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Influence of type and morphology of carbides on stress-rupture behavior of a cast cobalt-base superalloy

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ABSTRACT

The relationships between the type and morphology of carbides and stress-rupture property have been studied in a cast cobalt-base superalloy. Different types and morphologies of carbides are achieved by varying the heat treatment conditions. After heat treatment at 1240 °C/4 h, the primary M_7C_3 decomposes into $M_{23}C_6$, and the formed $M_{23}C_6$ and primary MC partially dissolve into the matrix. After heat treatment at 1280 °C/4 h, the primary M_7C_3 melts, resulting in the formation of a highly developed lamellar structure of $M_{23}C_6$, and the primary MC mostly dissolves into the matrix. The heat treatment at 1100 °C/300 h gives rise to the carbide transformation of $M_7C_3 \rightarrow M_{23}C_6$ and a profusion of secondary $M_{23}C_6$ carbide around $M_{23}C_6$ and MC. The samples in stress-rupture test at 980 °C for 83 MPa manifest the following rupture life: 1280 °C sample > 1240 °C sample > as-cast sample > 1100 °C sample. The longer rupture life of the samples of 1240 °C and 1280 °C is derived from the stable microstructure, dispersed MC carbide morphology and the supersaturated matrix. The shortest rupture life of the 1100 °C sample is mainly attributed to the overaging. Additionally, the carbide transformations of $M_7C_3 \rightarrow M_{23}C_6$, $MC \rightarrow M_{23}C_6$, $M_{23}C_6 \rightarrow M_6C$ take place in the as-cast sample during creep exposure.

1. Introduction

Cobalt-base superalloys have been widely used in both aero and industrial gas turbine fields. The superior creep resistance, hot corrosion oxidation resistance and the higher temperature capabilities over nickel-base superalloys are the advantages of cobalt-base superalloys in producing turbine components [1–3].

Carbide precipitation is the primary strengthening mechanism in cobalt-base superalloys and the amount, morphology and type of carbides have the decisive effect on the mechanical properties [1]. The main types of carbides in cast cobalt-base superalloys are MC, $M_{23}C_6$ and M_7C_3 [1–4]. Extensive studies have been carried out to discuss the effects of heat treatments on the microstructure and mechanical properties of cobalt-base superalloys [1–3,5–7]. These studies suggest that the use of appropriate heat treatment can significantly improve the mechanical properties of cobalt-base superalloys. The heat treatments reported in these studies mainly cause the dissolution of coarse primary carbides and the precipitation of fine secondary carbides.

Moreover, the heat treatment also results in carbide transformation. It is well known that primary carbides are unstable and tend to degenerate during high temperature heat treatment. The carbide reactions of $M_7C_3 \rightarrow M_{23}C_6$, $M_7C_3 \rightarrow M_6C$, and $MC \rightarrow M_6C$ at elevated temperatures have been reported in cobalt-base superalloys [8–12]. In addition, it should be noted that the melting of primary eutectic carbides can also bring about the changes in the carbide types. Recently, Gui et al. [13] have found that finer lamellar $M_{23}C_6$ is produced by the melting and re-solidification of primary network M_7C_3 eutectic carbide. Obviously, these reactions will certainly affect the microstructure, and thereby the mechanical properties of cobalt-base superalloys. Nevertheless, until recently, the influence of type and morphology of carbides on the mechanical properties in cobalt-base superalloys has not been studied.

Therefore, the purpose of the present paper is to investigate the influences of type and morphology of carbides caused by heat treatment upon stress-rupture property in a cast cobalt-base superalloy. The microstructural evolution of primary carbides during creep rupture is examined as well.

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Table 1
Chemical composition of the test alloy (wt.%).

Cr	Ni	W	C	Ta	Ti	Zr	Al	Co
25.5	10.7	7.81	0.42	0.34	0.19	0.16	0.97	bal.

2. Experimental

The chemical composition of the test cobalt-base superalloy is listed in Table 1. The cast single crystal specimens were prepared by means of the Bridgman method at a constant withdrawal rate of 6 mm/min in a directional solidification vacuum furnace. Longitudinal orientation of all specimens was within 10° deviating from [001]. Four alloy states varied by heat treatments thereby variation in carbide microstructure were selected for this investigation: as-cast, 1240 °C/4 h, 1280 °C/4 h and 1100 °C/300 h. Samples were air cooled after heat treatment. The stress-rupture test was conducted at 980 °C in air at a stress level of 83 MPa.

