# Fatigue Crack Extension and Life Calculation Based on Finite Element Analysis

Yifan Zhang[1, *], Yunlei Ma[2, a], Mingyu Liang[2, b]

[1]Suzhou university of science and technology, Suzhou, China

[2]Shijiangzhuang N0.16 Middle School, Shijiazhuang, China

*Corresponding Author Email: yfan_zhang@qq.com, [a]Yunlei_ma@qq.com, [b]mingyu_liang@hotmail.com

**Abstract.** With compact tension specimen static stress analysis and fatigue life of crack as the research object, through the three-dimensional modeling software to establish compact tension specimen, using the finite element analysis software to sample statics analysis, get the maximum deformation and maximum stress, and the compact tensile samples prefabricated crack, using the fatigue crack propagation analysis software, The cycle times and a-N curves were obtained. This method can be used to calculate the fatigue crack propagation life and visualize the crack propagation process, which is convenient to analyze and master the fatigue mechanism.

**Keywords:** finite element analysis, Compact tensile specimen, Fatigue crack propagation, Life calculation, Stress intensity factor.

## 1. Introduction

The rapid development of finite element analysis and the reliability of its solution results are gradually recognized by people. It is more and more common to use finite element to analyze various engineering problems, which not only has a more scientific solution method for the problem, but also can more truly understand the stress and strain of the structure or components in the relevant engineering problems. From cracking based on metal microscopic mechanism.

By extending the analysis to fatigue life calculation based on S-N curve, finite element method has also been widely used in the field of metal fatigue analysis, accelerating the development of the field of fatigue analysis. For example, ANSYS finite element analysis software, Workbench large-scale integration software, Ncode fatigue life analysis software, as well as ABAQUS, fatigue sub-software Fe-Safe, Franc3D and so on with the same powerful function as ANSYS. Due to the high cost of fatigue test, long time consumption and single function of fatigue testing machine, it is difficult to do the test under the composite conditions of temperature correlation and multi-dimensional alternating stress, and the correlation of material shape is often ignored in the test, so that the test data obtained is too large, which has no guiding significance for engineering practice. Therefore, people began to use the finite element analysis of components and combined with the powerful computing power of the computer to obtain the life data, which not only makes the life results closer to the actual situation, but also reduces the cost to a large extent.

A finite element analysis software and its fatigue sub-software were used to calculate the fatigue crack growth of the compact tensile specimen (hereinafter referred to as CT specimen), and the fatigue crack growth of the compact tensile specimen was simulated under the load control of the fatigue testing machine, in order to visualize the fatigue crack growth. The direction of crack propagation and stress change of compact tensile specimen during crack propagation were analyzed, and the fracture process was simulated dynamically. This method can realize the propagation of fatigue crack more realistically, and obtain the key parameters such as stress intensity factor which is difficult to obtain by other methods.

## 2. Stress strength factor calculation

The specimens used were CT specimens prepared from fatigue test specimens methods. The size used in this design is shown in Figure 1 [1]. The stress of type I, type II and type III can be expressed as follows Equation [2] :

$$\sigma_{i,j} = \frac{k_N}{\sqrt{2\pi r}} f_{i,j}(\theta) \tag{1}$$

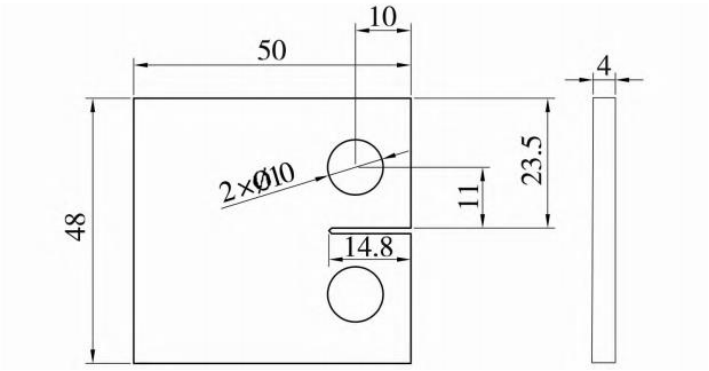



**Figure 1.** Diagram of compact tensile sample

In Formula (1), i and j are 1, 2, 3 respectively, corresponding to X, Y and Z directions respectively. The subscript of kN is the stress intensity factor of I, II and III corresponding to different types of cracks. $F_{ij}(\theta)$ is a function of $\theta$.

