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Influence of surfacing modes on the properties of high-carbon coatings

V. Shenfeld * 0000-0002-5548-6971, **O. Bodnar** 0009-0002-4400-9173 **O. Shylina** 0009-0082-4123-5822

Vinnytsia National Technical University, Vinnytsia, Ukraine
**E-mail: leravntu@gmail.com*

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Abstract

The paper presents the results of a study of the influence of surfacing modes on the hardness and wear intensity of high-carbon coatings under dry friction. The coatings were deposited by electric-arc surfacing using carbon fibrous materials. A mathematical model is proposed that describes the influence of the selected parameters ($v_н$, U, I) on the hardness of the surfaced layer (*HRC*) and the wear intensity $I_З$. Using the obtained mathematical models, it is possible to solve current problems of obtaining coatings with a given hardness and wear resistance, which arise during the design of technological processes that use the deposition of coatings. For real technological processes, the problems should be solved by the graph-analytical method or linear programming methods using response surfaces. Analysis of response surfaces showed that increasing the deposition rate increases the hardness of the deposited coating and the intensity of wear under dry friction conditions.

Keywords: Surfacing, hardness, wear resistance, friction, coatings, regression analysis

Introduction and review of publications

At present, a wide range of methods is used under industrial conditions to deposit high-carbon layers with good wear resistance. First and foremost, this refers to laser surfacing [1–3], as well as electron-beam, plasma, and electric-arc surfacing processes [4–10]. The lifetime of the weld pool in the liquid state, the cooling rate and the crystallisation time of the surfaced metal depend on the parameters of the surfacing process. As a result, the structure of the obtained coatings, their hardness and wear intensity will change. Among the main factors that affect these characteristics are the surfacing speed $v_н$, the electrode wire feed rate $v_д$, the arc voltage U and the surfacing current I [11–13].

Aims of the paper

In this connection, an urgent task is to determine the optimal values of the surfacing process parameters that ensure the required hardness of the surfaced layer (*HRC*) and minimal wear intensity $I_З$ under conditions of dry and abrasive friction.

Results

The wire feed speed in the UD-209M unit is structurally linked to the surfacing speed. Therefore, the following parameters were chosen as variable factors: surfacing speed $v_н$, arc voltage U and surfacing current I.

To solve the stated problem a mathematical model was developed that describes the influence of the selected parameters ($v_н$, U, I) on the hardness of the surfaced layer *(HRC)* and the wear intensity $I_З$. It is expedient to use a full factorial experimental design and regression analysis.

The methodology of regression analysis is described in detail in a number of works, and therefore only the results of its application are presented here.

The experiments were carried out using the UD-209M unit. Surfacing was performed with NP-30HGSA electrode wire and carbon fabric on flat specimens made of 45 steel. Carbon dioxide was used as the shielding atmosphere, and reverse polarity was applied.

The preliminarily obtained linear model was found to be inadequate. Therefore, it is reasonable to approximate the response functions y_{HRC} and $y_{I_з}$ by a second-order polynomial of the form.

$$y = b_0 + \sum_{1 \le i \le k} b_i x_i + \sum_{1 \le i \le l \le k} b_{il} x_i x_l + \sum_{1 \le i \le k} b_{il} x_i^2 , \tag{1}$$

The intervals of variation and factor levels are given in Table 1.

Table 1

Intervals of variation and factor levels influencing the hardness and wear intensity of the high-carbon surfaced layer are shown below

Factors	Variation interval	Factor levels		
		Base 0	Upper +1	Lower -1
x_1 – arc voltage, V	4	28	32	24
x_2 – surfacing speed, m/h	7.5	18.5	26	11
x_3 – current, A	20	100	120	80

Four samples were cut from each surfaced specimen, on which the hardness of the surfaced layer and the wear intensity were measured. The TK-2M hardness tester was used to measure the hardness of the surfaced layer.

A rotatable second-order experimental design matrix for three factors was compiled.

For each macrosection the hardness *HRC* was determined as the average of 10 measurements, and the wear intensity $I_з$ was determined from the mass loss measurements. The columns y_{HRC} and $y_{I_з}$ in Table 2 present the average values of hardness HRC and wear intensity $I_з$, respectively.

