Microstructure evolution analysis on creep behavior of Grade 91 steel under multiaxial state of stress

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Abstract. Creep tests of Grade 91 heat-resistant martensitic steel under multiaxial state of stress were conducted at 923K with stress ranging from 125 to 200MPa. The test results showed that the creep time of Grade 91 steel increases with the decreasing of applied stress. The microstructure evolution during creep of Grade 91 heat-resistant martensitic steel was investigated based on the optical microscope and scanning electron microscope analysis.

1. Introduction

Grade 91 steel is widely used in the power plants. This kind of steel has high thermal conductivity and lower coefficient of thermal expansion. The creep behaviors of different metals under multiaxial state of stress were investigated by researchers of all over the world.

Yu et al. [1] investigated the notch effect during creep using the double notched plate mini-specimens. The results show that the void growth is the primary mechanism of creep rupture by the analysis of scanning electron microscopy photos of fractured surfaces. Alang et al. [2] proposed the relationship between Monkman-Grant failure strain and local sub-grain stress state and predicted creep rupture and creep cracking rates of P92 steel under uniaxial and multiaxial conditions. Luo et al. [3] investigated the creep strain, fracture and failure mechanisms of HastelloyC276-BNi2 brazed joint under multiaxial stress by experiment and finite element modeling. The results show that the brazed joint under multiaxial stress was mainly fractured by intergranular brittle mode. Kobayashi et al. [4] studied the creep behavior of 304 stainless steel under biaxial, triaxial and uniaxial conditions and proposed a new equivalent stress taking account of the stress multiaxiality based on the multiaxial creep rupture data. Goyal et al. [5] assessed the creep rupture life of 9Cr-1Mo steel under multiaxial state of stress at 873K with stress ranging from 110 to 210Mpa. The results show that the creep rupture life of 9Cr-1Mo steel is higher in the presence of notch than that of smooth specimen. Chang et al. [6] studied the creep rupture behavior of P92 steel by plain and double U-type notch specimens at 650 °C. The results show that the fracture mechanism of P92 steel altered due to the presence of the notch. Sui et al. [7] studied the creep behavior of copper by conducting multiaxial creep tests with three different notch profiles at 75 °C with net section stresses ranging from 170 MPa to 245 MPa. The results show that copper has notch strengthening phenomenon. Yang et al. [8] established a finite element model based on ductility exhaustion model to estimate the deformation features of small punch creep test.
In this paper, the microstructure evolution of Grade 91 steel under multiaxial state of stress was investigated. The effects of different parameters on the microstructure evolution during creep process were analyzed.

2. Material and Experimental

The chemical composition of Grade 91 heat-resistant steel is shown in Table 1. The size of multiaxial creep test specimen is shown in Fig. 1. The gauge length and diameter of test specimens are 100mm and 10mm, respectively. The notch throat diameter and notch root radii of doubled circumferentially U-notched specimens are 6mm and 0.6mm, respectively. The creep experiments referred to GB/T2039-2002 Metallic material-creep and stress-rupture test in tension. The multiaxial creep tests were conducted at 923K with the applied stress of 125MPa, 175MPa and 200MPa on the high temperature creep and stress-rupture testing machines.

Table 1. Chemical composition of Grade 91 steel (wt.%).

| Element | C    | Mn  | Si  | Ni  | Cr  | Mo  | Cu  | Al  | S   |
|---------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Amount  | 0.10 | 0.40| 0.23| 0.13| 8.34| 0.98| 0.06| 0.009|0.002|
| Element | Sn   | V   | Nb  | N   | Ti  | Zr  | P   | N/A | 4.9 |
| Amount  | 0.005| 0.229|0.079|0.044|0.002|0.001|0.0101|4.9  |

Figure 1. Size of multiaxial creep test specimen.

3. Results and Discussions

3.1. Creep strain-time curves

The creep strain-time curves of Grade 91 heat-resistant steel at 923K is shown in Fig. 2. The applied stresses are 125MPa, 175MPa and 200MPa. It can be seen that the creep strain-time curves of Grade 91 heat-resistant steel of 200MPa and 175MPa exhibit typical three stages, namely, primary stage, steady-state stage and tertiary stage. However, the curve under 125MPa has no obvious tertiary creep stage in this study. It also can be seen that the creep time at the same temperature was found to decrease with the increase of stress level.

Figure 2. Creep strain-time curves.
3.2. Microstructure evolution analysis

The microscopic morphologies of longitudinal section crept at 923K and 125MPa near the fracture of notched specimen are shown in Fig. 3. As shown in Fig. 3(a), the fracture zone has no obvious shrinkage deformation phenomenon, which means that the creep specimen has little plastic deformation before fracture. It can be seen from Fig. 3(b) that there are more cavities located on the fracture zone. There are lots of carbides with different sizes in the grain as shown in Fig. 3(c).

![Figure 3. Microscopic morphology of longitudinal section near the fracture.](image)

The longitudinal section for non-fracture notch is shown in Fig. 4. No obvious cavity or crack is found in this zone. The microstructure of notch zone is martensite.

![Figure 4. Longitudinal section for non-fracture notch.](image)

The microstructure of undeformed zone is shown in Fig. 5. It can be seen that the microstructure is martensite and the grains are not uniform. In the high multiple, the carbides in the grain are parallel.
4. Conclusion

The microstructure evolution during creep of Grade 91 steel under multiaxial state of stress has been studied by optical microscope and scanning electron microscope analysis. The results show that the fracture zone has no obvious shrinkage deformation phenomenon.

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