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THE INFLUENCE OF THE AMOUNT OF POLYPROPYLENE FIBER AND SUPERPLASTICIZER ON THE STRENGTH OF CONCRETES FOR RIGID ROAD SURFACES AND TRANSPORT STRUCTURES

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Abstract. The article presents an analysis of the influence of the amount of polypropylene fiber, cement and polycarboxylate-type superplasticizer on the strength characteristics of concrete for rigid road surfaces and transport structures. Portland cement PC II/A-Sh-500R-N, polypropylene fiber Baumesh with a fiber length of 36 mm and a diameter of 0.68 mm, and polycarboxylate-type superplasticizer MC-PowerFlow 3200 were used.

A 3-factor experiment was conducted in which the following composition factors were varied: the amount of Portland cement, 300 to 380 kg/m^3; the amount of polypropylene fiber Baumesh, 2.5 to 3.5 kg/m^3; the amount of superplasticizer, 1.0 to 1.6% of the cement mass. The compressive strength of fiber-reinforced concretes was determined at the age of 3 and 28 days, and the tensile strength at the age of 28 days. All studied concrete mixtures had equal mobility class P2.

The influence of varied factors on the W/C ratio of mixtures was assessed. The amount of Portland cement has the greatest influence on this indicator. Increasing the dosage of superplasticizer from 1.0% to 1.6% allows reducing the W/C ratio by 8-24%. The amount of polypropylene fiber has a limited effect on the W/C ratio.

The amount of Portland cement has the greatest influence on the compressive strength of the studied fiber-reinforced concretes. When the dosage of binder is increased from 300 kg/m^3 to 380 kg/m^3, the strength of fiber-reinforced concretes at the age of 3 increases by 74-80%, the strength at the project age increases by 38-47%. Increasing the amount of superplasticizer provides an increase in compressive strength at an early age by 10-12%, at a project age by 12-14%. Increasing the amount of reinforcing fibers from 2.5 to 3.5 kg/m^3 at a high content in the mixture of binder and plasticizer does not significantly affect. By increasing the amount of fiber at a low amount of cement and superplasticizer, the early and project compressive strength of fiber-reinforced concretes increases insignificantly.

By increasing the dosage of the binder to 380 kg/m^3, the tensile strength of fiber-reinforced concretes increases by 9-12%. A similar increase in tensile strength at bending is achieved by increasing the dosage of the superplasticizer from 1.0 to 1.6%. The nature of the influence of polypropylene fiber on this strength indicator is nonlinear. An increase in strength by 9-12% is observed with an increase in fiber dosage from 2.5 kg/m^3 to 3.0 kg/m^3 both at high and low amount of binder and superplasticizer. It has been established that in general, from the point of view of achieving the highest compressive and tensile strength when bending, it is rational to introduce Baumesh polypropylene fiber in an amount of about 3.0 kg/m^3 and MC-PowerFlow 3200 additive in an amount of 1.5-1.6% of the cement mass.

Keywords: road surface, polypropylene fiber, superplasticizer, strength, planned experiment.

Introduction. Disperse reinforcement is a well-known method that allows to improve the properties important for concrete road surfaces and transport structures. Due to the use of fiber, it is possible to reduce the thickness of road surfaces without losing their bearing capacity and increase the service life. The use of disperse reinforcement allows to improve the tensile strength, frost resistance and wear resistance of concrete, which has a positive effect on the durability of road surfaces and transport structures [1-3].

The crack resistance characteristics of dispersed reinforced concrete (fiber concrete) are significantly different from conventional concrete. Dispersed reinforcement helps to reduce the risk of cracking [4-8], which is one of the main causes of the failure of concrete structures. The fibers are distributed in the volume of concrete, which holds individual structural blocks together and prevents the expansion of cracks. Cracks occur at the maximum load level, they have a homogeneous distribution in the matrix structure and develop with a smaller opening compared to regular concrete [9]. This shows the effectiveness of the use of dispersed reinforcement in road pavement and transport structures and the relevance of research aimed at the development of fiber concretes for the transport industry.

