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# Research of factors affecting thickness of the covering obtained by electro contact sintering of composite materials

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**Abstract.** This article is devoted to research of qualitative characteristics of composite materials, and it includes the introduction, the technique of research, the results of research and the basic conclusions. In the introduction, the urgency of the theme is substantiated, and the object and research problems are formulated. In the research technique, the factors directly affecting the thickness of the covering are revealed, research is carried out, experiments are set up. The impulse and pause times are chosen so that the covering had enough time to conglomerate, whilst there was no burning out of the composite material and the unit's overheating was also avoided. The pressure of a roller clip should guarantee a uniform covering however without allowing the powder material to be expelled from the sintering zone. Powder PK40C2, in its mass structure consisting of: iron - more than 96 %; carbon – 0,3-06%; chrome – 1-3%, will be the material to be tested. Based on the conditions of the experiment the planning matrix is built, and after processing the matrix, the regress equation is obtained. In order to assess the uniformity of the equation dependences obtained, Kohren's criterion was used; for verification of the importance of the polynom members - Student's criterion was used, and for verification of the adequacy of the equation of the regression - Fisher's criterion was used. As a result of the research, the diagram of dependence of the covering thickness upon impulse and pause time is constructed; quantity of the heat emitted in burning of the composite material is calculated. In the course of research, the optimum modes of applying the covering and their parametrical influence on the thickness of the covering were estimated. Recommendations regarding applying the composite covering by a method of electro-contact method were given. Dependences of the impulse and pause time to the thickness of a received covering are found and graphically presented. In the final part of the article, the basic conclusions and recommendations relating to applying the covering by the electro-contact method are formulated. The disadvantages of the given method of components restoration are revealed, and the ways to improve these are offered.

## 1. Introduction

The quality of the covering is one of the fundamental parameters that affect its lifetime and therefore its reliability. The restoration and manufacturing of parts using modern composite materials allow forming the component's surface layer with specific parameters. The alteration of the physical-mechanical properties of the component's surface in a certain unit may positively affect its lifetime in the general. Unlike foreign mechanical engineering, in Russian industry the use of covering with



special characteristics is very limited. This enables wide space for the research of modern coverings, as applied to Russian lumber machinery.

The aim of our research is to receive data related to optimal quality and thickness of the covering obtained by the electro contact sintering method of the composite material to a component's surface.

## 2. Methodology of the research

The following factors affecting the process of experimental production of the covering were found in analysis of special literature:

- Pressure of the roller clip to the component being restored, P.
- Current load, I.
- Voltage, U.
- Impulse time,  $t_i$ .
- Pause time,  $t_p$ .
- Loading, s.
- Number of rotations of the work spindle, n.

Mainly, the above factors affect other qualitative parameters of the covering, such for example as cohesive strength, endurance, coefficient of sintering and etc. It was found, that the following factors will immediately affect the thickness of the covering:

- pressure of the roller clip to the component being restored, P.
- impulse time,  $t_i$ .
- pause time,  $t_p$ .

On the basis of the a priori information, the following variability intervals of the factors will be taken:

- $t_i = 0.04 - 0.12$  sec.
- $t_p = 0.04 - 0.12$  sec.
- $P = 0.5 - 1.5$  kN.

The impulse and pause time were chosen so that the covering had enough time to conglomerate, whilst there was no burning out of the composite material and part's overheating. The pressure of a roller clip should guarantee applying of a uniform covering however not allowing the powder material to be expelled from the sintering zone.

The following factors will be taken as invariable:

- $I = 12$  kA.
- $U = 3$  V.
- $s = 2$  mm/rev.
- $n = 3$  rev/min.

In the course of preliminary research, it was found that the pressure of the roller clip within the given limits does not affect the process of forming the covering and its thickness; however, the process of sintering is impracticable outside the accepted intervals. Let us therefore take this factor equal to  $P = 1$  kN. The number of experiments is to be found as:

$$N = n^k, \quad (1)$$

where n – is the number of levels and k – is the number of factors.

$$N = 2^2 = 4.$$

The part rotation number is to be left as ( $n = 3$  rev/min), and of the filler head supply is to be set to 0.15 mm/rev. The result of the experiment is rollers, obtained in three complete rotations of the component. The initial pressure of the filler head roller is to be taken invariable  $P = 1$  kN. Powder PK40C2, in its mass structure consisting of more than 96 % of iron, 0.3-0.6% of carbon and 1-3% of chrome will be the experiment material. The result of the experiment is to be considered as thickness of the covering obtained, in millimetres. For more accuracy, each experiment, with the given set of factors, will be carried out three times.

