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Structural stability of nickel superalloy IN740H after ageing in 750°C

A. Hernas, B. Kościelniak*, I. Bednarczyk
Silesian University of Technology, Faculty of Materials Science and Metallurgy,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding e-mail address: barbara.koscielniak@polsl.pl

ABSTRACT

Purpose: Constant demand for electric energy as well as legal and ecological conditions of the country motivate the construction of advanced ultra-supercritical AUSC power units. Increase of the steam parameters to about 700°C and pressure to over 30 MPa requires the application of modern nickel superalloys, which need to be characterized by structural stability at high temperature. The paper presents the results of analysis of structural changes of IN740H superalloy after ageing at 750°C.

Design/methodology/approach: Alloy specimens were aged at 750°C for 100 h, 500 h and 1000 h. Evaluation of structure was carried out with the use of light, scanning and scanning-transmission microscopy techniques as well as microanalysis of chemical composition with the use of X-ray spectrometer with energy dispersion (EDS).

Findings: The microstructure analyses applying light and electron microscopy revealed the precipitation processes occurring in the structure of IN740H alloy. It has been shown the changes of morphology of γ' phases and carbides due to heat treatment.

Practical implications: The research carried out enabled to know the structural changes of IN740H during ageing at high temperature, which are determined the mechanical and physicochemical properties of alloy.

Originality/value: Applied quantity and quality methodology of testing and achieved results of tests broaden the state of knowledge which refers to superalloys of nickel which are recommended to be applied in construction of super-ultra-supercritical boilers (AUSC).

Keywords: Metallic alloys; Electron microscopy; Microstructure; Heat treatment

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MATERIALS

1. Introduction

A development of new energy technologies is moving towards the construction of power units, which provided 50% thermal efficiency with a significant reduction of harmful substances in the atmosphere. The most effective way to improve the efficiency of modern coal fired plants is increasing the thermodynamic parameters of steam. In the near future, it will be build boilers for superultrasupercritical parameters (AUSC) with a steam temperature of 700°C and a vapor pressure to over 30 MPa [1-4].

Power units development required the application of materials, which have high creep rupture strength at a temperature of about 750°C, together with good resistance to oxidation in steam and resistance to high-temperature corrosion. For long-term operating at high temperature and pressure, nickel superalloys are recommended for the construction of critical elements [5,6].

One of the most promising superalloy, which could be used in production of superheaters and reheaters for AUSC boilers is IN740H nickel superalloy. The IN740H is developed by Special Metal Corporation to resist coal ash corrosion up to temperature of 700°C and resist creep-rupture for 100 000 h at 100 MPa [7-11].

However, knowledge and experience in the scope of application of IN740H superalloy is not sufficient. The design of reference boiler for AUSC parameters was prepared by RAFAKO S.A. within the strategic project PBS-1 and takes into account the application of the above mentioned alloy on the heaviest loaded elements of boiler superheater [10].

That is why a research started to assess the structure stability of tested alloys in temperature of 750°C which is close to operational temperature. The paper presents the results of test analyses of precipitation processes occurring in the structure of IN740H after annealing for 100 h, 500 h and 1000 h.

2. Materials and methodology

The material subjected to the research was samples cut from thin-walled tube made of IN740H nickel superalloy with dimensions of Ø 38 x 4.5 mm. The chemical composition of the superalloy is presented in Table 1. The samples were aged with furnace cooling at temperature of 750°C in times of 100 h, 500 h and 1000 h.

Evaluation of the microstructure of samples after ageing was performed with the used of Olympus GX71 light microscope (LM), Hitachi S-4200 scanning electron microscope with secondary electrons detector (SEM) and Hitachi HD-2300A scanning transmission electron microscope (STEM). Chemical composition was described by using an energy dispersive X-ray spectroscopy (EDS) with Thermo NORAN (System Seven). Samples for LM and SEM observation were prepared by electrolytic etching in a solution of oxalic acid. Thin films for STEM were prepared by electrolytic polishing in a solution consisting of 70% CH_3OH, 20% $HClO_4$ and 10% glycerine at temperature of - 20°C and voltage 11.5 V.