Analysis of recent research and publications. As shown in [10-12], dispersed reinforcement provides a reduction in shrinkage that occurs during the hardening process of concrete. This is especially important for large areas where significant cracks can occur, for example, hard coatings. According to the results of research [13], the relative deformation index of the studied samples of concretes dispersed reinforced with polypropylene fiber in comparison with concrete without fiber is reduced by 26%. In addition, the stabilization of shrinkage deformation of concrete with dispersed reinforcement is reduced to 22 days, and for unreinforced concrete this process lasts 32 days.

Disperse reinforcement provides increased resistance of fiber concrete to aggressive environments, such as salt solutions, moisture, low temperatures. Basalt and polypropylene fibers are chemically inert, so dispersion-reinforced concrete with this composition is used in construction where high corrosion resistance is required [13-16].

The use of reinforcing fibers increases the tensile strength and impact toughness of concrete, making it more resistant to mechanical loads, improves the workability of the concrete mixture, which allows achieving better density and uniformity in the material. Depending on the type of dispersed reinforcement, the compressive strength indicators increase by an average of 12% compared to concrete without fibers, and the tensile strength indicators increase by 35% [10, 17].

When constructing rigid road surfaces, steel, polypropylene, basalt and glass fibers are most actively used for dispersed reinforcement of concrete today [1, 3, 5, 13, 18-21]. Thus, in the studies of L. Y. Dvorkin [22] on the assessment of the influence of basalt fiber on the strength characteristics of concrete, an increase in the tensile strength of concrete by 55% and an increase in compressive strength by 16% were recorded. In the work [23] using polypropylene fiber, a slight increase in the compressive strength of concrete was noted, and the tensile strength during bending with the introduction of 1 kg/m^3 of polypropylene fiber increased by 40%.

Previous experimental studies of the properties of fiber-reinforced concrete [24, 25] have shown that the use of dispersed reinforcement with polypropylene fiber allows to increase the tensile strength of concrete in bending and the corrosion resistance of concrete in fact no less than the use of steel fiber. At the same time, from an economic point of view, the use of polypropylene fiber is much more expedient.

However, in previous experimental studies, the issue of changing the efficiency of fiber use when varying the amount of cement and superplasticizer was not studied. This is important considering that the work of dispersed reinforcement in the structure of the composite material significantly depends on its adhesion to the cement-sand matrix [26].

The objective of this study is to determine the effect of the amount of polypropylene fiber and polycarboxylate-type superplasticizer on the strength of concrete for hard road surfaces and transport structures.

Materials and Methods. The following materials were used for manufacturing fiber concrete:

– Portland cement PC II/A-Sh-500R-N produced by YuGcement (branch of PJSC Dykerhoff Cement Ukraine);

– Baumesh polypropylene fiber manufactured by LLC "BAUTEKH-UKRAINE" with a fiber length of 36 mm and a diameter of 0.68 mm;

– polycarboxylate type superplasticizer MC-PowerFlow 3200 manufactured by MC-Bauchemie Müller GmbH & Co. KG (Germany);

– granite crushed stone of fraction 5-20 mm;

– washed quartz sand with a particle size modulus of 2.5.

The experiment was conducted according to the optimal 3-factor 15-point plan [27]. The following factors of the composition of fiber-reinforced concrete for hard road surfaces and transport structures were varied:

– X_1, amount of Portland cement, 300 to 380 kg/m^3;

– X_2, amount of Baumesh polypropylene fiber, 2.5 to 3.5 kg/m^3;

– X_3, amount of superplasticizer MC-PowerFlow 3200, 1.0 to 1.6% of the cement mass.

This choice of variable factors and the range of their variation was due to the results of previous experimental studies of the properties of fiber-reinforced concretes [24, 25].

To determine the compressive strength of concrete, cube specimens measuring 10×10×10 cm were tested according to [28], and to determine the tensile strength during bending, beam specimens measuring 10×10×40 cm were tested.

The plan of the implemented 3-factor experiment and the compositions of the studied fiber-reinforced concretes are given in Table 1.