Let us identify factors and levels of their variability (Table 1).

**Table1 . Factor levels of the experiment.**

Symbol	Factors	Variability levels			Variability interval
		Lower -1	basic 0	upper +1	
$x_1$	Impulse time, sec	0.03	0.04	0.05	0.01
$x_2$	Pause time, sec	0.03	0.04	0.05	0.01

Let us formulate the planning matrix in real and dimensionless figures (Table 2).

**Table 2.** The planning matrix of  $2^2$  experiment.

Number of the experiment	Factors in real figures		Factors in dimensionless figures	
	$x_1$	$x_2$	$x_1$	$x_2$
1	0.03	0.03	-1	-1
2	0.03	0.05	-1	+1
3	0.05	0.03	+1	-1
4	0.05	0.05	+1	+1

The next step is to formulate the planning matrix with a fictitious variable  $x_0=1$  (Table 3).

**Table3.** The planning matrix with a fictitious variable.

Number of the experiment	$x_0$	$x_1$	$x_2$	$y_1$	$y_2$	$y_3$	$Y^{avr}$
1	+1	-1	-1	$y_1$	$y_1$	$y_1$	$y_1^{cp}$
2	+1	-1	+1	$y_2$	$y_2$	$y_2$	$y_2^{cp}$
3	+1	+1	-1	$y_3$	$y_3$	$y_3$	$y_3^{cp}$
4	+1	+1	+1	$y_4$	$y_4$	$y_4$	$y_4^{cp}$

The planning matrix shown in Table 3 has the following parameters, in accordance with the formula (2):

$$\begin{aligned}
 \sum x_{ui}x_{ji} &= 0; u \neq j; u, j = 0, 1, \dots, k \\
 \sum x_{ji} &= 0; j = 1, 2, \dots, k; j \neq 0 \\
 \sum x_{ji}^2 &= N; j = 0, 1, \dots, k
 \end{aligned}
 \quad (2)$$

where  $k$  – is the number of independent factors,  $N$  – is the number of experiments in the planning matrix. The matrix containing results of experiments will be as follows (Table 4):

**Table 4.** The planning matrix with a fictitious variable.

Number of the experiment t	$x_0$	$x_1$	$x_2$	$y_1$	$y_2$	$y_3$	$Y^{avr}$
1	+1	-1	-1	0.50	0.10	0.55	0.40
2	+1	-1	+1	0.20	0.20	0.25	0.22
3	+1	+1	-1	0.50	0.80	0.45	0.58
4	+1	+1	+1	0.90	1.30	0.95	1.05

The coefficients of the regression equation given by least-squares method are as follows:

$$B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = (X^T X)^{-1} X^T Y \quad (3)$$

The moment matrix (XTX), corresponding to Table 4, is as follows:

$$(X^T X) = \begin{bmatrix} \sum x_{0i}^2 & \sum x_{0i} x_{1i} & \sum x_{0i} x_{2i} \\ \sum x_{1i} x_{0i} & \sum x_{1i}^2 & \sum x_{1i} x_{2i} \\ \sum x_{2i} x_{0i} & \sum x_{2i} x_{1i} & \sum x_{2i}^2 \end{bmatrix} \quad (4)$$

Having considered parameters (2), we come to:

$$(X^T X) = \begin{pmatrix} 4 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 4 \end{pmatrix} \quad (5)$$

The matrix, inverse to the moment matrix (XTX)<sup>-1</sup>, is equal to

$$(X^T X)^{-1} = \begin{pmatrix} 1/4 & 0 & 0 \\ 0 & 1/4 & 0 \\ 0 & 0 & 1/4 \end{pmatrix} \quad (6)$$

and

$$(X^T Y) = \begin{bmatrix} \sum x_{0i} Y_i \\ \sum x_{1i} Y_i \\ \sum x_{2i} Y_i \end{bmatrix} \quad (7)$$

Therefore,

$$B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{pmatrix} 1/4 & 0 & 0 \\ 0 & 1/4 & 0 \\ 0 & 0 & 1/4 \end{pmatrix} \times \begin{bmatrix} \sum x_{0i} Y_i \\ \sum x_{1i} Y_i \\ \sum x_{2i} Y_i \end{bmatrix} \quad (8)$$

Consequently, and coefficient to the regress equation b is determined by a scalar product of column y to the correspondent column x<sub>j</sub>, divided by the number of tests in the planning matrix N:

$$b_j = \frac{1}{N} \sum x_{ji} y_i \quad (9)$$

Using the plan shown in Table 2, let us first calculate the coefficient of linear regression equation

