Discussion of a Characteristic Temperature in Single Crystal Superalloy DD6

Jinqian Zhao

ABSTRACT

It is concluded that there is a characteristic temperature present between 800 ºC and 850 ºC in the single crystal superalloy DD6, symbolized as Tc after the long-term crept microstructures are analysed, with investigation into the fracture mechanism of the specimens with low angle grain boundary (LAB) as well as the relationship between modulus and temperature. When the temperature rises beyond Tc, the rafting microstructure comes to arise in the long-term crept specimens. The cohesive strength of the LAB will be weaker than that of alloy at the condition of the temperature beyond Tc so that the inter granular fracture would arise in the specimens with LAB.

INTRODUCTION

The single crystal superalloys are characterized with the super ability to withstand high temperature and have been widely used as aeronautical engine turbine blades because almost all the grain boundaries are eliminated [1]. DD6 alloy is a second generation single crystal superalloy with a composition characterized by low rhenium content [2]. The alloy shows an attractive blend of mechanical strength and environmental resistance.

The deformation mechanism of single crystal superalloy is mainly controlled by dislocation sliding at low temperature [3,4]. It has been found that the plastic deformation of single crystal superalloy under high temperature is controlled by diffusion mechanism [5].

1 Jinqian Zhao, Science and Technology on Advanced High Temperature Structural Materials Laboratory, Beijing Institute of Aeronautical Materials, Beijing, 100095, China.
Many mechanical behaviors of an alloy will change with temperature increasing up to some extent. In this paper, a characteristic temperature is discussed with respect to the single crystal superalloy DD6.

PROCEDURE

As for single crystal superalloy DD6, the long term creep tests are conducted at the conditions of at 800ºC/700MPa, 850ºC/550MPa and 900ºC/450MPa, respectively. The tensile tests were performed at the same temperature conditions as the creep tests. On the other hand, the relationship between modulus and temperature is analyzed.

RESULTS AND DISCUSSION

It is well known that the mechanical properties are critical for the structural materials, some essential aspects of mechanical properties of the alloy DD6 are investigated in terms of influence of temperature on the mechanical properties. Firstly, microstructures of long-term crept specimens tested under several elevated temperatures conditions are investigated, considering single crystal superalloys are usually working on at the condition of high temperature. Secondly, the tensile fracture mechanism of specimens with low angle grain boundaries (LABs) is analyzed, because LABs are inevitable because single crystal superalloys are solidified as structural materials of which the chemistry composition is complex and solidification rates are much fast. Thirdly, the relationship between modulus and temperature is considered.

Long-term Crept Microstructure

The long-term creep conditions are shown in table 1, as well as the period of duration time holding under creep. The microstructures crept at the condition of 850ºC /550MPa, as shown in figure 1(b), indicates that the γ' precipitates already evolves into absolute rafting structure in the alloy being crept for 384 hours almost as same as that crept at the condition of 900ºC /450MPa for 266 hours, as shown in figure 1(c). However, the γ' precipitates in the specimen crept at the condition of 800ºC /700MPa for 426 hours, still are with their shape unchanged, namely cubic, as shown in figure 1(a).

It is mentioned in the [6] that the γ' precipitates also keep their cubic shape at the creep conditions of 760ºC 758MPa after testing 513.2 hours.

The rafting in the single crystal superalloy is the directional coarsening process, therefore it is expected to be a diffusion-controlled process. Moreover, the rafting of single crystal superalloy is not only related to temperature, but also to the stress and the creep duration time. It is likely that time plays an important role in the evolution
of the rafted structure because it is controlled by diffusion. However, with respect to
the as-observed microstructures, the longer the period of creep time is, the more
difficulty the rafting process, when the long-term creep tests are performed at the
temperature conditions of 760 ºC, 800 ºC, 850 ºC and 900 ºC, respectively, and their
period of creep duration time is 513.2 hours, 429 hours, 384 hours and 266 hours,
respectively. So, time is not the controlling factor for the rafting.