3. Results

The microstructure of IN740H after ageing at 750°C in different times, as observed in the light microscope, are presented in Fig. 1. The microstructure characterized by coarse grain structure of austenite, which contains annealing twins. The large particles of MC carbides were dispersed within the grain of alloy, which have been shown to be of (Nb,Ti)C composition. MC carbides are stable at high temperatures and have the typical blocky morphology (Fig. 2).

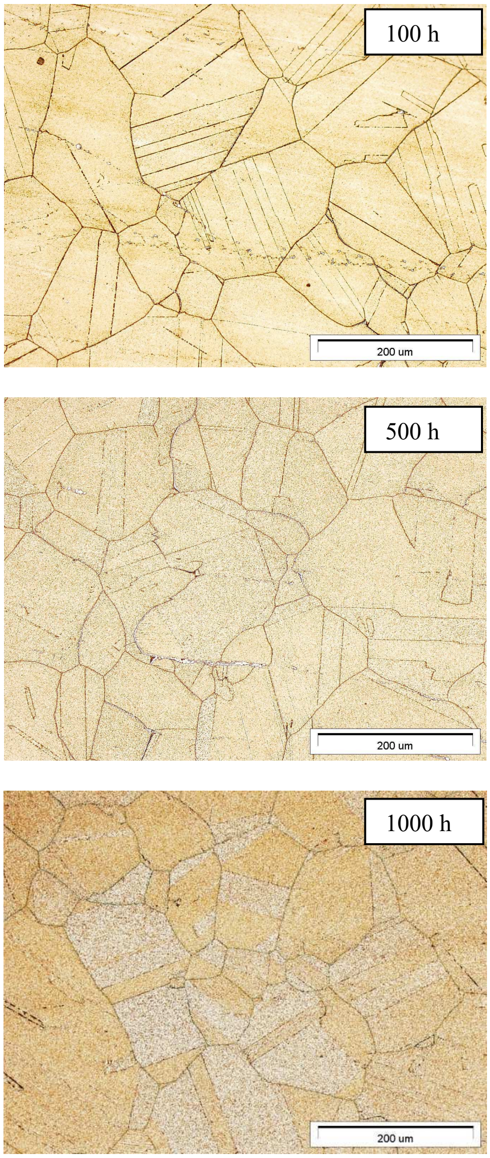

Fig. 1. LM micrographs of samples of IN740H after ageing at 750°C in different times

Table 1.
The chemical composition of the investigated superalloy

Concentration of major elements (in wt. %)								
C	Mn	Cr	Ni	Ti	Mo	Co	Nb	Al
0.03	0.10	24.41	51.86	0.81	1.65	20.19	0.49	1.35

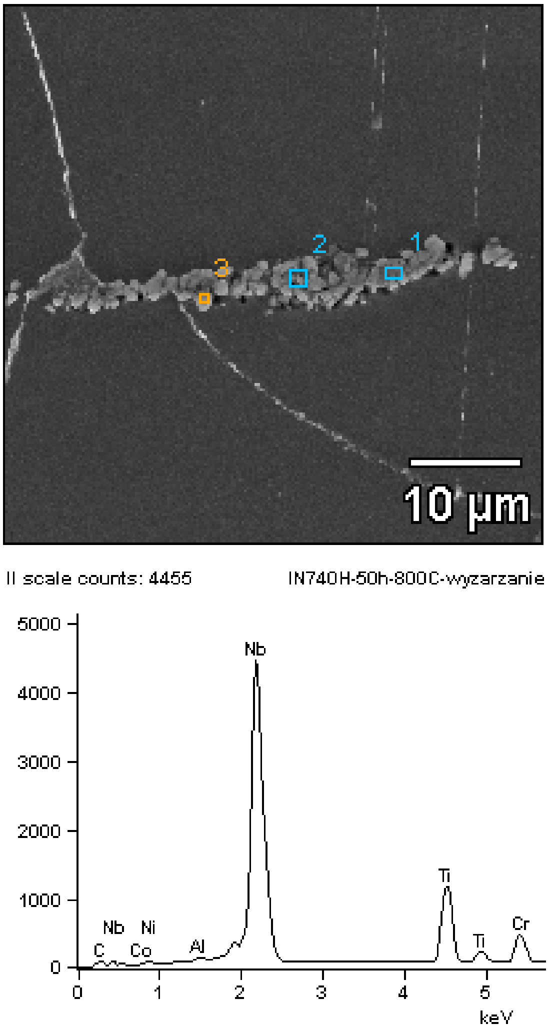

Fig. 2. Chemical composition of MC carbides in IN740H after ageing at 750°C/100 h

