Amendment of High-Altitude Corrosion Environment to the Fatigue Life of Aircraft

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Abstract

As is well known to all that the corrosion environment has effect on the fatigue life of aircraft. In order to analyze and resolve the above-mentioned problem, the corrosion environment of aircraft flying at high altitudes is simulated on ground in testing room and, corrosion test and statistics are made for numerous metals. Here in this Paper, corrosion test curves of three kinds of aeronautical materials (Ly12cz and Lc4cs aluminum alloys and 30CrMnSiA alloy steel) are given, as shown in Fig. 1, Fig. 2 and Fig. 3. It can be obtained from the three corrosion curves that there does exist a critical corrosion temperature T_c and, under the corrosion environment at high altitudes, i.e. at an environmental temperature of -50 ℃, there is almost no effect of flight corrosion environment on the fatigue life of aircraft, therefore, no amendment is necessary to the fatigue life of aircraft under corrosion environment at high altitudes.

1 Introduction

It is generally known that the corrosion environment has an effect on the fatigue life of aircraft structure [1], [2]. Up till now, a lot of researches have been made in the international field of fatigue researching, however, no results satisfactory to engineering circles have been obtained. In determination of fatigue life of aircraft, it is known to all that corrosion does have effect on the aircraft fatigue life [3], [4]. However, how and how much the corrosion exerts influences on the fatigue life of aircraft remain a problem being frequently faced by engineering technical personnel, a problem of no reasonable explanations and no accurately quantitative amendments. Scientific circles have put forward some formulas and methods for quantitative amendment, however, the fatigue life of aircraft is often made relatively short, even unacceptably short in some cases, i.e. far from the actual conditions of aircraft operation. In such a way, a number of uncertain factors would be brought to the determination of aircraft fatigue life and consequently, there may exist hidden dangers to the flight safety.

For probing into the above-mentioned subject, in this Paper, the research has been made on corrosion temperature factor (other corrosion factors are put in media for consideration, in which the corrosion test is made). In the past, however, researches were made only under normal temperature on the ground, losing sight of effects of high-altitude and low-temperature corrosion on the fatigue life of aircraft. Results obtained from those researches, therefore, could not reflect the true fatigue life of aircraft.

During corrosion tests mentioned in this Paper, for reproducing the temperature environment in which the aircraft flies at high altitudes, stresses have been put on simulating a temperature environment of 0℃ to –50℃ in addition to consideration of the normal temperature on the ground. Within such a range of temperature and under the condition of the same corrosion amount D, the variation law of corrosion time H with respect to corrosion temperature T has been studied for the purpose of analyzing the effect of corrosion temperature on the fatigue life of aircraft.

2 Corrosion Test

2.1 Materials for Corrosion test

Three kinds of commonly used aeronautical materials, i.e. Ly12cz and Lc4cs aluminum alloys and 30CrMnSiA alloy steel, have been chosen for the present corrosion tests.

2.2 Basic Mechanical Properties of Materials for Corrosion Test

The mechanical properties of three kinds of materials used for corrosion tests meet the standard for aeronautical materials, refer to Table 1.

Table 1 Static properties of three materials: Ly12cz and Lc4cs aluminum alloy sheets and 30CrMnSiA alloy steel sheet

Material	E GPa	$\sigma_{0.2}$ MPa	σ_b MPa	δ_5 %	Test Method
Ly12cz	65.7	362.3	470.7	19.5	HB-5134 -96
Lc4cs	65	510.3	558	12.1	
30CrMnSiA		1056.7	1130.7	13.4	

2.3 Test Method

Before test, the aluminum-clad layer of Ly12cz and Lc4cs aluminum alloy specimens is removed, the thickness of the specimen is measured and a protective layer of 901-M acid-resistant insulating varnish is applied on the non-testing surface of the specimens. For 30CrMnSiA alloy steel specimens, the rust on the surface is removed and the specimens are weighed by means of a JJ200 electronic balance.

