Reliability evaluation for shot peened specimen of the aircraft components manufactured Al7075-T6 by accelerated life tests

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Abstract
The object of this work is to consider reliability evaluation for shot peened specimen of the aircraft material Al7075-T6 by accelerated life tests (ALTs), which provides information more quickly on the life-time distribution of components. ALT, is commonly used under not only higher stress level but also higher temperature to induce early failures and to reduce testing efforts. Fatigue test of the shot peened specimen was executed by using the reasonable variety temperatures for the estimated life time with four-point rotary bending fatigue test. By changing the test temperature and the test profile amplitude, a simple equation was proposed to relate ALT durable durations to the equivalent stress. The laboratory testing of the ALT was carried out and the possible effects of errors in estimate of life time were investigated and discussed.

Keywords: Accelerated life testing (ALT), shot peening, reliability evaluation, fatigue test.

Introduction

Shot peening (SP) is the most commonly used surface treatment technique, which has been widely applied to improve fatigue performance of components [1][2]. Since it is one of the most important factors for the safety structures, many studies on SP have been conducted in the industry for over six decades [1]. However, it is difficult to determine life because of the difficulty of the test, such as a fatigue test which requires longtime even under perfect handling. Moreover the rapid development of technology and the advanced mechanical product in the industry field are become change much faster than before [3]. In order to satisfy the competition of the industry, it is urgent to reduce the new technology development cycle and to decrease development cost greatly. As we know, fatigue test is way to demonstrate the effect of the shot peening. However, it takes long time to perform fatigue test of the shot peened specimen at normal condition, such as at a room temperature, which means long time and high cost. The relatively short time of fatigue test usually does not allow observing failures of test specimen, so the accelerated life testing (ALT) is applied to overcome this shortcoming. In ALT, the specimen is tested under more severe conditions than usual, such as load, temperature, humidity level and other possible, to shorten test time [4][5]. During the ALT test, more failures may be observed. With the given the ALT data, it is possible to estimate and to predict the fatigue life of the test specimen under usual stress level at shorten test time. The primary standard for determining test acceleration severe conditions is that the failure mode or failure mechanism must be from the same as that expected from a non-accelerated test [6]. ALT is one of the best ways to predict life time compare with experiment result. This paper presents a combination between actual fatigue test processing with shot peened specimen and ALT methods for reliability evaluation.

Experimental Methods

ALT is based on the principle that under the accelerated test conditions, the information of products or materials can be obtained quickly than that at the normal test conditions [5]. In general, operational life test under normal conditions would be so long that for testing at those conditions would not be possible for many structures and materials. The life testing can be applied to validate the predictions by ALT models. This testing can be performed either at the operating environment such as room temperature at around 25℃ or at an elevated temperatures (373K, 423K, 473K) to accelerate failure mechanism. The method used is the accelerated life testing and is based on failure using four pointing bending fatigue test on metallic materials. The mechanism was describe by the Arrhenius life-stress model (or relationship) and the Inverse power law model (or relationship). Both models can be used to predict the reduction of the fatigue life from the operating temperature.

Arrhenius model

The Arrhenius life-stress model is the most widely used life-stress relationship method in the ALT [5]. It is used when the accelerate factor is thermal such as a temperature. It is from the Arrhenius reaction rate equation. The Arrhenius model is formulated by assuming that life is proportional to the inverse rate of the process. The Arrhenius life-stress relationship is given by:

$$t_f = A \cdot \exp(E_a / kT) \qquad (1)$$

where t_f is failure time, A is a constant factor, E_a is activation energy , k is Boltzman's constant(8.617×10^{-5} eV/K) and T is reaction temperature, in K.

Inverse power law model

The inverse power law(IPL) model (or relationship) is commonly used for thermal cycling (in general [5]) accelerated stress and is given by:

$$t_f = \frac{C}{V^A} \qquad (2)$$

Where t_f is failure time, C is a constant characteristic of the metal and V^A is accelerated stress level.

