Effect of different surface conditions on fatigue properties of 7N01 aluminum alloy and the behavioral mechanism of crack of the alloy under alternating load

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Abstract

In this paper, the surface of 7N01 aluminum alloy profile is sandblasted or electropolished. The influence of different surface conditions on its conditional fatigue strength and fatigue mechanism under the alternating load after prefabricated short crack are studied. Results show that the 7N01 aluminum alloy with sandblasting treatment has formed a work hardened layer and its fatigue strength is increased by 42.9% comparing with the original surface specimens. The fatigue strength of the 7N01 aluminum alloy after electropolishing is almost unchanged compared with the original specimen. The fatigue behavior of the 7N01 aluminum alloy after prefabricated side straight through the notch deviated from the theoretical smooth specimen law and long crack propagation law in which is a ‘shortage effect’. When the notch size is smaller than the transition crack size $a_0$, the fatigue limit of the notched specimen is lower than the fatigue limit of the smooth specimen. When the notch size is larger than the transition crack size, the fatigue limit of the long-notched specimen is still lower than that predicted by linear elastic fracture mechanics. Due to the ‘short notch effect’, the effective notch propagation threshold $\Delta K_{eff, th}$ of the long crack is $0.39 \text{ Mpa m}^{1/2}$ based on the effective notch propagation size $a_{0\text{eff}}$ of the alloy.

1. Introduction

Al–Zn–Mg alloy (7000 series aluminum alloy) is widely used in aerospace, high-speed railway and other fields due to its low density, high strength, high specific strength and good weldability [1, 2]. 7N01 aluminum alloy is one of the representative alloys of 7000 series aluminum alloy. It not only has the characteristics of 7000 series aluminum alloy, but also has excellent extrusion performance, effective performance and good corrosion resistance. It is often used as structural material for brackets, section beams, end walls and other essential elements on high-speed train to meet the requirements of easy design, manufacturing, strength, light weight, and safety [3–6]. These applications are mostly high-speed, complex environments, and prevention of fatigue fracture under catastrophic alternating stress so that it becomes a critical challenge for the current application of the alloy.

The factors that determine the safety and stability of 7N01 aluminum alloy on high-speed train include strength, oxidation resistance, corrosion resistance, creep performance, low cycle and high cycle fatigue performance, among which the most critical is the ability to resist fatigue crack initiation. This is because the alternating stress experienced in the actual operation of high-speed train components is composed of a variety of simplified stresses, such as different loading frequencies or amplitudes, which makes the alternating stress very complicated [7]. Under the long-term effect of complex alternating stress, these structures will undergo cumulative damage and cause fatigue fracture. Previous studies have shown that about 70%–80% of structural failures are caused by fatigue fracture [8–10]. Therefore, these structures need to be additionally protected.
According to the standard of GB 2.2. Surface treatment specimen by wire cut electrical discharge machining perchloric acid the specimen is placed with the power anode and the cathode in stainless steel plate. The electrolyte is 10% original surfaces. The specimens solution treatment was performed at 475°C–500°C for 2 h, followed by water quenching process immediately and then artificial ageing at 120°C for 24 h.

However, the maximum resistance of crack initiation based on smooth specimens is not completely consistent with the actual service of aluminum alloys. This is because the fatigue life of the structures is highly dependent on surface conditions and fatigue cracks usually begin with the free surface of the material [12]. Whether it is the true evaluation of the fatigue life of the aluminum alloy during service, or the design of high-life aluminum alloy components, the different surface conditions of the aluminum alloy must be considered. Relevant literature showed that surface strengthening or smooth treatment of alloys can play an important role in delaying the initiation and propagation of fatigue cracks, such as shot peening and electro polishing [13, 14]. For example, after shot peening, the surface of some aluminum alloys undergoes local plastic deformation can form a compressive stress field due to the introduced compressive residual stress, in this way the fatigue property is obviously improved [15–19]. After electropolishing, the surface is free from stress concentration, then it will hinder the fatigue crack nucleation, which has different effects on alloys with different strength, which is reported in some alloy steels and titanium aluminum alloys [14, 20–22]. However, the research on the influence of surface conditions on the fatigue performance of aluminum alloys is mostly focused on surface strengthening treatment. The effect of surface smoothness on the fatigue of aluminum alloy has rarely been reported. The study on the fatigue effects of various surface conditions on the same kind of aluminum alloy is rarely involved.

