Progress in Natural Science: Materials International 26 (2016) 204–209

Contents lists available at ScienceDirect

Progress in Natural Science: Materials International

journal homepage: www.elsevier.com/locate/pnsmi

Original Research

Effect of heat treatment on the microstructure of a Ni–Fe based superalloy for advanced ultra-supercritical power plant applications

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ARTICLE INFO

Article history:
Received 30 September 2015
Accepted 24 December 2015
Available online 20 April 2016

Keywords:
Ultra-supercritical power plant
Ni–Fe based superalloy
Heat treatment
Microstructure
Microhardness

ABSTRACT

The effect of heat treatment on the microstructure and microhardness of a Ni–Fe based superalloy for 700 °C advanced ultra-supercritical coal-fired power plants was investigated. Results showed that the main phases in the alloy were γ, γ', MC and $M_{23}C_6$, and no harmful phase was observed in the alloy. $M_{23}C_6$-type carbides discretely distributed nearby grain boundaries as the alloy was aged at above 840 °C. The microhardness decreased with increasing aging temperature. The coarsening of γ' led to the increment of microhardness at 780 °C and 810 °C for a short aging time, and a significant decrease in microhardness after aging at 840 °C. The aging temperature had more significant role on the microstructure than holding time. Therefore, to obtain optimum strengthening effect for this alloy, the aging temperature should not exceed 810 °C.

1. Introduction

It is well known that steam temperature and pressure are essential to the thermal efficiency of conventional fossil power plants. Improving steam parameters and the use of secondary reheat system to increase the efficiency and reduce pollutants emissions of power plants have been pursued worldwide. Researches indicate that while the plants operating under 35 MPa/700 °C, it had high thermal efficiency more than 50% and reduction of CO_2 emissions about 30% [1–3]. The main enabling technology in achieving the above goals has been the development of stronger high temperature materials. The requirements for candidate materials of the key components are excellent creep rupture strength, tensile strength, high oxidation resistance, good workability and low costs. With respect to the working conditions, Ni–Fe based superalloys with high creep rupture strength and corrosion resistance have become one of the main candidate materials [4,5].

Microstructure of a crystalline superalloy is a key factor in its technological application as it determines a wide variety of properties, which is greatly determined by the heat treatments. Both grain size and distribution of precipitates can significantly influence the mechanical properties [6,7]. The heat treatment recommended for nickel-base superalloys are suggested primarily to produce better distribution of γ' and carbides. Generally, a solid solution heat treatment is intended to obtain moderate grain size and dissolve the precipitating phase for subsequent re-precipitation in an optimized morphology and size. Then, with the subsequent one or double steps of aging treatments, it is possible to achieve controlled γ' re-precipitation and $M_{23}C_6$ typed carbides growth at grain boundaries. Meanwhile, it is noted that the high temperature aging treatment always is used for the formation of carbides and large size of γ' particles, while lots of fine γ' particles are formed during the low temperature aging term [8,9]. Previous studies showed that the solution treatment and double aging were applied on the heat treatment of GH 2984 alloy and Waspaloy, while solution treatment and one-step aging treatment were used for heat treatment of Inconel 740 alloy [9–11]. Both the one-step and two-step aging treatments are expected to obtain optimum matching between the grain interior strengthening and grain boundaries strengthening, which could resulted in excellent comprehensive properties. Therefore, in the light of one new superalloy and its service conditions, systematic analyses of heat treatment process and its corresponding microstructure are crucial to the mechanical properties.

The aim of present work is to optimize the temperatures and hold times of heat treatments for a new Ni–Fe based superalloy of 700 °C advanced ultra-supercritical (A-USC) coal-fired power plants, to

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Peer review under responsibility of Chinese Materials Research Society.

http://dx.doi.org/10.1016/j.pnsc.2016.03.013

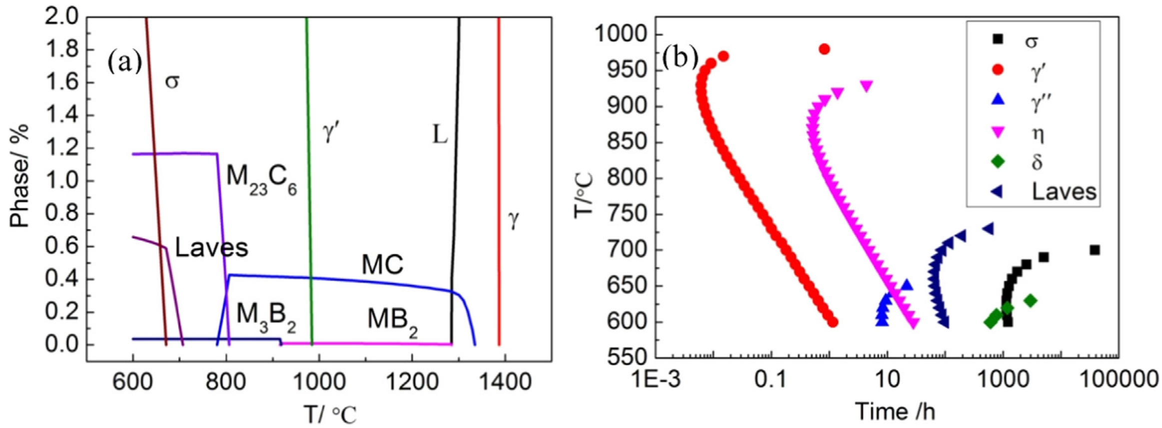

Fig. 1. Predicted phase diagram of the alloy. (a) Equilibrium phase diagram, and (b) TTT curves.

