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ADDITIONAL STRENGTENING OF SUPERALLOY NIMONIC 80A BY WORM ROLLING

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ABSTRACT

Superalloy Nimonic 80A is regularly used in heat-treated condition. Heat treatment includes solution annealing at 1080°C/8h and precipitation aging at 700°C/16h. Maximal hardness that can be achieved after that treatment is around 360HV. For certain needs automotive industry requires the hardness of this superalloy to be more than 360HV. Taking into consideration the fact that during solution annealing the grains coarse significantly, it is not possible to achieve needed additional strengthening of superalloy Nimonic 80A by grain size control. In spite of that, additional strengthening is possible to achieve by controlled worm rolling of the superalloy, after performing its solution annealing and all is done, through partial recrystallization after worm rolling. Accordingly it is possible to control the hardness.

Key words: superalloys, worm rolling, strengthening mechanisms

1. INTRODUCTION

Superalloy Nimonic 80A is the alloy from series NIMONIC nickel-base superalloys that contain 20% of chromium [1]. It is intended for use at elevated and high temperatures at which the creep process occurs significantly. The primary strengthening mechanism of this superalloy is based on precipitation of fine and coherent particle of intermetallic γ' phase $Ni_3(Al,Ti)$, which ensure needed creep strength. This strengthening mechanism for such superalloy is more favorable in relation to other strengthening mechanisms [2]. The effect of hardening that can be achieved by γ' phase depends on amount, dispersion, and size of γ' phase. All mentioned is controlled by heat treatment. Standard heat treatment includes solution annealing at 1080°C/8h and precipitation aging at 700°C/16h. Maximal hardness of the superalloy Nimonic 80A that can be achieved after this treatment is around 360HV, but for certain needs automotive industry requires higher hardness values. Since after long-lasting solution annealing at high temperature, the grains become coarse, it is not possible to increase the hardness (additional strengthening) significantly through reducing of the grain size. An increasing of the dislocation density, after solution annealing and before precipitation aging, through warm deformation, is effective way to increase the hardness of that superalloy. A partial recrystallization after such a deformation enables the hardness control.

2. EXPERIMENTAL RESULTS

On the semi-industrial equipment of the Institute of Metalurgy “Kemal Kapetanović” Zenica three experimental heats of the superalloy Nimonic 80A were produced and processed to the ϕ15mm bars. The heats were produced in 20kg vacuum induction furnace. Chemical composition of all heats is shown in Table 1. and satisfy requirements of standard ASTM B 637 for alloy N07080, since it allows that content of aluminum may be less than 1,0% - variant I. Aluminum content in variants II and III is higher then 1,0%, so these two variants, according to chemical composition, satisfy requirements of the other standards defining chemical composition of the superalloy Nimonic 80A.

Table 1. Chemical composition of experimental heats [3].

Variant	Content of elements in %											
	C	Cr	Si	Mn	Fe	Co	S	P	Ti	Al	Ni	Al+Ti
Variant I	0.04	18.8	0.20	0.14	1.58	1.20	0,006	0.004	**2.28**	**0.77**	Bala-nce	**3.05**
Variant II	0.05	19.7	0.25	0.03	2.10	1.25	0,007	0.005	**2.52**	**1.32**		**3.84**
Variant III	0.04	20.8	0.23	0.16	1.48	1.30	0,006	0.005	**2.68**	**1.44**		**4.12**

Hot plastic deformation of all variants were performed on hydraulic press capacity 2.0MN, pneumatic hammer capacity 2.5kN, and the light section rolling mill ϕ370 mm in temperature interval 950-1170^{o}C. After hot plastic deformation different bars for each variant were obtained (Figure 1.). The bars with diameter 15 mm are intended for determining of the superalloy mechanical properties in standard heat-treated condition, and the others for controlled rolling with different amount of deformation.