<table>
<thead>
<tr>
<th>Temperature, / ºC</th>
<th>Stress, /MPa</th>
<th>Creeping time, /h</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>700</td>
<td>429</td>
</tr>
<tr>
<td>850</td>
<td>550</td>
<td>384</td>
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<tr>
<td>900</td>
<td>450</td>
<td>266</td>
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</table>

Figure 1. Microstructures of long-term crept DD6 alloy, (a) 800 ºC /700MPa,
(b) 850 ºC /550MPa, (c) 900 ºC /450MPa.

Considering the applied stress being in the elastic regime, the driving force for
rafting is proportional to the stress[7]. Just like the trend in time, in as-observed
microstructures, the higher the applied stress is, the more difficulty the rafting
process. When the long-term creep tests are performed at the temperature conditions
of 760 ºC, 800 ºC, 850 ºC and 900 ºC, respectively, and their applied stress is
758MPa, 700MPa, 550 MPa and 450 MPa, respectively. So, applied stress is not the
controlling factor for the rafting, either. Obviously, it is expected that temperature is
the controlling factor for rafting. From the view of as-observed crept microstructures, there is a characteristic temperature in the single crystal super alloy
DD6, which is symbolized as Tc, beyond which the temperature rises, the rafting
microstructure comes to arise in the long-term crept specimens.

Fracture Mechanism of the Specimens with LAB

The observation of fracture surface shows that the fracture model of the
specimens with LAB in the temperatures range from 800ºC to 900ºC is quasi-
cleavage, or a combination of quasi-cleavage and inter granular. In the same temperature range, the fracture mechanism is similar to that of alloy DD6 without LAB [8], and the quasi-cleavage fracture model is common in single crystal super alloys such as PWA1472, PWA1484[9,10].

At the condition of 800 ºC, the specimens with LAB usually fracture by the model of quasi-cleavage during the tensile test, as shown in figure 2(a). In addition, at the lower temperature of 760 ºC, the fracture mechanism is also quasi-cleavage [11]. The inter granular fracture model, however, comes to arise at the temperature of 850ºC in the specimens with LAB, shown as figure 2(b). Moreover, with the temperature increasing, the trend toward inter granular fracture increases.

![Figure 2. Typical fractographys of the specimens with LAB, (a) at 800 ºC, (b) at 850 ºC.](image)

It is well known that in the common metal materials there is usually an equal-strength temperature, beyond which the grain boundary strength is lower than that of grains themselves. Concerning LAB in single crystal super alloys, there should also exist the equal-strength temperature. When the temperature rises up to some point, the inter granular fracture can be observed in the tensile testing specimens with LAB, which reflects the cohesive strength of the LAB becomes lower than the bonding strength of the alloy itself. The temperature should be the equal-strength temperature of the LAB in single crystal super alloys.

It is expected that there is a characteristic temperature in single crystal super alloy DD6 between 800 ºC to 850 ºC, concerning the strength of LAB. When the temperature rise beyond the characteristic value, the strength of low angle grain boundaries became lower than that of the grain itself to some extent.

**Relationship Between Modulus, Yield Strength And Temperature**

As for alloy DD6, yield strength increases up to peak with temperature increasing in the range from room temperature to about 800 ºC[8], then decreases
with temperature increasing. It could be expected that there is a characteristic temperature in alloy DD6 as for the yield strength. At same time, the characteristic value lies between 800 ºC and 850 ºC.

Figure 3. Relationship between modulus of the alloy DD6 and temperature.

According to the alloy data[12], the elastic modulus as a function of varying temperature is shown as in figure 3. It is well known that the elastic modulus of alloy decreases with temperature increasing. However, for alloy DD6, when the temperature is higher than about 800 ºC, the decreasing rate of elastic modulus seems suddenly to accelerate with temperature increasing. Because there is a linear relationship between the elastic modulus of the alloy and the theoretical bonding strength of the material[13], the elastic modulus and yield strength should have the same respondence.

So, just like considering yield strength, it is expected that there should be a characteristic temperature in single crystal superalloy DD6 between 800 ºC to 850 ºC as for the elastic modulus.

CONCLUSIONS

Several aspects: microstructure of long-term crept specimens, fracture mechanism of low angle grain boundaries, elastic modulus and yield strength all indicate that there exists a characteristic temperature, which is symbolized as Tc, in single crystal superalloy DD6 between 800 ºC and 850 ºC.
REFERENCES