In this study, both Arrhenius model and the Inverse power law model are used predict the ALT high temperature conditions in the process.

Test specimen preparation

The material used in this study was the high-strength aluminum alloy Al7075-T6 which is mostly used in the aircraft manufactured components. All the specimens was around 90±0.1mm, the minimum diameter was around 8±0.1mm. Each specimen was polished with #2000 sand paper and then treated with metal polish solution. Fatigue test specimens were machined as shown in Figure 1. Table 1 and Table 2 show the chemical composition and mechanical properties, respectively.

Shot peening treatment

The process of SP treatment is illustrated in Figure 2. It was performed according to the optimized peening intensity as well as controlled surface coverage, impeller rotational velocity and the specimen masking. The SP process uses conditioned cut wire shot with mean diameter of 0.8mm. Especially, the impeller type peening machine can be controlled rotational speed. From above conditions, we were determined optimal arc height from for this alloy and more specific peening conditions shown in Table 3.

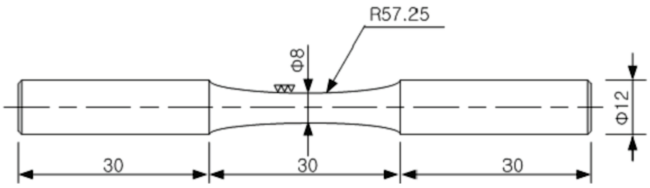

Figure 1. The shape of rotating beam fatigue specimen.

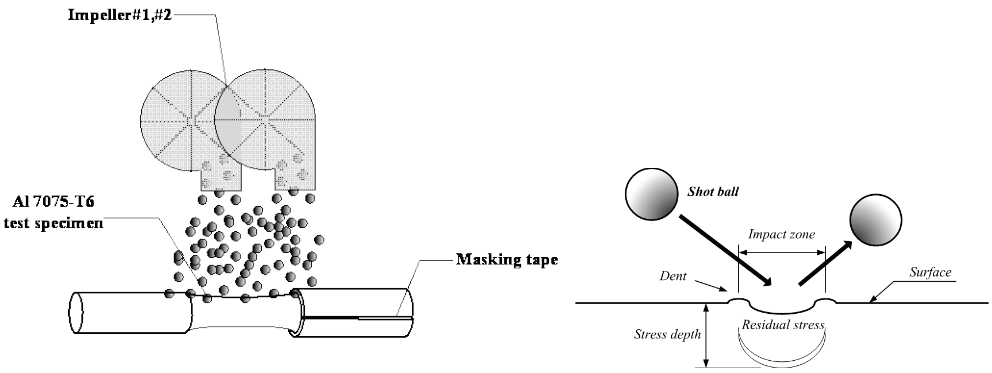

Figure 2. Process of the Shot peening treatment.

Table 1. Chemical composition of Al 7075-T6.

Mn	Si	Fe	Cu	Mg	Ti	Ti+ Zr	Cr	Zn
0.14	0.15	0.29	1.60 1.65	2.4 2.5	0.03	0.25	0.19 0.20	5.7 5.8

Table 2 Mechanical properties of Al 7075-T6.

Element	Ultimate Strength (MPa)	Yield Strength (MPa)	Elongation(%)
Values	635	578	9

Table 3 Shot peening process conditions.

Content	Shot peening
Shot ball diameter	0.8 mm
Impeller rotational speed	40 m/s
Time	6 min
Coverage	above 100%
Arc height	0.269 mmA

Experimental Results

The test for determine to optimize peening conditions through the fatigue test with Almen intensity (Figure. 3) and results are shown in Figure. 4 where was a large variation in mean temperature range which carried the accelerated level. The results indicate that the fatigue life decrease due to high temperature of un-peened test specimens and shot peened test specimens. Both results are significantly decreased at 573K test conditions.

