Mechanics Transport Communications

ISSN 1312-3823 (print)
ISSN 2367-6620 (online)
volume 21, issue 3/3, 2023

Academic journal http://www.mtc-aj.com **article № 2444**

INVESTIGATION OF THE INFLUENCE OF THE CHEMICAL COMPOSITION OF THE COATING ON TECHNOLOGICAL AND MECHANICAL INDICATORS BY APPLYING DEFMOT

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Key words*: DEFMOT, modeling, Regression analysis, Optimization.*

Abstract: *The research adapted a five-factor problem with the DEFMOT computational approach [3] to a four-factor one using published experimental data [7] regarding the influence of coating component combinations on technological and mechanical performance. A methodology for the transformed adaptation from 5D to 4D has been compiled. The example of the effect of plastering [7] is used to illustrate the adapted approach. Analysis and optimization were performed after the transformation. An optimal composition was determined, guaranteeing the highest impact strength and the highest stability at a graphite quantity of 1 mass percent.*

1. INTRODUCTION AND PURPOSE OF THE RESEARCH

Ambitious tasks in research programs related to manufacturing competitiveness require the use of modern design approaches. With the help of these approaches, existing technologies are improved through the variables that describe them and the corresponding desired indicators [1]. All variables in the operative process must be measured, controlled, and optimized to obtain the desired results. Optimization of welding process parameters depends on the ability to measure and control the variables defined for it. This fully applies to the designed composition of electrode coatings for manual arc welding, which must maintain high desired characteristics resulting from the task, both for the technological parameters of the process and for the quality of the product. These features ensure continued economic operation under normal conditions. One of the possible approaches in this case is to switch to more expensive coatings, and the other, more economical, is to optimize traditional compositions of the ingredients used in terms of their number and their quantity. The second approach is the core of the research used in this paper, and it enjoys continued attention because of the resulting benefits of its application. In [2, 3], the DEFMOT approach was applied for the analysis of technological factors with up to four factors in different engineering technologies for the purpose of their optimization.

Optimization via the design of the experiment has been applied to the research of electrode coating for manual arc welding. In [4], the physicochemical and thermophysical properties of slags obtained from electrodes for arc welding based on $CaO–CaF_2–SiO_2–Al_2O_3$

were examined. The methodology to design the coating according to the criteria cited below uses twenty-one roofing compositions. Experiments were performed with the welding slag to evaluate the weight loss, density, specific heat, enthalpy, thermal conductivity, and diffusion coefficient. Regression analysis was used to explore the effect of coating ingredients on slag properties. The resulting aggregate criterion of properties is further optimized.

A statistical analysis to identify the welding process parameters affecting the average strength and variability of weld strength by design of experiment (DOE) was performed in [5]. The results of this research encouraged the manufacturing engineering team to extend the application of DOE to other core business processes such as the process efficiency improvement technique.

The stability of the welding process has a significant impact on ensuring the required level of quality of the welded joints. The increased stability of the welding process reduces the likelihood of imperfections forming in the weld metal. This parameter is the focus of one of the investigations in this paper. Statistical data analysis was obtained with real-time welding monitoring. Similar research analyzing the effect of parameters on the stability of the welding process of a metal electrode in an active gas are presented in [6].

The quality of the coatings and the content of the components of the coating of the electrodes determines the complex of their welding, technological, sanitary and hygienic characteristics, as well as the mechanical properties of the welded joints. In [7], the influence of electrode coating components on such important characteristics as the stability of the welding arc and the critical brittleness temperature of the weld seam was examined. The composition of the coating plays a decisive role in the complex of the above properties. In this research, the coating composition of the MP-3 electrode was taken as a basis. Only ferromanganese in [7] is replaced by ferrosilicon, other components vary. From the composition of the coating, five main most significant components were identified, which became optimization factors: the content of the coating composition silicomanganese (X_1), mica (X_2), ferrotitanium (X_3), graphite (X_4), and marble (X_5). The variation of these components is indicated in Table 1.

Table 1. Range in mass percent variation of coating components in Russian rutile electrodes

Levels and intervals	X_1 (SiMn)	X_2 (mica)	X_3 (FeTi)	X_4 (graphite)	X_5 (marble)
Levels 0	14	12	2	1	12
Steps	4	3	1	1	3
Levels -1	10	9	1	0	9
Levels +1	18	15	3	2	15
Add levels	22-6	18-6	4-0	3-0	18-6

The purpose of the research is to adapt a five-factor DEFMOT problem to a four-factor one by using published experimental data regarding the influence of coating component combinations on technological and mechanical performance.

