1951-2021 SMEITS

DOIEE

IAUS УАУС

PRIVREDNA KOMORA SRBIJE 1857

Република Србија
МИНИСТАРСТВО НАУКЕ, ТЕХНОЛОШКОГ РАЗВОЈА И ИНОВАЦИЈА

11th International Conference on Renewable Electrical Power Sources

PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023

P R O C E E D I N G S

11th International Conference on Renewable Electrical Power Sources

MKOIEE/ICREPS

1951-2021 SMEITS

DOIEE

2023

PROCEEDINGS
11th International Conference
on Renewable Electrical Power Sources

Chamber of Commerce and Industry of Serbia,
Belgrade, November 2 and 3, 2023

Publisher
Union of Mechanical and
Electrotechnical Engineers and
Technicians of Serbia (SMEITS)
Society for Renewable Electrical
Power Sources
Kneza Miloša str. 7a/II,
11000 Beograd

President to the Society
for Renewable Electrical
Power Sources
within the SMEITS
Prof. dr Zoran Lazarević

Editor
Dr Milica Vlahović

Tiraž
50 primeraka

CD umnožava
MT-KOMEX doo, Beograd

ISBN
978-86-85535-16-1

CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

MEĐUNARODNA konferencija o obnovljivim izvorima električne energije (11 ; 2023 ; Beograd)
Zbornik radova pisanih za 11. Međunarodnu konferenciju o obnovljivim izvorima električne energije [Elektronski izvor]: [Beograd, 2. i 3. novembar 2023.] / [urednik Milica Vlahović] = Proceedings / 11th International Conference on Renewable Electrical Power Sources : [Belgrade, October 2 and 3, 2023] ; [editor Milica Vlahović]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije SMEITS, Društvo za obnovljive izvore električne energije = Union of Mechanical and Electrotechnical Engineers and Technicians of Serbia (SMEITS), Society for Renewable Electrical Power Sources, 2023.

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 50. - Bibliografija uz svaki rad.

ISBN 978-86-85535-16-1

а) Енергетски извори - Одрживи развој - Зборници

COBISS.SR-

STATISTICAL MODELING OF SOME ENVIRONMENTALLY-FRIENDLY COPPER-BASED ALLOYS

STATISTIČKO MODELOVANJE NEKIH EKOLOŠKI PRIHVATLJIVIH LEGURA NA BAZI BAKRA

Aleksandra T. IVANOVIC[1,*], Silvana B. DIMITRIJEVIC[1], Stevan P. DIMITRIJEVIC[2], Branka B. PETKOVIC[3]

[1]Mining and Metallurgy Institute Bor, Serbia
[2]Innovation Centre of TMF Belgrade, University of Belgrade, Belgrade
[3]Department of Chemistry, Faculty of Natural Sciences and Mathematics, University of Pristina, Kosovska Mitrovica, Serbia

aleksandra.ivanovic@irmbor.co.rs (*Correspondence)

Apstrakt

U ovom radu su prikazani rezultati definisanja matematičkog modela koji opisuje zavisnost zatezne čvrstoće od uticajnih ulaznih parametara, u cilju razvoja netoksičnih legura koje bi u potpunosti mogle da odgovore zahtevima elektrifikacije saobraćajnih mreža zamenom trenutno korišćene legure Cu-Cd sistema. Upotreba legura sistema Cu-Cd uvek dovodi do mnogih ekoloških problema. Matematički model je definisan primenom enter MLRA metode, što je rezultiralo linearnim modelom čiji je koeficijent determinacije R^2=0,826. Validacija dobijenog modela izvršena je korišćenjem podataka iz laboratorijskog ispitivanja koji se ne koriste pri definisanju modela, što daje istu statističku pouzdanost, sa R^2=0,815.

Ključne reči: *predviđanje, MLRA, enter metoda, niskolegirani bakar, matematičko modelovanje*

Abstract

This paper present the results of defining the mathematical model which describes the dependence of tensile strength from the influential input parameters, aimed at developing non-toxic alloys that could completely respond to the requirements in traffic networks electrification by replacing the currently used Cu-Cd alloy system. The use of Cu-Cd alloys system is always resulting in many environmental problems. Mathematical model is defined using the enter MLRA method, resulted in a linear model whose coefficient of determination was R^2=0.826. Validation of the acquired model was performed using the data from the laboratory investigation that are not used when defining the model, rendering the same statistical reliability, with R^2=0.815.