Table 2

Central composite second-order design matrix for three factors

Plan structure	Test No.	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	y_{HRC}	$y_{I_з}$, mg/km
Design 2^3	1	+	+	+	+	+	+	+	+	+	+	54	0,06
	2	+	-	+	+	-	-	+	+	+	+	56	0,05
	3	+	+	-	+	-	+	-	+	+	+	46	0,09
	4	+	-	-	+	+	-	-	+	+	+	44	0,08
	5	+	+	+	-	+	-	-	+	+	+	52	0,07
	6	+	-	+	-	-	+	-	+	+	+	48	0,08
	7	+	+	-	-	-	-	+	+	+	+	42	0,1
	8	+	-	-	-	+	+	+	+	+	+	40	0,12
Star points	9	+	+α	0	0	0	0	0	α^2	0	0	45	0,09
	10	+	-α	0	0	0	0	0	α^2	0	0	48	0,08
	11	+	0	+α	0	0	0	0	0	α^2	0	56	0,05
	12	+	0	-α	0	0	0	0	0	α^2	0	40	0,12
	13	+	0	0	+α	0	0	0	0	0	α^2	44	0,08
	14	+	0	0	-α	0	0	0	0	0	α^2	42	0,1
Centre point	15	+	0	0	0	0	0	0	0	0	0	46	0,09
	16	+	0	0	0	0	0	0	0	0	0	44	0,08
	17	+	0	0	0	0	0	0	0	0	0	42	0,1
	18	+	0	0	0	0	0	0	0	0	0	45	0,09
	19	+	0	0	0	0	0	0	0	0	0	44	0,08
	20	+	0	0	0	0	0	0	0	0	0	48	0,07

The coefficients of the regression equations for the functions $y_{HRC} = f(U, v_н, I)$, $y_{I_з} = f(U, v_н, I)$, as well as the dispersions of the regression coefficients, were determined. The calculation results are summarised in Table 3.

Taking into account the significance of the regression coefficients, the equations assume the form:

$$y_{HRC} = 44{,}8 - 4{,}753 \cdot x_2 - 1{,}564 \cdot x_3 - 0{,}75 \cdot x_1 \cdot x_3 - 0{,}25 \cdot x_2 \cdot x_3 - 0{,}256 \cdot x_3^2 . \tag{2}$$

$$y_{I_з} = 0{,}523 + 0{,}203 \cdot x_1 + 0{,}172 \cdot x_3 + 0{,}131 \cdot x_1 \cdot x_3 - 0{,}111 \cdot x_3^2 \tag{3}$$

Table 3

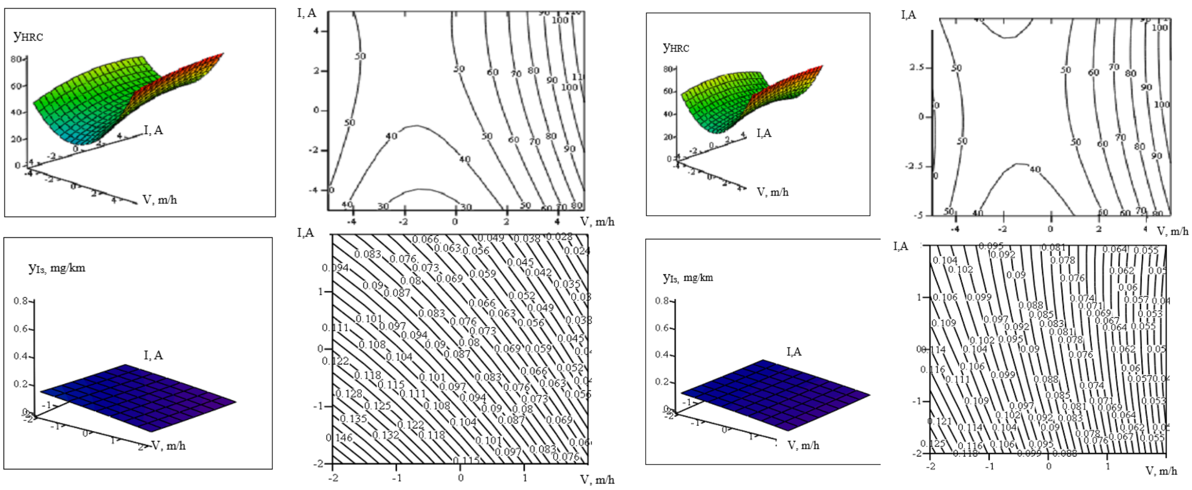
Results of the study according to the experimental design

