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THE INFLUENCE OF ALUMINIUM, TITAN AND COBALT ON TENSILE PROPERTIES OF THE SUPERALLOY NIMONIC 80A AT ELEVATED TEMPERATURES

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ABSTRACT
The modern automotive industry has been expressing the need for engines with a turbocharger whose parts are made of materials that operate at high temperatures. Due to that in many cases the existing materials with modified characteristics are used. Chemical composition of alloys Nimonic 80A has a dominant influence on its mechanical and technological properties. The effect of alloying elements Al, Ti and Co for superalloy Nimonic 80A is very important. Investigations which were carried out have included testing of tensile properties of superalloy Nimonic 80A, followed by regression analysis of the influence of chemical composition on mechanical properties.
Keywords: superalloys, Nimonic 80A, tensile properties, regression analysis

1. 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 ºC [1]. Because of its good stress relaxation resistance it is widely used for mechanical joining of high temperature parts [2, 3], such as insert bolts in the combustion chamber of the gas turbine unit, which operates at temperatures about 650 ºC.
The Ni-base superalloys Nimonic 80A gains its appropriate microstructure and high temperature strength through precipitation hardening. Precipitation hardening is obtained by forming γ' phases Ni_3 (Al, Ti). Further strengthening and increasing the resistance to elevated temperatures is performed by adding Co [4].
This paper presents an analysis of influence of wt.%Al, wt.%Ti and wt.%Co on tensile properties at elevated temperatures (650 °C).

2. DESIGN OF EXPERIMENT
For specific analysis of the effect of alloying elements on tensile properties, the multifactorial experimental design was used. The influential factors were wt. contents of Al, Ti and Co. The essence of this method is in the planning, implementation and analysis of the appropriate number of experimental measurements of tensile properties of alloy Nimonic 80A through simultaneous variation of main factors. This approach enables analysis not only of the individual effect of factors, but also their mutual - coupled effects, as well as determining the optimal values of the factors [5].
The MATLAB software (version 7.0) and its module *Model-Based Calibration Toolbox* was used for design of experiments [6]. The second order mathematical model i.e. square regression model was assumed. The three-factorial experimental design was adopted for obtaing the data and the appropriate experimental matrix are given in Table 1.

Table 1. Values of input parameters in three-factorial experimental design

Input parameter	Label	Meaning	Level 1 Lower level	Level 2 Upper level	Degree of freedom
x_1	Al [%]	Wt. % Al	1,00	1,80	1
x_2	Ti [%]	Wt. % Ti	1,80	2,70	1
x_3	Co [%]	Wt. % Co	1,00	2,00	1
The interaction of input parameters will also be analysed, i.e.: $x_1 \cdot x_2$, $x_1 \cdot x_3$, $x_2 \cdot x_3$					

According to the 2^k plan of experiments the number of melts was determined. The factors were varied at two levels, with repeated experiments for each mesurements of the plan. Tests were conducted using 16 different melts.

Making melts and tensile testing were performed on University of Zenica, Institute „Kemal Kapetanović“ Zenica. The results of chemical analysis are shown in Table 2. Chemical analysis of the used melts are in accordance to the standard chemical composition for Nimonic 80A superalloy (DIN 17742, Alloy designation NiCr20TiAl). After forging and rolling to ϕ 15mm bars 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 [4].

Testing of tensile properties was carried out in Laboratories for mechanical testing Institute „Kemal Kapetanović“ Zenica (Table 2.). Specimens for testing and tensile testing were prepared according to standard BAS EN 10002-5 (for testing at elevated temperature) [7].

Table 2. The chemical composition of Nimonic 80A (Ni remainder) and tensile properties of the speciments