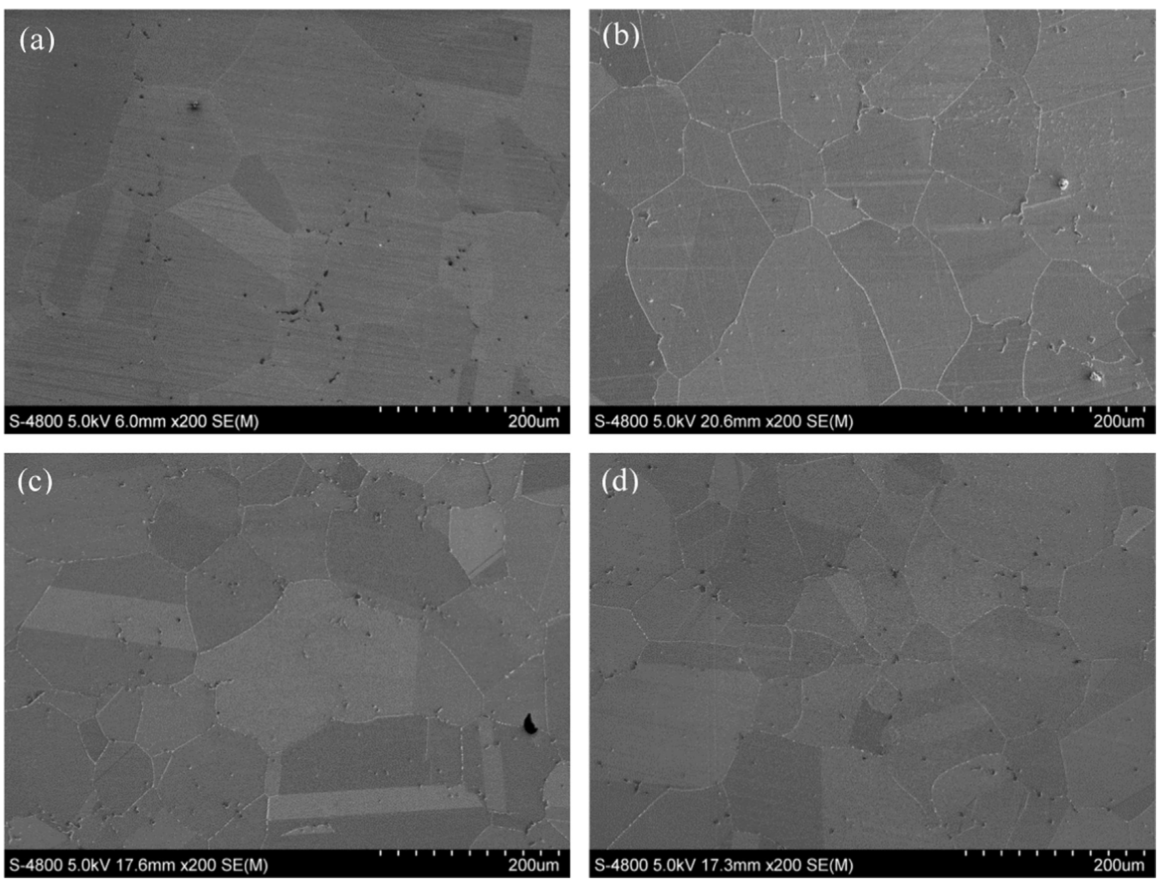

Fig. 2. Microstructure of alloys after different aging temperatures. (a) 810 °C, (b) 840 °C, (c) 870 °C, and (d) 900 °C.

elucidate the formation mechanism of precipitates morphologies and its role on micro-hardness with various heat treatments.

2. Experimental procedures

The experimental alloy used in this work was a Ni–Fe based superalloy with the nominal composition of Ni-16.0Cr-1.0Mo-1.0W-0.8Nb-2.4Ti-1.8Al-0.15Si-0.5Mn-0.15Cu-25Fe-0.003B-0.06 C (in wt%). Microstructure analyses were focused mainly on the carbides and γ' precipitation of the alloy with different heat treatments processes. All the samples were heated with one solution treatment 1150 °C/1 h, air cooling, to obtain a moderate grain size. Then high temperature aging treatment were conducted at temperature of 810–900 °C for 1 h, and low temperature aging treatment varied from 780 °C to 840 °C for 1 h, 8 h and 16 h, respectively. The microstructures of the heat-treated samples were examined after etching with 20 ml H_2O+20 ml HCl+4 g $CuSO_4$ +5 ml H_2SO_4. Micrographic examinations were made on Hitachi-S4800 field scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS). The microhardness tests were examined by microhardness tester (MHVD-1000IS) with load of 100 g for 10 s. The current work focused on the phase transformation was assisted by JMatPro simulations (Version 7.0).