Since the simulation of compact tensile specimens only simulated tensile load, the subsequent stress intensity factor I calculation is emphasized. For finite size components in engineering, the stress intensity factor of type I is modified as:

$$k_1 = \sigma\sqrt{\pi a} f(a, w) \tag{2}$$

In Formula (2), $\sigma$ is the principal stress and $f(a, w)$ is the geometric correction coefficient, reflecting the influence of component and crack geometry size on the stress field at the crack tip. Different from type I , the stress in stress intensity factor expressions of type II and type III cracks is shear stress. For an infinite central cracked plate subjected to tension f = 1, and for semi-infinite single-side cracked plate, f=1.1215. In addition, J integral is applicable to the solution of pure type I crack, and its expression is [3]

$$J = \int_{\Gamma} [Wdy - (T_x \frac{\partial u_x}{\partial x} + T_y \frac{\partial u_y}{\partial x})ds], \tag{3}$$

In formula (3), $\Gamma$ is a curve around the crack tip, Ti is the stress vector, ds is the arc length, Ux and Uy are the displacement components, and W is the strain energy density.

Ricejr [4] generalized and established M integral on the basis of J integral, which can respectively calculate type I , type II and type III stress intensity factors. The expression of M integral is [5]

$$M = \int_{\Gamma_i} (Wx_i n_i - T_k u_k x_k) ds \tag{4}$$

$\Gamma_1$、$\Gamma_2$ are the integral paths of any two counterclockwise paths around the crack tip. For a uniform infinite plate M = 2aJ [6].

Finite element analysis of fatigue samples

### 2.1. Model Establishment

Standard CT samples were established by a modeling software (Figure 1) to facilitate the application of boundary conditions and load, a reference point is established at the center of the upper and lower pin holes[7].

### 2.2. Setting of material property parameters and boundary conditions

For CT11 titanium alloy, material parameters are from aviation Materials manual [8], material density 4.48g/cm3, elastic modulus E=116.7MPa, Poisson ratio= 0.33, tensile strength= 1030 MPa, yield strength = 930 MPa, and fracture strain = 0.15.

Simulation test sample under axial force loading, first set at the reference point of the upper and lower pin hole shaft, for coupling with the pin hole end surface, the boundary condition of the lower pin hole along the shaft rotation freedom of the rotation freedom along the hole and the translation freedom with the load, and set at the upper pin hole reference point centralized force load, direction upward.The concentration force applied this time is 14,323 N, that is, the axial force applied when the stress is 60% b.Because the sample is a standard sample and the geometry is relatively regular, the default hexahedral grid method is adopted, and the grid size is set to 0. 05 mm. Since the prefabricated crack tip will be redivided later, the crack tip will not be refined here. The CT sample mesh division is shown in Figure 2.

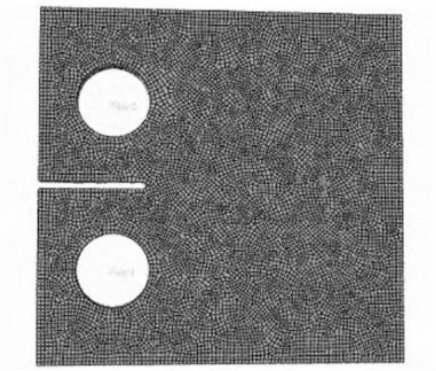


**Figure 2.** Meshing of compact tensile sample

### 2.3. Stress distribution

Through a finite element analysis software, the sample maximum stress position as shown in figure 3, the stress distribution is consistent with the actual, the maximum stress position is the prefabricated crack section, the stress reached 739.7 MPa, the stress from the prefabricated crack section to the pin shaft hole gradually reduced, because the uniform stress distribution, application section and stress concentration side, crack section and pin hole end stress changes.The simulation agrees with the reality, and this prestress can be used for the subsequent crack expansion analysis.

