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Effects of tantalum on microstructure and mechanical properties of cast IN617 alloy

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ABSTRACT

Effects of Ta on microstructure and mechanical properties of cast IN617 alloy were investigated. The results showed that the addition of Ta increased size and area fraction of MC carbides, which was in agreement with the prediction of thermodynamic calculation, rather than influencing as-cast microstructure features such as grain size, secondary dendrite arm spacing, and carbide distribution. Ta-doped cast microstructure showed that Ti (C, N) nitride-carbide was substituted by MC carbide and at the same time, M_6C and MC tended to form a eutectic structure. The lattice constant of the matrix in a heat treatment condition increased from 3.593 to 3.601 nm and the high temperature tensile strength also improved, when Ta content are from 0 to 2.0 wt%. It was attributed to the solution of Ta with solid solution strengthening in the matrix. However, when the Ta level exceeded 1.0 wt%, the ductility and fracture toughness significantly reduced. It was believed that remained Ta-rich MC carbides in the supersaturated matrix accelerated the initiation and propagation of cracks. Therefore, the optimized Ta content in cast IN617 alloy is suggested to below 1.0 wt% for balanced properties.

1. Introduction

The proposed steam inlet temperature in the Advanced Ultra Supercritical (A-USC) steam turbine is so high (e.g., 700 °C) that traditional turbine casing and valve body materials such as ferritic/martensitic steels, cannot meet the requirements due to their temperature limitation. Instead, Ni-based superalloys can meet the A-USC requirements and have been investigated [1–3]. Owing to large sizes of the components, certain Ni-based superalloys are difficult to be processed by forging for this application. In industrial production, wrought Ni-based superalloys are often used as cast alloys in order to reduce the cost and period of fabrication. A wrought alloy, IN617 in cast form is being considered as a primary candidate material for developed A-USC boiler components, due to its excellent oxidation and creep resistance and being weldable. At present, most researchers focused on wrought IN617 and literatures on cast IN617 are limited [4–7]. Wu et al. [8–11] showed that primary precipitates of wrought IN617 were Ti (C, N), M_6C, $M_{23}C_6$ and γ'. They did not observe that detrimental topology close phases (TCP) precipitated during long-term thermal exposure (e.g., from 482 to 871 °C for approximately 65,000 h). However, Kewther et al. [5,12] observed the presence of TCP-μ phase and lath-shaped δ-Ni_3Mo during elevated temperature exposure. And they confirmed that these phases were deleterious to the mechanical properties by depleting alloying elements from the matrix γ.

Although IN617 alloy has been considered as a primary candidate for larger castings or valve components applied in coal-fired power plants in Europe, US and Japan [13,14], the microstructures and mechanical properties of cast IN617 has not been made publically, especially microstructural evolution and creep resistance at elevated temperatures. Compared with fine-grain wrought IN617, tensile strength of cast IN617 is lower due to its coarse grains. Therefore, a new alloying approach needs to be applied to improve tensile strength and microstructural stability of cast IN617. Ta usually played a beneficial role in the development of Ni-base superalloys [15,16], because Ta is a strong formation element of MC carbide that can improve carbide stability, and also promotes the precipitation of γ' [17,18]. Zheng and co-workers [19] reported that Ta addition improved stress rupture properties as well as maintained good microstructural stability of the low Cr and high W Ni-base superalloy. Reed et al. [20,21] found that the formation tendency of freckle and hot cracking during directional solidification could be reduced by the addition of Ta. Therefore, this work investigated the effects of Ta on the microstructures and mechanical properties of cast IN617, providing essential experiment data for the optimization of alloy composition and design of related components with a reliable operation in A-USC steam power plants.

