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Fatigue-creep life analysis for powder metallurgy material with inclusion

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Abstract

To predict the life of the life limit parts is an important work for the airworthiness compliance. The compliance work of life limit parts involves typical flight profile, heat transfer analysis, stress analysis, materials data, and life predict method. In this study, fatigue-creep interaction behaviors of powder metallurgy materials with inclusion have been performed with the Kachanov-Rabotnov damage law to show the life compliance. On the constant fatigue-creep loading, different types of inclusion are investigated in the work. The research shows that the type of inclusion has strong influence on the damage of matrix. Generally, the elliptical inclusion has much more damage than the round inclusion. Furthermore, the fatigue-creep life of powder metallurgy materials is calculated by the damage model, which can be considered for the design of the engine life limit parts.

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Keyword: Engine life limit part; Compliance; Fatigue-creep interaction

1. Introduction

By a procedure approved by the FAA, the turbine disks are the typical engine life limited parts which have to specify the maximum allowable number of flight cycles. And powder metallurgy nickel-based superalloys have been developed of turbine disk applications in advanced turbo engines because homogeneous and fine grain alloys can be obtained providing high tensile properties. However, the manufacturing process introduces small defects such as non-metallic inclusion. These small particles are

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now well known to initiate small cracks and to be responsible for fatigue damage of the disks [1]. It has been proved that oxide and carbide particles [2-7] are the cause of fatigue crack initiation. In the recent study, many experiments were introduced to investigate the effects of inclusion on the damage of powder metallurgy material. The result shows that inclusions or defects are usually present and the fatigue properties are affected significantly by their shapes and dimensions [8-10]. Besides experiment, many theories were developed to study the effect of the inclusions. The damage analysis was carried out on the tensile specimens of metallurgy material including isolated big void [11]. Wang studied the effect of inclusion shape on the fatigue cracking behavior by the finite element method (FEM) analysis [12]. In fact, many damage of turbine disk was caused by the interaction of fatigue and creep. To predict the life of the turbine disc made of powder metallurgy material, the fatigue-creep life of powder metallurgy with inclusions should be analyzed.

In this work, the fatigue-creep life of powder metallurgy material with inclusions is investigated. The influence of the inclusion shape on the fatigue-creep life is studied. The work gives the suggestion to show the compliance of the disc material life.

2. Fatigue-creep damage law

Here, the creep damage equations are used to study the fatigue-creep interaction. The damage creep law is

$$\dot{\varepsilon}_e = \frac{\beta\sigma_e^n}{(1-\omega)^n} \tag{1}$$

and

$$\dot{\omega} = \frac{\theta[\alpha\sigma_1 + (1-\alpha)\sigma_e]^{X}}{(1-\omega)^{\phi}} \tag{2}$$

Where ε_e and σ_e are equivalent creep strain and stress, σ_1 is the maximum principal stress, and ω is the damage variable. The terms β, θ, n, X, α and Φ are all material parameters.

In this set of coupled differential equations, both strain rate $\dot{\varepsilon}_e$ and damage rate $\dot{\omega}$ increase while the damage variable ω of Eqns (1) and (2) increases. This represents the Kachanov-Rabothov [13-14] approach of continuum mechanics to creep damage accumulation. The parameter α describes the relative importance of σ_1 and σ_e on creep rupture. For some metals α is an acceptable simplification. We assumed this in order to scope the problem, and arrive at a reasonable solution. Furthermore, the damage parameter ω is dependent on the directions of stresses and has to be replaced by a damage tensor. In this work, we just consider it as a scalar variable for simplification. All the model parameters are material and temperature dependent, for which the numerical values used in this study are taken from [15] and given in Table 1.

Table 1 Model parameters β, θ, n, X, α and Φ

β [MPa^{-n}/s]	θ [MPa^{-X}/s]	n	X	α	Φ
1.523×10^{-22}	2.533×10^{-22}	6.5	6.5	0	6.5

The calculations are terminated by the program ABAQUS itself. The damage creep law presented by Eqns (1) and (2) has been implemented as a user subroutine 'CREEP' [16].

Further, the fatigue-creep life f can be expressed by

$$f = \frac{1}{\omega} \tag{3}$$

3. Finite element analysis

3.1. Analysis model

The analysis model is constituted by the matrix and inclusion. The dimension of the inclusion is approximate 50um which has obvious influence on the matrix. The model in the paper is a square cell, and the length of side is 0.4mm. Model1 has a round inclusion in the center of matrix. Model2 has an elliptical inclusion in the center of matrix. The radius of round inclusion is 0.05mm. The long axis of elliptical inclusion is 0.05mm, and the minor axis of elliptical inclusion is 0.02mm. The 1/4 model is taken to simulation in order to simplify calculation. The model1 and model2 are shown in the Fig.1 and Fig.2.