Key words: *prediction, MLRA, enter, low-alloyed copper, mathematical modeling*

1 Introduction

Alloys with tellurium are copper alloys with a high electrical conductivity and good mechanical workability [1]. A good thing about these alloys is the retention of good mechanical characteristics after plastic processing at increased temperatures and their corrosion resistance. Many researchers have investigated mechanical properties of copper alloys with tellurium [2-5] since these alloys were easily treated by cold drawing or cold rolling. Strengthening occurred during cold deformation characterized by the better strength and stretching limit and reduced elongation [6,7]. Loosening at different temperatures caused a change in mechanical properties. Small quantities of tellurium affected re-crystallization temperature towards higher values [7]. Small additions of Sn and Te in the amount of 0.0005 % to 0.003 % practically did not affect the microstructure of copper and mechanical properties at lower temperatures while at higher temperatures they caused reduced plasticity, of even 1.5 ÷ 2 times without affecting the strength value [7-10].

The motive for investigation presented in this paper was to perform statistical analysis of the mechanical and working properties of low-alloyed copper with tin and tellurium, since these alloys, as more environmentally friendly than copper-cadmium alloys presently used for the same purpose (traffic networks electrification), could completely replace them and to develop a mathematical model describing the influences of the alloying Sn and Te, and temperature on tensile strength. The obtained model should be helpful to determine adequate set of experimental conditions which will result with the adequate tensile strength for the traffic networks electrification [6]. The model for tensile strength were developed by the MLRA method but also were different models for the same purpose.

In this paper, the modeling was used MLRA regression model, but also were developed other methods [7].

2 Results and discussion

The database used in this work collected from the laboratory investigation. For the modeling of the dependence of tensile strength were used:

X_1 – concentration of Sn in the alloy (%)
X_2 – concentration of Te in the alloy (%)
X_3 – temperature of cold deformed metal (0ºC)

Samples are prepared according to literature review [2, 3,11]. Chemical composition of samples, after melting and casting, are given in Table 1. Chemical analysis of the sampling material was performed using ICP-AES devices for Sn and Te and using AAS devices for Cu.

It is noticed, from presented results of chemical analysis, that the preparation, melting and casting of samples were carried out under appropriate conditions as the samples after treatment have the required chemical composition which, based on literature data, would be the best suitable as a replacement for Cu-Cd alloy, used for electrification of transport networks [2, 3, 11,12].
After charge preparation, the smelting was carried out in IRM accredited laboratories, in the laboratory reverberatory furnace in a graphite crucible under a layer of charcoal (to maintain the low oxidation atmosphere), using gas. Then, the casting of samples was carried out in the graphite casting molds of square cross section, dimensions 20x20x270 mm and 20x20x200 mm, which were cooled in the air. The head of cooled castings (the largest concentration of casting defects) were cut off and the chemical composition was analyzed using the spectrophotometric methods. Plastic processing of samples was carried out primarily on cold, to the cross section dimensions 17x17 mm, in order to prevent the occurrence of "burrs" in the hot rolling, and then the obtained billets were annealed for 30 minutes at temperature of 850 ºC and immediately hot rolled to the cross section dimensions 10x10 mm on the rolling mill with calibrated rollers. The cooled samples were then annealed for 30 minutes at temperature of 600ºC, and then cooled in the air and rolled on the rolling mill with calibrated rollers to the cross-section dimensions 4x4 mm. Cold rolled samples were then annealed for 30 minutes at 600ºC, cooled in the air and drawn into a wire of circular cross section, on the tow bench through a series of matrices to a diameter of Ø = 2 mm. Upon the wire obtaining, the tensile strength and elongation were tested depending on the overall deformation degree as well as elongation at elevated temperatures on the Karl Frank testing machine, and metallographic testing to the aim of determination the effect of Sn and Te on a degree of copper recrystallization, that is the softening temperature of cold deformed metal [2,3,11]. The database was generated from the data measured during the laboratory investigation.

Table 1. Chemical composition of samples

Samples number	Sn (%)	Te (%)	Cu (%)
1.	0.058	0.0092	rest
2.	0.580	0.0920	rest
3.	0.130	0.04	rest
4.	1.140	-	rest
5.	0.066	-	rest
6.	0.130	-	rest
7.	-	0.760	rest

Linear dependence of the degree of influence of input parameters of the technological process an analyzed process output was calculated using SPSS software application [15]. Using the Multiple Linear Regression Analysis (MLRA), on the results presented in Table 2, the equation 1 was obtained [14]: The values of obtained model coefficients, which have statistical significance ($p<0.01$). Based on these results, the following final model equation is resulting from the regression analysis:

$$Y = 522{,}62 + 12{,}75X_1 - 1174{,}75X_2 - 0{,}62X_3 + 3535{,}16X_1X_2 - 0{,}16X_1X_3 + 0{,}098X_2X_3 \quad (2)$$

The analysis of the regression equation shows the principal effects of the three selected factors have an influence on the tensile strength. The Sn content (X_1 with b=12.75) has the strongest effect on the response since the corresponding coefficient is larger than the coefficients of the other investigated factors and means that the increase of Sn content in the sample causes an increase of tensile strength. Another important factor is the temperature (X_3 with b = -0.62). The negative sign of this coefficient indicates a constant decrease of Rm with a temperature rise. The design of experiments also exhibits interactions between the various factors studied. The strongest interaction is among the Sn content in the sample (X_1) and Te content in the sample (X_2), with b=3535,16. This result shows the potential weakness of conventional experiment methods which do not take into account those effects.

