Effect of Overage Hardening Heat Treatment on the Micro Structure and Hardness of Nickel-based Super Alloy Rene-80

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Abstract
Rene-80 nickel-base superalloy as an alloy for production of the jet turbine blades shows high mechanical properties as well as microstructure stability during the high temperature engine operation. In this research, age hardening heat treatment cycle was done on the as-cast Rene-80 superalloy. In the following, microstructure, elemental analysis of phases and macro-hardness of the alloy before and after of heat treatment were compared together with scanning electron microscopy (SEM) observation, X-ray spectrometry (EDS) and hardness test, respectively. The obtained results showed that γ' carbide particles in the as-cast alloy had cubic morphology, while these particles showed more spherical morphology after heat treatment and also the amount of this phase was reduced after heat treatment. Based on hardness test results, hardness of as-cast sample was reduce from 38.17 to 35.01 HRC after age hardening heat treatment, which can be due to the reduction of carbide particles and their morphological modification.

Keywords
Rene-80 Nickel-base Superalloy, Age Hardening Heat Treatment, Microstructure, Hardness

1. Introduction
Superalloys developed for use at high temperature and stress condition due to their high performance characteristics. The three major materials of these alloys are nickel, cobalt and iron and usually manufactured by casting and forming methods [1-5]. High thermomechanical strength, resistance to high temperature creep, surface stability and corrosion resistance are the key characteristics considered in using the superalloy parts.

Nickel based is critical superalloys use for turbine industry applications where high strength and creep resistance properties needed.

The cast nickel-based superalloy Rene-80 is a precipitation strengthening material use for manufacturing catastrophic parts including turbine blade, turbine disk and combustion chambers due to its high thermal fatigue and corrosion resistance [6-7]. The application of these superalloys is increasing in different industries. The authors have some efforts on welding, brazing and drilling of this material in the industry [8-11].

There are a few works concerning heat treatment of Rene-80 super alloy. Safari et al. [12] investigated the precipitation of different carbides in grain boundaries and alloy elements.

Yang et al. [13] studied the effect of heat treatment on the mechanical and stress rupture properties. Gao et al. [14] discovered the cooling rate effect on microstructure evolution and mechanical properties of Rene-80 super alloy. Du et al. [15] worked on microstructure and tensile behavior of In792 super alloy. In addition, some works [16, 17] conducted on newly developed nickel based super alloys. In them, mostly the microstructure evolution and hot temperature properties of the alloys studied due to heat treatment processes. Koul et al. investigated the formation of serrated grain boundary resulted from movement of γ' particles in Ni-based superalloys and the required heat treatment cycles in casting process was suggested [18].

According to the research [19-22] on Ni-based heat treatments, the correct selecting of solution and aging temperature is the more affective parameter for achieving proper mechanical behavior.

In this work, the effect of over aging heat treatment on the material microstructure, phases, morphology and hardness was investigated for Rene-80 superalloy. The OM and SEM images of casting and heat treated samples were studied and the analysis of elements performed by EDS tests.

2. Experiments

The average elemental composition of the cast nickel-based superalloy Rene-80 reported from XRF analysis on five samples is according to Table 1. This alloy is named C50TF28 in GE standard. This material is used for manufacturing of industrial gas turbines blades.

Table1. Chemical composition of Rene-80

Element	Ni	Cr	Co	Ti	Al	Mo	W	C	B	Fe
Wt%	Bal.	15.18	9.10	5.42	3.18	4.14	4.10	0.15	0.13	0.10

The over-aging heat treatment cycle performed on the casted samples according to Figure 1. A programmable argon vacuum furnace under vacuum pressure of 0.1 mbar was used for heat treatment. The performed heat treatment process was as follow: in the first step, solution treatment performed in 1204°C for two hours followed by cooling to 1093°C for 10 minutes in argon furnace. In the second step, the samples were kept in 1093° C for four hours and cooling to 843°C in argon furnace for 60 minutes. In the third step, the samples were kept in 843°C for 32 hours after that cooling to room temperature in 60 minutes. In the fourth step, the temperature of samples increased to 1000°C and kept for 10 hours in this temperature and then cooling to room temperature in vacuum furnace in 60 minutes.

