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ISSN 0543-5846
METABK 50(3) 155-158 (2011)
UDC – UDK 539.4.016:621.785:669.245=111

EFFECT OF TEMPERATURE ON MECHANICAL PROPERTIES AND TYPE OF FRACTURE OF SUPERALLOYS NIMONIC 80A

Received – Prispjelo: 2010-07-15
Accepted – Prihvaćeno: 2010-10-12
Original Scientific Paper – Izvorni znanstveni rad

The Ni-base superalloys Nimonic 80A gains its appropriate microstructure and high temperature strength through precipitation hardening.
In this paper, the results of mechanical testings are presented for temperature range from 25 to 850°C for the Nimonic 80A superalloys. The variation of ductility properties in dependence of temperature has been demonstrated by analysis on the stereo, optical and scanning electron microscopy and results of tensile test.
It was found that different fracture mechanisms occure in a different temperature ranges. Brittle fracture was dominant at high temperatures and a significant proportion of ductile fracture at room temperature was observed.

Key words: Nimonic 80A; tensile test, brittle fracture, ductile fracture

Uticaj temperature na mehanička svojstva i tip loma superlegure Nimonic 80A. Superlegura na bazi nikla Nimonic 80A precipitacionim očvršćavanjem na povišenim temperaturama dobija svoja odgovarajuća svojstva i mikrostrukturne karakteristike.
U ovom radu su predstavljeni rezultati ispitivanja mehaničkih svojstava u temperaturnom intervalu od 25 do 850 °C superlegure Nimonic 80A. Promjena duktilnih svojstava legure u zavisnosti od temperature potvrđena je analizom lomova epruveta na stereo, optičkom i skenirajućem mikroskopu i rezultatima vlačnih karakteristika.
Uočeno je da različiti tipovi lomova egzistiraju u različitom temperaturnom intervalu. Na povišenim temperaturama dominantan je krhki lom, dok je na sobnoj temperaturi znatan udio duktilnog loma.

Ključne riječi: Nimonic 80A, ispitivanje razvlačenjem, krhki lom, duktilni lom

INTRODUCTION

Nimonic 80A is a wrought nickel base superalloy which is particularly suitable for service under high stresses in temperature range from 600 to 750 °C [1]. Because of its good stress relaxation resistance it is widely used for mechanical joining of high temperature parts [2-4], such as insert bolts in the combustion chamber of the gas turbine unit, which operates at temperatures below about 650 °C.

This paper presents an analysis of fracture types after static tensile test at room and elevated temperatures.

EXPERIMENTAL METHODS

Tests were conducted using three different melts. The results of chemical analysis are shown in Table 1. Chemical analysis of the used melts are in accordance to the standard chemical composition for Nimonic 80A superalloy (ASTM B637).

After forging and rolling to bars Φ 15mm tested materials were heat treated using standard parameters for this type of superalloys. The standard heat treatment consists of solution annealing at 1080 °C/8 hours, cooling in air to room temperature, followed by precipitation annealing at 720 °C/16 hours, cooling in air [1].

The aim of solution annealing is solution of the γ' phase, and some types of carbides such as M_7C_3 and $M_{23}C_6$. The optimum parameters for this type of heat treatment are: 1080 °C/8 hours, cooling in air to room temperature. After solution anneling next step is precipitation annealing at 720 °C/16 hours, cooling in air. Temperatures of solution anneling below 1080 °C lead to increased creep rate, and higher temperatures caused an earlier failure with lower values of elongation [1, 5].

During the precipitation annealing precipitation of γ' strengthening phase and some type of fine carbides such as $M_{23}C_6$ mainly on grain boundaries occure. During this annealing, M_7C_3 carbides, which are not dissolved during solution annealing, transformed to $M_{23}C_6$ type of the carbides due to their instability at precipitacion annealing temperatures. After solution annealing alloys have an uniform grain size (ASTM ASTM 2 to 4, with a slightly smaller number of larger grains). Precipitation

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Table 1 **The chemical composition of Nimonic 80A / wt. %**

Prescribed / Melt	C	Si	Mn	S	Al	Co	Cr	Fe	Ti	P	Ni
	max. 0,10	max. 1,00	max. 1,00	max. 0,015	0,50-1,80	-	18-21	max. 3,00	1,80-2,70	-	remainder
V1653	0,05	0,04	0,01	0,013	1,66	0,9	19,7	0,18	1,82	0,007	remainder
V1657	0,05	0,01	0,01	0,007	1,59	1,82	19	0,76	1,8	0,007	remainder
V1664	0,05	0,02	<0,01	0,007	0,93	1,9	19,3	0,1	1,69	0,008	remainder