	Chemical composition [%]									Tensile properties	
Prescribed	C	Si	Mn	S	Al	Co	Cr	Fe	Ti	$R_{p0,2}$	R_m
Melt	Max. 0,10	Max. 1,00	Max. 1,00	Max. 0,015	0,50-1,80	Max. 2	18-21	Max. 3,00	1,80 - 2,70	MPa	MPa
V1647	0,06	0,46	0,01	0,008	1,14	1,67	20,1	0,34	2,13	602	880
V1653	0,05	0,04	0,01	0,013	1,66	0,9	19,7	0,18	1,82	634	845
V1651	0,05	0,23	0,01	0,007	1,08	0,83	18,3	2	2,9	710	817
V1669	0,03	0,06	<0,01	0,008	1,68	1,88	19,7	0,33	2,92	734	871
V1648	0,09	0,08	0,01	0,009	1,2	0,89	20,1	0,21	1,9	565	810
V1656	0,05	0,06	0,01	0,008	2,14	1,89	19	2,06	1,87	720	862
V1652	0,05	0,16	0,01	0,008	1,07	1,83	18,8	0,41	2,79	674	863
V1672	0,02	0,01	<0,01	0,008	1,81	1,09	19,7	0,52	2,8	770	859
V1664	0,05	0,02	<0,01	0,007	0,93	1,9	19,3	0,1	1,69	572	819
V1654	0,06	0,19	0,01	0,008	1,53	0,87	19,7	0,12	1,86	609	852
V1671	0,04	0,02	<0,01	0,009	1,15	1,1	19,7	0,13	2,78	666	815
V1670	0,02	<0,01	<0,01	0,008	1,4	1,69	19,6	0,34	2,73	704	830
V1665	0,05	<0,01	<0,01	0,007	0,98	1,04	19,7	0,14	1,71	477	697
V1657	0,05	0,01	0,01	0,007	1,59	1,82	19	0,76	1,8	581	781
V1666	0,03	0,01	<0,01	0,008	1,13	1,57	19,7	0,8	2,66	669	769
V1668	0,04	0,03	<0,01	0,006	1,64	1,16	18,8	0,12	2,67	726	827

3. ANALYSIS OF EXPERIMENTAL RESULTS

On the basis of the testing and statistical analysis, the optimal regression equation as a system response has been chosen:

$$R_{p0,2}=-101,2x_1+523,59x_2-207,8x_3-3,97x_1x_2-105,79x_1x_3-35,45x_2x_3+132,54x_1^2-71,27x_2^2+156,4x_3^2 \quad (1)$$

$$R_m=-140,81x_1+1327x_2-1065x_3+61,12x_1x_2-121,35x_1x_3+8,29x_2x_3+77,88x_1^2-296x_2^2+444,74x_3^2 \quad (2)$$

In general, an appropriate regression equation provides important information about the influence of factors over the regression coefficients. The calculated values of tensile properties for the given regression equations have a very good match with the data obtained by experiments which is given in Table 3.

Table 3. Statistical characteristics of used model

Tensile properties	R^2	Coefficient corelacion R	Standard error	SS regresion	SS residual	Ficher test		Signi-ficant
						Tabelar	Model	
$R_{p0,2}$	0,9998	0,9999	15,26648	6867350	1631,458	3,69	3273,93	YES
R_m	0,9995	0,9997	28,07471	10911682	5517,324	3,69	1538,22	YES

The regression surface given by (1) and (2) are multidimensional, and consequently it can not be represented by one graph. Therefore independent variables are substituted by their average values and 3D graphs of regression surface for different combinations of independent variables were plotted in the observed ranges, Figure 1.