Figure 1 shows the comparison between the Y-measured and the Y-calculated values, with the coefficient of determination $R^2=0.826$. Therefore, the model defined by equation (1) can be used for prediction of value of the tensile strength with known values of the predictors.

Reliability of the model was also tested using the ANOVA test. The results of ANOVA tests of developed model are presented in Table 5.

Table 5. Results of ANOVA test of finally obtained model

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	746751,993	3	248917,331	89,951	0,007[a]
	Residual	138363,233	50	2767,265		
	Total	885115,226	53			

a. Predictors: (Constant), Temperature, Te content, Sn content

b. Dependent Variable: Rm

The significance value of the F statistic is less than 0.05, which means that the variations explained by the model are not caused by chance. Coefficient of determination of the final model is $R^2=0.826$, as indicated in Figure 2.

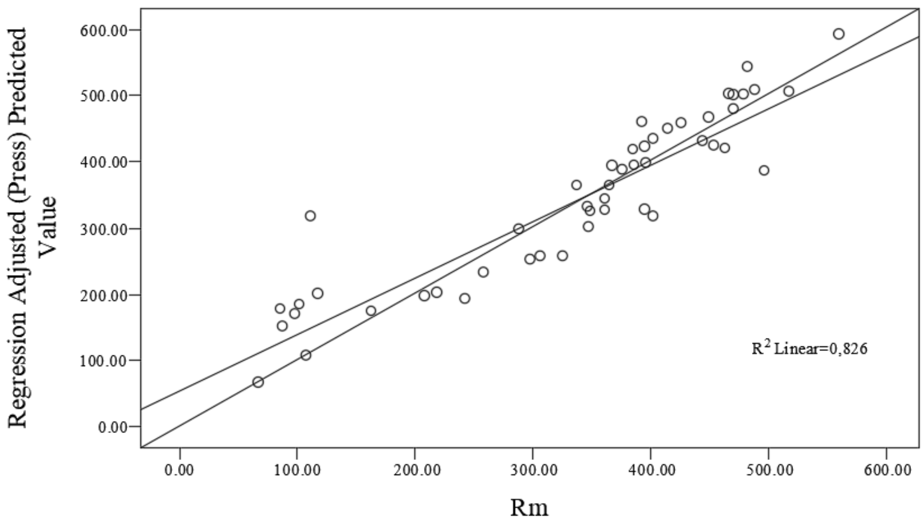

Fig. 1. Correlation between experimentally determined and model predicted values of the tensile strength

This coefficient presents the linear correlation between the observed and model predicted values of the dependent variable and it indicates a strong relationship. Validation of the mathematical model given by equation (2) was carried out through its application on data from the laboratory investigation that are not used when defining the model, using the statistical data set of 100 experiments. The results of defined model validation are shown in Fig.2 with the value of R^2=0.815 which is very close to the value determined in the phase of defining the model.