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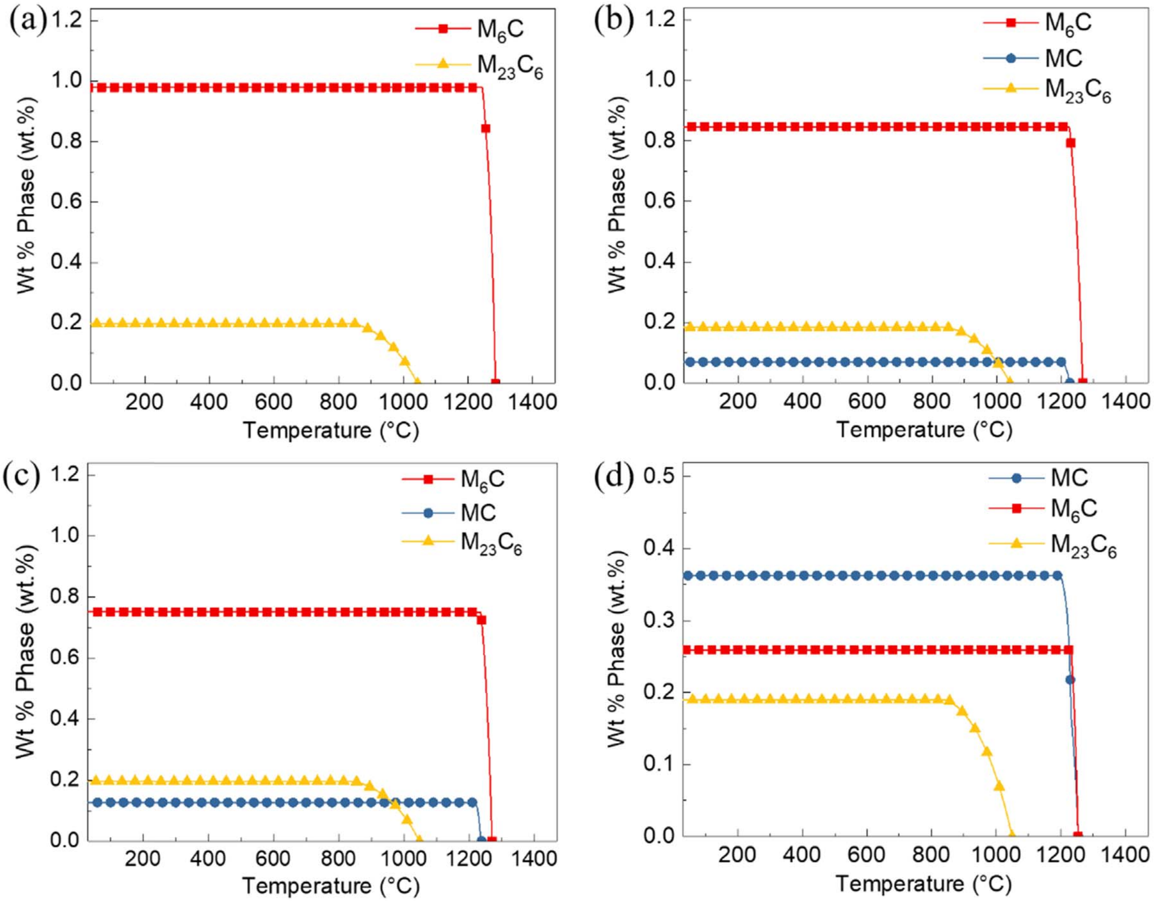

Fig. 1. Phase calculation results of main carbides in IN617 alloy with different levels of Ta: (a) 0 wt%Ta, (b) 0.5 wt%Ta, (c) 1.0 wt%Ta and (d) 2.0 wt%Ta. The main carbides are MC, M_6C and $M_{23}C_6$.

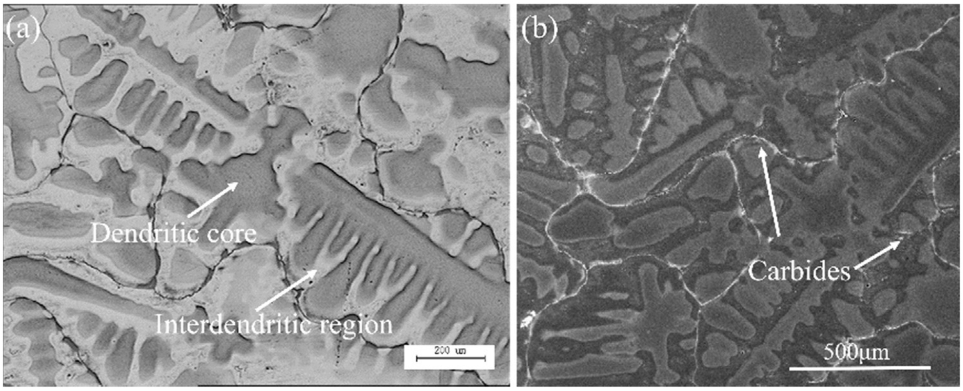

Fig. 2. The typical (a) OM and (b) SEM morphology of as-cast IN617 alloy.

Table 1
DTA results of the samples with different Ta levels.

Alloy	Liquidus temperature (°C)	Solidus temperature (°C)	Freezing range (°C)
A	1393	1369	24
B	1395	1365	30
C	1399	1370	29
D	1396	1371	25

2. Materials and experimental procedure

IN617 alloy with different Ta levels was produced by the vacuum induction melting followed by investment casting. Alloy A is the baseline alloy with a nominal composition of Ni-22Cr-12Co-9Mo-1.2Al-0.34Ti-0.15 C (wt%), which is free of Ta element. Alloy B, C and D were doped with 0.5 wt%, 1.0 wt% and 2.0 wt% Ta, respectively. All specimens were subjected to solution heat treatment of 1200 °C/ 2 h / water cooling and then machined to tensile specimens. Tensile tests were conducted at 700 °C with a strain rate of $10^{-3}s^{-1}$. Smooth cylindrical specimens had an overall length of 70 mm with gage length and diameter of 25 mm and 5 mm, respectively. The hardness of the alloy was measured by Rockwell hardness C (HRC) tester using a 120° diamond cone under a load of 140 kg and a dwell time of 10 s at room temperature.

Microstructural features were examined by optical microscope (OM), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), and selected area electron diffraction (SAD). The size and