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The Effect of Heat Treatment on the Microstructure of Cast Ni-based IN100 Superalloy

A. Rahimi[1]*, Sh. Mirdamadi[2], S.H. Razavi[3]

S.M. Abbasi[4]

1-Introduction

IN100 nickel-based superalloy is one of high temperature strength superalloys used for producing nozzles, blades, air jet turbine blades and forged molds at high temperatures. This superalloy is produced in the shape of castings and has the ability to be aged.

The microstructure of this superalloy consists of several phases including: austenitic matrix γ, coherent and regular deposits of primary γ' [(Ni_3(Ti, Al)] (~450nm), secondary γ' (~15-30nm) and tertiary γ' (<15nm) and various carbides. Carbides include: primary MC carbides which contain Ti and Mo, M_6C carbides rich in Ni, Co, Mo and Cr and $M_{23}C_6$ carbides rich in Cr. The microstructure of this alloy is highly dependent on the history of casting and heat treatment. Therefore, by selecting an optimum casting procedure and heat treatment cycles the desired microstructure and mechanical properties can be achieved. One of the most important heat treatment cycles that has attracted a lot of attention is full solution treatment (before partial solution and aging treatments). Therefore, studying the microstructural changes during the heat treatment cycles which includes complete solution, partial solution and aging can control the microstructure and mechanical properties of the final product. So far, some effort has been spent on modifying the microstructure of superalloys which will lead to performance improvements. Despite the history and widespread use of IN100 superalloy, limited research about the effects of heat treatment on the microstructure has been reported. The main reason is that this superalloy is used more often in the as-cast state. Thus, in the present work, microstructural changes of the alloy including morphology, size and volume fraction of different phases has been evaluated after various solution treatment cycles.

2- Materials and Experimental procedure

The chemical composition of IN100 superalloy used in this study, measured by Spark Emission Spectrometer is shown in Table 1.

Table 1 Chemical composition of IN100

Ni	Al	Ti	Cr	Co	Mo	C	V	S
Bal.	5.23	4.41	9.82	15.07	3.01	0.18	1.02	0.008

Samples with dimensions of 20×20×20mm were selected and subjected to heat treatment cycles according to Table 2. The microstructure of the as-cast sample was also evaluated to compare and understand the effects of heat treatment.

Table 2 Heat Treatment cycles

Number	Heat Treatment cycle	Full Solution(hr/°C)	Partial Solution(hr/°C)	Aging(hr/°C)
1	Partial Solution	-	4/1080	10/900
2	Full Solution	2/1210	-	10/900
3	Partial Solution+ Full Solution	2/1210	4/1080	10/900
4	Full Solution	2/1160	-	-
5	Full Solution	2/1185	-	-
6	Full Solution	2/1210	-	-
7	Full Solution	2/1235	-	-

The samples were cooled in air after each heat treatment and then the next stage of heat treatment was implemented. Metallographic samples were prepared using standard polishing procedures according to ASTM E3-01 with dimensions of 15×15×15mm. The microstructure was revealed using 10g Cu_2S+50ml HCl+50ml H_2O solution. A XMU TESCAN scanning electron microscope (SEM) with an energy dispersive spectroscopy (EDS) analyzer operating at 15kV and Olampya optical microscope (OM) were used to analyze the morphology and distribution of the phases. EDS analysis was also used to detect phases.

3- Results and Discussions

Fig. 1.a shows the SEM micrograph of the as-cast IN100 alloy. Unregulated cubic primary γ' precipitates aligned randomly with an average size of 420±20nm and a volume fraction of 25±3%. As a result of non-equilibrium solidification, the primary γ' with suitable morphology and desired volume fraction did not form. Primary γ' formed during solidification.

[1]* Corresponding Author, M.Sc. Student, Department of Materials Science and Metallurgical Engineering, Iran University of Science and Technology (IUST)
Email: ahmadrahimi1367@gmail.com

[2] Professor, Department of Materials Science and Metallurgical Engineering, Iran University of Science and Technology (IUST)

[3] Associate Professor, Department of Materials Science and Metallurgical Engineering, Iran University of Science and Technology (IUST)

[4] Metallic Materials Research Center (MMRC), Malek-Ashtar University of Technology

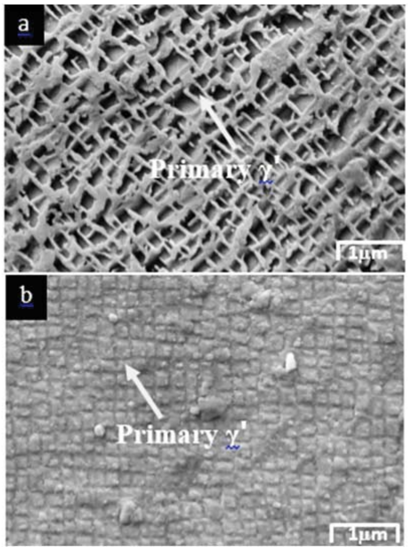

Fig. 1 SEM micrograph of a) as cast; b) after heat treatment number 3 from Table 2 showing primary γ'

Fig. 1.b shows the SEM micrograph of primary γ' in the sample subjected to heat treatment cycle 3 (Table 2). The primary γ' size in this sample is within the range of 470±10nm occupying 45±3vol% of the microstructure. Comparing the microstructure of the heat-treated alloy with the as-cast one (Fig. 1.a and Fig. 1.b), shows an 80% increase in the volume fraction and 50nm in the size of the primary γ' in the heat treated condition. The shape of the primary γ' is changed to ordered cubic structure compared to the as-cast structure. This morphology is most desired for high temperature mechanical properties of this alloy. The appearance of perfect cubic and increased volume fraction of primary γ' compared to other samples can be related to the heat treatment cycles with full solution which decrease the segregation caused during casting and also the partial solution implemented afterwards which set the conditions for the formation of primary γ' with the desired morphology and high volume fraction during aging.

4- Conclusions

1. The optimum heat treatment cycle to create the best microstructure for IN100 superalloy includes full solution at 1210°C for 2h and partial solution at 1080°C for 4h followed by aging at 900°C for 10h. The volume fraction and average size of primary γ' increase about 80% and 12% respectively compared to the as-cast condition.
2. Full solution with partial solution before aging treatment will cause the formation of ordered cubic primary γ' in the microstructure. It can be deduced that, by two stage solution, the decomposition of some MC carbides leads to change in the morphology of these carbides from blocky to spherical. In addition, some of the MC carbides during this cycle transformed to $M_{23}C_6$ and M_6C within the grains and at the grain boundaries.