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Optimization of components in development of polymeric coatings for restoration of transport vehicles

It is proved, that for improving the performance characteristics of vehicle parts, including their corrosion resistance and wear resistance, it is advisable to use protective polymeric composite coatings. It is shown that in order to increase the indexes of physical-mechanical and thermophysical properties in the epoxy binder, it is necessary to introduce additives: modifiers, plasticizers, dispersed and fiber fillers. The introduction of dispersed additives into the epoxy binder is actual. It this case, it is effective to use fillers of different dispersity in the complex. The influence of two-component polydispersed filler on the elasticity modulus in flexure of the developed epoxy composite is analyzed. The critical content of a two-component polydispersed filler is found by the method of mathematical planning of an experiment. a mixture of nanodispersed compounds 1 ($d = 20\ldots80\ nm$) $-$ $0.75\ldots1.0$ *pts.wt.*, a mixture of discrete fibers 1 ($l = 0.5\ldots1.0\ mm$, $d = 18\ldots25\ \mu m$) – 0.2 pts.wt. by the 100 pts.wt. of the epoxy oligomer ED-20. An introduction of the two-component polydispersed filler to the epoxy binder allows significantly to increase the values of the elasticity modulus in flexure of the protective coatings to $= 4.8\ldots5.0 hPa$. Additionally, the effect of two-component polydispersed filler on the impact resilience of the developed epoxy composite was determined. It is proved that the critical content of a two-component polydisperse filler is: a mixture of nanodispersed compounds 2 ($d = 30\ldots40\ nm$) $-$ $1.00\ldots1.25$ *pts.wt.*, a mixture of discrete fibers 2 ($l = 0.5\ldots1.0\ mm, d = 18\ldots25\ \mu m$) $-$ $0.1\ldots0.2$ *pts.wt.* by the 100 pts.wt. of epoxy ED-20. An introduction of the two-component polydispersed filler to the epoxy binder allows significantly to increase the values of the impact resilience to W' = 10.0...10.2 kJ/m^2. The obtained results allow us to create polymeric coating with improved indexes of the physical and mechanical properties in complex.

Keywords: composite, epoxy matrix, two-component polydispersed filler, method of mathematical design of experiment, regression equation.

Introduction

It is known [1–4], that for the protection of metals and alloys from corrosion and to increase physical and mechanical properties, widely used protective polymer composite materials (PCM). Important for the creation of PCM with improved properties is the introduction into its composition of various chemical additives. The content of the fillers can be controlled to influence the properties of the composite material and have a PCM with predetermined properties in the end. At the same time, the process of the development of the composite material is costly and takes significant time intervals to obtain reliable experimental data. In order to optimize the composition of the polymer coating and the effectiveness of its development (decreasing the cost of materials and time of study) and obtaining of improved properties of the material in the complex, it is relevant to use the method of mathematical planning of the experiment.

Analyzing the scientific work of leading scientists in the direction of creating polymer materials [5–8], it has been established that the use of materials based on epoxy resins is effective for the protection of metal surfaces from corrosion. In the works [3–13] is proved that for the creation of PCM with improved physical and mechanical properties in the complex, it is necessary to introduce particles of fillers of different chemical composition and dispersion at the critical content. Taking into account the interaction on the phase boundary «matrix-filler», this allows to create of composite materials with improved physical and mechanical properties in the complex.

In this context, in order to reduce the number of experimental studies, it is proposed to carry out mathematical experiment planning. In the previous stage, the authors of the work studied the influence of the number of dispersed fillers on the base properties of epoxy composite material (CM). It is found the critical content of the main and additional fillers in the polymeric matrix. In particular, as the main filler, powders which are a mixture of nanodispersed compounds (MNDC) are used and are characterized by the following composition, %:

– MNDC 1: Si3N4 – 59,5; Al2O3 – 24,4; AlN – 10,1; TiN – 6,0;

– MNDC 2: Si3N4 – 85; AlF3 – 5; IH – 5; ZrH – 5.

The grains of the particles are: MNDC 1 – $d = 20 \ldots 80\ nm, MNDC\ 2 - -d = 30 \ldots 40\ nm.$

As an additional filler, a mixture of discrete fibers (MDF) from the following ingredients is used, %:

– MDF 1: viscose – 37; polyamide – 23; matka silk – 18; rong – 18; cashmere – 4;

– MDF 2: wool – 60; polyacrylonitrile (PAN) – 30; cashmere – 10.

