Effects of Shot Peening on Fatigue Life of Ground Component of 7075-T6 Aluminum Alloy

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Abstract. The aircraft corroded components can continue to be used after removing the corroded portion by grinding and strengthening the ground area by shot peening. The finite element analysis model of the ground specimen with complex shape surface was established based on ABAQUS software. The residual stress distributions under three conditions of without shot peening, ground surface shot peening and three surfaces shot peening were analysed. On this basis, the cyclic alternating load was introduced into the shot peening model, and the fatigue analysis was carried out based on MSC. Fatigue software. The result shows that the position of the maximum tensile stress moves from the surface to the subsurface of the ground specimen after shot peening; shot peening conditions will affect the location of the crack sources, the propagation direction of the crack; with the increasing of the numbers of peened surface, the location of stress danger point shifts from ground surface to side surface or sub-surface, and the crack propagation velocity decreases. All of these increases the fatigue life. The experimental results conform well to the simulation one.

1. Introduction

Aircraft structural components are easily corroded due to the working environment. Some slight corroded components can continue to be used after removing the corroded material by grinding and then strengthening the ground area by shot peening before the final surface anti-corrosion treatment. Residual stress field is induced in the surface layer of the ground component after shot peening. The fatigue life and the corrosion resistance of the strengthened component improve substantially under the influence of residual compressive stress [1, 2].

In the past decades, fatigue life improvement by shot peening is a hot research topic [3, 4]. Y.K. Gao [5] investigated the fatigue properties of 7050-T7451 aluminum alloy after shot peening, and the results show that the fatigue life of the shot peened component improves significantly compared with the machined one. Y.K. Gao et al. [6] analyzed the influence of shot peening on small crack growth and fatigue life of 7475-T7351 aluminum alloy. Their results show that cracks initiate at the second phase particles of the alloy and the growth rate of fatigue crack reduces greatly after shot peening. G.H. Majzoobi et al. [7] focus on the fretting fatigue life of 7075 aluminum alloy after shot peening, and the results show that the low cycle fatigue life increased by 300% after shot peening.

In this paper, the 7075-T6 aluminum alloy ground specimen was taken as the researching object. The stress response of shot peened ground specimen under the cyclic alternating load was investigated. The comparison between the simulation and experimental results of fatigue life and the position of the most dangerous area or crack sources of the ground specimen was carried out.
2. Establishment of the Shot Peening Macro-scale Finite Element Analysis (FEA) Model

In practice, the corrosion penetrating through the width direction of the structural components occurs frequently, as shown in Figure 1. The specimen with corrosion is firstly disassembled and then ground the corroded area.

Afazov et al. [8] proposed an element mapping (EM) method, by which the residual stress was mapped from the micro-scale FEA model to the macro-scale one. Li et al. [9] analysed the influence of the residual stress and on the crack propagation based on the EM method. In Figure 2, the residual stress was obtained by the fixed peening angle (as shown in Figure 3) through the micro-scale FEA model established by ABAQUS software.

The macro-scale FEA model was shown in Figure 4. The depth of the ground portion $h_d=2$ mm, the concave and convex fillet radius $r_d=2$ mm, and the inclination angle of oblique plane $a_d=30^\circ$, which are the same as the micro-scale one; while the length, width, and height of the specimen is 30 mm, 2.5 mm and 10 mm. The model was used to obtained the residual stresses under three different shot peening conditions (condition-1: without shot peening; condition-2: top surface shot peening; condition-3: three surfaces shot peening).

Figure 5 shows the macro-scale FEA model based on the size of Figure 4. The establishment of the model includes two steps. The first one is to obtain the residual stress field of the micro-scale FEA model after shot peening and map it to the macro-scale FEA model. The second one is to set the
boundary conditions and loads of the macro-scale FEA model. In the macro-scale FEA model, the left end face is fixed constraint, and the right end face is applied with cyclic alternating load in X-axis direction (maximum stress is 120 MPa, stress ratio is 0.1, frequency is 100 Hz). Finally, the obtained stresses were used to analyze the fatigue crack growth of the ground specimens based on software MSC. Fatigue [10].