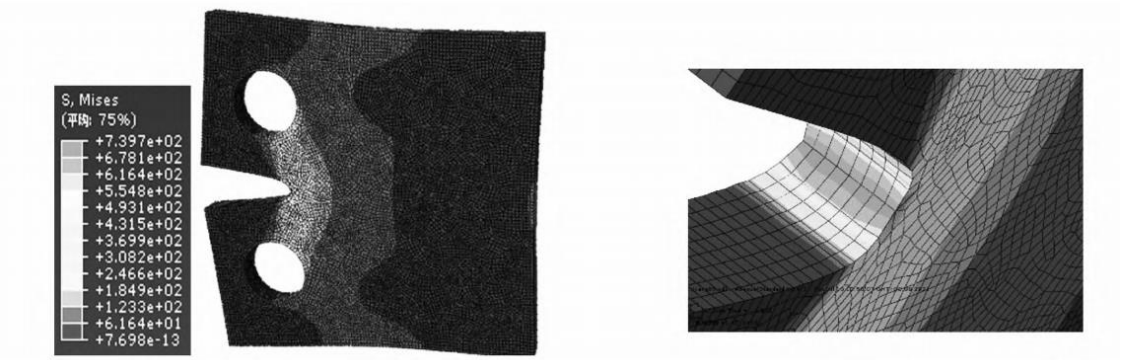



**Figure 3.** Prestress distribution of compact tensile sample

### 2.4. Crack extension analysis

For the simulated sample under fatigue crack expansion during axial force loading, the fatigue crack extension software used is a finite element analysis software sub-software. The initial crack is established at the maximum stress of the distance section, using the elliptical penetration crack, the crack depth and width size are set to 3 mm and 4. 5 mm respectively, and re-combined with the global model.The crack tips were redivided using the adaptive mesh Bessel sheets, with the samples locally adapted to mesh the sections as shown in Figure 4 and the crack tips as shown in Figure 5.

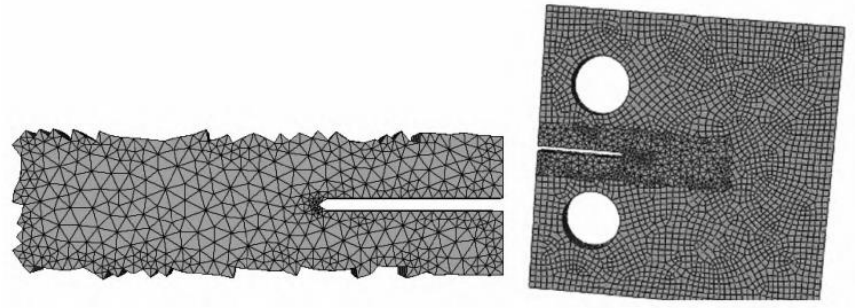


**Figure 4.** Local adaptive meshing of sample

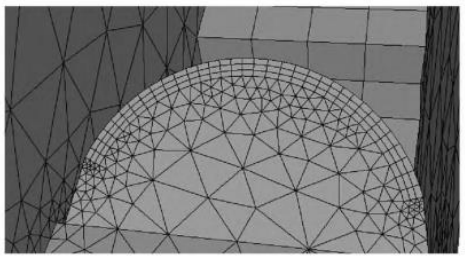


**Figure 5.** Grid section of crack tip

Generally by the stress strength factor to solve the crack expansion rate, stress strength factor size determines the size of the crack expansion rate, as can be seen from Figure 6, the type I stress strength factor, the largest, type stress strength factor is negligible, so the calculation of fatigue life should be using the maximum tension stress criterion, using type I stress strength factor to solve. The Paris formula $da/dn = C(\Delta k)^m$ is used. According to the aviation material manual, the TC11 titanium alloy related parameters c = 7. 837.83 $\times 10^{-19}$, m = 3.36 [3], and R = 0.1. The crack fatigue extension after 5 steps is shown in Figure 7, and the crack tip is the maximum stress area.