Dimensions of the discrete fibers: $l = 0.5 \ldots 1.0\ mm, d = 18 \ldots 25\ \mu m.$

However, interesting from the practical point of view is the formation of composites with two-component filler, which, in our opinion, will allow to improve the properties of the studied CM in complex. In this context, it is expedient and necessary to use the method of mathematical planning of the experiment, which will allow to reduce the number of studies conducted and optimize the content of ingredients for obtaining CM with the maximum indexes of the selected characteristics.

Aim of work – to optimize the content of two-component polydisperse filler for the protective coatings of the transport equipment by the method of mathematical planning of the experiment.

Results and Discussion

On the first stage, for the optimization of the ingredients content into the material PCM 1 the elasticity modulus in flexion of composites at the different content of the main and additional fillers (MNDC 1 and MDF 1 in accordance) is studied. For standardization, as well as for simplification of calculations, each component (filler) is encoded by conditional units taking into account variations (Table 1).

Table 1

Levels of variables on conditional and natural scale for PCM 1

Components	Factor	Average level, q, pts.wt.	Variation step, Δq, pts.wt.	Values of variables (pts.wt.), that corresponding to conditional units		
				-1	0	+1
Main filler – MNDC 1	*x1*	0.75	0.25	0.50	0.75	1.00
Additional filler – MDF 1	*x2*	0.02	0.01	0.01	0.02	0.03

According to the experiment planning Scheme 9 experiments (N = 9) were conducted, each of which was repeated three times (p = 3) in order to exclude system errors (Table 2).

Table 2

Scheme of experiment planning

No. of exp. (u)	x_0	x_1	x_2	$E_3 = E_1^2 - d$	$E_4 = E_2^2 - d$	E_1E_2
1	1	-1	-1	0.33	0.33	+1
2	1	+1	-1	0.33	0.33	-1
3	1	-1	+1	0.33	0.33	-1
4	1	+1	+1	0.33	0.33	+1
5	1	0	0	-0.67	-0.67	0
6	1	+1	0	0.33	-0.67	0
7	1	-1	0	0.33	-0.67	0
8	1	0	+1	-0.67	0.33	0
9	1	0	-1	-0.67	0.33	0
$\sum_{u-1}^{N} x_{iu}^2$	9	6	6	2	2	4

In order that planning matrix to be orthogonal [9, 11, 14, 16], the corrected values of E' level were entered, which were calculated by the formula:

$$x_i' = (x_i)^2 - \frac{\sum_{u-1}^{N} x_{iu}^2}{N}. \tag{1}$$

The expanded matrix of planning of complete factor experiment (CFE) and its results are shown in Table 2.

The mathematical model $y = f\ (x1,\ x2)$ was formed as a regression equation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2. \tag{2}$$

The regression coefficients were determined by the formula

$$b_{\mathrm{i}} = \frac{\sum_{u=1}^{N} x_i y_i}{\sum_{u-1}^{N} x_{iu}^2}. \tag{3}$$

Received coefficients of regression equation are given in Table 3.

Table 3

The coefficients of regression equation

b0	*b1*	*b2*	*b11*	*b22*	*b12*
4.92	0.40	0.35	-0.73	-0.58	0.28

As a result, in the analysis of the elasticity modulus in flexure, the following regression equation was determined:

$$y = 4.92 + 0.40x_1 + 0.35x_2 - 0.73x_1^2 - 0.58x_2^2 + 0.28x_1x_2.$$

For the statistical processing of experiment results, a test of reproducibility of experiments by the Cochran test was conducted:

$$G = \frac{S_{u\max}^2}{\sum_{u=1}^{N} S_u^2} \leq G_{(0{,}05;f_1;f_2)}, \tag{4}$$

where S_{ui}^2– dispersion of experiment results on combinations of few factor levels for m=3; m – number of parallel experiments; *S2u max* – the highest dispersion in design line.

Dispersions of adequacy were determined by the formula

$$S_{ui}^2 = \frac{\sum_{i=1}^{m} (y_i - \overline{y_i})^2}{m-1}, \tag{5}$$

where y_{im}– value, received from each parallel experiment; $\overline{y_i}$ – average value y, received in parallel experiments.

Mean square error was determined by formula

$$\sigma^2\{y\} = \frac{\sum_{i=1}^{N=9} \sigma^2\{y\}_i}{N(m-1)}, \tag{6}$$

where $\sigma^2\{y\}_i = \sum_{i=1}^{m=3} (y_i - \overline{y_i})^2$; $\sigma^2\{y_{av}\} = \frac{0^2\{C\}}{N}$,

$$S_{b_0}^2 = \frac{S_0^2}{N}. \tag{7}$$

Dispersion values are shown in Table 4.

