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Influence of reinforcement parameters on the properties of fibropenotoof concrete

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Abstract. The influence of the parameters of dispersed reinforcement on the properties of fibro-foam concrete analyzed. The experiment planning matrix was built. A series of samples of various compositions made of fibro-foam concrete were tested for compression and bending. The regression equations obtained in coded form, which are adequate to the calculated ones, based on the Fisher criterion. The analysis of the equations carried out and the response surfaces constructed from them, which showed that the highest values of the optimization parameters correspond to the design area with high μ_v and low l/d. It has been established that the introduction of a sufficient amount of short fibers into the foam concrete matrix leads to the strengthening of the material, which is provided not only by the reinforcing properties of the fibers, but also by their ability to positively influence the structure of aerated concrete.

1 Introduction

To study the influence of the parameters of dispersed reinforcement on the properties of fibro-foam concrete, a composite rotatable plan of the second order of the type of a regular hexagon was used [1-3].

The geometric interpretation of such a plan, which belongs to the class of simplex-summable, shown in Figure 1.

The main parameters of dispersed reinforcement taken as the factors under study:

- X1 - percentage of reinforcement by volume μv;
- X2 - the ratio of the length of the fibers to their diameter l / d (varied by changing the length of the fibers l).

The following considered as optimization parameters:

- Y1 - ultimate compressive strength R, MPa;
- Y2 - ultimate tensile strength in bending Rtf, MPa.

As Figure 1 shows, the design requires five levels for factor X1 and three levels of variable variation for factor X2.

To obtain the response function Y = f (X1; X2) described by a second-order polynomial

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$$Y = b_o + \sum_{i=1}^{n} b_i X_i + \sum_{i \neq j}^{n} b_{ij} X_i X_j + \sum_{i=1}^{n} b_{ii} X_i^2 \tag{1}$$

it is necessary to place the experience at seven points of the plan.

2 Materials and methods

When compiling the experiment matrix, proceed from the following (see Figure 1). Let experiment No. 1 be spaced from the center of the plan at a distance equal to 1.

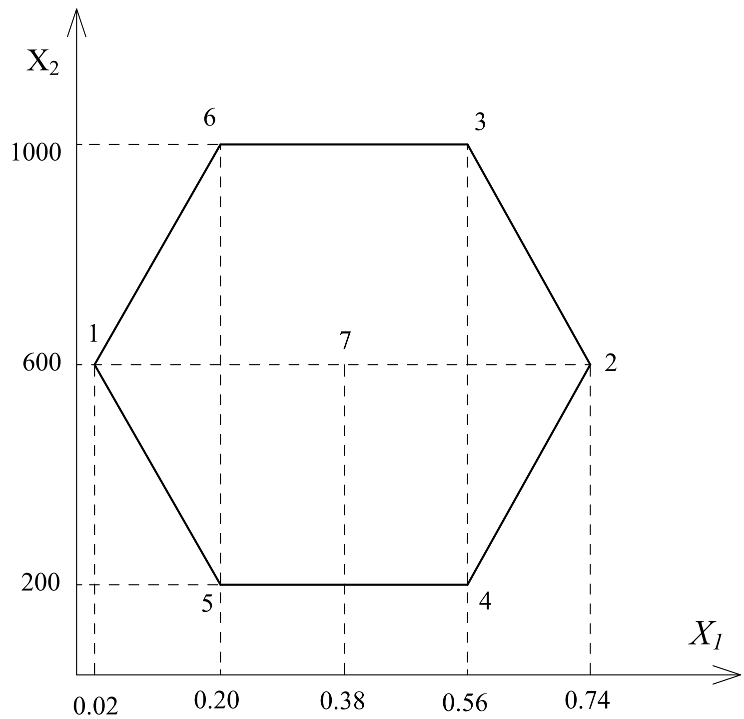

Fig. 1. Experiment design.

Then, based on the properties of the hexagon, the corresponding levels of the coded variables will be:

for X1 - (-1; -0.5; 0; +0.5; +1); for X2 - (-0.87; 0; -0.87).

The planning matrix constructed in this way shown in Table 1. The values of these values obtained as result of preliminary calculations and experiments taken as the main levels for the factors.

Table 1. Experiment Matrix.

Natural variables		**Experiment Matrix**				
1	2	3	4	5	6	7
x_1	x_2	X_1	X_2	X_1^2	X_2^2	$X_1 \cdot X_2$
0.02	600	-1	0	+1	0	0
0.74	600	+1	0	-1	0	0
0.56	1000	+0.5	+0.87	+0.25	+0.75	+0.43
0.56	200	+0.5	-0.87	+0.25	+0.75	-0.43
0.20	1000	-0.5	+0.87	+0.25	+0.75	-0.43
0.20	200	-0.5	-0.87	+0.25	+0.75	+0.43
0.38	600	0	0	0	0	0

In accordance with the plan, 7 series of samples of various compositions were made from fibro-foam concrete.