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2. \quad (10)$$

For instance, in order to determine the b<sub>1</sub> coefficient at x<sub>1</sub>, it is required to calculate the sum of products:

$$\begin{aligned} & \begin{bmatrix} -1 \\ -1 \\ +1 \\ +1 \end{bmatrix} \times \begin{bmatrix} 0.40 \\ 0.22 \\ 0.58 \\ 1.05 \end{bmatrix} = \begin{bmatrix} -0.40 \\ -0.22 \\ +0.58 \\ +1.05 \end{bmatrix} \\ & \sum x_{1i} Y_i = 1.01 \\ & b_1 = \frac{1}{4} \sum x_{1i} y_i = \frac{1.01}{4} = +0.25. \end{aligned}$$

In much the same way, we receive b<sub>0</sub> = 0.56; b<sub>2</sub> = 0.07. Hence, the regression equation will be as follows:

$$\hat{y} = 0.56 + 0.25x_1 + 0.07x_2 \quad (11)$$

If the complete regression equation containing interaction coefficients is considered

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2, \quad (12)$$

then, in order to determine the coefficient (pair interaction effect) it is necessary to extend the planning matrix as follows (Table 5).

**Table 5.** The extended planning matrix of complete factorial  $2^2$ .

Number of the experiment	$x_0$	$x_1$	$x_2$	$x_1x_2$	$y^{avr}$
1	+1	-1	-1	+1	0.40
2	+1	-1	+1	-1	0.22
3	+1	+1	-1	-1	0.58
4	+1	+1	+1	+1	1.05

Interaction coefficients are to be determined in the way similar to linear effects. In order to determine  $b_{12}$  it is necessary:

$$\begin{aligned} & \begin{matrix} X_1X_2 & Y^{avr} \\ \begin{bmatrix} +1 \\ -1 \\ -1 \\ +1 \end{bmatrix} \times \begin{bmatrix} 0.40 \\ 0.22 \\ 0.58 \\ 1.05 \end{bmatrix} = \begin{bmatrix} 0.40 \\ -0.22 \\ -0.58 \\ +1.05 \end{bmatrix} \end{matrix} \\ & \Sigma X_{12}Y_i = 0.65 \\ & b_{12} = \frac{1}{4} \Sigma (X_{12})_i Y_i = \frac{0.65}{4} = 0.16 \end{aligned}$$

Hence, the regression equation will be as follows:

$$\hat{y} = 0.56 + 0.25x_1 + 0.07x_2 + 0.16x_1x_2. \quad (13)$$

The significance of the coefficients of regression equation can be verified for each coefficient according to Student's criterion. The removal of any insignificant coefficient from the regression equation (13) will not affect other coefficients. Furthermore, the sample coefficients  $b_j$  become the so called *unconfined estimates* for the correspondent general coefficients  $\beta_j$ :

$$b_j \rightarrow \beta_j \quad (14)$$

that is, values of coefficients of the regression equation characterise the impact of every factor in the value of  $Y$ . The diagonal elements of covariation matrix are equal to each other, that is why all coefficients of equations (11) и (13) can be determined with same accuracy:

$$s_{bj} = \frac{s_{reprod}}{\sqrt{N}}. \quad (15)$$

Additionally, let us put three parallel experiments in the centre of the plan. The following values of  $y$  were received:

$$\begin{aligned} y_1^0 &= 0.34 \\ y_2^0 &= 0.55 \\ y_3^0 &= 0.35 \\ Y_{avr} &= \frac{\sum Y_u}{3} = 0.41 \\ s_{reprod}^2 &= \frac{\sum Y_u^2 - Y_{avr}^2}{2} = 0.014 \\ s_{reprod} &= 0.12 \\ s_{bj} &= \frac{0.12}{\sqrt{4}} = 0.06 \end{aligned}$$

Let us assess the significance of coefficients in accordance with Student's criterion:

$$t_0 = \frac{b_0}{s_{b0}} = \frac{0.56}{0.06} = 9.3$$

$$t_1 = \frac{b_1}{sb_1} = \frac{0.25}{0.06} = 4.2$$

$$t_2 = \frac{b_2}{sb_2} = \frac{0.07}{0.06} = 1.2$$

$$t_{12} = \frac{b_{12}}{sb_{12}} = \frac{0.16}{0.06} = 2.7.$$

The table value of the Student's criterion for the significance level is  $p = 0.20$  and number of degrees of freedom is  $f = 2$ ,  $tp(f) = 1.89$ . Consequently, the coefficient  $b_2$  is insignificant, and must be removed from the equation. After removal of the insignificant coefficient, the regression equation is as follows:

$$\hat{y} = 0.56 + 0.25x_1 + 0.16x_2.$$

Let us assess the adequacy of the obtained equation according to Fisher's criterion:

$$F = \frac{s_{ad}^2}{s_{reprod}^2} \quad (16)$$

$$s_{ad}^2 = \frac{\sum Y_{avr} - Y_i^2}{N-1} = \frac{0.40}{3} = 0.13 \quad (17)$$

where  $i$  – is the number of significant coefficients in the regression equation, equals to 3.