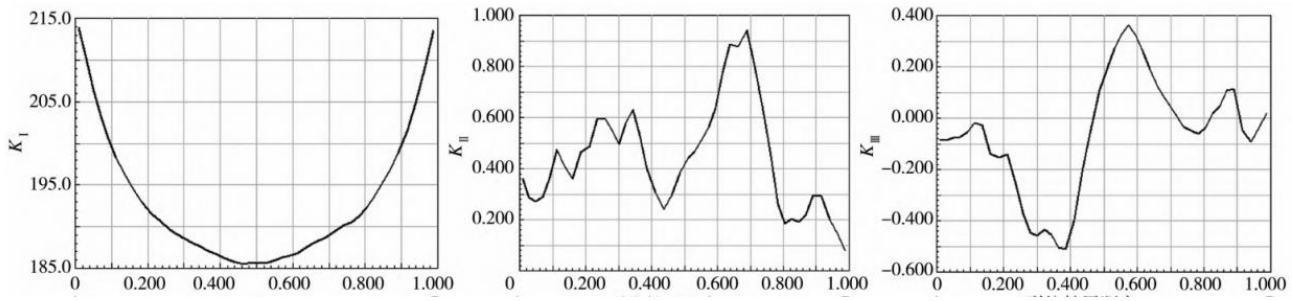
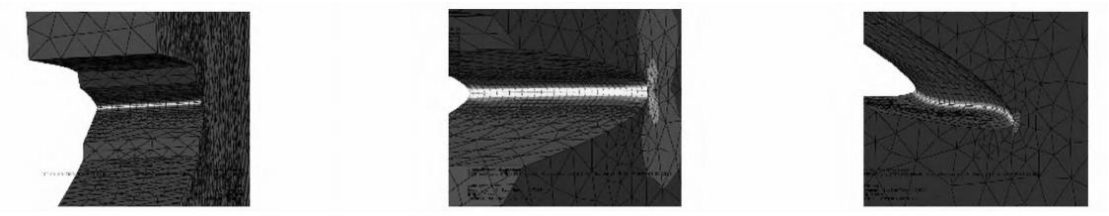



**Figure 6.** Variation range of different stress intensity factors at crack tip

In the initial stage of crack expansion, when crack expansion, the crack tip resistance is much large than in other parts, and the stress of the initial crack expansion is relatively large ( as shown in Figure 7a), and Figure 7b is the crack tip after 7054 times cycles, which can be observed after crack expansion 5 steps, compared with the first crack expansion, crack tip expansion rate is faster, crack tip stress is smaller than the first crack expansion, this is because the crack tip form local plastic zone, the more plastic area, the more energy can absorb, directly manifested as the smaller local

stress.Compared with Figure 7a and Figure 7b, Figure 7c has a larger crack length and less crack tip stress, corresponding to 40,534 crack cycles.



(a) Local diagram of Crack propagation after 5 steps (b) Local diagram of Crack propagation after 5 steps (C)Local diagram of Crack propagation after 5 steps

**Figure 7.** Fatigue crack propagation

After the calculation results get crack extension path as shown in Figure 8, the initial crack extension is semicircular, extension after 6 steps crack extension tip approximate into a straight line, along the vertical direction of the crack a-N curve, as the loading step is gradually increased, the crack expansion is slow after rapid increasing trend, the initial stage crack extension slowly, with increasing crack tip size, faster. The subsoftware life extension display mode is more direct, which can more intuitively understand the relevant parameters in the process of crack extension, and the generated a-N curve is more in line with the actual situation.

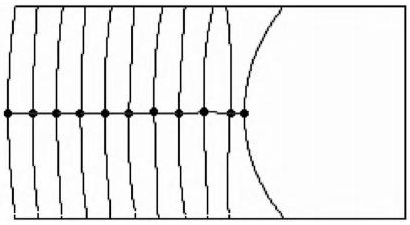


**Figure 8.** Path of crack propagation

## 3. Conclusion

Based on a finite element software and its fatigue sub-software, the fatigue crack propagation process of the compact tensile specimen was established, the static stress analysis of the compact tensile specimen was completed, and the subsequent crack propagation was completed.The number of fatigue cycles corresponding to the length of crack propagation is obtained.

Based on this part, a penetrating crack was created in the sub-software to calculate the crack propagation, and the fatigue cycle times corresponding to the length of crack propagation were obtained, and part of a-N curves of CT samples were obtained.

This method is used to calculate the fatigue crack propagation life and visualize the process of crack propagation. It is widely used in engineering field and is convenient to deeply analyze and master the fatigue mechanism. Process visualization, in the field of engineering applications, easy to deep analysis, palm grip fatigue mechanism.

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