2. SETTING, METHODOLOGY AND RESULTS OF THE RESEARCH

Welding electrodes MP-3 (rutile) are designed for manual arc welding of critical structures of carbon and low-alloy steel with a carbon content of up to 0.25%, with a tensile strength of up to 490 MPa. The electrode is used for welding in all spatial positions, except vertically from top to bottom. Thanks to the composition of the coating, a minimum of toxic substances are released during the welding process. It is used when working with an AC or DC power source. The length of the arc is medial, short. The advantages of MP-3 electrodes are easy first and second ignition, stable arc burning, welding through the entire depth of the seam, light splashes of metal, easy separation of the slag crust, application on rusty and wet surfaces. Mass percentage is one way to represent the amount of an element in a compound or component in a mixture. Mass percentage is calculated as the mass of the component divided by the total mass of the mixture multiplied by 100%. Summarizing a set of criteria in one quantitative characteristic is associated with a number of difficulties. Each criterion has its own meaning and dimension. In order to combine the criteria, each of them must be transformed into a single dimensionless scale that makes them comparable. Based on the mutual comparison of the coefficients of variation of the welding current intensity, it is possible to compare the stability of the welding process in cases where different process parameters are used. In this case, 32 combinations of coatings consisting of different amounts of five ingredients were explored – an experiment described in [7]. The levels of variation by which the combinations of the ingredients contained in the coating were determined are indicated in Table 1.

The methodology to transform the five-factor analysis to four-factor one is performed in the following sequence:

2.1. With a selected object and certain research problems, an experiment is conducted. For the considered case, the experiment is located in [7].

2.2. Based on experimental data, regression models are derived for the explored quantities under the influence of the five factors. The models were derived with the DSTAT-16 system.

CRITICAL STRENGTH TEMPERATURE MODEL

$$Y_1(X_1, X_2, X_3, X_4, X_5) = -50.7386 - 1.45833X_1 - 1.8750X_2 - 7.70833X_3 - 2.29167X_4 - 3.95833X_5 + 9.48864X_1^2 + 2.18750X_1X_2 + 2.81250X_1X_3 + 7.81250X_1X_4 - 1.56250X_1X_5 + 0.738638X_2^2 - 0.3125X_2X_3 + 2.18750X_2X_4 + 11.5625X_2X_5 + 6.36364X_3^2 + 2.81250X_3X_4 + 0.9375X_3X_5 + 1.98864X_4^2 - 0.31250X_4X_5 + 1.36364X_5^2.$$

Adequacy testing is characterized by a multiple correlation coefficient R = 0.9394 and Fisher’s test performed Fcalculated = 4.1298 > Ftable = 2.6464.

$$Y_2(X_1,X_2,X_3,X_4,X_5) = +0.141357 - 0.005750X_1 - 0.00408333X_2 + 0.006250X_4 - 0.00333333X_5 + 0.412500X_1X_5 - 0.00225X_2X_3 - 0.0033750X_2X_4 + 0.005250X_3X_5 - 0.00744643X_4X_5 - 0.00244645\ X_5^2$$

Adequacy testing is characterized by a multiple correlation coefficient $-R = 0.7343$ and Fisher's test performed $F_{calculated} = 2.4568 > F_{table} = 2.3210$.

2.3. One of the factors with the most acceptable step is selected, reducing the study to a single input variable. It varies with a very acceptable step 1 from 0 to 2 mass percent.

Looking at Table 1, it can be assumed that the X_4 parameter is the most suitable for fixing. It varies with a very acceptable step 1 from 0 to 2 mass percents.