The SEM and STEM investigation of $M_{23}C_6$ carbides, which are formed along the grain boundaries are shown in Figs. 3-5. The Cr-rich $M_{23}C_6$ is characterized by block and globular shape with various sizes. Prolonged annealing (up to 1000 h) at 750°C resulted in intensified precipitation and coagulation of $M_{23}C_6$ (Fig. 4). In addition, $M_{23}C_6$ carbides are also precipitated along the annealing twins (Fig. 5).

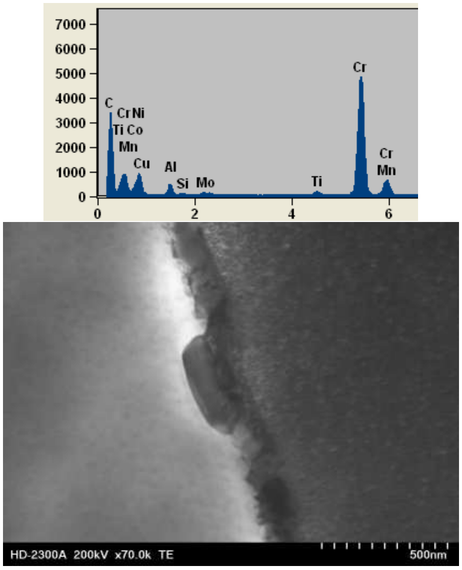

Fig.3. STEM micrograph of $M_{23}C_6$ carbides in IN740H after aging at 750°C /100 h

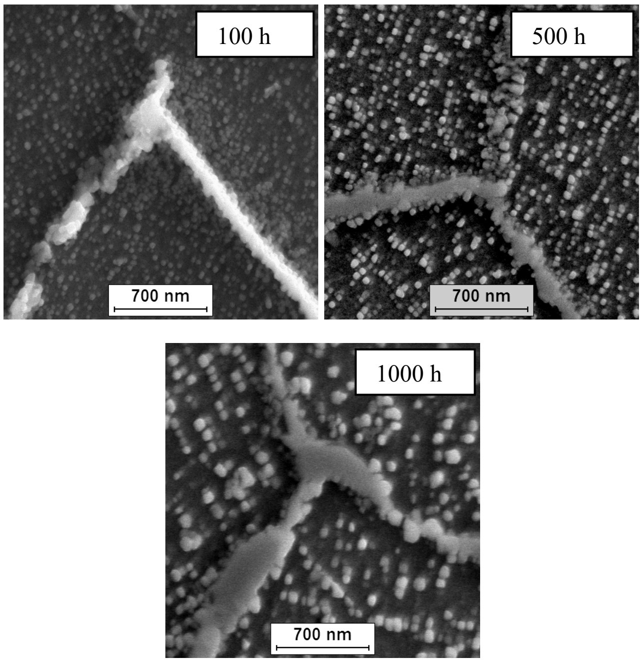

Fig. 4. SEM micrographs of $M_{23}C_6$ carbides in IN740H after ageing at 750°C in different times

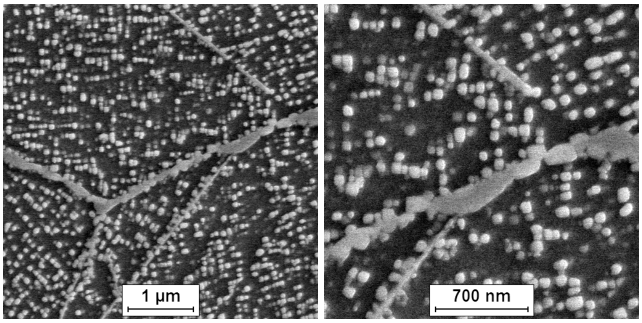

Fig. 5. SEM micrographs of $M_{23}C_6$ carbides along twins in IN740H after ageing at 750°C/1000 h