Table 1 – Experimental plan and compositions of the investigated fiber-reinforced concretes

Composition No.	Factor levels			Concrete composition, kg/m^3					
	X_1 Portland cement	X_2 Baumesh fiber	X_3 additive MC-PowerFlow 3200	Portland cement	Crushed stone	Sand	Fiber X Mesh	additive MC-PowerFlow 3200	Water
1	-1	-1	-1	300	1115	895	2.5	3	150
2	-1	-1	1	300	1115	910	2.5	4.8	125
3	-1	0	0	300	1115	905	3.0	3.9	137
4	-1	1	-1	300	1115	890	3.5	3	154
5	-1	1	1	300	1115	905	3.5	4.8	134
6	0	-1	0	340	1110	850	2.5	4.42	138
7	0	0	-1	340	1110	840	3	3.40	148
8	0	0	0	340	1110	848	3	4.42	137
9	0	0	1	340	1110	856	3	5.44	132
10	0	1	0	340	1110	847	3.5	4.42	138
11	1	-1	-1	380	1105	809	2.5	3.8	147
12	1	-1	1	380	1105	820	2.5	6.08	138
13	1	0	0	380	1105	814	3	4.94	142
14	1	1	-1	380	1105	808	3.5	3.8	148
15	1	1	1	380	1105	818	3.5	6.08	139

Results of the Study. During the experimental studies, data were obtained on the compressive strength at the age of 3 and 28 days, the tensile strength at the age of 28 days of fiber-reinforced concrete samples for hard road surfaces and transport structures, as well as W/C mixtures of equal mobility, which are given in Table 2.

Table 2 – Compressive strength at the age of 3 and 28 days (MPa), tensile strength in bending at the age of 28 days (MPa) and W/C of the mixtures of the tested fiber-reinforced concretes

Composition No.	Compressive strength at the age of 3 days $f_{ck.cube3}$	Compressive strength at the age of 28 days $f_{ck.cube28}$	Tensile strength when bending f_{ctk}	W/C
1	20.43	43.13	6.00	0.500
2	30.77	54.33	6.00	0.417
3	27.71	58.67	6.10	0.457
4	30.24	50.87	5.50	0.513
5	32.30	44.00	6.20	0.447
6	30.77	61.67	5.40	0.406
7	36.58	58.13	5.40	0.435
8	42.91	66.73	7.22	0.403
9	43.28	66.33	7.60	0.388
10	41.48	65.73	6.55	0.406
11	49.40	71.47	6.60	0.384
12	45.43	71.53	8.00	0.363
13	42.40	62.13	6.50	0.374
14	41.53	66.00	6.45	0.389
15	46.60	66.80	6.35	0.366

Since all the studied concrete mixtures had the same mobility class P2, their water consumption and W/C ratio depended on the composition of the fiber concrete. According to the data obtained at 15 experimental points, an experimental-statistical (ES) model [27] of the influence of composition factors on the W/C of the mixture was constructed:

$$\begin{aligned} W/C = \; 0.405 \; & - 0.046x_1 + 0.010x_1^2 - 0.004x_1x_2 + 0.013x_1x_3 \\ & + 0.005x_2 \pm 0x_2^2 + 0.002x_2x_3 \\ & - 0.024x_3 + 0.006x_3^2 \end{aligned} \qquad (1)$$

According to this EC model, single-factor diagrams were constructed, reflecting the influence of 3 varied composition factors on the W/C index of mixtures in the zones of extremes (the largest and smallest values of the index), shown in Fig. 1.