In addition, in the process of machining, transporting, assembling and loading, the aluminum alloy components may form stress concentrated micro-regions or crack on the surface/interior. Structural damages are also caused by sand erosion or strikes of foreign bodies when used as the high-speed train body material [23, 24]. These defects, cracks and damages formed on the surface are small in size and shallow in distribution as they have the characteristics of typical ‘short crack’. The study found that when other alloys have defects such as micro-notches, the fatigue limit does not meet the traditional linear elastic fracture mechanics theory and the high-cycle fatigue limit design criteria for smooth specimens [25, 26]. Therefore, it is necessary to conduct an in-depth study on the fatigue mechanical behavior of aluminum alloys with micro-cracks or notches, which will be related to the safety and reliability of aluminum alloys during service.

In this paper, 7N01 aluminum alloy profiles, which are key structural materials commonly used in high-speed train bodies, are selected to study the influence mechanism of different surface conditions (original, sandblasting, electropolishing) on the conditional fatigue strength and the behavior of the alloy crack under alternating load. This work aims to systematically investigate surface defects, crack initiation and propagation, and other stress concentrations, the defect/crack sensitivity of the alloy, and their relationship to the conditional fatigue strength.

2. Experimental

2.1. Material

The materials used in this experiment are 7N01-T55 aluminum alloy profiles which are directly used for high-speed railway after production and processing. The chemical composition is shown in table 1. T5 code relates to a status of aluminum alloys which is cooled in high-temperature molding process and then artificially aged. The solution treatment was performed at 475 °C for 2 h, followed by water quenching process immediately and then artificial ageing at 120 °C for 24 h.

2.2. Surface treatment

According to the standard of GB/T3075-2008 [27], the 7N01 aluminum alloy profile was cut into fatigue specimen by wire cut electrical discharge machining (WEDM), the dimensions of which are shown in figure 1. They were divided into three groups of A, B and C, each group with 10 specimens, and processed in different surface conditions, as shown in table 2. The specimens’ surfaces of group A were not treated and defined as the original surfaces. The specimens’ surface of group B were treated by electropolishing. During electropolishing, the specimen is placed with the power anode and the cathode in stainless steel plate. The electrolyte is 10% perchloric acid +90% absolute ethanol (volume fraction). The electrolyzing was processed at 10 °C–20 °C with

| Compositions | Zn | Mg | Mn | Si | Fe | Cu | Cr | Ti | Zr | Al |
|--------------|----|----|----|----|----|----|----|----|----|----|
| wt%          | 4.5–5.0 | 1.0–2.0 | 0.2–0.7 | <0.30 | <0.35 | <0.20 | <0.30 | <0.20 | <0.25 | Bal. |

| Table 1. Chemical composition of 7N01 aluminum alloy. |
voltage of 20 V. The two ends of the specimen enter the electrolyte in turn for electrolysis, and each end is electrolyzed for 40 s. In the process of electropolishing, the specimen is shaken slowly to avoid the attachment of electrolytic products on the surface of the specimen and affect the electrolytic effect. The specimens’ surface of group C were sandblasted. Sandblasting is performed on a YX-9060B sandblasting machine. When sandblasting, the surface of the specimen was made in the distance of 200 mm from the end of the blasting nozzle, and the spray angle is 65°. The sandblasting process was conducted with 46-mesh white corundum under the pressure of $5 \times 10^5$ Pa.

### 2.3. Roughness ($R_a$) and microhardness test

The surface roughness of 7N01 aluminum alloy specimens with different surface conditions was tested by GT-K-I white light interferometer. The average $R_a$ value of each group was from five specimens, and each specimen was tested for four values. The microhardness was tested by DHV-1000ZTEST digital microhardness tester with an indenter load of 50 g and a loading time of 15 s. One specimen is optional for each group, and each specimen is tested at four points at the same position from the surface, and then the average value is chosen.