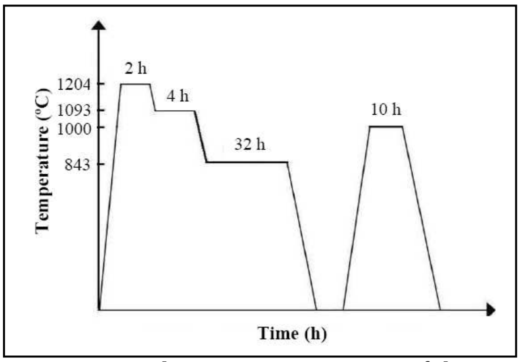


Figure1. Over aging heat treatment process of the samples

3. Results

Effects of over aging heat treatment on the material microstructure, phases, morphology and hardness investigated for Rene-80 superalloy. The following results presented for both casting and heat-treated samples.

3.1 Casting samples

Figure 2 shows optical microscopy result of a Rene 80 casting sample contains dendrites resulted from solidification process in a separation pattern. The heavy elements with high melting point temperature such as tungsten and molybdenum are concentrated in the center of dendrites. Boundary areas of dendrites are rich of aluminum and titanium element which shown in shaded color. Existence of these elements results in increasing the size of γ' particles in boundary areas relative to dendrites center [23].

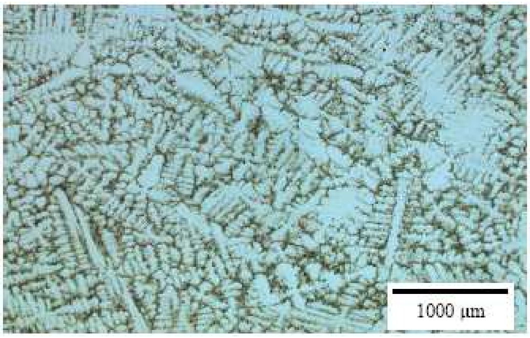


Figure2. OM image of Rene 80 casting dendritic microstructure

In Figure 3 the SEM image of casting microstructure is shown. In this image, the γ' particles have cubic shape in which some of them have extended corners due to forming of new γ' particles from older ones.

Ternary phase diagram of Ni-Al-Cr showed in Figure 4. Microstructure of eutectic γ-γ' areas are shown in Figure 5 which are formed in the last step of solidification step. Distribution of carbide particles in casting microstructure is shown in figure 6. Two types of carbides MC and $M_{23}C_6$ with different shapes in the grains and boundaries are recognizable. Usually $M_{23}C_6$ carbides form in grain boundaries but MC carbides create inside the grains more regularly as clarified in Figure 6 [23].

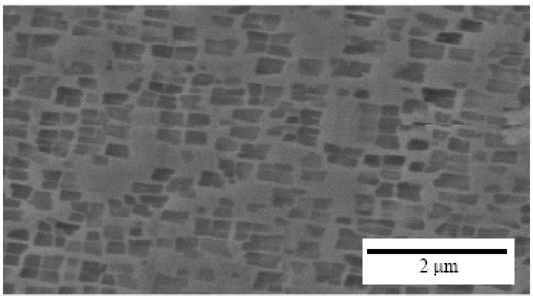


Figure3. SEM image of cubic γ' particles in Rene 80 casting microstructure

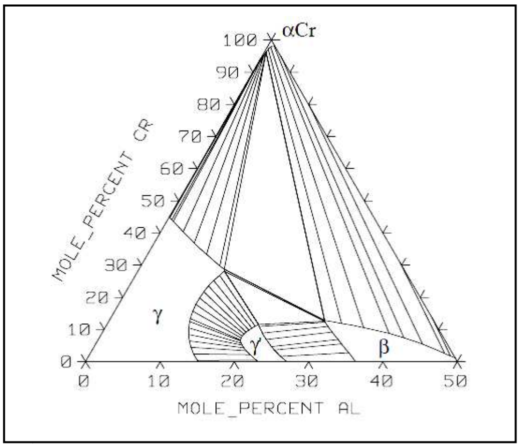


Figure4. Calculated isothermal section for Ni-Al-Cr at 1000 c [24]