Regression coefficient	y_{HRC}				y_{I3}			
	Coeff. value	$s^2\{b\}\cdot10^{-3}$	Δb ±	Significance	Coeff. value	$s^2\{b\}\cdot10^{-3}$	Δb ±	Significance
b_0	44,8	0,69	2,142	+	0,523	1,35	0,094	+
b_1	0,07	0,3	1,419	-	0,203	0,59	0,063	+
b_2	4,753	0,3	1,419	+	0,062	0,59	0,063	-
b_3	1,564	0,3	1,419	+	0,172	0,59	0,063	+
b_{12}	-0,25	0,52	1,855	-	0,041	1,01	0,082	-
b_{13}	-0,75	0,52	1,855	+	0,131	1,01	0,082	+
b_{23}	0,25	0,52	1,855	+	0,0013	1,01	0,082	-
b_{11}	0,983	0,29	1,383	-	0,032	0,56	0,061	-
b_{22}	1,514	0,29	1,383	-	0,0024	0,56	0,061	-
b_{33}	-0,26	0,29	1,383	+	-0,111	0,56	0,061	+

The adequacy of the obtained models was checked using the Fisher criterion. At the 5% significance level the tabulated value of the criterion is F_T = 4,7. The calculated values were F_{HRC} = 0,3 and F_{i3} = 0,8. Since the calculated values are lower than the tabulated one, the models can be considered adequate.

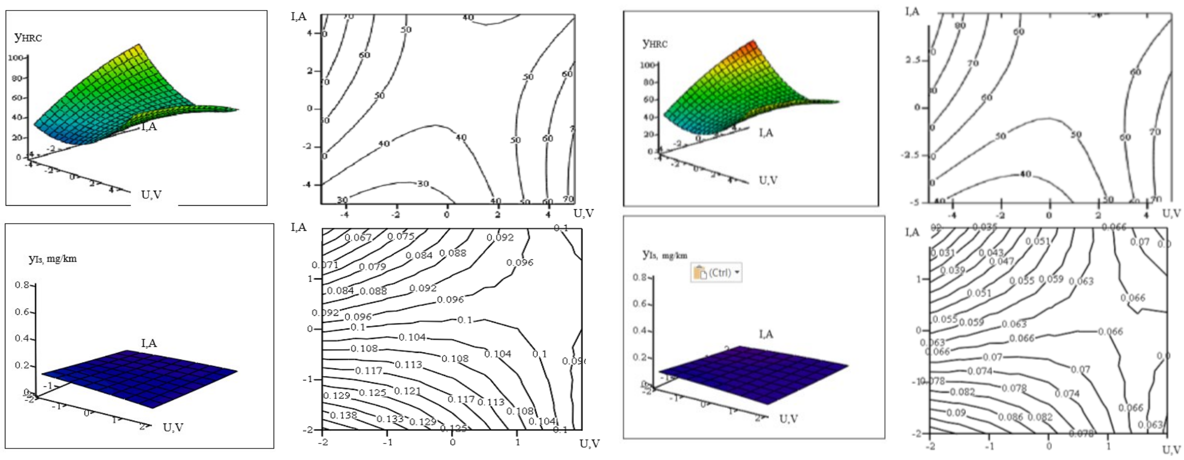
Using the obtained models (regression equations), and fixing one of the surfacing process parameters, response surfaces can be obtained that clearly show the influence of the other parameters on the hardness of the surfaced layer and the wear intensity under dry friction.