### 2.4. Fatigue strength and crack propagation test

The fatigue performance was tested by PLG-100 microcomputer controlled high frequency fatigue tester at room temperature. The stress ratio is $R = 0.3$ ($R = \sigma_{\text{min}}/\sigma_{\text{max}}$) and the test frequency is 65 Hz. The surface of different processing conditions is the maximum force surface. Side crack propagation was used in the fatigue crack propagation rate experiment at room temperature, the stress ratio is $R = 0.3$ and the test frequency is 75 Hz. According to the standard of GB/T6398–2017 [28], the straight through notch is prefabricated by WEDM on the side of the original surface fatigue specimen of 7N01 aluminum alloy. The depth of the notch is 2 mm~3 mm and the width is 150 $\mu$m. In this experiment, the DC voltage drop method was used to monitor the crack size during crack propagation.

### 2.5. Microstructure test

The microstructure of the 7N01 original specimen along the extrusion direction, the surface morphology of the specimens after different surface conditions, and the microstructure of the fracture surface were observed. The microstructure and corresponding microscopic morphology of the specimens were observed on JEM-7800F scanning electron microscope (SEM) using secondary electron imaging technology with an accelerating voltage of 20 kV. The metallographic observation of the specimens was performed on Zeiss Axio Imager.A1m optical microscope (OM), and the metallographic etching solution was HF:HCL:HNO$_3$:H$_2$O $= 1$ ml: 1.5 ml: 2.5 ml: 190 ml, and the etching time was 45 s.
3. Results

3.1. Surface roughness (Ra) results

The surface roughness is represented by the average Ra value of a certain length on the surface characterized by amplitude fluctuation. The three-dimensional morphology of white light interference of the three groups of specimens is shown in figure 2, and the surface roughness test results are shown in table 3. It can be known that the surface roughness of the sandblasted specimen is the highest, about 10 times of the other two surface roughness. The surface of the electropolished specimen has the lowest roughness, and the roughness is not significantly reduced compared with the original specimen surface.

3.2. Micro-hardness results

Figure 3 shows the change in microhardness of 7N01 aluminum alloy specimen with different surface conditions. Obviously, the surface of the specimen after sandblasting produced strain hardening. As a result, the Vickers hardness of the surface layer increased by 320 MPa (HV0.05) more than that of the core of specimens. The surface hardening is caused by plastic deformation due to surface compressive stress introduced by
sandblasting [15–19, 29]. It can be seen from the figure 3 that the surface compressive stress influencing layer has the depth of approximately 175 μm. However, the Vickers hardness of the surface of the original specimen and the electropolished specimen were almost unchanged compared with their core portions, and no strain hardening occurred. The Vickers hardness of the electropolished specimen was substantially the same as that of the original specimen.

3.3. Microstructure results

The 7N01 aluminum alloy profile has the extrusion effect during the manufacturing process. Under this action, the grain undergoes direct extrusion deformation, and there is a large amount of residual stress in the surface layer, which is different from the core structure. Therefore, the extrusion direction is chosen for the observation of the microstructure of 7N01 aluminum alloy profile.

Figures 4(a) and (b) show the metallographic structure of the 7N01 aluminum alloy along the extrusion direction. It can be observed that there are three different states from the surface layer to the core: the coarse grain layer (L1) with a depth of approximately 60 μm appears near the surface, and equiaxed grain region (L2) with a depth of approximately 520 μm appears between the surface and the core, and a significantly elongated fine grain region (L3). This is because the profile is affected by the residual stress of the process, the surface grains are equiaxed crystals in the as-extruded state. The inner layer is elongated and thinned in the direction of the maximum main deformation due to the tension of the grains in the ingot during the processing. The crystal sliding direction is parallel to the tensile axis, and most of the grains are aggregation to the preferred orientation of the tensile orientation. The grain phase changes from disordered state to ordered state, resulting in fibrous grain structure and a relatively strict orientation to form a deformation texture. SEM images of the 7N01 aluminum alloy profile in figures 4(b) and (c), and as in the case of the metallographic diagram, the grains are elongated into flat shape along the extrusion direction. The second phase at the grain boundary is larger than the void precipitation in the grain boundary. The second phase (black phase) is arranged in a chain along the extrusion direction, and a large number of fine dynamic recrystallized grains are gathered around it. This should be related to the stress corrosion cracking of 7N01 aluminum alloy.
3.4. Surface topographies results
The micromorphologies of the different surface conditions observed on the maximum stress surface in figure 5. There are many tiny defects and impurities on the original surface in figure 5(a). This may be caused by handling and service environments after forming. Figure 5(b) shows the surface after electropolishing, which is smoother than the original surface and the part of the microstructure can be observed due to the defect reduces. The roughness of the surface after electropolishing is only about 9% of that of sandblasting, but there are still certain defects and impurities and the electropolishing marks are obvious. After the surface of the alloy is sandblasted, and the strong impact of sandblasting resulted in more pits on the surface of the specimen. The surface plastic deformation was caused by sandblasting, and a compressive stress zone was formed on the surface, which was about 175 μm. The surface roughness after sandblasting was significantly higher than that of the original surface and the surface after electropolishing, but no micro-cracks were found on the surface, as shown in figure 5(c).