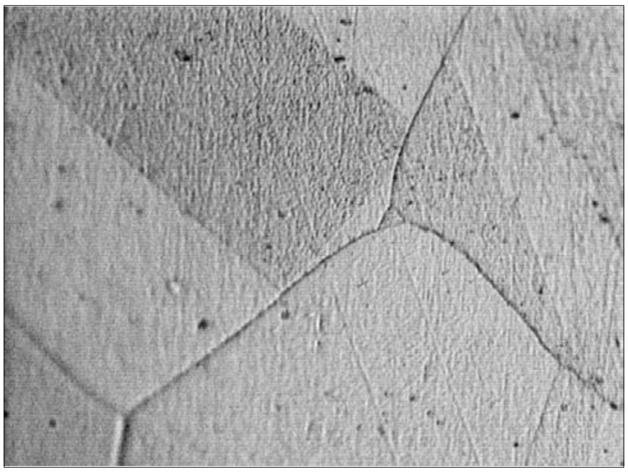


Figure 1 Microstructure of precipitation harden melt V1664, optical microscope, x500

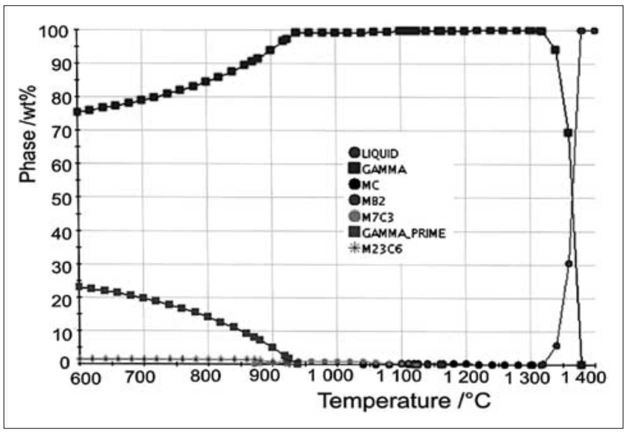


Figure 2 The phase diagram for the alloy Nimonic 80A [6]

annealing leads to increasing of hardness and changes in grain size. Data for hardness and grain size after the heat treatment is given in Table 2.

The microstructure examined on an optical microscope (Figure 1) is a typical austenitic structure with twins and carbides at boundaries and inside the grains.

Table 2 **The values of hardness and grain size**

Melt	Precipitation harden		
	hardness /HV10	Grain size*	
V1653	U	299	3 - 4
	P	299	
V1657	U	309	1 - 2
	P	308	
V1664	U	296	2 - 3
	P	296	

* The size of grains per standard ASTM E112
U – longitudinally to the direction of rolling
P – transversely to the direction of rolling

Figure 2 gives a phase diagram for superalloy Nimonic 80A. The structure of these alloys in heat treated condition consists of austenitic matrix, γ' phase and $M_{23}C_6$ type carbide, which occurs mainly in the form of fine particles along the grain boundaries. In addition to these carbides in the structure are present insoluble primary carbides of MC type.

ANALYSIS OF THE RESULTS

ANALYSIS OF TENSILE TEST

The samples were tested at following temperatures 20, 450, 650, 750 and 850 °C. Tensile test at room and elevated temperatures was conducted according to standard EN 10002-1/02 on hydraulic universal testing machine type Amsler max. capacity of 200 kN, in the mechanical laboratory of the Metallurgical Institute "Kemal Kapetanović" in Zenica.

In Figure 3 is presented the change of tensile properties of Nimonic 80A superalloy with increasing temperature. There is no significant change of tensile properties (R_m, and $R_{p0,2}$) below temperature of 650 °C. The γ' phases with increasing temperature strengthens the matrix, which to some extent eliminates the effect of softening of austenitic matrix.

The main mechanism of hardening of this alloy is based on the precipitation of a coherent - γ'phase or intermetallic compound $Ni_3(Al, Ti)$. Carbide, carbonitride, oxides and borides, in principle, the secondary phase, exist in basic structure depending on the chemical composition and heat treatment of alloys.

On the other hand, ductile properties (A, Z) first slightly decrease with increasing temperature (about 750 °C) due to significant differences in the flow of γ and γ' phases, and then significantly increase due to the dissolution of γ' phase.

