Microstructure Evolution of K6509 Cobalt-base Superalloy for Over-temperature

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Abstract

In this study, the K6509 cobalt-base superalloy were heat treated at different temperatures and the microstructure was detected by scanning electron microscopy and electrical probe micro-analyzer. In as-cast K6509, the MC carbides are present as a discrete, blocky dispersion with a well-distributed Chinese script morphology and the eutectics (\(\gamma + M23C6\)) and (\(\gamma + M7C3\)) can be seen. With the temperature increasing, the MC arise degeneration. Below 1150°C, the script-like MC is dominant; reaching 1200°C, the particle and block of MC are dominant; reaching 1250°C, few script-like MC is present. In as-cast alloy, the M23C6 and M7C3 carbides are lamellar eutectic with matrix. When temperature is up to 1150°C, the eutectic (\(\gamma + M23C6\)) disappears; however, much eutectic (\(\gamma + M7C3\)) can be found. When the temperature reaches 1200°C, a large amount of eutectic M7C3 is dissolved, and some pores form in the matrix, and some zones rich in Cr form around the pores. When the temperature is above 1250°C, many pores form in the matrix, the cause of pores is need to be studied further.

Keywords: K6509; Cobalt-base superalloy; over-temperature; M23C6; M7C3; MC
1. Introduction

The gas turbine often occur abnormal state during service, and the over-temperature have attracted the most attention. Over-temperature caused severe damage to the turbine vanes. This phenomenon may significantly reduce the service life and other properties of the gas turbine, cause premature failure, and even lead to the occurrence of major accidents [1]. Cobalt-base superalloys are widely used in industrial and aircraft turbines for vanes and combustor sections because of their intrinsic properties such as good stress–rupture parameters and excellent hot corrosion and oxidation resistance [2-4]. In industrial practice, cobalt-base superalloys are usually used in as-cast state [2]. The properties of vanes are governed by their microstructure, and the microstructure of superalloys can evolve during service at high temperature since the phases, their volume fractions and morphology, present at room temperature generally differ from those that are stable at high temperature [5,6]. The treat temperature can be defined according the microstructure.

K6509 alloy is a new cobalt-base superalloy developed by Beijing Institute of Aeronautical Materials for recent years, and suitable for guide vanes of gas turbine. K6509 has three types of carbides, the carbide phases in is quite complex, stemming from the relative stabilities and solubilities of the individual types. The carbides contribute significantly to strengthening [7]. There are few reports that studying the evolution of over-temperature microstructure on in the cobalt-base superalloys. In this study, the K6509 cobalt-base superalloy were heat treated at different temperatures and the microstructure was detected. This study aims to understand a relationship between over-temperature microstructure and temperature. It is important to evaluate the over-temperature failure of the gas turbine.

2. Experimental methods

The samples were cut from guide vanes of gas turbine, and were in the as-cast condition. The chemical composition of K6509 cobalt-base superalloy is listed in Table1. The K6509 is designed for using under 1100°C, and its melting point is 1350°C ~ 1400°C. In order to study the influence of the over-temperature on the microstructure, the samples were each treated for 2 h at 1100°C, 1150°C, 1200°C, 1225°C, 1250°C, 1275°C and 1300°C, respectively. These high temperature treatments were performed in a tubular VECstar high temperature furnace (The temperature difference is less than 2°C). The samples were then air quenched down to room temperature. Their initial microstructures of superalloy in the as-cast condition were also examined.

Polishing was done first with Al2O3 paper from 120 to 1000 grid under water and finished with 2.5μm diamond pastes. A scanning electron microscope (JEOL-5600LV SEM) was used in back scattered electrons mode (BSE) under an acceleration voltage of 20 kV. The phases present can be separated from one another since their average atomic numbers are significantly different. Spot microanalysis measurements allowed to clearly identify the present carbides by JXA-8100 electrical probe micro-analyzer.

3. Experimental results

3.1 Initial as-cast microstructures

Fig.1 shows the microstructures of as-cast K6509 alloy. As-cast K6509 consist of a continuous fcc matrix and a variety of carbides, mainly coarse primary eutectic M23C6, eutectic M7C3 and MC. The chemical composition of these carbides were showed in Table2, tested by electrical probe micro-analyzer. M23C6 is rich with Cr, M7C3 is rich with Cr and Co and MC is rich with Ta. The carbides form as alloys cooling down in shell mold. In this backscattered electron image, the chromium-rich M7C3 carbide appears dark, the MC carbide is rather light and the M23C6 is ashy. It is observed that M7C3 carbide and M23C6 carbide are lamellar eutectic with matrix, while MC is

| Element | C  | Cr  | W  | Ta  | Ni  | Ti  | Zr  | Co  |
|---------|----|-----|----|-----|-----|-----|-----|-----|
| wt%     | 0.60 | 23.5 | 7.0 | 3.5 | 10  | 0.20 | 0.5 | Bal. |
present as a discrete, blocky dispersion with a well-distributed Chinese script morphology. Evidently, the formation of MC is due to the addition of reactive elements, Ta, Ti and Zr. All the M23C6, M7C3 and MC carbides are located at grain boundaries or in interdendritic regions, forming a continuous network around the columnar grained matrix. Such a morphology of MC and M7C3 are also observed in DZ40M and M509 alloys [2,6].