Table 4

Values of dispersions of adequacy (S_{ui}^2) and mean square error ($\sigma^2\{y\}_i$)

No. of exp.	The dispersions of adequacy		The mean square error	
	conditional designation	value	conditional designation	value
1	S_{u1}^2	0.07	$\sigma^2\{y\}_1$	0.14
2	S_{u2}^2	0.01	$\sigma^2\{y\}_2$	0.02
3	S_{u3}^2	0.03	$\sigma^2\{y\}_3$	0.06
4	S_{u4}^2	0.09	$\sigma^2\{y\}_4$	0.18
5	S_{u5}^2	0.01	$\sigma^2\{y\}_5$	0.02
6	S_{u6}^2	0.03	$\sigma^2\{y\}_6$	0.06
7	S_{u7}^2	0.03	$\sigma^2\{y\}_7$	0.06
8	S_{u8}^2	0.03	$\sigma^2\{y\}_8$	0.06
9	S_{u9}^2	0.01	$\sigma^2\{y\}_9$	0.02

Moreover:

$$\sum_{i=1}^{N} S_{ui}^2 = 0.31;$$

$$\sigma^2\{y\} = S_0^2 = 0.034.$$

Then the calculated value of the Cochran test at the 5% level of significance:

$$G_{calc} = \frac{S_{u_{\max}}^2}{\sum_{i=1}^{N} S_{ui}^2}; \quad (8)$$

$$G_{calc} = \frac{0.09}{0.31} = 0.290.$$

Testing the experiment results by the Cochran test [14] for a fixed probability $\alpha = 0.05$ confirmed the reproducibility of the experiments. Dispersion of experiment results on combinations of few factor levels: $S_{u\max}^2 = 0.09$. Calculated value of Cochran test: $Gcalc = 0.290$.

Table value of Cochran test: $Gtab = 0.478$.

That is, the condition (7) is fulfilled:

$$G_{calc} = 0.290 \leq G_{tab} = 0.478.$$

Subsequently, the coefficients significance of regression equation was determined by analyzing the results according to the experimental design (Table 5).

Table 5

The experimental results of study of the elasticity modulus in flexure of PCM 1

No. of exp.	Content of components, q, pts.wt.		Elasticity modulus in flexure, E, hPa			Average value, E, hPa
	x1	*x2*	1	2	3	
1	0.50	0.01	3.0	3.4	3.5	3.3
2	1.00	0.01	3.2	3.1	3.3	3.2
3	0.50	0.03	3.3	3.6	3.6	3.5
4	1.00	0.03	4.2	4.8	4.5	4.5
5	0.75	0.02	5.0	4.9	5.1	5.0
6	1.00	0.02	5.1	4.8	4.8	4.9
7	0.50	0.02	3.3	3.3	3.6	3.4
8	0.75	0.03	4.5	4.8	4.5	4.6
9	0.75	0.01	3.9	4.0	4.1	4.0

Then the dispersions of regression coefficients (Table 6) were determined by the formula

$$S_{b_i}^2 = \frac{S_0^2}{\sum_{u-1}^{N} x_{iu}^2}. \qquad (9)$$

The significance of the regression coefficients was determined by the Student's test [14, 15]. Here with the table (*tm*) and calculated criterion (*tcalc*) of Student's test (Table 6) were determined.

Table 6

Dispersion of coefficients of regression (S_b^2) and calculated values of Student's criterion (*tcalc*)

No. of exp.	Dispersion of of exp.coefficients of regression		Calculated values of Student's criterion	
	conditional designation	value	conditional designation	value
1	$S_{b_0}^2$	0.004	*t0*	72.88
2	$S_{b_1}^2$	0.006	*t1*	5.28
3	$S_{b_2}^2$	0.006	*t2*	4.62
4	$S_{b_{11}}^2$	0.017	*t11*	5.59
5	$S_{b_{22}}^2$	0.017	*t22*	4.45
6	$S_{b_{12}}^2$	0.009	*t12*	3.0

Depending on freeness: f = N (n - 1) = 9 (3 - 1) = 18 the Student's test value was calculated, which is $tT = 2.1$.

Calculated values of Student's test (*tcalc*) and coefficients significance were determined: *t0, t1, t2, t11, t22, t12* > *tT*.