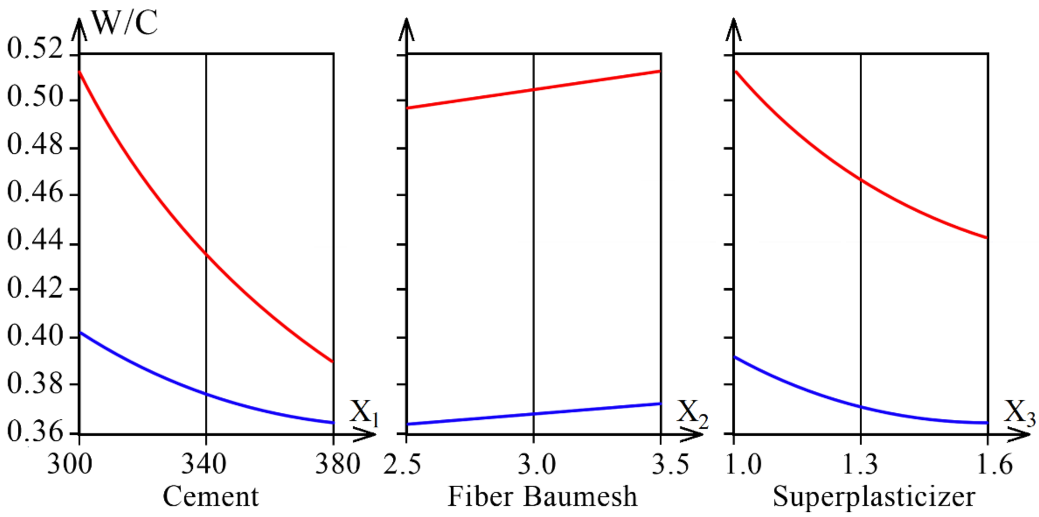

Fig. 1. Influence of varied composition factors on W/C mixtures of equal mobility in the zones of minimum and maximum values

Their analysis shows that within the factor space of this series of experiments, the amount of Portland cement has the greatest influence on the level of the W/C index of equal mobility mixtures. The content of the superplasticizer additive, due to its water-reducing principle of action, exhibits a similar effect in terms of the scale of the W/C reduction in the minimum zone, and in the maximum zone, when the dosage is increased from 1.0% to 1.6%, it reduces the W/C from 0.51 to 0.44. The amount of polypropylene fiber has a limited influence on the W/C index.

Early strength is important for concretes of hard road surfaces and transport structures. This indicator largely determines the shrinkage of concrete and the possibility of carrying out subsequent technological operations [3]. The influence of varied composition factors on the early compressive strength of fiber-reinforced concrete at the age of 3 days is described by the EC model (2), according to which single-factor dependences of the influence of factors in the zone of extrema are constructed (Fig. 2).

$$f_{ck.cube3}\,(\text{MPa}) = 39.00 + 8.69x_1 - 2.03x_1^2 - 2.94x_1x_2 \pm 0x_1x_3 \pm 0x_2 \pm 0x_2^2 \pm 0x_2x_3 + 2.31x_3 \pm 0x_3^2 \quad (2)$$

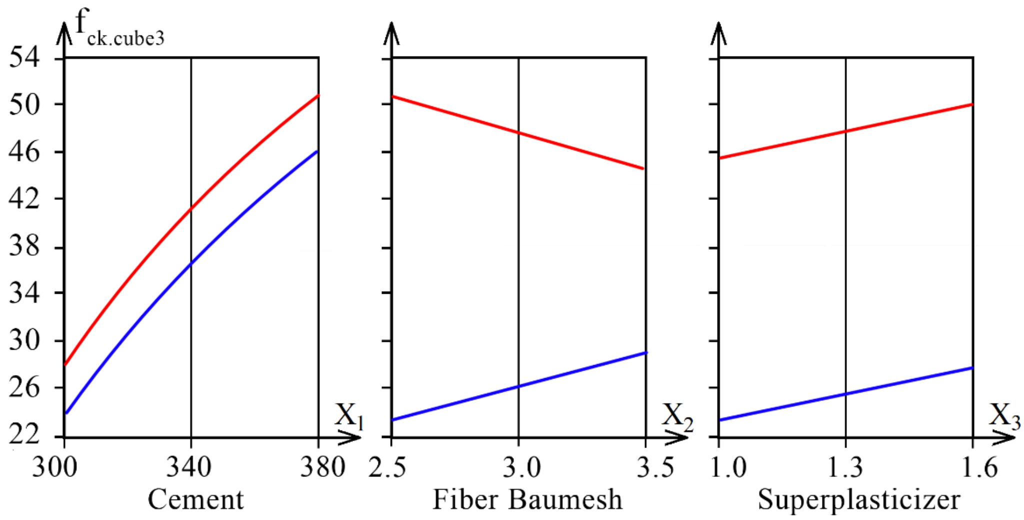

Fig. 2. The influence of varied composition factors on the compressive strength of fiber-reinforced concrete at the age of 3 days in the zones of minimum and maximum values