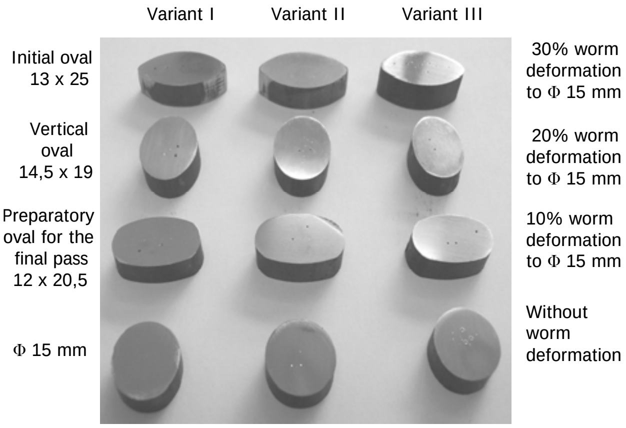

Figure 1. Cross section of the bars after hot rolling

All hot rolled bars were subjected to solution annealing at 1080^{o}C/8h, and then bars, except those with diameter 15mm, were rolled to the same diameter (15mm) with 10, 20 or 30% of worm deformation. The starting temperature for controlled rolling was 1080^{o}C in the case of the variants II and III, but in the case of variant I, the starting temperature was 1040^{o}C, because of preliminary research, which showed that recrystallization temperature of the variant I bars is significantly lower in comparison to the temperature of variants II and III bars. Also the preliminary research showed that aluminum and titanium have determinative influence on the recrystallization temperature [3].

After controlled rolling all bars were subjected to recrystallization on different temperatures (960^{o}C, 1000^{o}C and 1040^{o}C) in duration of one or two hours. At the end all bars were subjected to precipitation aging at 700^{o}C/16h in order to perform hardness and tensile testing in precipitation aged state. All thermal and thermomechanical treatments were carried out on the bars from all chemical composition variants, and are shown in Figure 2.

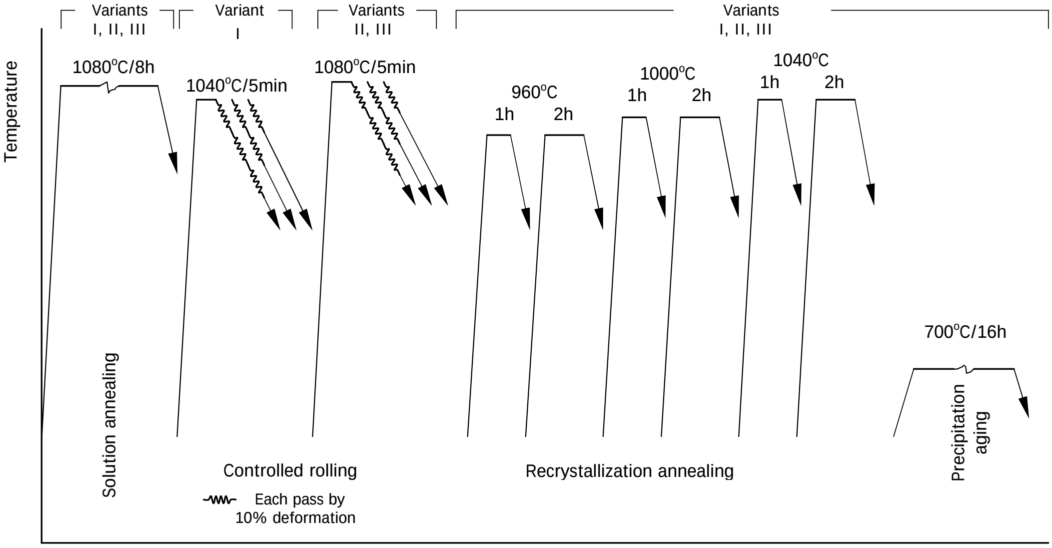

Figure 2. Controlled rolling in combination with corresponding heat treatments

As a result of lower content of aluminium and titanium the bars of variant I chemical compiosition show lower hardness values and lower recrystallization temperature in comparison to the bars of the variants II and III (Table 2.). Taking into account the fact that the recrystallization temperature of the variant I is less than 960°C, it means that through recrystallization annealing is not possible to achieve the hardness of the variat I bars to be higher than 360HV, because the temperature of γ' phase precipitation of Nimonic 80A is around 960°C. For the difference to that variant, the hardness of variant II and III bars can be controlled through a partial recrystallization.