3.5. Fatigue results of specimens
The S-N graph of the 7N01 aluminum alloy specimens at different surface conditions at room temperature is shown in figure 6. It can be seen from the figure that the surface quality of the maximum stress surface has a critical influence on the conditional fatigue strength. The conditional fatigue strength of the sandblasted specimen is 200 MPa at 10^7 cycles, and the ability to resist fatigue crack initiation was significantly improved compared with the original surface specimen, which was increased by about 42.9%. As can be seen from figures 3 and 5(b), the surface after sandblasting produces strain hardening with a depth of approximately 175 μm, and certain degree of plastic deformation occurs on the surface, so that the crack resistance is improved. The conditional fatigue strength of the electropolished specimens was not much different from that of the original surface specimen, and it was only increased from 140 MPa to 145 MPa. As shown in figure 5, figures 5(a), and (b), although the surface after electropolishing is smoother and flawless, but the improvement is not large compared with the original surface, and there is no surface strain hardening phenomenon, so the fatigue strength is not substantial improvement.

Figure 5. SEM image of 7N01 aluminum alloy after different surface conditions: (a) original surface (Specimen A); (b) surface after electropolishing (Specimen B); c surface after sandblasting (Specimen C).
3.6. Fracture morphology of fatigue specimens
The SEM of fatigue fracture of 7N01 aluminum alloy with different surface conditions after high alternating stress and different cycles is shown in figure 7. Figure 7(a) shows the fatigue fracture morphology of the original surface specimen. It can be seen that there is dimple, which belongs to a typical ductile fracture. The traces of crack propagating transversely to the central part are uneven, which are similar to the characteristics of static tearing. This may be due to the nucleation of cracks in other locations as crack source. Figure 7(b) shows the fatigue fracture morphology of the electropolished surface specimen. When the crack grows downward, it is transgranular fracture and produces a large number of secondary cracks appear radial growth. Figure 7(c) shows the fatigue fracture morphology of the sandblasted specimen. In fatigue final rupture region, obvious static load tearing characteristics and large-sized cleavage steps can be seen. The pits caused by sand particles may cause fatigue crack initiation, and the residual compressive stress caused by sandblasting impact may transfer the crack initiation area to the deep surface, thereby affecting the crack propagation.

From the microstructure observation of fracture surface, the fracture modes of 7N01 aluminum alloy fatigue specimens with different surface are ductile transgranular fracture, as shown in figures 7(b) and (c). This shows that the fatigue fracture mechanism of 7N01 aluminum alloy with different surface conditions is consistent, and the difference may be the location of the crack source. This ductile transgranular fracture mode has also been reported in other literatures related to fatigue fracture of 7N01 aluminum alloys [6, 7, 30]. Relevant research shows that the fatigue source of the original surface specimen is the coarse grain layer on the aluminum alloy surface, and the fatigue source of the sandblasted surface specimen is introduced into the inner layer [31]. The surface treatment of aluminum alloy by electropolishing is rare, but the fatigue cracks are on the surface or near surface after electropolishing of titanium aluminum alloy surface [21]. Therefore, the location of crack initiation caused by different surfaces may be an important factor affecting the fatigue life of 7N01 aluminum alloy.