Moreover:

$$t_i = \frac{|b_i|}{S_{b_i}}. \qquad (10)$$

Calculated values of Student's criterion *t0, t1, t2, t11, t22, t12* are larger than *tT*, so it was considered that all coefficients of the regression equation are significant. As a result of rejection of insignificant coefficients, the following regression equation was received:

$$y = 4.92 + 0.40x_1 + 0.35x_2 - 0.73x_1^2 - 0.58x_2^2 + 0.28x_1x_2.$$

The adequacy of the model was checked by Fisher test [16]:

$$F_{calc} = \frac{S_{u\max}^2}{S_y^2} \leq F_{(0.05;f_{0d};f_y)}, \qquad (11)$$

where $S_{umax}^2 = 0.09$ – calculated value of dispersion of adequacy (Table 4):

$$S_y^2 = \frac{\sum_{i=1}^{N} S_{ui}^2}{N}, \qquad (12)$$

$S2 = 0.034$ – mean square error;

So: $Fcalc = 2.65$.

$F_{(0.05;f_{0d};f_u)}$– table value of Fisher test in 5% significance level (*f1* = N - (k + 1) = 9 - (6 + 1) = 2, *f2* = N (n - 1) = 9 (3 - 1) = 18). So: $F(t) = 3.55$ [14, 15].

Calculated value of Fisher test is less than table one, so the requirement (10) is fulfilled. It is possible to assume that equation adequately characterizes the composition.

Interpretation process of received mathematical model, as a rule, is not just determination of factors influence. A simple comparison of absolute value of linear coefficients does not determine the relative degree factors influence, since there are also quadratic squared terms and paired interactions. In a detailed analysis of the received adequate model, it is necessary to take into account the fact that for a quadratic model the degree of factor influence on the change of output value is not constant.

Dependencies that connect normalized and natural values of the variables are as follows:

$$x_i = \frac{q_i - q_{i0}}{\Delta q_i}, \qquad (13)$$

where q_i – value of i experiment factor; q_{i0} – value of zero level; Δq_i – variation interval [14].

Substituting these values in accordance with the formula (13) into the regression equation and transforming it, we receive the following regression equation with the natural values of the variables:

$$E = 10.93 - 12.04q_1 - 573q_2 - 11.68q_1^2 - 5800q_2^2 + 1120q_1q_2.$$

Given equation in natural values allows only predicting the output value for any point in the middle of range of factor variations. However, with its help it is possible to construct graphs of dependence of output value (elasticity modulus in flexure of composites) from any factor (or two factors). Geometric interpretation of the response surface is shown on Figures 1–3.

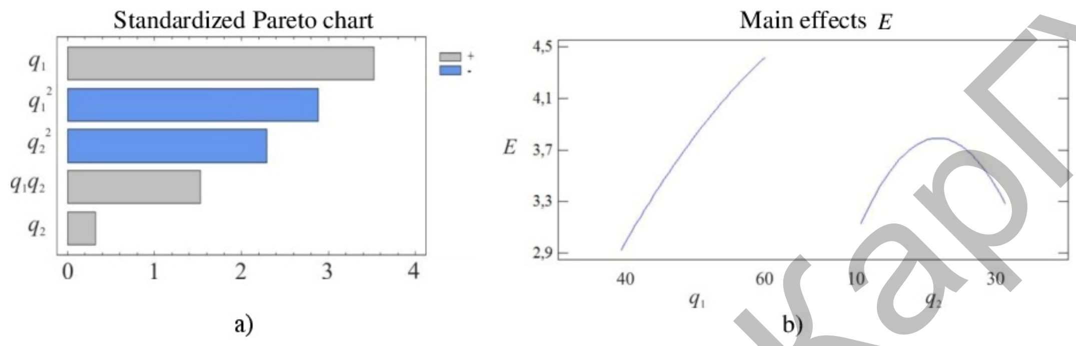

Figure 1. Standardized Pareto chart (a) and main effects (b)

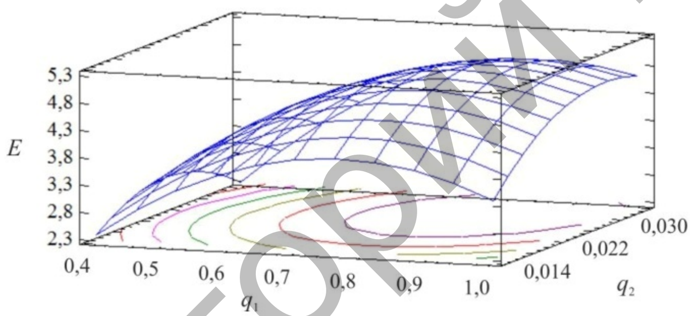

Figure 2. Estimated surface = f(q1,q2)