The metallographic samples in longitudinal section of the fracture specimens were prepared and etched with HCl, H_2O and H_2O_2 in 50:50:10 proportions. Microstructures of the longitudinal sections were observed by a JEOL JSM-5800 scanning electron microscopy (SEM) with back-scattered electron (BSE) mode. Phase compositions were determined by energy dispersive X-ray spectroscopy (EDS) equipped in the SEM. Phase changes were characterized by X-ray diffraction (XRD) method using Rigaku D/MAX 2500 diffractometer. Samples for transmission electron microscopy (TEM) were obtained from thin slices cut at a distance of 3 mm away from the fracture surface of rupture specimens. Thin foils were prepared by twin-jet thinning electrolytically in a solution of 5% perchloric acid and 95% ethanol at 50 V and −20 °C. The resulting foils were examined using a JEM 2100 TEM operating at 200 kV.

3. Results

3.1. Initial microstructure of the test samples

Microstructures of the test samples in four states, as-cast, 1240 °C/4 h, 1280 °C/4 h and 1100 °C/300 h, are given in Fig. 1. As

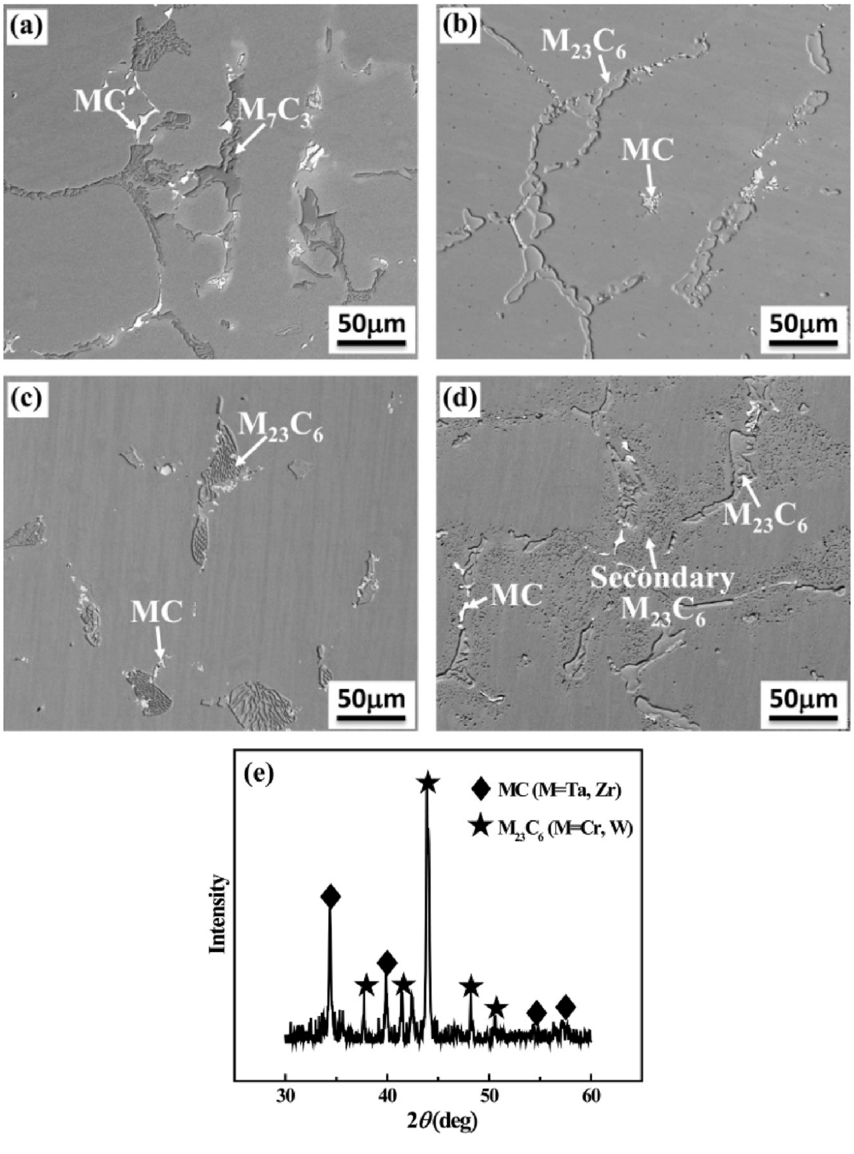

Fig. 1. Microstructures of the as-cast and heat-treated samples used in stress-rupture test: (a) as-cast, (b) 1240 °C/4 h, (c) 1280 °C/4 h, (d) 1100 °C/300 h and (e) XRD pattern of 1100 °C/300 h sample.