The test results shown in Tables 2 and 3.

Table 2. Compression test results for specimens.

No	**Values of parallel measurements of the response function Y_1, MPa**						**Average value Y_1, MPa**	**Dispersion S_j^2**	**Coefficient of variation, %**
	y_1	y_2	y_3	y_4	y_5	y_6			
1	1.45	1.46	1.25	1.10	1.16	1.44	1.31	0.0258	0.020
2	0.63	0.78	1.02	0.83	0.90	0.67	0.81	0.0211	0.026
3	0.66	0.82	0.50	0.50	0.62	0,52	0.60	0.0176	0.029
4	1.16	1.64	1.22	1.82	1.36	1.78	1.50	0.0856	0.057
5	1.28	1.58	1.58	1.06	1.40	1.14	1.34	0.0480	0.035
6	1.72	1.57	1.16	1.12	1.59	1.22	1.39	0.0672	0.048
7	1.70	1.58	1.30	1.42	1.02	1.16	1.36	0.0652	0.048

Table 3. Bend sample test results.

No	**Values of parallel measurements of the response function Y_2, MPa**						**Average value Y_2, MPa**	**Dispersion S_j^2**	**Coefficient of variation, %**
	y_1	y_2	y_3	y_4	y_5	y_6			
1	2	3	4	5	6	7	8	9	10
1	0.41	0.46	0.39	0.42	0.48	0.41	0.43	0.0014	0.003
2	0.82	0.76	0.57	0.48	0.71	0.50	0.64	0.0204	0.032
3	0.58	0.64	0.71	0.72	0.59	0.61	0.64	0.0037	0.006
4	0.70	0.75	1.02	0.89	1.00	0.79	0.86	0.0177	0.021
5	0.60	0.88	0.91	0.70	0.61	0.68	0.73	0.0179	0.025
6	0.37	0.41	0.50	0.44	0.45	0.40	0.43	0.0021	0.005
7	0.68	0.82	0.79	0.53	0.56	0.77	0.69	0.0152	0.022

The average performance values of the response calculated by formula

$$\overline{Y}_j = \frac{1}{k} \sum_{i=1}^{k} y_{ji} \tag{2}$$

Where j - is the number of the series of experiments (j =1.2,...,7); i - Experience number in the series (i =1,2,...,6); k - the number of parallel experiences in the series (k = 6).

3 Results

Statistical processing of the data carried out according to the method. The results of the analysis presented in Table 4.

Table 4. Statistical analysis of test results.

No	Optimization option	Variance of reproducibility of experiments S_y^2	Mid-value variance $S_{\bar{y}}^2$	The value of the Kohren criterion	
				Estimated G_p	Table G_T
1	Temporary resistance to compression R	0.0472	0.0079	0.259	0.397
2	Temporary stretching resistance when bending R_{tf}	0.0111	0.0018	0.263	0.397

The table shows that the estimated value of the Kohren criterion (G_P) for all optimization parameters is smaller than table (G_m), hence the experiments are reproducible.

The calculation of regression rates reduced to tables 5 and 6.

Table 5. Compression Matrix.

No	Estimated matrix					
	X_0	X_1	X_2	X_1^2	X_2^2	$X_1 \cdot X_2$
1	1.31	-1.31	0	1.31	0	0
2	0.81	0.81	0	0.81	0	0
3	0.60	0.30	0.52	0.15	0.45	0.26
4	1.50	0.75	-1.31	0.38	1.13	-0.65
5	1.34	-0.67	1.17	0.37	1.01	-0.58
6	1.39	-0.70	-1.21	0.35	1.04	0.60
7	1.36	0	0	0	0	0
	(0y)	(1y)	(2y)	(11y)	(22y)	(12y)
	8.31	-0.82	-0.83	3.37	3.63	-0.37
$\Sigma(iiy) = 7{,}00$						
Coefficient of regression	b_0	b_1	b_2	b_{11}	b_{22}	b_{12}
	1.31	-0.27	-0.28	-0.23	-0.06	-0.49

Table 6. Calculating curve matrix.