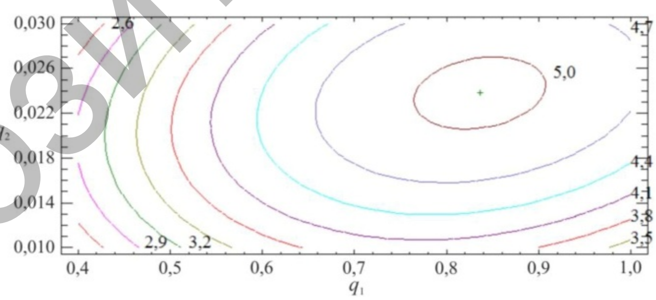

Figure 3. Contours of estimated response surface

Based on experimental studies it is set that both factors are significant. It should be noted that the effect of the additional filler content on the parameters of elasticity modulus in flexure is higher in comparison with the main one (according to Pareto chart). Analyzing the calculated response surface, it is determined that the optimum parameters of elasticity modulus in flexure have developed epoxy composite with two-component polydispersed filler with the following content of particles: MNDC 1 – 0.75. . . 1.0 pts.wt., MDF 1 – 0.2 pts.wt. (E = 4.8. . . 5.0 hPa).

On the second stage for optimization of the ingredients content in the material PCM 2 the impact resilience of the composites with different content of the main and additional fillers (MNDC 2 and MDF 2 in accordance) was studied. For standardization, as well as for simplification of calculations, each component (filler) is encoded by conditional units taking into account variations (Table 7).

Table 7

Levels of variables on conditional and natural scale for PCM 2

Components	Factor	Average level, q, pts.wt.	Variation step, Δq, pts.wt.	Values of variables (pts.wt.), that corresponding to conditional units		
				-1	0	+1
Main filler – MNDC 2	*x1*	1.00	0.25	0.75	1.00	1.25
Additional filler – MDF 2	*x2*	0.02	0.01	0.01	0.02	0.03

Similarly, to the above calculations scheme, the composition of the CM was optimized according to the values of the impact resilience. The encoding of natural components values and the experimental design scheme are chosen according to Table 2 and Table 7.

In the process of study results analysis of composites impact resilience, the following values of the regression coefficients were received (Table 8).

Table 8

The coefficients of regression equation

b0	*b1*	*b2*	*b11*	*b22*	*b12*
9.18	0.42	-0.22	-0.22	-0.12	-0.15

As a result, the following regression equation was found:

$$y = 9.18 + 0.42x_1 - 0.22x_2 - 0.22x_1^2 - 0.12x_2^2 - 0.15x_1x_2.$$

For statistical processing of experiment results, a test of experiments reproducibility was conducted according to the Cochran test [14].

Dispersions values that were calculated by formula (5-7) are shown in Table 9.

Table 9

Values of dispersions of adequacy (S_{ui}^2) and mean square error ($\sigma^2\{y\}_i$)

No. of exp.	The dispersions of adequacy		The mean square errors	
	conditional designation	value	conditional designation	value
1	S_{u1}^2	0.010	$\sigma^2\{y\}_1$	0.020
2	S_{u2}^2	0.010	$\sigma^2\{y\}_2$	0.020
3	S_{u3}^2	0.010	$\sigma^2\{y\}_3$	0.020
4	S_{u4}^2	0.030	$\sigma^2\{y\}_4$	0.060
5	S_{u5}^2	0.010	$\sigma^2\{y\}_5$	0.020
6	S_{u6}^2	0.040	$\sigma^2\{y\}_6$	0.080
7	S_{u7}^2	0.040	$\sigma^2\{y\}_7$	0.080
8	S_{u8}^2	0.010	$\sigma^2\{y\}_8$	0.020
9	S_{u9}^2	0.010	$\sigma^2\{y\}_9$	0.020

Moreover:

$$\sum_{i=1}^{N} S_{ui}^2 = 0.170;$$

$$\sigma^2\{y\} = S_0^2 = 0.019.$$

Calculated value of the Cochran test at the 5% significance level was determined by formula (8):

$$G_{calc} = \frac{0.040}{0.170} = 0.235.$$

Testing the experiment results by the Cochran test [9, 14, 15] for a fixed probability $\alpha = 0.05$ confirmed the experiments reproducibility. Dispersion characterizing dispersal of the experiments results in combination of few factor levels: $S_{u\max}^2 = 0.040$. Calculated value of Cochran test: $Gcalc = 0.235$.

Table value of Cochran test: $Gtab = 0.478$.

So, the requirement is fulfilled:

$$G_{calc} = 0.235 \leq G_{tab} = 0.478.$$

At the next stage, the coefficients significance of regression equation is determined, analyzing the results according to the experimental design (Table 10).