| Element | C   | Cr | W  | Ta  | Ni  | Ti  | Zr  | Co  |
|---------|-----|----|----|-----|-----|-----|-----|-----|
| MC      | 6.946 | 2.000 | 2.614 | 79.638 | 0.231 | 3.829 | 1.704 | 2.997 |
| M7C3    | 9.166 | 58.328 | 7.279 | 0.542 | 3.016 | 0.048 | 0.028 | 22.300 |
| M23C6   | 7.733 | 72.794 | 7.759 | 0.409 | 0.611 | -     | 0.089 | 8.981 |

Fig.1 Initial as-cast microstructure of K6509 (BSE)

3.2 Microstructures for over-temperature

The microstructure of K6509 treated at 1100°C for 2h is showed in Fig.2. The carbides distributed well. Compared to as-cast, fewer eutectic M23C6 is seen because of being dissolved, and eutectic M7C3 is seen surrounding the eutectic M23C6. MC is present as a discrete, blocky dispersion with a well-distributed Chinese script morphology in interdendritic zones. Some MC carbides are dissolved and fine particles MC form in the edge of blocky MC.
When the K6509 was treated at 1150°C for 2h, the eutectic (γ+M23C6) is not seen, but much eutectic(γ+M7C3) is seen, while some MC particles are seen in the edge of eutectic M7C3. Some script-like MC carbides are dissolved, forming short rods and block. But script-like MC carbides are dominant. The carbides in the edge of sample are oxidized. These characters are showed in Fig.3.
The microstructures of K6509 treated at 1200°C for 2h is showed in Fig.4. Many script-like and blocky MC carbides are dissolved, forming short rods and particles. The MC carbides with morphology of short rods and particles are dominant. The eutectic is not seen in the matrix. The eutectic M7C3 are dissolved and some regions where are not corroded easily and pores form because of dissolved eutectic M7C3.
The microstructures of K6509 treated at 1250°C for 2h is showed in Fig.5. The MC carbides are block and particles, the script-like MC carbides are not seen. The size of MC carbides becomes finer. Many pores can be found in the matrix. In the edge of samples, the carbides are oxidized severely.
When the K6509 was treated at 1275°C for 2h, the size of MC carbides becomes finer and the fraction also becomes fewer. The pores in the matrix become big. These are showed in Fig.6. In the Fig.7, the K6509 is treated at 1300°C for 2h, only particle MC carbides particles can be seen, and its content becomes fewer. More pores can be seen in the matrix, and the size is bigger comparing to K6509 treated at 1275°C.
4. Discussion

The microstructure of K6509 can be modified by heat treatment. Many researchers studied the microstructure evolution of cobalt-base superalloys in the ageing process [8-11]. It simulates the normal service process of the alloys. However, the alloys may endure some abnormal process, like as overheat or burnt sometimes. If the microstructure characters for over-temperature at different temperatures can be definite. The failure temperature can be defined quickly by contrasting the microstructures. The study of microstructure evolution for over-temperature is a very important and essential to failure analysis. This method is suitable for every alloy servicing at high temperature.

Comparing to other cobalt-base superalloys, the K6509 alloy adds much formation element of MC, so the MC is the dominant strengthening phase [7]. At high temperature, the as-cast alloy is thermodynamically unstable. The primary carbides, all the MC, M7C3 and M23C6, dissolve gradually with the increasing of temperature [2]. The stability of carbides is relevant to temperature. During the service, the M23C6 can be recognized the most stable carbides, and the M7C3 can transfer into M23C6 by a reaction mechanism (\(\text{M7C3} \rightarrow \text{M23C6+C}\)) [9]. But when the temperature reaches to 1150°C, the M23C6 dissolves into matrix and the M7C3 is stable. When the temperature arrives at 1200°C, the M7C3 dissolves and many pores form in the matrix. MC is very stable and can be present to
initial melt temperature of the alloy. When the temperature arises, the morphology of MC changes and some MC dissolves into matrix.

5. Conclusion

The microstructure of K6509 alloy is different treated at different temperature. In as-cast K6509, the MC carbides are present as a discrete, blocky dispersion with a well-distributed Chinese script morphology. The eutectics (γ+M23C6) and (γ+M7C3) can be seen. Below 1150°C, the script-like MC is dominant; reaching 1200°C, the particle and block of MC are dominant; reaching 1250°C, few script-like MC is present. In as-cast alloy, the M23C6 and M7C3 carbides are lamellar eutectic with matrix. When temperature is up to 1150°C, the eutectic (γ+M23C6) disappears; however, much eutectic (γ+M7C3) can be found. When the temperature reaches 1200°C, a large amount of eutectic M7C3 is dissolved, and some pores form in the matrix, and some zones rich in Cr form around the pores. When the temperature is above 1250°C, many pores form in the matrix, the cause of pores is need to be studied further.

The types and morphology of microstructures are different when the alloy is treated in different temperature. When the vanes are over heated or burnt, the temperature can be defined by examining the microstructure. It is useful for the researchers to check the over-temperature and analysis the failure mode and cause of vanes quickly. This method is suitable for every alloy servicing at high temperature.

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