No	Estimated matrix					
	X_0	X_1	X_2	X_1^2	X_2^2	$X_1 \cdot X_2$
1	0.43	-0.43	0	0.43	0	0
2	0.64	0.64	0	0.64	0	0
3	0.64	0.32	0.56	0.16	0.48	0.28
4	0.86	0.43	-0.75	0.22	0.65	-0.37
5	0.73	-0.37	0.63	0.18	0.55	-0.31
6	0.43	-0.22	-0.37	0.11	0.32	0.18
7	0.69	0	0	0	0	0
	(0*y*)	(1*y*)	(2*y*)	(11*y*)	(22*y*)	(12*y*)
	4.42	0.37	0.07	1.74	2.00	-0.22
$\Sigma(iiy) = 3{,}74$						
Coefficient of regression	b_0	b_1	b_2	b_{11}	b_{22}	b_{12}
	0.68	0.12	0.02	-0.14	0.03	-0.29

Formulas used to calculate:

$$
\begin{aligned}
&b_o = \tfrac{1}{4}\left[(0y) - \Sigma(iiy)\right];\\
&b_i = \tfrac{1}{3}(iy);\\
&b_{ii} = \tfrac{2}{3}(iiy) + \tfrac{1}{12}\Sigma(iiy) - \tfrac{1}{4}(0y);\\
&b_{ij} = \tfrac{4}{3}(ijy);
\end{aligned}
\qquad (3)
$$

where j - is the experience number, I - is the factor number.

To assess the significance of regression ratios, their variance was calculated according to the formula $S_b = \sqrt{S_y^2 / N}$ and multiplied by the Student t=2.03 criterion with degrees of freedom $f=N\cdot(k\text{-}1)=7\cdot(6\text{-}1)=35$ and the level of significance $|b| \le S_b\cdot t$, the coefficient was taken in insignificantly (b=0).

After checking the significance of all the regression ratios, the coded regression ratios look like this:

$$
\begin{aligned}
&Y_1 = 1.31 - 0.27X_1 - 0.28X_2 - 0.23X_1^2 - 0.49X_1X_2;\\
&Y_2 = 0.68 + 0.12X_1 - 0.14X_1^2 - 0.29X_1X_2.
\end{aligned}
\qquad (4)
$$

4 Discussion

To prove the adequacy of the models presented, a statistical analysis was carried out on the methodology of the [3, 4], the results of which are presented in Table 7.

Table 7. Testing the model adequacy hypothesis.

Optimization options	Continuity of adequacy S_{ad}^2	Fisher's Criterion Value	
		Estimated F_p	Table F_m
Temporary resistance to axial compression Y_1	0.0016	1.25	19.47
Temporary stretching resistance when bending Y_2	0.0021	1.17	2.85

All equations are adequate, as the calculated values of the Fisher criterion do not exceed the table values.

Analysis of equations (4) and the response surfaces built on them $R=f\cdot(\mu;\ l/d)$ и $Rtf=f\cdot(\mu;\ l/d)$ (Figure 2) showed that the highest optimization values correspond to a high-plan area μ_v and low l/d, which contradicts the equation of the rules of mixtures [2, 5].

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$$R_{fb} = 2\tau_c \frac{l}{d}\mu_v + (100 - \mu)R_b \tag{5}$$

where R_{fb} - the strength of cell fibrobeton, MPa;
τ_c - the strength of the grip between the fiber and the mesh concrete, MPa;
d - fiber diameter, mm;
l - fiber length, mm;
μ_v - Percentage of reinforcement by volume, %;
R_b - strength of the original mesh concrete, MPa.

According to the equation (5), reducing the ratio of the length of fibers to their diameter should lead to a decrease in the strength of the material. This contradiction can explained as follows. Dispersed fibers not only reinforce the matrix, but also significantly change the indicators of its structure, in particular, porosity indicators (homogeneity of the distribution of pores by diameter, average pore size), which in turn affects the strength characteristics of the material [1-3]. When a sufficient number of short fibers (4 mm) inserted into the matrix, fibre reinforcement, acquiring a discrete chaotic character, forms the structure of the material more homogeneous, evenly distributed in volume segments of fibers and pores, approximately equal diameter, which also leads to an increase in the strength of concrete.

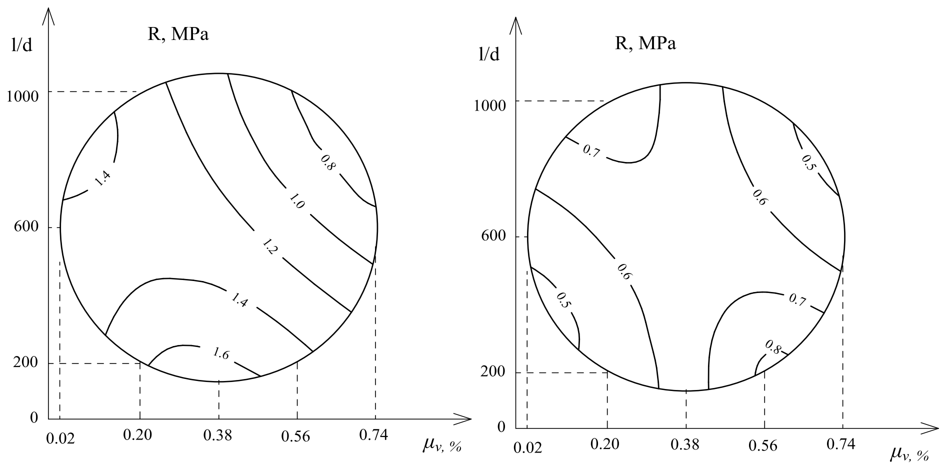

Fig. 2. The response surfaces.