3.7. Crack propagation
The crack propagation rate refers to the increase of the crack per cycle of the specimen under the alternating load, and is usually expressed by $\frac{\Delta a}{\Delta N}$ (mm / cycle) or $da/dN$ under the limit condition. By measuring the crack length ($a$) corresponding to each stress cycle number ($N$), the $a-N$ curve of the fatigue crack propagation can be plotted and obtain $da/dN$. For the unilateral notched specimens, according to the standard of GB/T 6398–2017 [28], the crack stress intensity factor ($\Delta K$) corresponding to crack length ($a$) is obtained by the following equation during crack propagation:

$$K = \frac{F}{BW^\frac{1}{2}} g\left(\frac{a}{W}\right)$$  \hspace{1cm} (1)

Where $B$ is the thickness of the specimen; $W$ is the width of the specimen; $a$ is the length of the crack; $g(a/w)$ is the shape factor corresponding to the specimen.

For a single-side notched clamp specimen, when the net distance between the clamps is equal to 4 $W$, $g(a/w)$ is calculated by following equation [28]:

![Figure 6. S-N graph of 7N01 aluminum alloy after different surface conditions at room temperature.](image)
\[
\phi \left( \frac{a}{W} \right) = (1 - \alpha)^{-3/2} \left[ 1.9878 \alpha^{1/2} - 2.9726 \alpha^2 + 6.9503 \alpha^3 - 14.4476 \alpha^4 + 10.0548 \alpha^5 + 3.4047 \alpha^6 - 8.7143 \alpha^7 + 3.7417 \alpha^{15/2} \right]
\]

Where \( \alpha = a/W \); the equation is valid when \( 0 < a/W < 0.95 \).

The corresponding relationship between the crack propagation rate \((da/dN)\) of the 7N01 aluminum alloy profile and the stress intensity factor \((\Delta K)\) at the crack length \((a)\) is established as shown in figure 8.

When the stress intensity factor \((\Delta K)\) of the crack component is lower than a certain level \(\Delta K_{th}\), under the alternating load and the component does not substantially undergo crack propagation, \(\Delta K_{th}\) is called the fatigue crack propagation threshold of the component. When the crack propagation threshold is actually measured, it is difficult to make the crack propagation rate \(da/dN = 0\). Therefore, the stress intensity factor \((\Delta K)\) corresponding to \(da/dN = 10^6\) to \(10^7\) (mm/cycle) is usually referred to as the fatigue crack propagation threshold \((\Delta K_{th})\). It is known from figure 8 that the fatigue crack propagation threshold of the original specimen of 7N01 aluminum alloy is 2.46 MPa m\(^{1/2}\).

The Kitagawa-Takahashi graph was proposed by Kitagawa and Takahashi in 1976 [32]. The critical crack size \((a_0)\) is such that when the actual crack length \(a < a_0\), the \(\Delta K_{th}\) decreases as the crack length decreases, and the fatigue limit can be used to describe \(\Delta K_{th}\), when \(a > a_0\), the crack propagation threshold \(\Delta K_{th}\) is a constant value independent of the crack size. Combined with the fatigue limit amplitude and fatigue crack propagation threshold of the original specimen of 7N01 aluminum alloy (notch depth of 0 \(\mu m\)), the Kitagawa-Takahashi graph of 7N01 aluminum alloy can be constructed, as shown in figure 9. The horizontal solid line in the figure corresponds to the fatigue limit amplitude of the original surface specimen of the alloy. It represents the critical stress intensity of the aluminum alloy material without cracks or tiny cracks, and the material does not crack. When the externally applied stress exceeds the ultimate stress strength, the material will gradually develop crack growth or even cause damage. The experimental data of the fatigue specimen with single linear notch are approximated by the oblique line in the figure. The intersection of the dotted line and the solid line is the effective transition crack size \(a_{0\text{ eff}}\), which is 10.81 \(\mu m\). This indicates that only micro-notches smaller than the...
effective transition crack size will not cause a decrease in the fatigue strength of the material. From the test results of the actual notched specimen, a gap larger than \(a_{0,\text{eff}}\) will cause a decrease in the fatigue strength of the material.