As can be seen from the diagrams, the amount of Portland cement has the greatest influence on the value of the $f_{ck.cube3}$ indicator. Increasing the dosage of the binder from 300 kg/m^3 to 380 kg/m^3 increases the early strength of the studied fiber-reinforced concretes by 74-80%. The increase in the early compressive strength with an increase in the amount of superplasticizer is linear and within the factor space of the experiment provides an increase in this indicator by 10-12%. Increasing the amount of reinforcing fibers from 2.5 to 3.5 kg/m^3 with a high content in the mixture of Portland cement and plasticizer leads to a slight decrease in the $f_{ck.cube3}$ indicator, which can be explained by the difficulty of uniform distribution of fibers in a highly filled binder and admixture-modified concrete mixture. With an increase in the amount of polypropylene fiber in the zone of minimum values, that is, with a smaller amount of cement and superplasticizer, the early strength, on the contrary, increases insignificantly.

The influence of varied composition factors on the compressive strength of fiber-reinforced concrete at the age of 28 days $f_{ck.cube28}$ describes the EC model (3), according to which single-factor dependences of the influence of composition factors are constructed (Fig. 3).

$$f_{ck.cube28}\,(\text{MPa}) = 63.72 + 8.91x_1 - 4.61x_1^2 \pm 0x_1x_2 \pm 0x_1x_3 \pm 0x_2 \pm 0x_2^2 - 2.20x_2x_3 + 1.56x_3 \pm 0x_3^2 \quad (3)$$

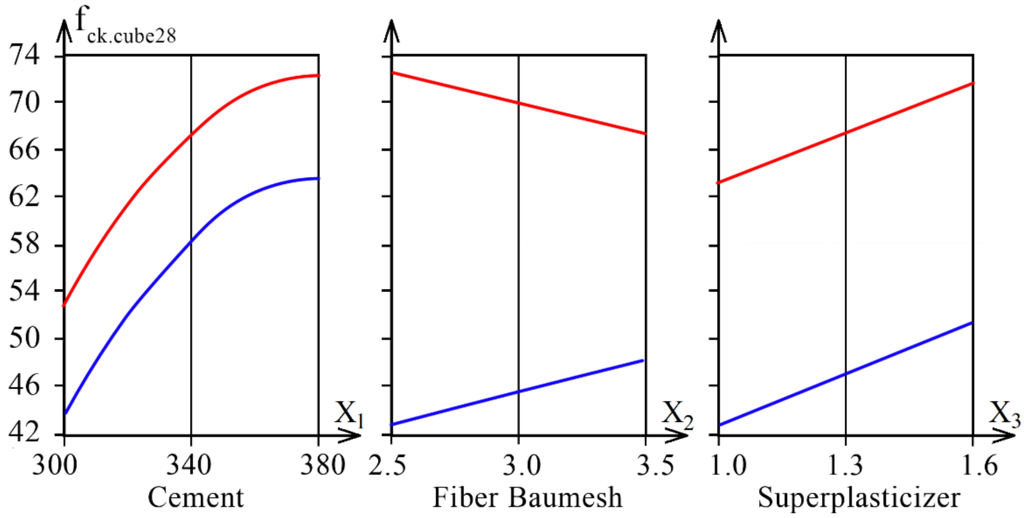

Fig. 3. The influence of varied composition factors on the compressive strength of fiber-reinforced concrete at the project age in the zones of minimum and maximum values

Analysis of the EC model (3) and the diagram shows that the strength of fiber-reinforced concretes at the project age of the samples increases to the greatest extent with an increase in the amount of Portland cement. This effect is nonlinear and changing the dosage of the binder from 300 to 340 kg/m^3 has a greater effect than from 340 to 380 kg/m^3. Increasing the dosage of the superplasticizer within the factorial space of the experiment while reducing the water consumption of the mixture also linearly provides an increase in the strength index by approximately 12-14%. The introduction of polypropylene fiber at a dosage of the binder at the level of 300 kg/m^3 and a low content of the superplasticizer additive, as in the case of early strength, retains a linear character and reveals an increase in strength by 8%.