Table 2. Hardness (HV10) of the bars after corresponding treatments including final precipitation aging (700°C/16h)

Variant	Solution anneal. 1080°C/8h	Worm def. (%)	Solution anneal. + worm def.	Solution anneal. 1080°C/8h + worm def. + recrystallization anneal.					
				960°C 1h	960°C 2h	1000°C 1h	1000°C 2h	1040°C 1h	1040°C 2h
Variant I	298	10	366	298	299	298	296	283	294
		20	401	299	299	297	294	285	295
		30	405	296	295	297	296	286	293
Variant II	352	10	462	403	402	403	393	355	352
		20	443	431	429	431	394	356	353
		30	471	442	442	416	359	358	353
Variant III	361	10	416	422	401	393	392	369	356
		20	460	434	430	431	414	371	356
		30	473	438	446	420	421	372	355

The results of tensile testing at room temperature of the bars with a different thermo-mechanical treatments are presented in Table 3. The worm deformation causes a significant increase of the strength, but also a significant decrease in ductile properties, especially in the case of bars of the variant II and III. The partial recrystallization of the specific bars (variant II-1000°C/1h, variant III-1020°C/1h) results in a significant increase in ductile properties and retaining of the strength ones.

3. CONCLUSION

Aluminium and titanium show the most significant influence on mechanical properties and recrystallization temperature of the superalloy Nimonic 80A. Its hardness and strength can be significantly increased through worm deformation carried out after the solution annealing. By the subsequent partial recrystallization annealing the values of hardness and tensile properties of the alloy can be controlled. For that reason it is needed that the alloy contains high enough content of aluminium and titanium, so that the recommended partial recrystallization temperature should be higher than solvus temperature of the γ' phase. Otherwise the precipitation of the γ' phase will appear, and as a result of that it will decrease the effect of precipitation strengthening as the primary strengthening mechanism of the superalloy Nimonic 80A.

Table 3. Tensile test results at room temperature (The mean value of the two test pieces)

Variant	Order number	$R_{p0,2}$ (MPa)	Rm (MPa)	Rm/ $R_{p0,2}$	$A^{1)}$ (%)	Z (%)	Treatment
I	1.	565	977	1,73	39,5	41,5	1080°C/8h +700°C/16h
	2.	923	1134	1,23	21,4	42,5	1080°C/8h+20%worm def. +700°C/16h
II	1.	745	1143	1,53	29,7	39,0	1080°C/8h +700°C/16h
	2.	1011	1233	1,22	11,5	17,0	1080°C/8h+10%worm def.+ 1000°C/1h +700°C/16h
	3.	970	1242	1,28	18,5	31,5	1080°C/8h+20%worm def.+ 1000°C/1h +700°C/16h
	4.	1008	1315	1,30	18,0	26,5	1080°C/8h+30%worm def.+ 1000°C/1h +700°C/16h
III	1.	731	1122	1,53	29,6	38,0	1080°C/8h +700°C/16h
	2.	1027	1151	1,12	9,6	14,0	1080°C/8h+20%worm def.+ 1000°C/1h +700°C/16h
	3.	1051	1291	1,23	17,3	22,0	1080°C/8h+20%worm def.+ 1020°C/1h +700°C/16h

Note: 1) Tests were carried out on test pieces with nominal diameter D= 7,5 mm and original gage length L_0=30mm, so the testing results are related to 4D.

4. REFERENCES

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