The oblique line segment (slope about \(-\frac{1}{2}\)) in the figure represents the law of long crack propagation. When the stress intensity factor \((K)\) loaded in the long crack exceeds fatigue crack propagation threshold \(\Delta K_{\text{th}}\), the crack will initiate, propagate and fail. Based on the linear elastic fracture mechanics formula, the fatigue failure stress amplitude values corresponding to different cracks in the long crack region can be obtained from the following equation [33]:

\[
\Delta \sigma_f = \frac{\Delta K_{\text{th}}}{Y(1-R)(\pi a)^{0.5}}
\]

Where \(\Delta \sigma_f\) is the fatigue failure stress intensity of the material; \(Y\) is the relevant geometric parameter; \(R\) is the stress ratio at crack propagation; \(\Delta K_{\text{th}}\) is the fatigue crack propagation threshold; \(a\) is the crack length.

The crack size corresponding to the intersection of the horizontal solid line and the oblique line becomes the material transition crack size \(a_0\) in figure 9, that is, when the crack size of the material is less than \(a_0\), the micro-crack theoretically does not affect the fatigue behavior of the material. The fatigue limit is the same as the fatigue limit of the crack-free material. However, when the crack size is larger than \(a_0\), the fatigue behavior of the material will be affected by the crack. As the crack size increases, the fatigue limit of the fatigue failure will gradually decrease according to fatigue crack propagation threshold \(\Delta K_{\text{th}}\). According to the method of Haddad and Topper [34], the transition crack size \(a_0\) can be calculated from the following equation:
\[
a_0 = \frac{1}{\pi} \times \left( \frac{\Delta K_{th}}{\Delta\sigma_f Y} \right)
\]

Where \(\Delta K_{th}\) is fatigue crack propagation threshold, \(\Delta\sigma_f\) is the material fatigue limit, and \(Y\) is the shape factor of the specimen.

The transition crack size \(a_0\) of the 7N01 aluminum alloy profile was calculated to be 72.68 \(\mu m\).

4. Discussion

For the 7N01 aluminum alloy profile, it can be seen from the fatigue behavior of S-N graph that the surface conditions had a certain influence on the resistance of the alloy to crack initiation. The fatigue properties of the specimens after sandblasting on the surface are well improved. The roughness of the blasted surface is increased, and the surface is more likely to cause stress concentration under external force, thereby generating cracks, which adversely affects the fatigue properties of the material. On the other hand, the stress layer implanted in the surface layer can refine the surface grains, and the generated dislocations can hinder the crack growth. According to the test results, the positive influence of the surface stress layer on the improvement of fatigue strength is significantly greater than the adverse effect of the increase in surface roughness on fatigue. The hardening of the sandblasted surface retards the crack nucleation, enhances the resistance to plastic deformation and improves the stress distribution, thus providing the ability to resist crack propagation [15–19]. However, the fatigue properties of the specimens after electropolishing on the surface were not substantially improved compared with the original specimens. This is because the 7N01 aluminum alloy has a good production process, and the original surface finish is already high, and the surface improvement after electropolishing is limited.

Previous studies have shown that the yield strength of 7N01 aluminum alloy is greater than 300 MPa [5, 7]. The maximum force on the maximum stress surface of the specimen under fatigue fracture is less than its yield strength in this study. Therefore, the crack initiation of different machined surfaces belongs to the early crack initiation before the alloy yields. At this time, the surface conditions have a great influence on the fatigue behavior of the alloy. However, this paper found that fatigue fractures under different surface conditions are ductile transgranular fracture. The different fatigue life of 7N01 aluminum alloy with different surface conditions is attributed to the location of the crack source. For the original specimen and the electropolished specimen, fatigue crack initiation occurs in the surface region of the specimen, that is, the coarse grain layer region of the alloy. For specimens after sandblasting, the residual stress of the sandblasting process affects the location of local stress concentration in the fatigue test, and the crack initiation source is basically in the subsurface layer [31]. This is because the pits caused by the sand particles may cause the fatigue cracks initiation, and the residual compressive stress caused by the sandblasting impact can transfer the crack initiation zone to the inner layer, thereby affecting the fatigue crack propagation.