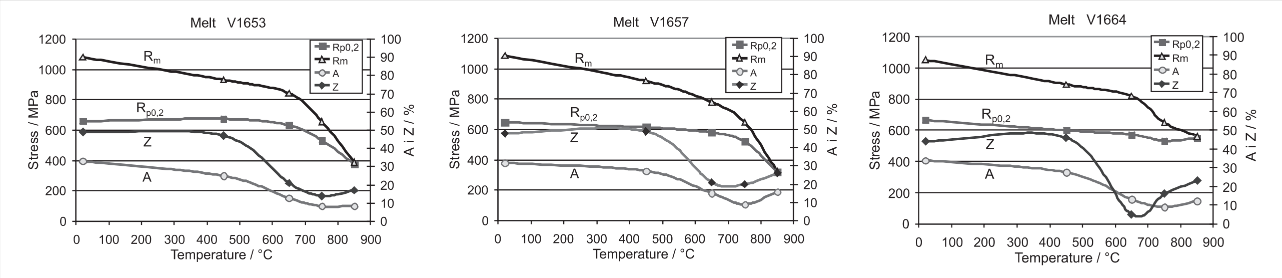
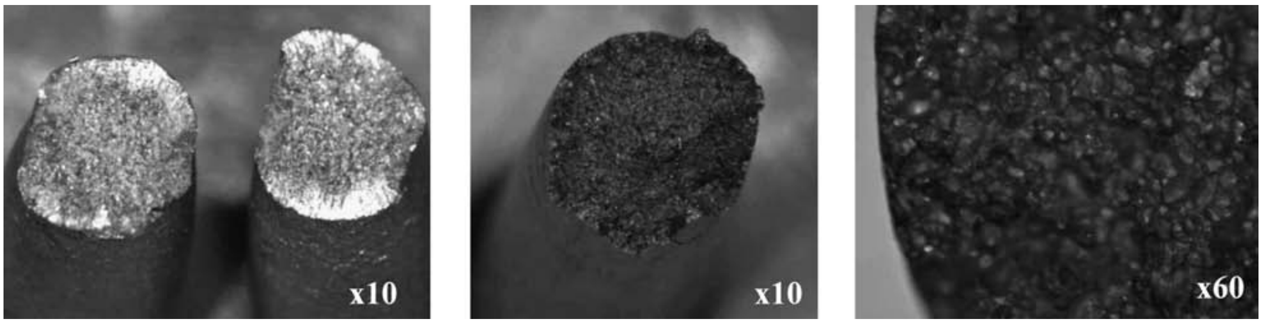


Figure 3 Change of tensile properties of the investigated melts

METALLOGRAPHIC ANALYSIS

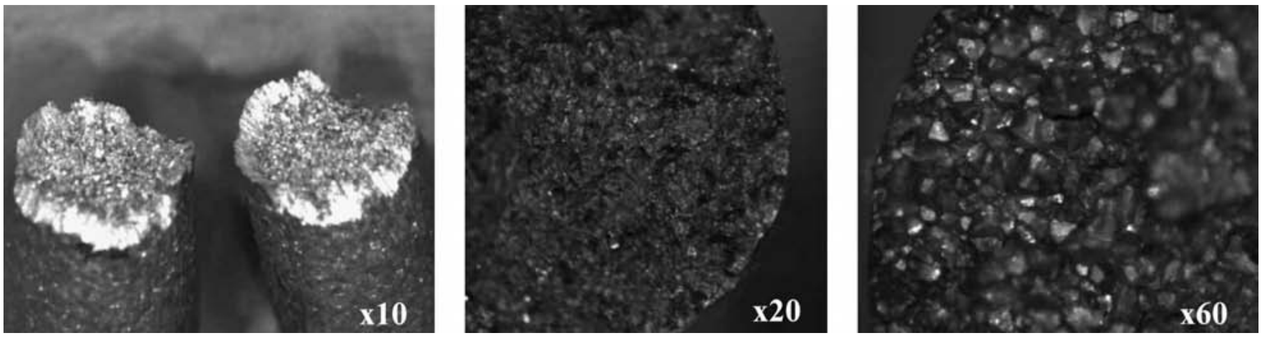
Fracture surface of specimens after tensile test at the temperatures (20, 650, 750, 850 °C) is presented in Figures 4, 5 and 6 (the stereo microscope Leica Mz 9,5 W, ICD digital camera, magnifications 10 – 60 x). From the Figures 4, 5 and 6 can be seen that the fracture at room temperature for all three melts is brittle with ductile areas at the edges of the specimens.

At elevated temperatures the fracture is brittle with a different grains size, depending on the test temperature. After visual and optical examinations, microfractographic studies of the fracture surfaces were conducted using scanning electron microscope. Figure 7.*a)* shows



