Influence of Inclusions’ Position on Stress Distribution of Inclusion-matrix Interface

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Abstract: In this paper, the influence of inclusions’ position on stress & strain distribution was researched when inclusions were same size and shape. The finite element method was used to study the position effect of inclusions in the FGH95 P/M superalloys. The shape of inclusions was simplified rotundity in the model. The influence of inclusions which was on the surface, in the sub-surface and in the basic material on stress & strain distribution was studied. There were two cases, the inclusion connected basic material tightly and there was a hole between the inclusion and the basic material. The change rule of interfacial stress & strain distribution caused by the variation of inclusions’ position was given.

1. Introduction

Inclusions have an obviously effect on the fatigue performance of P/M superalloys. It is closely related to the style, shape, size, position and number of inclusions. The research on inclusions at present focuses on about three respects. Firstly, improve the processing and manufacturing technology of P/M superalloys [1-2]. Secondly, research the influence of inclusions on the fatigue life especially the LCF life. The influence of inclusions’ size and position on the LCF life is studied [3-4]. Thirdly, Life prediction model and methods which consider the influence of inclusions are researched. Although most research achievements pay attention to the influence of inclusions’ size and position on the LCF life, all of them are semi quantitative. Few scholars quantificationally study the influence of inclusions’ position on the fatigue life.

2. Experimental

The basic material used in the experiment is FGH95 P/M superalloy and this material is regarded as elastic plastic material. The inclusion Al2O3 is also regarded as elastic plastic material. The cyclic stress strain equation is showed as blow.

\[ \frac{\Delta \varepsilon_1}{2} = \frac{\Delta \sigma}{2E} + \left( \frac{\Delta \sigma}{2K} \right)^n \]  \hspace{1cm} (1)

In this equation, the elasticity modulus E=193000MPa, the hardening parameter K=1730MPa, the
hardening exponent n=0.051.

The rectangular coordinate system can be transformed to polar coordinate system in the finite element software. So the stress component $\sigma_x$, $\sigma_y$ and $\tau_{xy}$ can be switched to $\sigma_n$ and $\tau_t$. They can be described as blow:

$$
\begin{align*}
\sigma_n &= \tau_{xy} \sin 2\alpha + \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}\cos 2\alpha (\sigma_y - \sigma_x) \\
\tau_t &= \frac{1}{2} \sin 2\alpha (\sigma_x - \sigma_y) + \tau_{xy} \cos 2\alpha
\end{align*}
$$

The influence of inclusions which was on the surface, in the sub-surface and in the basic material on stress & strain distribution was studied. The maximum strain is set as 0.85% in the test to simulate influence of inclusions in the real turbine disk dangerous position, which means that the top and bottom surface displacement is 0.0425mm. Symmetric boundary condition is set on the boundary of model.

3. Results and discussions

3.1. Position effect of inclusion-matrix interface without holes

3.1.1. The finite element model

Both length of the 2D board are 100mm and the material is FGH95 P/M superalloy. There is a round Al$_2$O$_3$ inclusion at the center of the board and the radius R is 100 um (Figure 1a). Two half-circle are set on the left and right middle boundary and the radius is 100 um in the second model (Figure 1b). A round Al$_2$O$_3$ inclusion is 0.1mm away the left boundary and the radius R is 100 um (Figure 1c).

![Figure 1. Inclusions in different position](image)
3.1.2. Results and discussions

The interfacial stress component change curves are showed in Figure 2 and Figure 3 when the inclusion is at the center of the 2D board, on the surface and in the sub-surface. The x-coordinate is the angle of circumference. When it is parallel to the x-coordinate, its value is 0. The y-coordinate is the stress component.

![Figure 2. The radial stress comparison about different position.](image1)

![Figure 3. The shear stress comparison about different position.](image2)

The radial stress distribution of inclusion-matrix interface and the trend are similar for these three models. The maximum stress can be gotten in the direction of paralleling to the load and the stress is nearly 0 in the vertically direction of the load. The stress distribution of inclusion-matrix interface is symmetric to the y-coordinate, because the shape of the center inclusion and the surface inclusion is symmetric as well as the load is symmetric too. The stress distribution of inclusion-matrix interface is symmetrical weakly because the position of the sub-surface inclusion is not symmetrical, the radial stress is a little bigger than the other models at the position near the 180° especially. The basic material near the 90° has already gotten to be plastic for the three models. The maximum stress of the surface inclusion is bigger about 10% than the other models because of the free surface. The boundary at the 90° has to bear more loads and the load-transferring way is more concentrated. So it can be guessed that the fatigue life of surface inclusion is shorter and the structure is more dangerous in this case. The shear stress distribution of inclusion-matrix interface presents dissymmetry at the 90° because of the sign convention. The center inclusion and the surface inclusion have a strict symmetry. The sub-surface is symmetrical weakly because the position of the sub-surface inclusion is not symmetrical. The maximum shear stress is at the 45° and 135° position for the three models.

3.2. Position effect of inclusion-matrix interface with holes

3.2.1. The finite element model

Both length of the 2D board are 100mm and the material is FGH95 P/M superalloy. There is a round Al₂O₃ inclusion at the center of the board and the radius R is 50 µm, furthermore, there is a round hole at the 45° on the interface and the radius r is 2 µm (Figure 4).
3.2.2. Results and discussions
The normal stress distribution of the surface and the inner inclusion interface increases with the angle of circumference $\theta$ increases for the same size inclusions. The shear stress distribution of the surface and the inner inclusion interface increases first and then decreases with the angle of circumference $\theta$ increases for the same size inclusions (Figure 5).

![Figure 4. Inclusion with a hole](image)

![Figure 5. Position effect of inclusion-matrix interface with holes](image)

When the inclusion connects the basic material well, the maximum stress point is on the interface because the interface made up with the inclusion and the basic material is not singularity. The interface normal stress and shear stress presents an inverse pattern on the free surface where the $\sigma_r=0$ and $\sigma_\theta=0$. When there is a hole on the interface, the maximum stress point is in the interface hole because the interface made up with the inclusion and the basic material is not singularity too. The interface normal stress and shear stress presents an inverse pattern on the free surface where the $\sigma_r=0$ and $\sigma_\theta=0$ too.

4. Conclusions
(1) When the inclusion connects the basic material well, the interfacial normal stress of the surface inclusion is bigger than the inner inclusion when the angle of circumference ranges 0 to 90°. The maximum stress is at the 90°. The interfacial shear stress is nearly same with the inner inclusion when the angle of circumference ranges 0 to 45°, but the interfacial shear stress is less than the inner...
inclusion when the angle of circumference ranges 45 to 90°.

(2) When there is a hole on the interface, the interfacial normal stress of the surface inclusion is bigger than the inner inclusion when the angle of circumference ranges 0 to 90°. The maximum stress is at the 42.5°, 47.5° and 90°. The interfacial shear stress is nearly same with the inner inclusion when the angle of circumference ranges 0 to 30°, but the interfacial shear stress is less than the inner inclusion when the angle of circumference around 42.5° and 47.5°. The interfacial shear stress is nearly same with the inner inclusion first when the angle of circumference ranges 60° to 90°.

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