2.4. Derived four-factor models with the fixed parameter varying with a certain step are analyzed.

Table 2a

Y1- Critical embrittlement temperature		
X_4=-1	X_4=0	X_4=+1
B_0=-46.50329	-50.7386	-51.08663
B_1=-9.27133	1.45883	6.35367
B_2=-3.9635	-1.875	0.3935
B_3=-10.5208	-7.70833	-4.8958
B_5=-3.64583	-3.95833	-4.27083
B_{11}=-3.64583	-9.48864	-4.27083
B_{12}=-3.64583	2,1875	-4.27083
B_{13}=-3.64583	2.8125	-4.27083
B_5=-3.64583	-1.56250	-4.27083
B_{15}=-3.64583	0.73868	-4.27083
B_{22}=-3.64583	-0.73868	-4.27083
B_{23}=-3.64583	-0.3125	-4.27083
B_{25}=-3.64583	11.5625	-4.27083
B_{33}=-3.64583	6.36364	-4.27083
B_{35}=-3.64583	0.937500	-4.27083
B_{55}=-3.64583	1.36364	-4.27083
max -1 -1 -1 -1 Y1= 14.4776 min 0.5 -1 0.5 1 Y2= -62.1257	max -1 -1 -1 -1 Y1=96.1688 min 0 -1 0.5 1 Y2= 37.5568	max -1 -1 -1 -1 Y1= -8.6252 min 0.25 -1 0.25 1 Y2=-65.9191

Table 2b

Coefficient of stable arc burning		
X_4=-1	X_4=0	X_4=+1
B_{00}=-0.1488034	0.14157	0.1488034
B_{10}=0.1488034	-000575	0.1488034
B_{20}=0.0007083	-0.00408	0.0074583
B_{50}=0.0007083	-0.0033	0.0074583
B_{15}=-3.64583	0.004125	0.0074583
B_{23}=-3.64583	-0.00225	0.0074583
B_{35}=-3.64583	0.00525	0.0074583
B_{55}=-3.64583	-0.0024464	0.0074583
max -1 -1 -1- 1 Y1= 0.1663 min 0.5 -1 0.5 1 Y2= 0.1316	max -1; -1; -1; -1 Y1= 0.1594 min 0 -1 0.5 1 Y2= 0.1210	max-1 -1 -1 -1 Y1= 0.1679 min 0.25 -1 0.25 1 Y2= 0.1227

2.5. Single-criteria optimization is performed and the given task is analyzed. The results of the multi-criteria optimization are as follows.

Table 3

X4=-1	X4=0	X4=1
max -0.5; -1; 0.5; +1; Y1=43.54010 min-0.5; -1; 0.5; +1; Y2=0.1467	max 0; -1; 0.5; 1; Y1=59.06070 min 0; -1; 0.5; 1; Y2=0.1437	max -0.25; -1; 0.25; 1; Y1=48.1790 min 0.25; -1; 0.25; 1; Y2= 0.1445

CONCLUSION:

It has been proven that by adaptation, DEFMOT can reduce a five-factor problem to a four-factor problem. New data on the combinations of the coating components on the technological and mechanical indicators were obtained. The compiled methodology for the transformed adaptation from 5D to 4D is implemented for a specific technological process. The analysis and optimization performed after the transformation. An optimal composition was determined, guaranteeing the highest impact strength and the highest stability at a graphite quantity of 1 (one) mass percent.

Acknowledgments: The authors of the study thank the Higher School of Transport for the financial support from the project "Identification of governing parameters to the quality indicators of the example of ion nitriding of heat-resistant steels" for the implementation of which this article was written.

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ИЗСЛЕДВАНЕ ВЛИЯНИЕТО НА ХИМИЧЕСКИЯ СЪСТАВ НА ОБМАЗКАТА ВЪРХУ ТЕХНОЛОГИЧНИ И МЕХАНИЧНИ ПОКАЗАТЕЛИ ЧРЕЗ ПРИЛАГАНЕ НА DEFMOT

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Ключови думи*: DEFMOT, Моделиране, Регресионен анализ, Оптимизация.*

Резюме: *В изследването е адаптиран пет-факторен проблем с изчислителният подход DEFMOT [3] до четири-факторен чрез ползване на публикувани експериментални данни [7] по отношение влиянието на комбинациите от компонентите на обмазката върху технологичните и механичните показатели. Съставена е методика на трансформираната адаптация от 5D в 4D. Примерът за влиянието на обмазката [7] е използван за онагледяване на адаптирания подход. Осъществен е анализ и оптимизация след направената трансформация. Определен е оптимален състав, гарантиращ най-висока ударна якост и най-висока стабилност при количество на графит 1 (един) масов процент.*