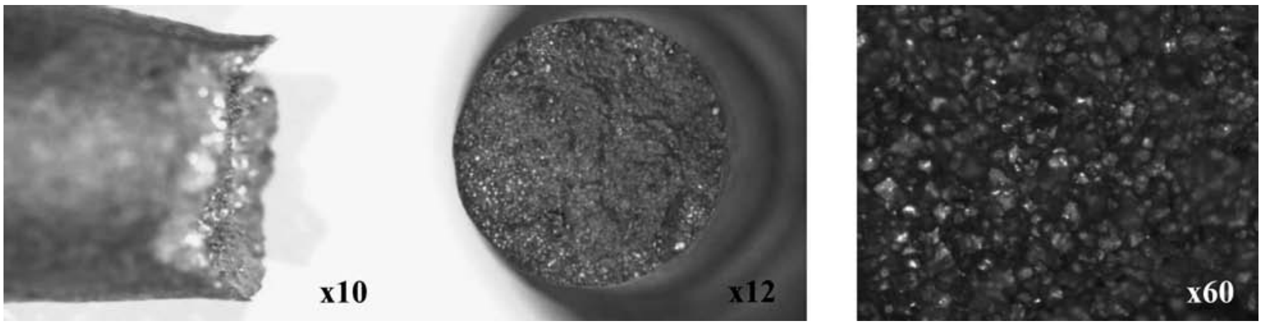
a) b) c)

Figure 4 Melt V1653 - fracture after tensile test at room temperature (a), 650°C (b) and 850°C (c)



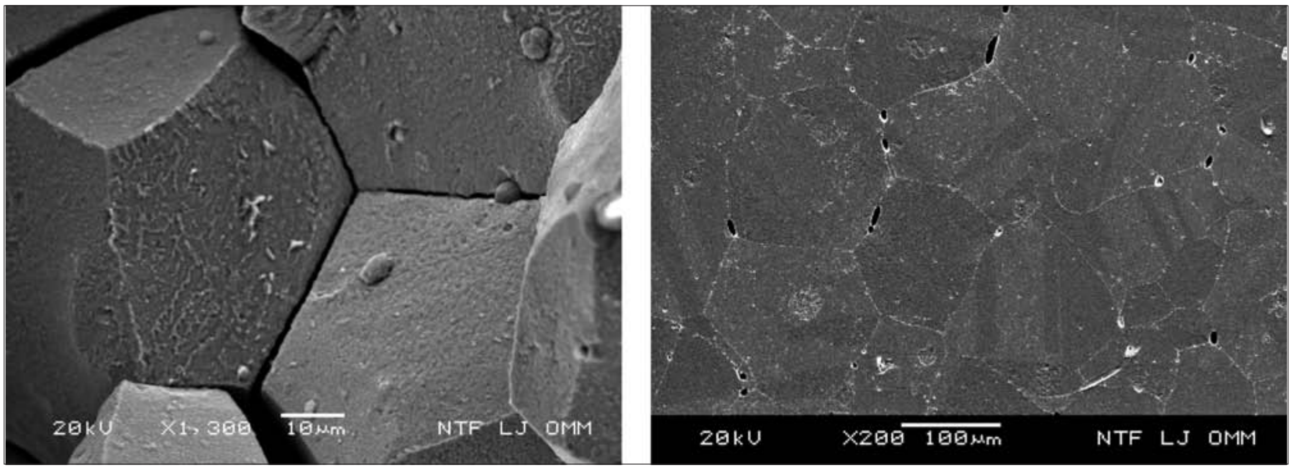
a) b) c)

Figure 5 Melt V1657 - fracture after tensile test at room temperature (a), 650 °C (b) and 750 °C (c)



a) b) c)

Figure 6 Melt V1664 -fracture after tensile test at room temperature (a), 750 °C (b) and 850 °C (c)



a. intergranular fracture *b.* micro cracks on grain boundaries

Figure 7 Fracture (melt V1653) on the SEM

tipical brittle intergranular fracture (test temperature 750 °C, SEM, 1 300 x) and (*b*) visible micro cracks along grain boundaries (SEM, x 200).

In order to strengthen the grain boundaries and change the type of fracture from intergranular to transgranular with a corresponding increase in ductility alloying boron, zirconia, magnesium and hafnium is recommended [3, 7]. Borides occur in the form of small solid particles distributed along grain boundaries. Boron atoms, which are not chemicaly bonded, together with the atoms of zircon, hafnium and magnesium segregate to grain boundaries and contribute significantly to improving the resistance of superalloys at elevated temperatures. In addition, boron and magnesium in nickel base superalloys reduce precipitation of carbides at grain boundaries releasing carbon that is dissolved in the matrix [5, 7].

CONCLUSIONS

On the basis of performed research we can conclude:

- After tensile testing at room temperature fracture is brittle with elements of ductility.
- Increasing temperature leads to precipitation of γ' phase which causes hardening and increasing of participation of brittle intergranular fracture.
- At the operating temperatures of this alloy, ie higher temperatures, there is no significant plastic deformation and brittle intergranular fracture is predominant.
- At temperatures higher than 750 °C, due to the dissolution of γ' phase, increasing of ductile properties is present, ie an increase in plastic deformation which can be seen through the increase of elongation and reduction of area.
- The tensile fracture behavior is in accordance with the strength and ductility variation with test temperatures.

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