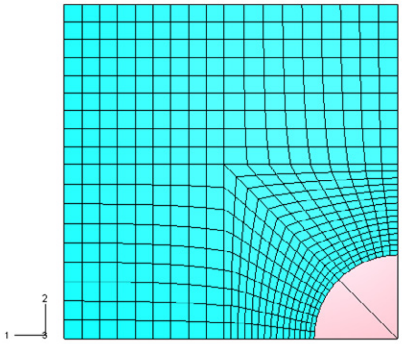

Fig.1 model 1

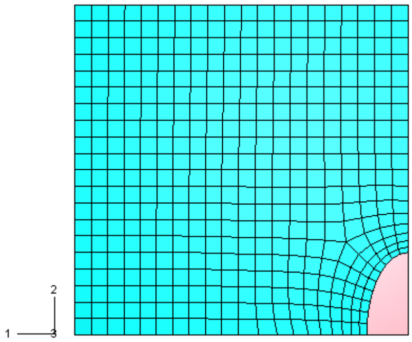

Fig.2 model 2

3.2. Material parameters

The material parameters of matrix are shown in table 2. The inclusion of Al_2O_3 looks as elastic material. The young's modulus of inclusion E =390000MPa, and the Poisson'ratio ν =0.25.

Table 2 Table 2 Material parameters of matrix

E/MPa	ν	σ_s /MPa
192000	0.3	1000

3.3. Boundary condition

There is a boundary condition Uy＝0 at the lower extreme of model, and there is a boundary condition Ux＝0 at the left end and the right end of model. The load is applied to the upper extreme in the Y direction. The magnitude of the load is 300MPa, which is calculated by the stress analysis of the turbine disc. In the fatigue calculations, Trapezoidal wave type tensile stresses are applied, as shown in Fig.3. In this work, the temperature cycle is not considered due to the little influence of temperature on the young's modulus and Poisson' ratio, and the temperature is 600℃.

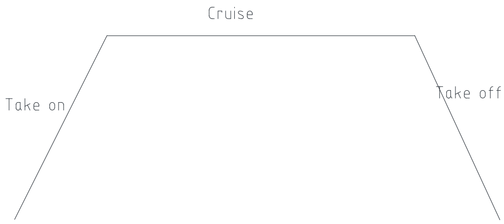

Fig.3 The load spectrum of one typical cycle

3.4. Results and discussions

The distributions of damage with model 1 and model 2 under one cycle fatigue-creep load are shown in Figure.4 and Figure.5.

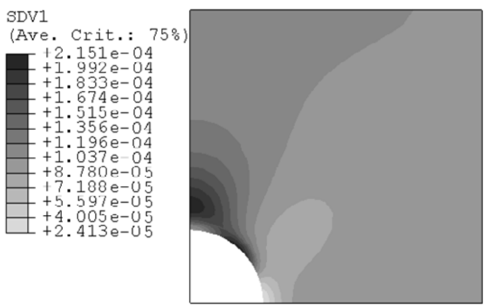

Fig.4 The distributions of damage with model 1 under one cycle fatigue-creep load

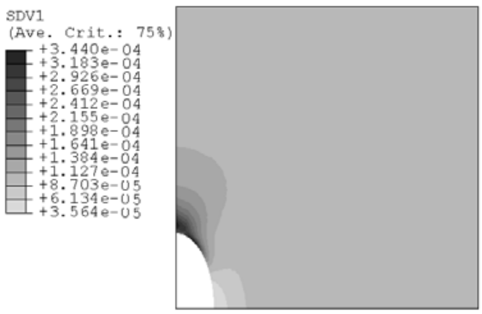

Fig.5 The distributions of damage with model2 under one cycle fatigue-creep load

The above figures show that the distributions of damage of fatigue-creep interaction load is influenced by the inclusions. The value of damage resulted in the elliptical inclusion is larger than that resulted in the round inclusion. The fatigue-creep life with round inclusion is 4640 cycles, while the fatigue-creep life with elliptical inclusions is 2900 cycles. The inclusion shape should be considered in the process of determining the life of turbine disc with powder metallurgy materials. It can be concluded that the maximum life of powder metallurgy material at this fatigue-creep load is 2900 cycles.

4. Conclusions

Based on Kachanov-Rabotnov damage law, the fatigue-creep interaction behaviour of powder metallurgy materials with different type of inclusion has been studied. The main conclusions have been drawn as follows:

1).The FEM results show that the type of inclusion shape has strong influence on the distributions of damage of fatigue-creep interaction load, and the elliptical inclusion has much more damage than the round inclusion;

2).The results of this work can be used to predict the life of the powder metallurgy materials with different inclusions, which is benefit to determine the engine life limit part of turbine disc made of powder metallurgy materials.

5. Copyright

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