Here: R - Temporary Resistance to Compression, MPa; R_{tf} - temporary stretching resistance when bending, MPa; l/d - the ratio of the length of fibers to their diameter; μ_v - the percentage of reinforcement by volume.

These assumptions supported by the results of an experiment that examined the impact of the parameters of reinforcement of μ_v and l/d on the porosity of the fibrofoamtautconcrete. The parameters of porosity (the homogeneity of the distribution of pores by the diameter of α, the average size of the pores λ) investigated according to the method described in the [2-4]. This technique is a study of the kinetics of water absorption, and used for heavy concrete in the definition of capillary porosity and was first used in cell concrete. Here are the advantages of the method. It qualitatively identifies and quantifies a large range of the size of the pores and capillaries of concrete, actively affecting its properties, is sensitive to changes in the parameters of the porosity of concrete and gives reliable, well-reproducible results.

The calculation of the parameters of α and λ was made according to the formulas:

$$\alpha = \frac{\ln\left[\frac{\ln\left(1-W_1/W_{24}\right)}{\ln\left(1-W_{0,25}/W_{24}\right)}\right]}{\ln\left(1/0,25\right)}; \quad (6)$$

$$\lambda = \alpha\sqrt{\ln\left(\frac{W_{24}}{W_{24}-W_1}\right)}; \quad (7)$$

where $W_{0.25}$, W_1, W_{24} - water-absorbing samples through 0,25 respectively; 1 and 24 hours after immersing them in the water.

The results of the experiment summarized in table 8 show the following.

Table 8. Effect of reinforcement parameters on the porosity of fibrofoamtautconcrete.

Porosity indicators	**Reinforcement percentage μ_v, %**	**The ratio of fiber length to their diameter *l/d***		
		150	**200**	**1000**
α	0.20	0.150	0.177	0.260
	0.56	0.161	0.319	0.280
λ	0.20	0.120	0.141	0.107
	0.56	0.212	0.174	0.208

Indeed, when l/d is reduced from 1000 to 200 at μ_v=0,56% and the increase in μ_v from 0.20% to 0.56% with l/d =200 there is an increase in the indicator α – homogeneous distribution of pores by diameter. It also noted that as the number of fibers introduced, the average pore size increases (index λ). The reason for this is the "consumption" of cement test for enveloping fibers due to the layer that forms the contact zones of cell pores, because of which they are enlarged. With low saturation percentages (μ_v=0.20%) decrease in l/d leads to an increase in the average size of pores, due to a decrease in the number of contacts (contacts) between fibers and reduced ability to dispers large pores. With high saturation rates (μ_v=0.56%) reducing the length does not result in loss of contact between the fibers, as the mixture is saturated enough with them, and there is a decrease in the size of the pores, which also increases the homogeneity of the material and, therefore, its durability.

It can concluded that the introduction of sufficient short fibers into the foam-phobic matrix leads to the hardening of the material, which is not provided only by the reinforcement properties of fibers, but also their ability to positively influence the structure of mesh concrete.

5 Conclusions

1. Introduction of lime and plaster in the composition of astringent additives has a positive effect on the strength characteristics of penotuphobeton in steaming conditions, but when hardening in normal conditions, the composition of penotophobic in place without additives, which reduce the water resistance of the material, which limits its scope.
2. The effect of the filler's grain composition on the properties of foam concrete is ambiguous: while the increase in the content of dust particles in the filler increases temporary resistance

to compression, the presence of medium and large filler grains have a positive effect on temporary stretching resistance when bending and cracking.
3. Dispersal reinforcement has a positive effect on the strength characteristics, as well as on the structure (character of porosity) of the original foamtufoconcrete.
4. With the percentage of reinforcement of μ_v=0.56% in volume and reduced respect of l/d=200 (l=4 mm) there is an increase in the strength characteristics of fibropenotuphobeton, that is associated not only with the reinforcement properties of fibers, but also with their ability to positively influence the character of porosity (increasing homogeneity of porosity, reduction of the average diameter of pores).

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