$$s_{reprod}^2 = 0.014$$

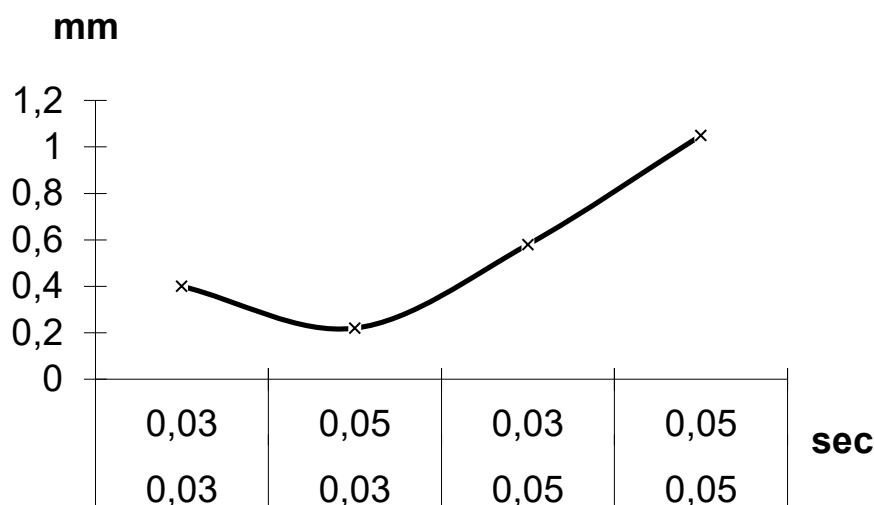
$$F = \frac{0.13}{0.014} = 9.3$$

The tabulated value of the Fisher criterion is for  $p = 0.20$ ,  $f_1 = 2$ ,  $f_2 = 1$ ,  $F_{1-p}(f_1, f_2) = 12.0$ ,  $F < F_{1-p}(f_1, f_2)$ .

Consequently, the obtained equation corresponds to the experiment in an adequate way.

### 3. Results of the research

As a result of the research, a graph of dependence of the thickness of the coating  $\delta$  upon impulse and pause time, as per the equation obtained was received (Figure 1).



**Figure. 1.** The graph of the dependence  $\delta$  ( $t_i, t_p$ ).

In order to receive the additional information related to the process, the current strength in sintering the powder and the time of experiments was measured. It was determined that the current strength varies within 12.1kA to 12.5 kA, whereas the time of experiment was 40 sec. Let us calculate the amount of heat emitted by current through the component, as per Joule law. The formula will be as follows:

$$Q = I^2 R t = I U t. \quad (18)$$

In this case, the amount of heat emitted by current through the component will be as follows:

$$Q_{\min} = 12100 \cdot 3 \cdot 40 = 1452 \text{ kJ}$$

$$Q_{\max} = 12500 \cdot 3 \cdot 40 = 1500 \text{ kJ}.$$

#### 4. Conclusions

As a result of the research, the following conclusions can be made:

- The method of restoring of used components opens wide possibilities for using it together with mechanical rolling and other methods where high quality coverings are needed.
- As a matter of fusion-bonded metal, together with powder, a wire, simple or cored, can be used.
- By choosing the correspondent grade of the powder hence its composition, it is possible to obtain required characteristics of the component surface.
- The components restoring method does not imply corrosion of the powder being sintered and the significant alterations of the structure of basement metal, which is normally the effect of other methods of components restoring.
- The method can result in creation the covering of 1.2 mm thickness, and the only limitation will be size of the apparatus.
- The apparatus for the sintering of powder materials does not require high qualification of the worker engaged in components restoring and is simple in use. From the other hand, such apparatus requires additional safety engineering, as the high strength current of kilo amperes is used.
- Disadvantages of the above method include relatively low ratio of the powder used, its significant part gets dropped, and to compensate this disadvantage, construction shapes can be used followed by drying and sifting of the powder.
- The negative impact on getting homogenous high quality covering in sintering of powder materials, is given by irregular supply of the powder from a bin, and a dispensing unit can be designed as a solution.

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