Table 10

The experimental results of study of the impact resilience of PCM 2

No. of exp.	Content of components, q, pts.wt.		Impact resilience, W', kJ/m2			Average value W', kJ/m2
	x1	*x2*	1	2	3	
1	0.75	0.01	8.9	8.8	8.7	8.8
2	1.25	0.01	10.3	10.1	10.2	10.2
3	0.75	0.03	8.1	8.3	8.2	8.2
4	1.25	0.03	8.9	9.2	8.9	9.0
5	1.00	0.02	10.0	10.1	9.9	10.0
6	1.25	0.02	8.9	8.5	8.7	8.7
7	0.75	0.02	8.2	8.6	8.4	8.4
8	1.00	0.03	8.8	9.0	8.9	8.9
9	1.00	0.01	8.3	8.5	8.4	8.4

Subsequently, dispersion of regression coefficients is determined by formulas (9-10). The significance of regression coefficients is determined according to Student's criterion, which Table value is $tT = 2.1$ [15, 16]. Calculated values of Student's criterion are shown in Table 11.

Table 11

Dispersion of coefficients of regression (S_b^2) and calculated values of Student's criterion (*tcalc*)

No. of exp.	Dispersion of coefficients of regression		Calculated values of Student's criterion	
	conditional designation	value	conditional designation	value
1	$S_{b_0}^2$	0.002	*t0*	198.05
2	$S_{b_1}^2$	0.003	*t1*	7.43
3	$S_{b_2}^2$	0.003	*t2*	3.86
4	$S_{b_{11}}^2$	0.009	*t11*	2.23
5	$S_{b_{22}}^2$	0.009	*t22*	1.20
6	$S_{b_{12}}^2$	0.005	*t12*	2.2

Calculated values of Student's criterion *t0, t1, t2, t11, t12* are larger than *tT*, so it is considered that coefficients *b0, b1, b2, b11, b12* of regression equation are significant. Calculated value *t22,* is smaller than *tT*, so coefficients *b22,* is insignificant. As a result, the following regression equation is received:

$$y = 9.18 + 0.42x_1 - 0.22x_2 - 0.22x_1^2 - 0.15x_1x_2.$$

The adequacy of the model was checked by Fisher's test [15, 16].

Calculated value of adequacy dispersion: $S_{u\,\max}^2 = 0.04$ (Table 9).

The mean square error: $S_y^2 = 0.019$.

So: $F_{calc} = 0.475$.

$F_{(0{,}05;f_W;f_u)}$– table value of Fisher's test in 5% significance level ($F(t) = 2.77$) [15, 16].

Calculated value of Fisher's test is smaller than table on, so requirement (11) is fulfilled. Consequently, the equation adequately shows the composition formula.

After transformations in accordance with formula (13), the following regression equation with the natural values of variables was received:

$$W' = 3.22 + 9.92q_1 + 38q_2 - 3.52q_1^2 - 60q_1q_2.$$

Geometric interpretation of response surface is shown on Figures 4–6.

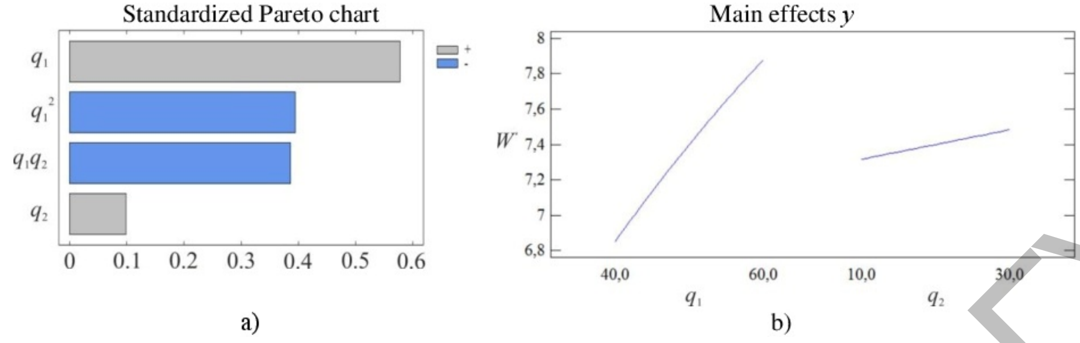

Figure 4. Standardized Pareto chart (a) and main effects (b)

