloys; low load truncation; flight-by-flight spectrum

1. Introduction

The fatigue crack growth (FCG) analysis under the repeated load expected in service is the basis of damage tolerance evaluation. This evaluation ensures that should serious fatigue, corrosion, or accidental damage occur within the design service goal of the airplane, the remaining structure can withstand reasonable loads without failure or excessive structural deformation until the damage is detected[1]. However, the analysis must be supported by test evidence. The airplane structures suffer lots of gust loads including a large number of low amplitude loads. For full scale fatigue test (FSFT) loading spectrum, these low loads, which are considered to be non-damaging, tend to cause an unacceptable waste of time and cost. It is an economic and common practice to eliminate these low loads in each flight cycle, which will result in significant saving of testing time without changing the FCG characteristics. Nevertheless, the loss of small loading cycles might shift the balance between crack initiation and crack growth[2], and the delay of the FCG occurring after an overloading cycle is strongly sensitive to subsequent underloading cycle[3]. A great number of investigations have been emphasized on the influence of load sequence on FCG[4-11]. However, the amplitude level, below which the loads should be truncated, is affected by the property of structural material, the characteristic of loading spectrum, etc[12-16]. The truncated spectrum used in the FSFT must be substantiated by the FCG tests of specimens to show its validity.

The aim of this study is to investigate the influence of the load level to be truncated on fatigue crack growth life (FCGL), via the tests of standard specimens for two typical kinds of aluminum alloys which are widely used in civil airplane structures. The test results will be able to provide a reasonable support for establishing the FSFT truncated spectrum without unneglectable influence on FCGL.

2. Tests

The materials studied are alloys Al 2324-T39 and Al 7050-T7451. The mechanical properties of these alloys are given in Table 1. Middle-crack tension (M(T)) specimens are used in the tests. The dimensions of the specimens are shown in Table 2, where L-S represents that the tension load is applied in the longitudinal direction and the crack propagates along the short transverse direction, and L-T represents that the

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tension load is also applied in longitudinal direction and the crack propagates along the transverse direction.

Table 1 Mechanical properties of the alloys MPa

Alloy	Tensile strength	Yield strength	Shear strength	Elastic modules
Al 7050-T7451	510	441	289.0	71 000
Al 2324-T39	489	393	275.8	71 000

Table 2 Dimensions of M(T) specimens mm

Alloy	Length	Width	Thickness	Half length of linear cut	Orientation
Al 7050-T7451	350	98.5	6.0	4	L-S
Al 2324-T39	350	98.5	4.5	4	L-T

The basic loading spectrum S0 is a 5×10 flight-by-flight spectrum which consists of five different flight types and a block is composed of 4 200 flights. The five flight types are arranged randomly within the block. Flight type 1 is the most severe loading condition and occurs only once during 4 200 flights, while flight type 5 is the least severe and occurs 2 958 times in 4 200 flights.

The spectrum S0 is then filtered by removing small cycles to study the effects of spectral truncation on the FCGL. The first truncated spectrum, marked with spectrum S1, is obtained by removing the cycles of which amplitude is less than 9.82% of the maximum amplitude in spectrum S0, while the taxiing loads during each flight are retained. About 26.56% loading cycles are eliminated compared with spectrum S0. The other four truncated spectra, i.e. spectra S2, S3, S4, and S5 can be gained in the same way. Table 3 gives the details of the spectra with different truncation levels and the percentage of eliminated cycles in each block. Fig.1 illustrates the segments of the flight-by-flight loading spectrum, including flight type 1 and flight type 5 with different truncation levels, where σ is the stress in the loading spectrum, σ_{max} the maximum value of σ, and N the load cycle.

Table 3 Comparisons of spectra

Parameter	Spectrum					
	S0	S1	S2	S3	S4	S5
Truncation level/%	0	9.82	11.72	13.98	17.11	21.36
Percentage of eliminated cycles/%	0	26.56	46.87	62.95	73.35	78.58

All the tests are conducted with MTS880 fatigue test system, and an observation system consisting of digital microscope, servo motor, and raster ruler is used to register the position of crack tip.

All the specimens are fatigue precracked under constant amplitude load of $R = 0.06$ and $\sigma_{max} = 90$ MPa and result in an initial crack of about 5.5 mm from the symmetry axis of the specimen, and then the FCG tests are conducted under spectral loads. The test frequency is 8 Hz. Under each loading spectrum, there are 5 specimens for Al 7050-T7451 and 6 specimens for Al 2324-T39, respectively.

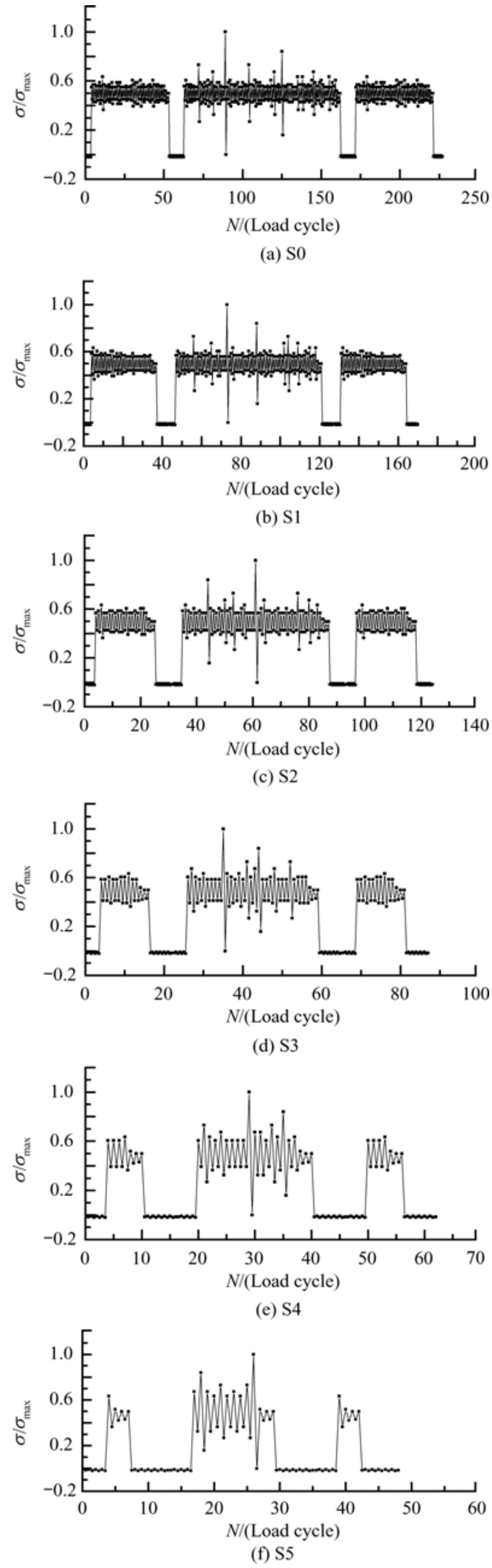

Fig.1 Segments of flight-by-flight loading spectrum with different truncation levels.

3. Results and Discussion

In order to investigate the influence of load trunca-