The fatigue behavior of 7N01 aluminum alloy profile after prefabricated side straight through the notch deviates from the theoretical smooth specimen law and long crack propagation law. As shown in figure 9, the experimental data (indicated by the dispersed dots) of the fatigue specimen containing the notch deviates from the horizontal straight line and the oblique straight line of the K-T line within a certain defect scale. When the notch size is smaller than the transition crack size \(a_0\), the fatigue limit of the notched specimen is lower than the fatigue limit of the smooth specimen in varying degrees; the notch size is larger than the transition size, the fatigue limit of the long notched specimen is still lower than that predicted by linear elastic fracture mechanics. This shows that the fatigue behavior of the 7N01 aluminum alloy profile after the introduction of the notch is different from that of the smooth specimen and the long crack fatigue behavior of the notched specimen, but the unique behavior characteristics of the surface defect in a scale range. Thus, K-T line diagram is fitted to form a transitional region of the curved shape, which represents the relationship between the notch length of the notched specimen and the fatigue strength. When the notch size increases to a certain critical value, the corresponding fatigue limit amplitude value intersects with the oblique solid line (long crack propagation law) in the figure. This intersection is a critical notch size, defined as \(a_{cr}\), which is approximately 650 \(\mu m\). The long crack fatigue behavior of the material on the right side of the intersection point will be higher than the expected value obtained by the oblique solid line. The prediction of the crack is conservative, which is a safe behavior; while for the short crack area on the left side, it is unsafe, the notch strength will be lower than the predicted value of the solid line. The physical meaning of this intersection is that when the notch size is larger than the critical value, the material will fail according to the fatigue limit predicted by the long crack threshold of the linear elastic fracture mechanics, and when the notch size is smaller than the critical value, the material will occur fracture failure at a fatigue limit below the predicted threshold. The notch in the entire transition range is usually referred to as the shortage port, and the significant drop effect of the fatigue limit caused by the notch is referred to as the shortage effect of the fatigue limit of the material. Due to the adverse influence of the shortage effect on the fatigue limit of
the material, the effective notch propagation threshold ($\Delta K_{\text{eff,th}}$) of the 7N01 aluminum alloy profile can be re-determined according to the formula 3 by the effective notch propagation size ($a_{0, \text{eff}}$), which is 0.39 Mpa m$^{1/2}$.

5. Conclusion

(1) Different surface conditions have different effects on the fatigue strength of 7N01 aluminum alloy profiles in direct service. The conditional fatigue strength of the alloy can be improved by strengthening the surface of the alloy. The improvement of surface smoothness has a little effect on the fatigue strength of the alloy.

(2) After the surface of the alloy was sandblasted, a surface compressive stress layer of about 175 $\mu$m was introduced on the surface, and the resistance (fatigue strength) against fatigue crack initiation was improved by about 2/5. The surface of the alloy is electropolished to make the surface smoother, flatter and without defects, but its fatigue strength life is not much different from the original specimen.

(3) According to the crack propagation experiment, fatigue crack propagation threshold $\Delta K_{\text{th}}$ of 7N01 aluminum alloy profile is 2.46 Mpa m$^{1/2}$, and the transition crack size $a_0$ is calculated to be 72.68 $\mu$m. The fatigue limit test of notched specimens shows that effective notch propagation size $a_{0, \text{eff}}$ of the 7N01 aluminum alloy profile was 10.81 $\mu$m.

(4) In the range of transitional dimensions after the harmless notch size, the fatigue behavior of aluminum alloy is different from that of smooth specimen and long crack behavior of notched specimen. When the fatigue failure is below the fatigue limit predicted by linear elastic fracture mechanics, the fatigue behavior of the alloy has a 'shortage effect'.

(5) Due to the existence of 'shortage effect', the effective notch propagation threshold $\Delta K_{\text{eff,th}}$ of the long crack of the 7N01 aluminum alloy profile is re-established according to the effective notch propagation size $a_{0, \text{eff}}$ of the alloy, which is 0.39Mpa m$^{1/2}$.

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