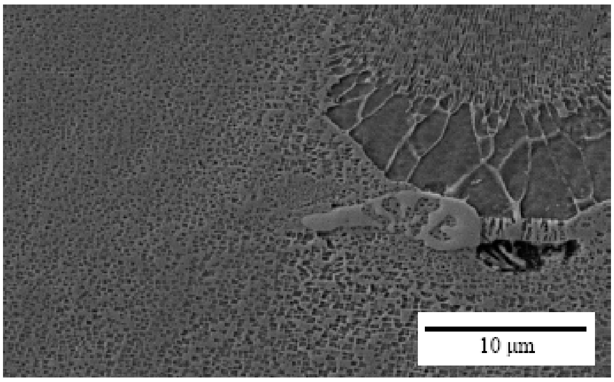


Figure5. SEM image of eutectic microstructure in Rene 80 casting microstructure

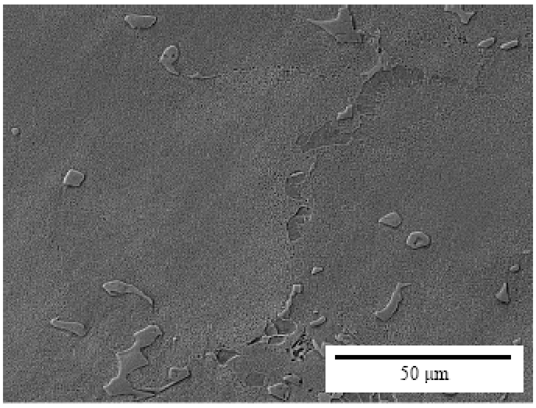


Figure6. distribution of carbides in casting microstructure of Rene 80

The image of MC carbides with 6.00 KX magnification is declared in Figure 7. In Figure 8 the analysis of this element is shown. Accordingly these carbides are rich of titanium, tungsten and molybdenum.

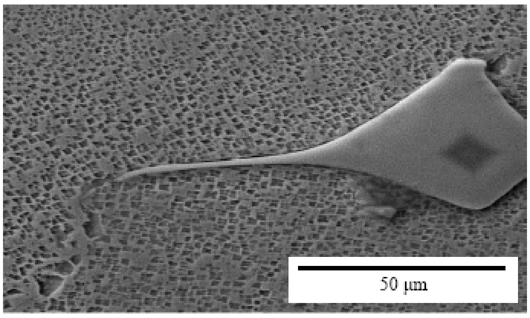
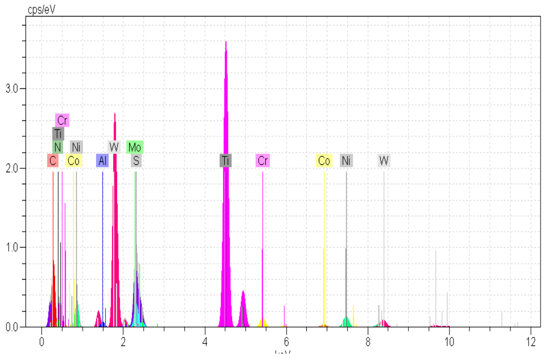


Figure7. MC carbide in casting microstructure of Rene-80



Element	Weight %
Ti	20.2
W	16.3
Mo	12.5
Cr	11.1
Ni	8.1
Co	10
C	15
Al	6.3
N	0.2
S	0.3

Figure8. Elemental analysis of MC carbides in Rene 80 mirostructure

As shown in the SEM results, the phase γ’ with semi cubic morphology exist in the microstructure, which can lead to significant reduction in the material flexibility and increasing its hardness.

3.2 Heat Treated Samples

The influence of over-aging heat treatment process on the morphology of γ’ microstructure is shown in Figure 9. The cubic γ’ of casting microstructure is converted to spherical γ’ and in some zones the γ’ particles are united which result in reducing mechanical properties and increasing the weldability. Figure 10 displays the carbides distribution in heat treated microstructure. According to dissolution temperature of MC carbides (more than 1040°C) and $M_{23}C_6$ carbides (750 to 980°C), the carbides of heat treated samples are less than casting microstructure shown in figure 5 and eutectic zone γ’-γ disappeared.

The MC carbide enriched of titanium, tungsten and molybdenum is displayed in Figure 11 with the element analysis presented in Figure 12. Figure 13 demonstrates the boundary carbide $M_{23}C_6$. The element analysis of this carbide shown in Figure 14 reveals that this carbide is full of molybdenum, chromium and tungsten.