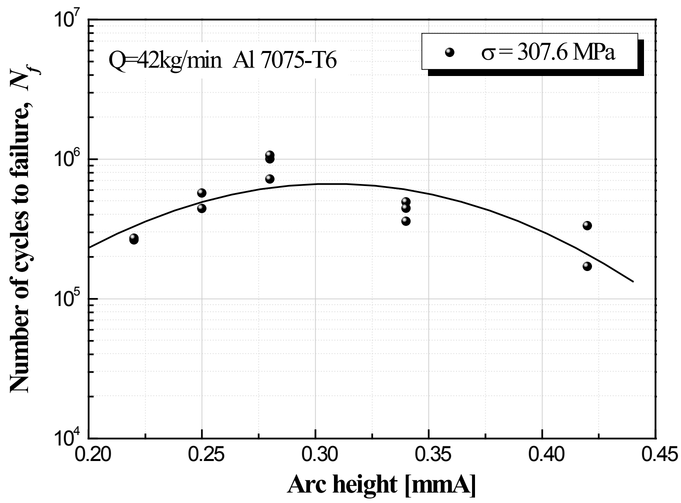

Figure 3. Effect of arc height on the fatigue life.

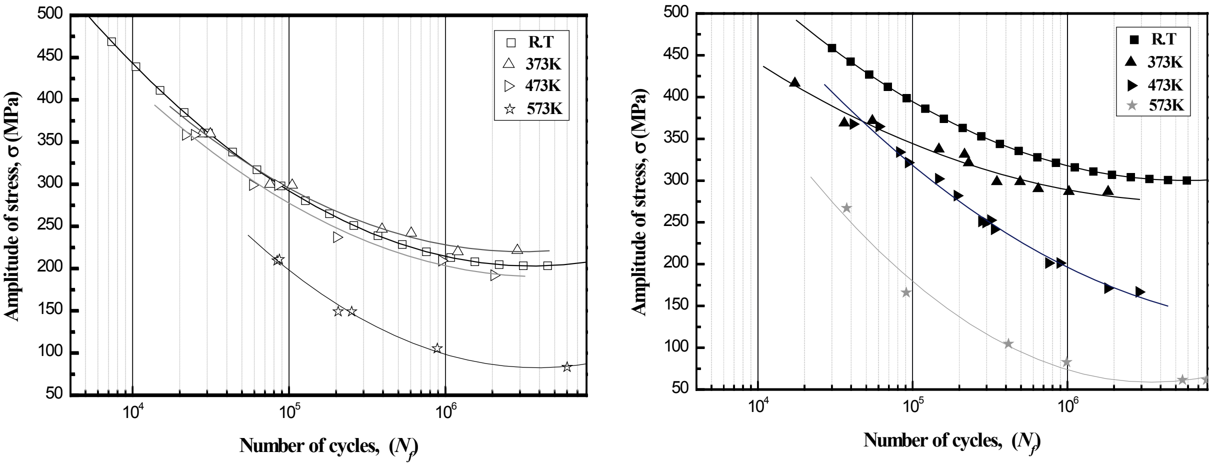

Figure 4. S-N curves for shot peened specimens under high temperature conditions.