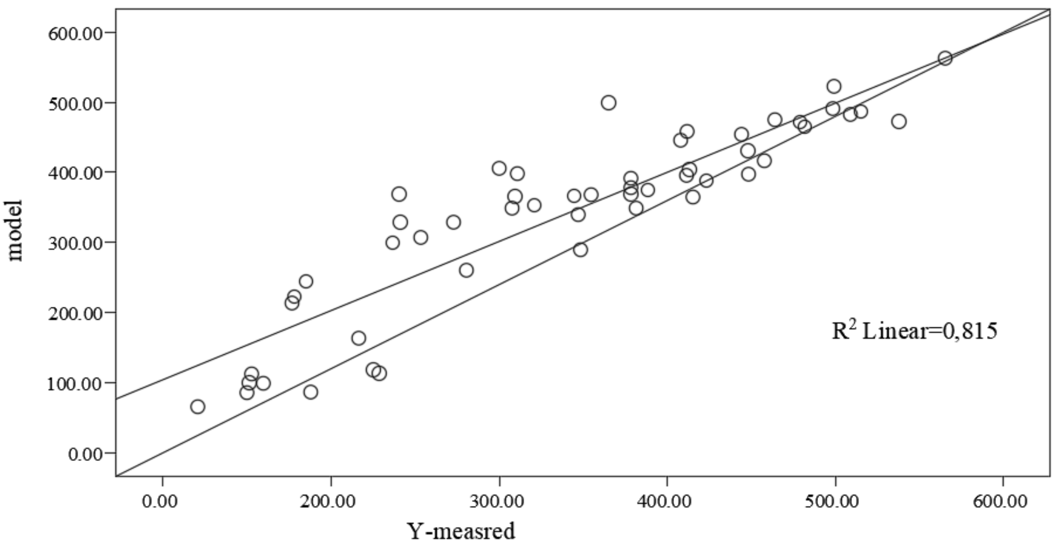

Fig.2. Validation of the model (2) on a sample of 100 measurements

3 Conclusion

The obtained linear correlation dependence was obtained using the experimental data acquisition, with experiments prepared according to the factorial experimental design methodology. Enter MLRA method was used to define mathematical model for the dependence of the tensile strength of input parameters (temperature of cold deformed metal, Sn and Te content in alloys).The value of R^2=0.826 in the phase of defining the model and 0.815 in the model validation phase, indicates the satisfactory degree of fitting of obtained results.

This model can predict the tensile strength of alloys Cu-Sn, Cu-Te and Cu-Sn-Te, which should be used as a substitute for the modified copper or the Cu-Cd alloy for the traffic networks electrification, they are required to have the tensile strength of over 400 N/mm^2 in the total deformation degree of 50% with the electro conductivity of over 50 SM (86.21% IACS).

Further research of the model developed in this paper, aiming to increase value of R2, should be focused on applying this model to the industry data.

4 Acknowledgement

This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, contract number: 451-03-47/2023-01/ 200052

5 References

[1] J.P. Tardent, B. Demestral, New Copper Alloys for Electrical, Electronic and Mechanical Applications, Wire Industry, 68, pp.173-176(2001).

[2] A.Ivanovic, B.Cađenovic, E.Pozega, S.Ivanovic, Modified Copper: Ecological Alternative to Cu-Cd alloy, Innovation and Development, (2008)2, 13-25 (in Serbian).

[3] Aleksandra Ivanovic, Vesna Marjanovic, Silvana Dimitrijevic, Miroslav Ignjatovic, Vlastimir Trujic, Miroslav R. Ignjatovic, Development of environmental copper-based alloys, TTEM, Volume 7 / Number 2 / 2012,pp. 572-579

[4] A. S. Pashinkin, V. A. Fedorov, Phase Equilibria in the Cu–Te System, Inorganic Materials, Vol. 39, No. 6, 2003, pp. 539–554.

[5] J.S.Smart, A.A.Smith, Effect of Phosphorus, Arsenic, Sulphur and Selenium on Some Properties of High-purity Copper,Metals Technology, American Institute of Mining and Metallurgical Engineers, 12, 1807 (1945).

[6] H.Graveman, H.J.Wallbaum, Z.Metallkunde, 47, 433-441(1956).

[7] L. Gusel, R. Rudolf, N. Romcevic, B. Buchmeister , Genetic programming approach for modelling of tensile strength of cold drawn material, Journal of Optoelectronics and Advanced Materials – Rapid Communications, (2012), vol 6 no. 3-4, pp.446-450

[8] A. M. Pimenov, Z. I. Gofenshefer, Vlitnie malih dobavor Se i Te na soistva medi, Izdatelstvo Metallurgia, Moscow (1958).

[9] M. T. Naus, P. J. Lee, and D. C. Larbalestier, "The Interdiffusion of Cu and Sn in Internal Sn Nb_3Sn Superconductors“, IEEE Transactions on Applied Superconductivity, Vol.10, No 1, 2000, pp. 983-987.

[10]G.Kosec, V.Gonatarev, Mater. Technol., 37(3-4), 161-166 (2003).

[11]V.J.Marino, M.V.Yokelson and G.J.Fisher, The Effect of Lead and Tin on the Annealability and Electrical Conductivity of Commercially Hot-Rolled ETP Copper Rod, Wire Association meeting, Atlanta, Georgia (1975).

[12]A. Mitic Ivanovic, Graduation Thesis, Testing the Effect of Tin and Tellurium Content on Temperature of Copper Recrystallization, Technical Faculty, Bor (1997) (in Serbian).

[13]Z. Popovic, Electro-technical and Electronic Materials, Promezzia Press, Belgrade (1995) (in Serbian).

[14]Ivan Mihajlovic, Nada Strbac, Predrag Djordjevic, Aleksandra Ivanovic, Zivan Zivkovic, Technological Process Modeling Aiming to Improve Its Operations Management,Serbian Journal of Management 6 (2) (2011), pp 135 – 144.

[15]SPSS inc. PASW Statistics 18, Predictive Analysis Software Portfolio, www.spss.com