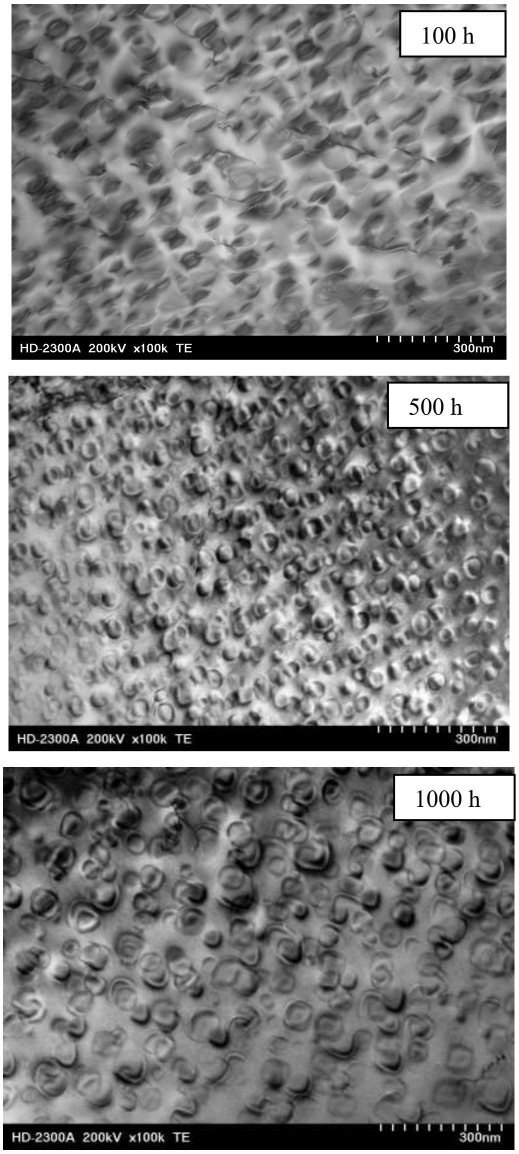

Fig. 6. STEM micrographs of γ' phase in IN740H after aging at 750°C in different times

The morphology of γ' phases after aging at 750°C in different time are shown in Fig. 6. This strengthening phase is typically distributed throughout the grain interiors of superalloy. The size and shape of precipitation of γ' are changed due to time of ageing. After 100 h of annealing, γ' phase has coherent spherical morphology with average diameter in range of 20-40 nm (Fig. 7). During heat treatment up to 1000 h, precipitates of γ' were coagulated and took semi-coherent cuboidal morphology. The average diameter of cuboidal particles of γ' is in range of 50-90 nm (Fig. 7). The small particles of γ' with rounded cubic shape also occurred.

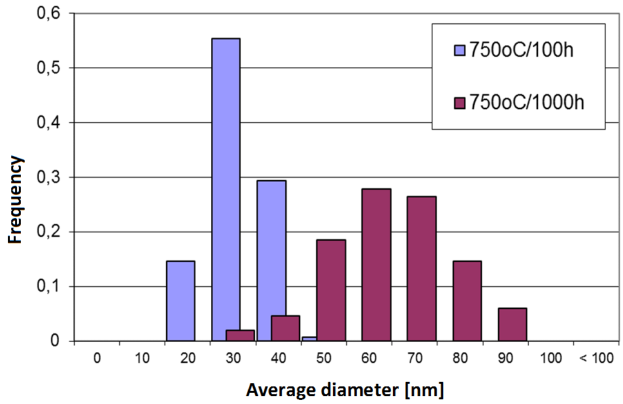

Fig. 7. Size distribution of γ' phase in IN740H after aging at 750°C in different times

The η, G-phases and topologically close-packed phases have not been observed during the research.

4. Conclusions

Based on the results of the tests that have been carried out, the following conclusions have been formulated about the microstructural changes of IN740H superalloy after ageing at temperature of 750°C:

1. Particles of MC carbides were dispersed within the grain of austenite, which are stable at high temperatures.
2. The $M_{23}C_6$ carbides occurred along the grain boundaries and coagulated with ageing time. $M_{23}C_6$ carbides also formed along the annealing twins.
3. During annealing up to 1000 h, particles of γ' phases increased and changed the shape from a coherent spherical morphology to a semi-coherent cuboidal morphology.
4. The η, G-phases and topologically close-packed phases have not been observed during the research.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME’2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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