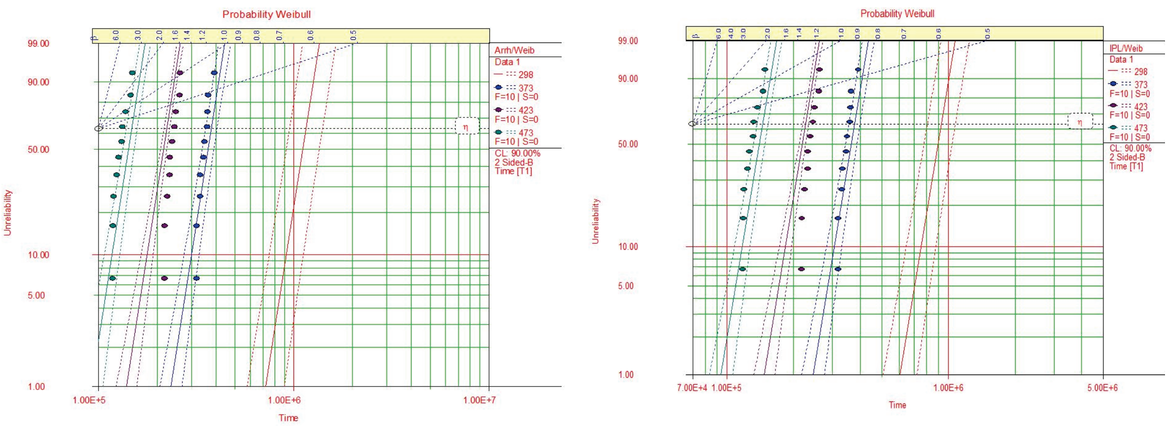

Figure 5. Probability Weibull plot for accelerated conditions of three temperature level.

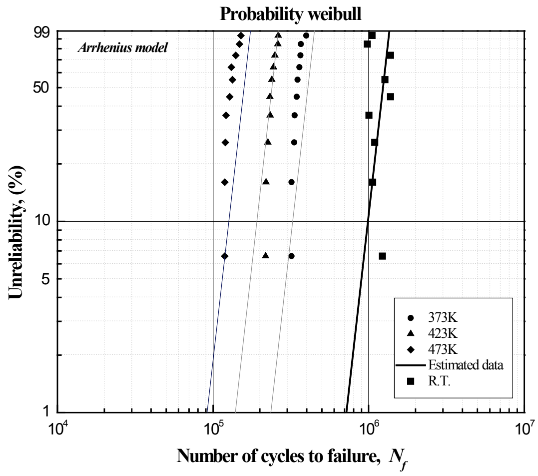

Figure 6. Comparison between Arrhenius model data and experimental data.

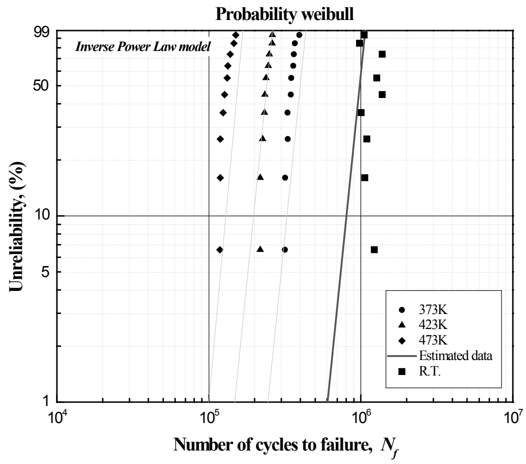

Figure 7. Comparison between Inverse power law model data and experimental data.

Figure 5. shows that the data analysis by ALTA 6.0. Thus temperature(373K, 423K, 473K) should be held constant and equal to the intended values. Such distribution lines must be parallel. However, if two lines crossed, it would mean that the test units under accelerated conditions where happened unexpected failure mode [4]. As a result at Fig.6 and Fig.7, we estimated fatigue life of the standard test, the data from ALT models. In addition, we can gain the approximately balanced estimation of fatigue life and failure rate at the normal condition using the ALT methods.

Discussion and Conclusions

In this study is experimentally obtained by shot peened specimens testing and it contains operational failure data with high temperature conditions for analysis. The accelerated life test methods that can reduce the fatigue life test time of shot peened materials. The failure criterion acceleration method applied Arrhenius model and Inverse power law model. In the temperature acceleration method, the acceleration linearity existed between 373K and 473K, it is assumed that the range of test temperature for optimum test plan, so the life test will be completed within a reasonable time as judged by previous experience. However, the approach used in this study could be applied on the other test which may be more critical in different test condition levels.

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