The influence of varied composition factors of fiber-reinforced concrete on the tensile strength of the material at the age of 28 days f_{ctk} is described by the EC model (4), according to which single-factor dependences of the influence of composition factors are constructed (Fig. 4).

$$f_{ctk}\,(\text{MPa}) = \begin{array}{lllll} 6.68 & + 0.36x_1 & \pm 0x_1^2 & \pm 0x_1x_2 & \pm 0x_1x_3 \\ & \pm 0x_2 & - 0.48x_2^2 & & \pm 0x_2x_3 \\ & + 0.37x_3 & \pm 0x_3^2 & & \end{array} \quad (4)$$

For road surfaces, the tensile strength in bending is one of the most important physical and mechanical indicators [7, 13]. By increasing the dosage of the binder to 380 kg/m^3 both in the minimum and maximum zones, the tensile strength of fiber-reinforced concrete in bending increases by 9-12%. A similar increase in the tensile strength in bending is achieved by increasing the dosage of the superplasticizer from 1.0 to 1.6%. The nature of the influence of polypropylene fiber on this strength indicator is nonlinear. The increase is observed with an increase in the dosage of fibers from 2.5 kg/m^3 to 3.0 kg/m^3 both at high and low amount of binder and superplasticizer.

Thus, the analysis of the influence of the amount of polypropylene fiber and superplasticizer on the strength of concrete for hard road surfaces and transport structures showed that, in general, from the point of view of achieving the highest compressive and tensile strength during bending, it is rational to introduce Baumesh polypropylene fiber in an amount of about 3.0 kg/m^3 and MC-PowerFlow 3200 additive in an amount of 1.5-1.6% of the cement mass.

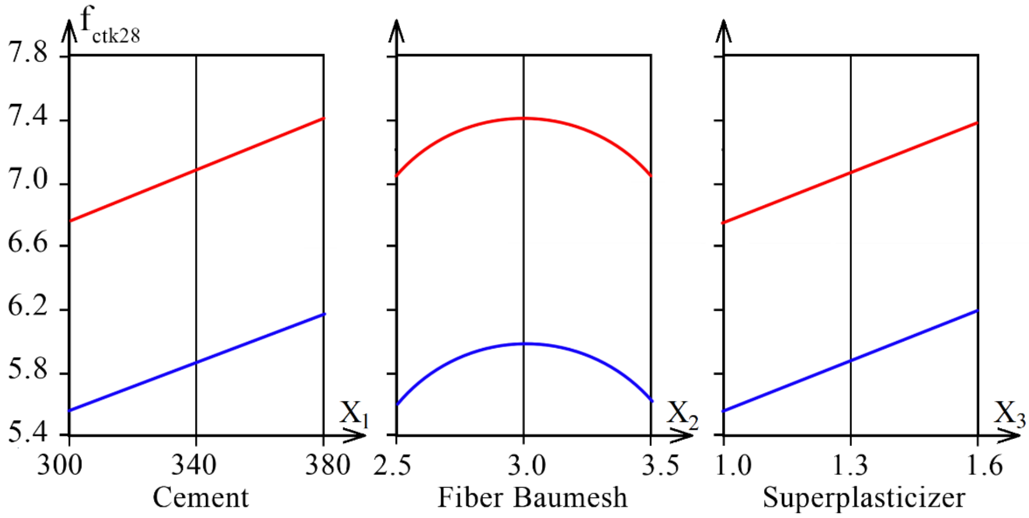

Fig. 4. The influence of varied composition factors on the bending tensile strength of fiber-reinforced concrete in the zones of minimum and maximum values

Conclusions and Prospects for Further Research. As a result of experimental studies, data were obtained on the change in the strength indicators of concrete for hard road surfaces and transport structures depending on the amount of polypropylene fiber and polycarboxylate-type superplasticizer.

It was established that changing the amount of Baumesh reinforcing fibers within the factor space of the experiment does not significantly affect the compressive strength of fiber-reinforced concrete. An increase in the amount of polypropylene fiber from 2.5 to 3.5 kg/m^3 at a binder dosage of 300-340 kg/m^3 and a superplasticizer additive content of 1-1.3% causes an increase in compressive strength by 4-8%. With the maximum amount of binder and superplasticizer, an increase in the amount of fiber above 2.5 kg/m^3, on the contrary, slightly reduces the compressive strength of concrete.