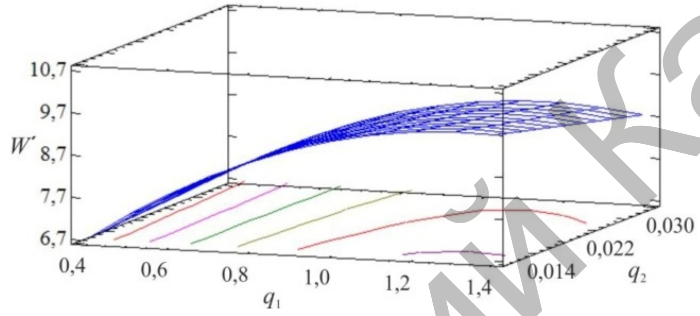

Figure 5. Estimated surface W'= f(q1,q2)

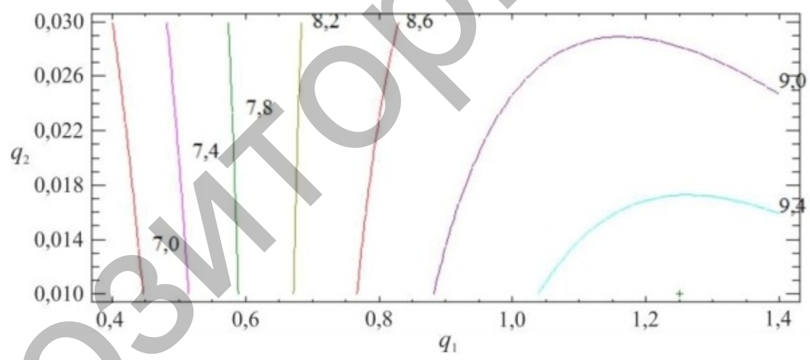

Figure 6. Contours of estimated response surface

Received results indicate that both factors of regression equation are significant. In the process of analysis, it was determined that the impact resilience values show maximum values for the fillers contents: MNDC 2 – 1.00. . . 1.25 pts.wt., MDF 2 – 0.1. . . 0.2 pts.wt. (W' = 10.0. . . 10.2 kJ/m2). With further increase the content of particles the decreasing of impact resilience was observed. Therefore, it is advisable to add two-component polydispersed filler with the aforementioned content into modified epoxy matrix to improve performance in the repair of marine transport elements.

Conclusions

The critical content of a two-component polydispersed filler is found by the method of mathematical planning of the experiment: a mixture of nanodispersed compounds 1 $(d = 20 \ldots 80\ nm) - -0.75 \ldots 1.0\ pts.wt.$, a mixture of discrete fibers 1 $(l = 0.5 \ldots 1.0\ mm, d = 18 \ldots 25\ \mu m) - -0.2\ pts.wt.bythe 100\ pts.wt.$ of the epoxy oligomer ED-20. An introduction of the two-component polydispersed filler to the epoxy binder allows significantly to increase the values of the elasticity modulus in flexure of the protective coatings to $= 4.8 \ldots 5.0\ hPa$.

It is proved that in order to create a composite material with improved impact resilience, it is necessary to introduce: a mixture of nanodispersed compounds 2 ($d = 30\ldots 40\ nm$) – $-1.00\ldots 1.25$ *pts.wt.*, a mixture of discrete fibers 2 ($l = 0.5\ldots 1.0\ mm, d = 18\ldots 25\ \mu m$) – $-0.1\ldots 0.2$ *pts.wt.* by the 100 pts.wt. of epoxy ED-20. At the same time, the values of impact resilience increase to the $W' = 10.0\ldots 10.2\ kJ/m2$. The obtained results allow us to create materials with improved indexes of the physical and mechanical properties in complex. These materials can be used in the form of protective coatings to improve the performance and repair of parts of transport equipment.

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А.В. Букетов, Н.В. Браило, Д.П. Стухляк, С.В. Якущенко, О.О. Сапронов, В.В. Чернявский, В.Н. Гусев, Д.А. Дмитриев, В.Н. Яцюк, О.М. Безбах, Р.Ю. Негруца

Автокөліктерді қалпына келтіру үшін полимерлік жабындардың дамуындағы компоненттерді оңтайландыру