Test temperature: Solutions for corrosion test are kept in such six different temperatures as 50 ℃, 28℃, 5℃, 0℃, –5℃ and –25℃. The volumetric ratios of corrosion test solutions are as follows: NaCl, 4 mol/L; KNO_3, 0.5 mol/L; HNO_3, 0.1 mol/L. The area-volume ratio is 13.3. After corrosion test, the Ly12cz and Lc4cs aluminum alloy specimens are lengthwise cut apart and made into metallographic specimens, and the corrosion depth is checked by using a Neopht-1 horizontal-type metalloscope. The corrosion amount of 30CrMnSiA alloy steel specimens is checked by weighing, i.e. by comparing the weight difference of specimens before and after the corrosion test. 5 specimens are sampled from each kind of material, and the average value of the maximum corrosion amount of the 5 specimens is taken as the test result.

3 Test Result

3.1 The corrosion test data of Ly12cz aluminum alloy sheet is as shown in Table 2; the T-H test curve is as shown in Fig. 1.

Table 2 T-H curve data of average corrosion up to 1 mm for Ly12cz aluminum alloy sheet

Test Temp. T(℃)	-25	-5	0	5	28	50
Test time (H)	114	114	114	114	114	114
Average corrosion depth (mm)	0	0	0.24	0.32	0.81	1.83
Time required for average corrosion up to 1 mm (H)	∞	∞	475	356.3	140.7	62.3

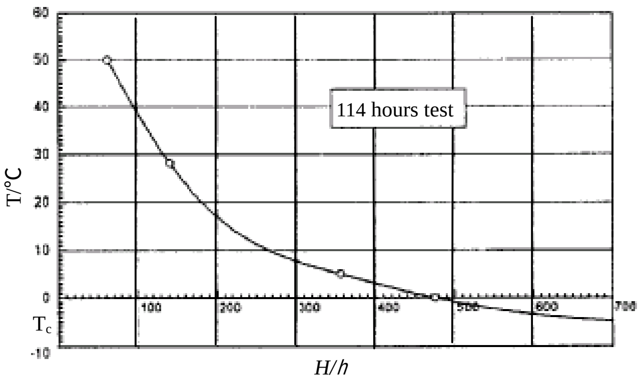

Fig. 1 T-H test curve of average corrosion up to 1 mm for Ly12cz aluminum alloy sheet

3.2 The corrosion test data of Lc4cs aluminum alloy sheet is as shown in Table 3; the T-H test curve is as shown in Fig. 2.

Table 3 T-H curve data of average corrosion up to 1 mm for Lc4cs aluminum alloy sheet

Test Temp. T(℃)	-25	-5	0	28	50
Test time (H)	40	40	40	40	40
Average corrosion depth (mm)	0	0.28	0.33	0.52	0.90
Time required for average corrosion up to 1 mm (H)	∞	142.9	121.2	76.9	44.4

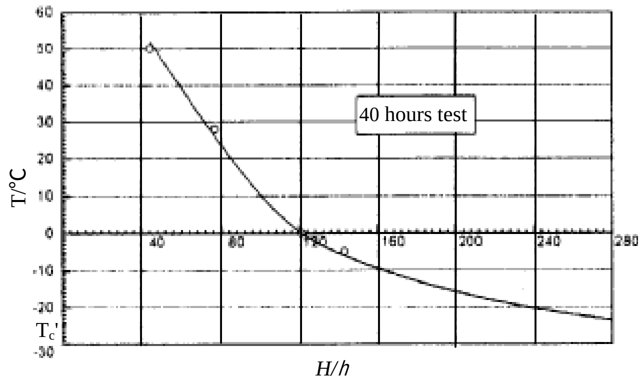

Fig. 2 T-H test curve of average corrosion up to 1 mm for Lc4cs aluminum alloy sheet

3.3 The corrosion test data of 30CrMnSiA alloy steel sheet is as shown in Table 4; the T-H test curve is as shown in Fig. 3.

Table 4 T-H curve data of average corrosion up to 1 mg per square centimeter for 30CrMnSiA alloy steel sheet

Test Temp. T(℃)	-25	0	5	28	60
Test time (H)	120	120	120	120	120
Average corrosion weight (mg)	0.9	5	6.8	44.9	63.5
Time required for average corrosion up to 1 mg (H)	133.3	24	17.6	2.67	1.89