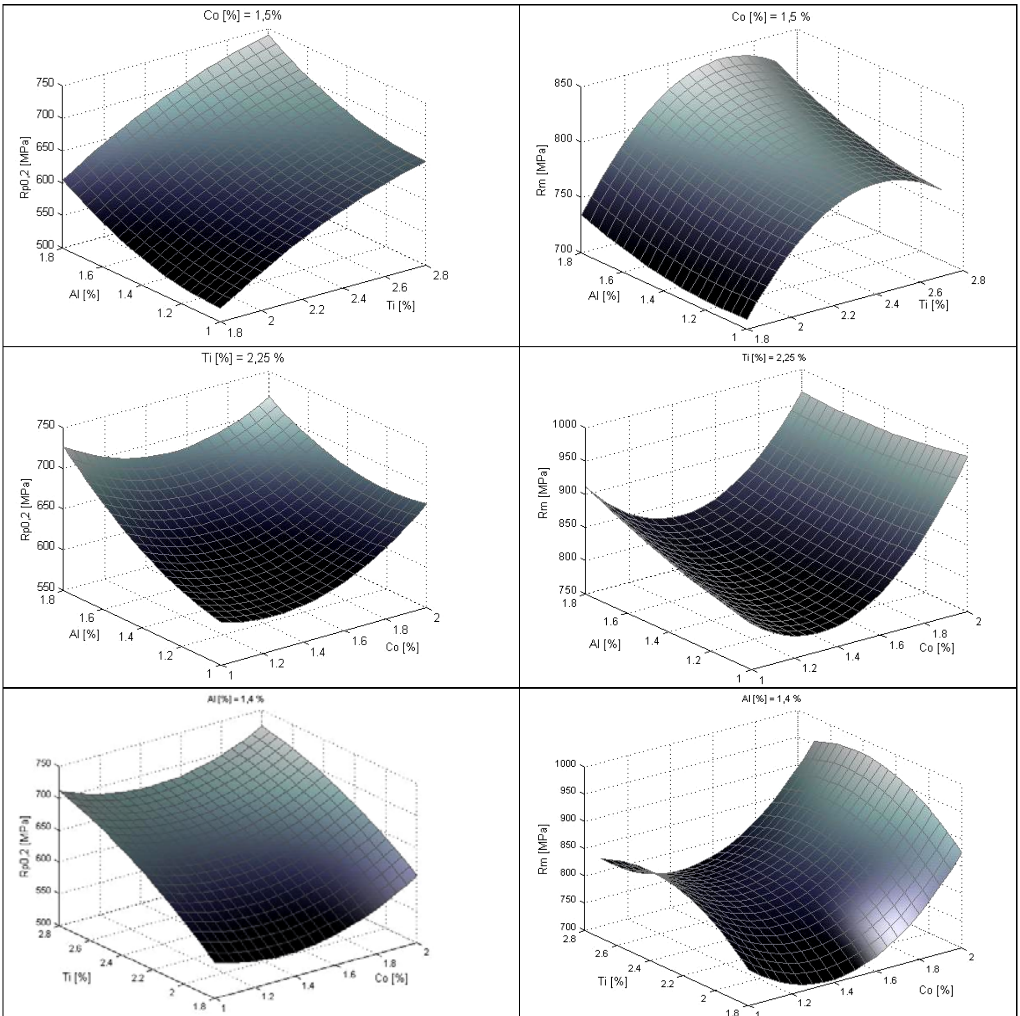

Figure 1. Functional dependence of $R_{p0,2}$ and R_m and influenting factors Wt.% Al, Wt.% Ti and Wt.% Co

As a result of research and insight into the qualitative and quantitative strength contributions of superalloy Nimonic 80A of all acting strengthen mechanisms was set acceptable theoretical model of the formation of optimum strength. The results of regression are equations by which on the basis of known chemical composition, i.e. content of main alloying elements Al, Ti and Co can predict the mechanical properties of materials at room and elevated temperatures. On the basis of the square regression equations, was carried out an optimization of the chemical composition of materials for selected values of mechanical properties.

4. CONCLUSIONS

After analysing experimental investigation of the influence of contents the aluminium, titan and cobalt on tensile properties of the superalloy Nimonic 80A at 650 °C can be concluded:

- A mathematical model that establishes a corellation between the main alloying elements (Al, Ti and Co) and mechanical properties at 650 °C satisfy both the adequacy of the model, as well as accuracy;
- All the selected parameters relating to the chemical composition varied on two levels affect the mechanical properties, i.e., all are significant;
- Each influential parameters in real working conditions have a different significance and different effects on the tensile properties. The greatest impact has Ti and Al. Increasing the contens of these factors, the increase tensile properties. Influence of Co on the properties is the lowest;
- Forms (1) and (2), can be used in the calculation of tensile properties at 650 °C for specific values of the individual factors. In this way we get the values for $R_{p0,2}$, and R_m, in accordance with experimentals.
- Conducted research and analysis provide a contribution in terms of establishing a methodology for determining the parameters of the process and decision making in terms of proper design of parts of superalloy Nimonic 80A.

It is obvious that the previously proposed methodology can successfully multi factor experiments, fast, high quality and relatively cheap to solve various complex tasks of modeling, numerical simulation and optimization of alloy composition.

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