Автокөлік құралдарының бөліктерінің, соның ішінде олардың коррозияға қарсы қасиеттерін және тозуға төзімділігін жақсарту үшін, қорғаныш полимерлі композитті жабындарды пайдалану ұсынылады. Эпоксидті байланыстырушы физика-механикалық және жылулық қасиеттерін жақсарту үшін қоспаларды: модификаторларды, пластификаторларды, дисперсті және талшықты толтырғыштарды енгізу қажет. Эпоксидті байланыстырғышқа дисперсті қоспаларды енгізу өзекті болып табылады және кешенде әртүрлі дисперсті толтырғыштарды қолдануға тиімді. Екікомпонентті полидисперсті толтырғыштың дамыған эпоксидті композиттің иілу кезінде серпімді модульге әсері талданды. Екікомпонентті полидисперстік толтырғыштың сыни мазмұны эксперименттің математикалық жоспарлау әдісімен анықталды: нанодисперсті қосылыстардың қоспасы 1 (d = 20 ... 80 нм) - 0,75 ... 1,0 масс. Бөлшектер, дискреттік талшықтардың қоспасы 1 (л = 0,5 ... 1,0 мм, д = 18 ... 25 мкм) - 0,2 вт.ч. 100 вт.ч. эпоксидті олигомер ED-20. Екікомпонентті полидисперсті толтырғыштың эпоксидті байланыстырушы құралына кіріспе E = 4.9 ... 5.0 ГПа дейін қорғаныш қабаттардың иілгіш модулін едәуір арттыра алады. Бұдан басқа, екікомпонентті полидисперсті толтырғыштың дамыған эпоксидтік композиттің соңғыға төзімділігіне әсері белгіленді. Екікомпонентті полидисперсті толтырғыштың сыни мазмұны: нанодисперсті қосылыстардың қоспасы 2 (d = 30 ... 40 нм) - 1,0 ... 1,25 массалық бөлшектер, дискреттік талшықтардың қоспасы 2 (л = 0,5). .. 1.0 мм, d = 18 ... 25 мкм) - 0,1 ... 0,2 масс. б. 100 масс. б. эпоксидті олигомер ED-20. Екікомпонентті полидисперсті толтырғышты эпоксидті байланыстырғышқа енгізу W = 10,0 ... 10,2 кДж / м^2 дейін әсер ету күшін айтарлықтай арттыра алады. Алынған нәтижелер күрделі физика-механикалық қасиеттері бар полимерлі жабынды жасауға мүмкіндік береді.

Кілт сөздер: композит, эпоксидті матрица, екікомпонентті полидисперстік толтырғыш, экспериментті математикалық жоспарлау әдісі, регрессия теңдеуі.

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В.В. Чернявский, В.Н. Гусев, Д.А. Дмитриев, В.Н. Яцюк, О.М. Безбах, Р.Ю. Негруца

Оптимизация компонентов при разработке полимерных покрытий для восстановления средств транспорта

Обосновано, что для повышения эксплуатационных характеристик деталей транспортных средств, в том числе их антикоррозийных свойств и износостойкости, целесообразно использовать защитные полимерные композитные покрытия. Показано, что для повышения показателей физико-механических и теплофизических свойств в эпоксидное связующее необходимо вводить добавки: модификаторы, пластификаторы, дисперсные и волокнистые наполнители. Актуальным является введение в эпоксидное связующее дисперсных добавок, причем эффективно использовать наполнители различной дисперсности в комплексе. Проанализировано влияние двухкомпонентного полидисперсного наполнителя на модуль упругости при изгибе разработанного эпоксидного композита. Методом математического планирования эксперимента установлено критическое содержание двухкомпонентного полидисперсного наполнителя: смесь нанодисперсных соединений 1 (d = 20 ... 80 нм) – 0,75 ... 1,0 масс.ч., смесь дискретных волокон 1 (l = 0,5 ... 1,0 мм, d = 18 ... 25 мкм) – 0,2 масс.ч. на 100 масс.ч. эпоксидного олигомера ЭД-20. Введение в эпоксидное связующее двухкомпонентного полидисперсного наполнителя позволяет значительно повысить показатели модуля упругости при изгибе защитных покрытий до E = 4,9 ... 5,0 ГПа. Дополнительно установлено влияние двухкомпонентного полидисперсного наполнителя на ударную вязкость разработанного эпоксидного композита. Доказано, что критическое содержание двухкомпонентного полидисперсного наполнителя: смесь нанодисперсных соединений 2 (d = 30 ... 40 нм) – 1,0 ... 1,25 масс.ч., смесь дискретных волокон 2 (l = 0,5 ... 1,0 мм, d = 18 ... 25 мкм) – 0,1 ... 0,2 масс.ч. на 100 масс.ч. эпоксидного олигомера ЭД -20. Введение в эпоксидное связующее двухкомпонентного полидисперсного наполнителя ведет к значительному повышению показателей ударной вязкости до W = 10,0 ... 10,2 кДж/м^2. Полученные результаты позволяют создать полимерное покрытие с улучшенными в комплексе показателями физико-механических свойств.

Ключевые слова: композит, эпоксидная матрица, двухкомпонентный полидисперсный наполнитель, метод математического планирования эксперимента, уравнение регрессии.

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