By using the obtained mathematical models (equations (2) and (3)), a number of problems arising in the design of technological processes involving surfacing of coatings can be solved. Among them, the most common are problems related to obtaining coatings with specified hardness and wear resistance.



a **b**

Fig. 1. Response surfaces of the functions y_{HRC} and y_{I3} at: a – U_{min}; b – U_{max}



a **b**

Fig. 2. Response surfaces of the functions y_{HRC} and y_{I3} at: a – V_{min}; b – V_{max}

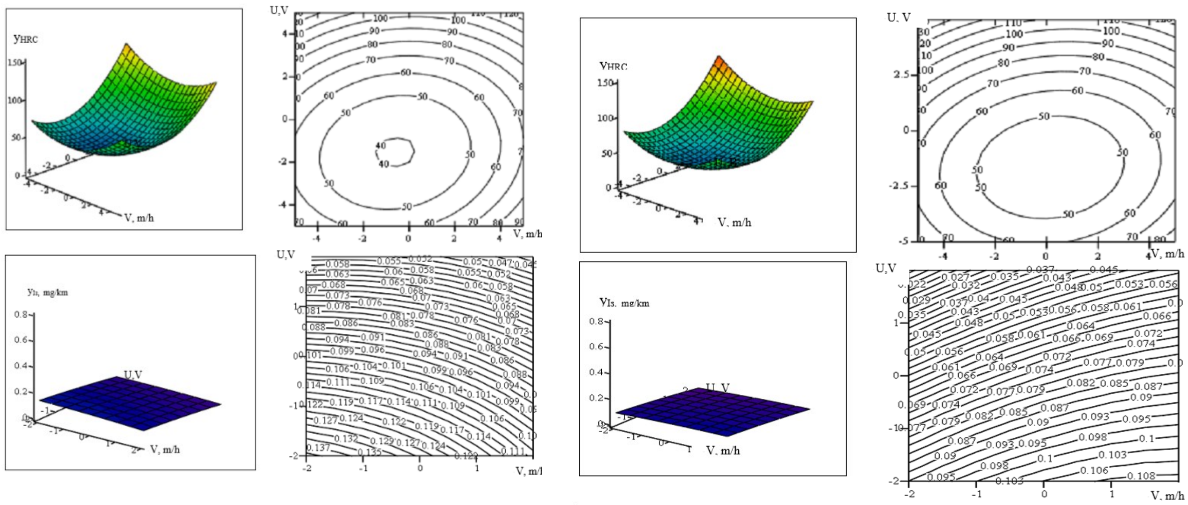


Fig. 3. Response surfaces of the functions y_{HRC} and y_{I_3} at: a – I_{min}; b – I_{max}

Figures 1–3 show the response surfaces that illustrate the influence of arc voltage, surfacing speed and current on the hardness of the surfaced layer and on the wear intensity**.**

Conclusions

The influence of the voltage on the welding arc and the deposition rate on the hardness of the deposited coating is nonlinear, and on the wear intensity - linear. Response surfaces (Fig. 1-2) show the presence of extrema, the smallest and largest values of functions in the area of parameter variation. It is advisable for real technological processes to solve the problems set by the graph-analytical method or linear programming methods using response surfaces.

From the analysis of the response surfaces (Fig. 3) it follows that an increase in the deposition rate increases the hardness of the deposited coating and the wear intensity under dry friction conditions.

The determination of surfacing modes for applying wear-resistant high-carbon coatings under dry friction conditions should reasonably be based on regression equations. This makes it possible to obtain the required hardness and wear resistance in accordance with the requirements imposed on the working surfaces of the part.

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Шенфельд В.Й., Боднар О.І., Шиліна О.П. Вплив режимів наплавлювання на властивості високовуглецевих покриттів

У статті подано результати дослідження впливу режимів наплавлення на твердість та інтенсивність зношування високовуглецевих покриттів в умовах сухого тертя, нанесених методом електродугового наплавлення з використанням вуглецевих волокнистих матеріалів. Показані математичні моделі, які описують вплив визначених параметрів ($v_н$, U, I) на твердість наплавленого шару *(HRC)* та інтенсивність зношування $I_З$. За допомогою отриманих математичних моделей можна розв'язувати актуальні задачі отримання покриттів із заданою твердістю та зносостійкістю, які виникають під час проектування технологічних процесів, що використовують наплавлення покриттів. Для реальних технологічних процесів поставлені задачі потрібно розв'язувати графо-аналітичним методом або методами лінійного програмування з використанням поверхонь відгуків. Аналіз поверхонь відгуків показав, що збільшення швидкості наплавлення збільшує твердість наплавленого покриття та інтенсивність зношування в умовах сухого тертя.

Ключові слова: наплавлення, твердість, зносостійкість, тертя, покриття, регресійний аналіз