The tensile strength of fiber-reinforced concrete during bending is expected to increase with an increase in the amount of Portland cement. The increase in the amount of superplasticizer also has a positive effect on the value of f_{ctk}. At the same time, increasing the amount of fiber from 2.5 to 3.0 kg/m^3 also effectively increases the tensile strength of concrete in bending. This effect is observed both at high and low amounts of binder and superplasticizer.

In the future, it is planned to investigate the wear resistance and frost resistance of fiber concretes modified with a superplasticizer additive, and also, taking into account the analysis of the obtained experimental data on the compressive and tensile strength in bending, it is planned to determine the possibility of increasing the efficiency of using reinforcing polypropylene fibers by changing the mixing conditions at the stage of preparing the mixture.

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ВПЛИВ КІЛЬКОСТІ ПОЛІПРОПІЛЕНОВОЇ ФІБРИ І СУПЕРПЛАСТИФІКАТОРУ НА МІЦНІСТЬ БЕТОНІВ ЖОРСТКИХ ДОРОЖНІХ ПОКРИТТІВ ТА ТРАНСПОРТНИХ СПОРУД

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Анотація. У статті наведено аналіз впливу кількості поліпропіленової фібри, цементу і суперпластифікатору полікарбоксилатного типу на міцнісні характеристики бетонів для жорстких дорожніх покриттів та транспортних споруд. Використовувались портландцемент ПЦ II/А-Ш-500Р-Н, поліпропіленова фібра Baumesh з довжиною волокон 36 мм і діаметром 0,68 мм, суперпластифікатор полікарбоксилатного типу MC-PowerFlow 3200.

Проведений 3-х факторний експеримент, у якому варіювалися наступні фактори складу: кількість портландцементу, від 300 до 380 кг/м^3; кількість поліпропіленової фібри Baumesh, від 2,5 до 3,5 кг/м^3; кількість суперпластифікатору, від 1,0 до 1,6% від маси цементу. Визначалася міцність фібробетонів на стиск у віці 3 та 28 діб, міцність на розтяг при згині у віці 28 суток. Всі досліджувані бетонні суміші мали рівну рухомість П2.

Оцінено вплив варійованих факторів на В/Ц сумішей. Найбільший вплив на даний показник має кількість портландцементу. Збільшення дозування суперпластифікатору з 1,0% до 1,6% дозволяє знизити В/Ц на 8–24%. Кількість поліпропіленової фібри має обмежений вплив на В/Ц.

Кількість портландцементу має найбільший вплив на міцність досліджених фібробетонів на стиск. При збільшенні дозування в'яжучого з 300 кг/м^3 до 380 кг/м^3 міцність фібробетонів на 3 добу збільшується на 74–80%, міцність у проєктному віці збільшується 38–47%. Збільшення кількості суперпластифікатору забезпечує зростання міцності на стиск у ранньому віці на 10–12%, у проєктному віці на 12–14%. Збільшення кількості армуючих волокон з 2,5 до 3,5 кг/м^3 при високому вмісті у суміші в'яжучого та пластифікатору впливає не суттєво. За рахунок збільшення кількості фібри при невисокій кількості цементу та суперпластифікатору рання і проєктна міцність фібробетонів на стиск несуттєво зростає.

За рахунок збільшенні дозування в'яжучого до 380 кг/м^3 міцність фібробетонів на розтяг при згині зростає на 9–12%. Аналогічне зростання міцності на розтяг при згині досягається при збільшенні дозування суперпластифікатору з 1,0 до 1,6%. Характер впливу поліпропіленової фібри на цей показник міцності є нелінійним. Підвищення міцності на 9–12% спостерігається при зростанні дозування волокон з 2,5 кг/м^3 до 3,0 кг/м^3 як при високих так і при низьких кількостях в'яжучого та суперпластифікатору.

Встановлено, що в цілому з точки зору досягнення найбільшої міцності на стиск і на розтяг при згині раціональним є введення поліпропіленової фібри Baumesh у кількості близько 3,0 кг/м^3 та добавки MC-PowerFlow 3200 у кількості 1,5-1,6 % від маси цементу.

Ключові слова: дорожнє покриття, поліпропіленова фібра, суперпластифікатор, міцність, планований експеримент.

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