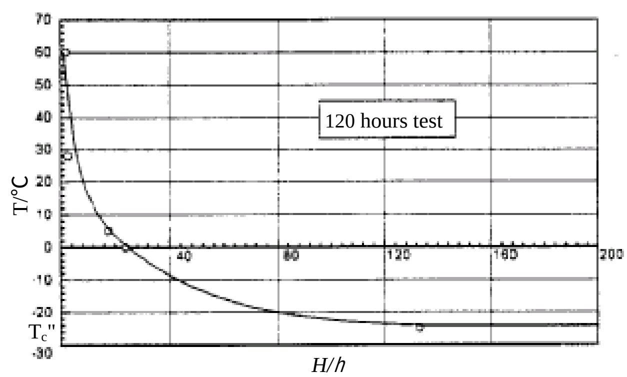

Fig. 3 T-H test curve of average corrosion up to 1 mg per square centimeter for 30CrMnSiA alloy steel sheet

4 Test Analysis

It can be obtained from the three corrosion test T-H curves of Fig. 1, Fig. 2 and Fig. 3 that:

4.1 The corrosion test T-H curves of three kinds of materials have a common law, i.e. when the average corrosion is 1 mm in depth (or 1 mg in weight), the corrosion time increases with the decrease in corrosion temperature. When the temperature decreases to a critical value of T_c, the corrosion time tends to be infinite, i.e. the material tends to be of no corrosion.

4.2 Profiles of the three T-H curves and the critical temperature T_c of the three materials are different from one another. Such a difference indicates that different materials have their own corrosion characteristics. It can also be obviously seen that the critical corrosion temperature T_c of Ly12cz is higher than the critical corrosion temperatures T_c' and T_c'' of Lc4cs and 30CrMnSiA.

4.3 Corrosion test T-H curves of three kinds of materials have different slopes.

5 Conclusion and Discussion

5.1 Through the corrosion test and research on the said three materials, the law of distribution as shown in Figs. 1, 2 and 3 has been obtained, the critical corrosion temperature T_c for each of the three materials has been found. Such a conclusion indicates that if a piece of metal is immersed in some corrosive solution, the corrosion process stops whenever the corrosion temperature T_i is lower than the critical corrosion temperature T_c (i.e. $T_c > T_i$) of the metallic material.

Such a conclusion is not only valuable to the determination of calendar service life of aircraft, but also important to the amendment to fatigue life of aircraft under corrosion environment. As everybody knows that the aircraft, in most cases, flies at high altitudes where the ambient temperature is usually about –50℃. We can see from Figs. 1, 2 and 3 that the critical corrosion temperature T_c of Ly12cz is around –5 ℃, while critical corrosion temperatures T_c' and T_c'' of Lc4cs and 30CrMnSiA are about –25℃. It means that the corrosion of the aircraft structure stops when the aircraft flies at high altitudes under an environmental temperature of –50 ℃. Hence maybe, an amendment is not necessary to the fatigue life of the aircraft when the structure of the aircraft suffers no corrosion damage and, the flight time under such an environment may be counted directly into the total calendar life of the aircraft. Therefore, such a conclusion of research is of importance to both determination of calendar service life of aircraft and amendment to the fatigue life of the aircraft.

5.2 The corrosion test and research on the three materials of Ly12cz, Lc4cs and 30CrMnSiA, not only derives the law of distribution as shown in Figs. 1, 2 and 3, but also verifies that the law of change in corrosion time with respect to the corrosion temperature is correct when metals are put in corrosive solution as described in Reference [5], and that the prediction model (1), derived in Reference [5], on calendar life of metal corrosion is tenable.

$$\lambda \sum_{j=1}^{m} \sum_{i=1}^{k} \frac{h_i}{H_i} = 1 \qquad (1)$$

Where, H_i denotes the time in hours in which a corrodible part, being placed in certain medium and under a temperature of class i, is corroded to a specified depth D_c; h_i denotes the time in hours corresponding to temperature of class i in an adopted temperature spectrum; λ, the total blocks of cycles of the adopted temperature spectrum when the corrodible part is corroded to a specified depth D_c under the combined action of m kinds of media; k denotes the numbers of classes of a given temperature spectrum and m is the number of corrosion media.

5.3 Problems Pending further Discussions and Explanations

5.3.1 Conclusions drawn in this Paper are only confined to the three kinds of materials of Ly12cz, Lc4cs and 30CrMnSiA. Other materials should normally follow the same law as the three materials do. However, this is pending on further tests and researches.

5.3.2 Tests under an environment of –50℃ were planned at the beginning. Tests thereafter of the three materials show that there exists almost no corrosion to the specimens when the temperature reaches –25℃. Therefore, no further tests have been done for specimens at temperatures below –25℃.

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