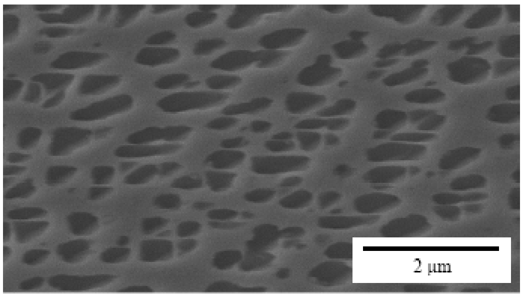


Figure9. The morphology of γ’ in microstructure of heat treated Rene 80

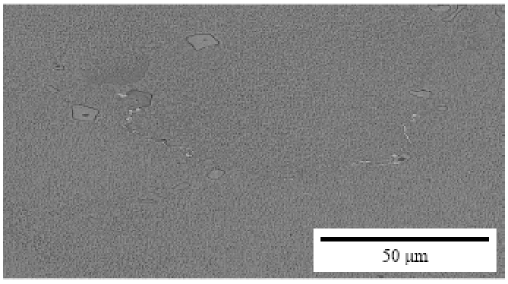


Figure10. Distribution of carbides in Rene 80 microstructure

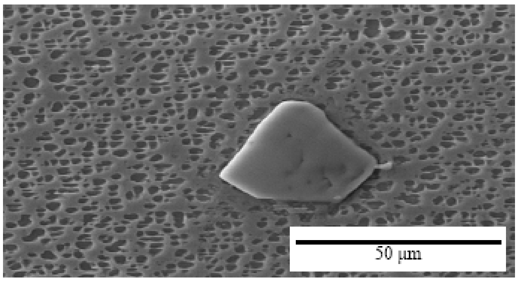
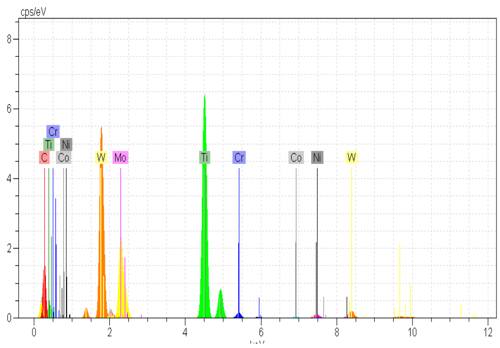


Figure11. MC carbide in heat treated Rene 80 sample



Element	Weight %
Ti	25.8
W	17.9
Mo	14.4
Cr	11.8
Ni	7.9
Co	5.5
C	16.7

Figure12. MC carbide in heat treated Rene 80 sample

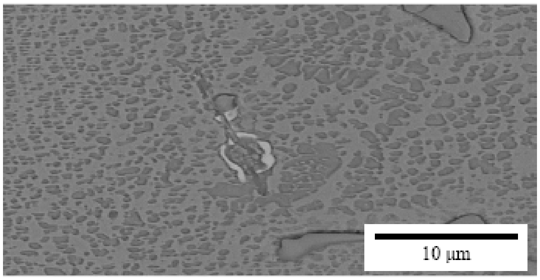


Figure13. Existence of boundry $M_{23}C_6$ carbides in heat treated sample

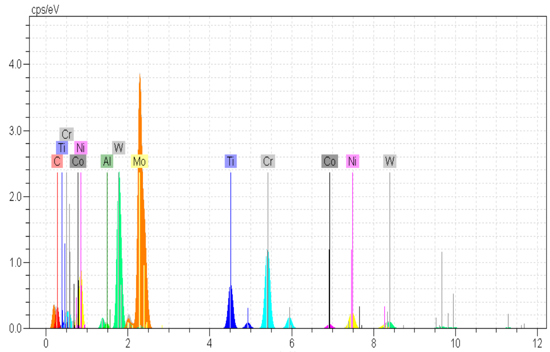


Figure14. Element analysis of $M_{23}C_6$ carbides in heat treated samples

3.3 Hardness

The hardness average of heat treated sample is 35.01 HRC while for casting sample is less (about 38.17 HRC). The reason may be due to decreasing of carbides in the matrix and also changing the morphology of them from cubic form to semi spherical.

4. Conclusion

In this work, the microstructure, element analysis and macro hardness of Rene 80 super alloy is studied in casting and heat treated condition and the following results obtained:

1. In casting microstructure, some dendrites with separation pattern exist.
2. Conducting over aging heat treatment result in changing of particles shapes from cubic to spherical. In some zones, the particles are inter connected and larger particle created.
3. In both samples, the MC and M23C6 carbides are visible while in heat treated one their value is lower.
4. The macro hardness of heat treated sample is lower in comparison with casting ones. The possible cause is declining of carbides after process and transforming of them from cubic to spherical forms.

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