To verify the reliability of the residual stress obtained by the micro-scale FEA model, X-ray diffraction method was used to measure the residual stress on the specimen surface. The results show that the maximum deviation between the simulated and measured values is 5.15%. This means that the residual stress field obtained by the model is reliable.

3. Numerical Simulation Analyses

3.1. Stress Distributions of the Shot Peened Specimens under the Cyclic Alternating Load

Figure 6 shows the simulation results of the peened specimen with cyclic alternating load. The results show that the maximum stress on the ground surface $\sigma_{\text{max-surf}}$ locates near the centre point of the concave surface due to the stress concentration; the maximum stress on the side surface $\sigma_{\text{max-side}}$ locates at the point B, which is in the centreline of the side surface and near the upper surface.

Table 1 shows the maximum stress $\sigma_{\text{max-surf}}$ at the concave surface point A, the maximum stress $\sigma_{\text{max-side}}$ at the side surface point B, the maximum stress $\sigma_{\max}$ in the specimen. Li et al. [11] proposed the concepts of surface fatigue limit (SFL) and interior fatigue limit (IFL), and investigated the relationship of the critical stress causing the mesoscopic-yield between the surface material and the interior material. The results show that the ratio of the interior maximum stress to the surface one is approximately $\sqrt{2}$. It indicates that the fatigue crack source is more difficult to initiate from the interior than from the surface of specimens.

![Figure 6. Simulation results of the ground specimen with cyclic alternating load](image)

| Condition | $\sigma_{\text{max-surf}}$ (MPa) | $\sigma_{\text{max-side}}$ (MPa) | $\sigma_{\max}$ (MPa) | $\sigma_{\max}/\sigma_{\text{max-surf}}$ | $\sigma_{\max}/\sigma_{\text{max-side}}$ |
|-----------|-------------------------------|-------------------------------|-----------------|-----------------------------|-----------------------------|
| Condition-1 | 330.1 | 272.3 | 330.1 | 1.000 | 1.212 |
| Condition-2 | 212.9 | 260.1 | 346.0 | 1.625 | 1.330 |
| Condition-3 | 238.5 | 167.3 | 351.5 | 1.625 | 2.101 |

The ratio $\sigma_{\max}/\sigma_{\text{max-surf}}$ and $\sigma_{\max}/\sigma_{\text{max-side}}$ listed in Table 1 shows that:

1) Under condition-1, both the value of $\sigma_{\max}/\sigma_{\text{max-surf}}$ and $\sigma_{\max}/\sigma_{\text{max-side}}$ are smaller than $\sqrt{2}$ and $\sigma_{\max}$ is greater than $\sigma_{\max-side}$. It indicates that the fatigue crack source is located on surface near point A.

2) Under condition-2, the value of $\sigma_{\max}/\sigma_{\text{max-surf}}$ is bigger than $\sqrt{2}$, and the $\sigma_{\max}/\sigma_{\text{max-side}}$ is still smaller than $\sqrt{2}$. The ground surface is strengthened by shot peening. However, the two side surfaces become the new dangerous areas, the fatigue crack source is located on side surface near point B.

3) Under condition-3, both the value of $\sigma_{\max}/\sigma_{\text{max-surf}}$ and $\sigma_{\max}/\sigma_{\text{max-side}}$ are bigger than $\sqrt{2}$. It indicates that the whole ground specimen is strengthened by shot peening, and the position of fatigue crack source moves to the sub-surface of specimen. The fatigue property of the ground specimen
improves effectively. Meanwhile $\sigma_{\text{max-surf}}$ is greater than $\sigma_{\text{max-side}}$ under condition-3. The stress dangerous point of fatigue crack source is located on the sub-surface near the point A.

3.2. Effect of Shot Peening on the Fatigue Life of the Specimens

Figure 7 shows the simulation results of fatigue crack propagation under the three different shot peening conditions. The results show that when the crack length propagated to 5mm, the specimen almost fatigue fracture. The propagating lives were $8.29 \times 10^4$ cycles, $1.53 \times 10^5$ cycles, and $1.29 \times 10^6$ cycles. When the crack length is below 1 mm, the crack propagation velocity is significantly affected by the surface stress level of the specimen, while the crack propagation velocity increases rapidly after the crack length exceeds 1 mm. From condition-1 to condition-3, the initial crack propagation velocity gradually decreases due to the gradual increase of the surface residual compressive stress, which resulted in a gradual increase in the total fatigue life.

![Figure 7. Fatigue crack growth under three different shot peening conditions](image)

4. Experimental Research on the Effect of Shot Peening on the Fatigue Life

4.1. Experimental Conditions

The shape and size of the fatigue specimen is shown in Figure 8, all of the specimens were machined along with the rolling direction of material, where the shaded areas of the specimens being shot peened under condition-2 (only ground surface $A_1$ was shot peened) and condition-3 (ground surface $A_1$, two side surfaces $A_2$ and $A_3$ were shot peened). Four specimens were tested repeatedly for each condition and the average value of cycles was regard as the fatigue life of each condition. The definition of three shot peening conditions, the process parameters of shot peening, the cyclic alternating load and the main geometry sizes of specimen are the same as that in simulation. All of the fatigue tests were carried out according to the standard HB 5287-96 [12] by using MAG-100 KN high frequency fatigue testing machine.

![Figure 8. Shape and size of the fatigue specimens (mm)](image)
4.2. Results and analysis

4.2.1. Position of fatigue fracture

Figure 9 shows the fatigue fracture of specimens. It shows that the fracture under condition-1 and -3 located near point A. As analyzed above, the dangerous area of the fatigue specimen located on the concave surface (near point A) under condition-1, and in sub-surface near point A under condition-3. Therefore, both of the two positions of fractures locate near the concave surface. For the specimen under condition-2, the dangerous area locates in the center-line of the side surface near the ground surface (near point B). Therefore, the fracture located near the center of the specimen.

Figure 9. Fracture location of fatigue specimens

4.2.2. Initiating position and propagating direction of crack

Figure 10 shows the fatigue fracture morphology. The small circles mean the position of the fatigue crack sources and the arrows indicate the cracks propagating direction. The results show that: 1) For the specimen under condition-1, multiple fatigue crack sources occur and located on the concave arc of the ground surface. The cracks propagate mainly along the thickness direction of the specimen; 2) For the specimen under condition-2, only one fatigue crack source occurs and located on the side surface of the specimen, the crack propagates mainly along the width direction of the specimen; 3) For the specimen under condition-3, also only one fatigue crack source occurs and located in the sub-surface of concave arc below point A, the crack propagates mainly along the thickness direction of the specimen.

Figure 10. Initiating position and propagating direction of fatigue cracks

4.3. Comparison between Simulation and Experimental Results

Under the experimental and simulation conditions of this article, the average fatigue life obtained by experimental under three different shot peening conditions were $8 \times 10^4$ cycles, $1.52 \times 10^5$ cycles, and $1.50 \times 10^6$ cycles, and that obtained by the simulation were $8.29 \times 10^4$ cycles, $1.53 \times 10^5$ cycles, and $1.29 \times 10^6$ cycles. The fatigue life coincides well each other.
5. Conclusions
The main conclusions are as follows:
1) The stress dangerous points of fatigue cracks for the ground specimen without shot peening is located on the ground surface, while that of the specimen with ground surface or three surfaces shot peening is located on the side surface or the sub-surface.
2) Shot peening can reduce the number of specimen crack sources. For the specimen without shot peening, there are multiple fatigue crack sources; for the ground specimen with shot peening, there is only one fatigue crack source.
3) The fatigue life improves greatly by shot peening. The fatigue life of the ground specimen with ground surface and three surfaces shot peening are 1.84 times and 15.56 times of that without shot peening, respectively.

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7. References
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