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COMPARISON OF FIBER CONCRETE PROPERTIES FOR INDUSTRIAL FLOORS AND ROAD PAVEMENTS WITH STEEL AND POLYPROPYLENE FIBER

[1]**Kroviakov S.O.**, Doctor of Engineering, Assistant Professor,
skrovyakov@ukr.net, ORCID: 0000-0002-0800-0123
[1]**Hedulian D.Iu.**, postgraduate,
hedulian@ogasa.org.ua, ORCID: 0000-0003-1754-6854
[1]**Kryzhanovskyi V.O.**, postgraduate,
vitolloscience@gmail.com, ORCID: 0000-0003-1332-1922
[1]**Zavoloka M.V.,** PhD, Professor,
mvzavoloka@ukr.net, ORCID: 0000-0002-2080-1230
[2]**Yelkin A.V.,** PhD,
elkin-alex@ukr.net, ORCID: 0000-0002-3043-5107
[1]*Odessa State Academy of Civil Engineering and Architecture*
4, Didrichson street, Odessa, 65029, Ukraine
[2]*KP «BUDOVA»*
25, Osipova street, Odessa, 65012, Ukraine

Abstract. The article presents a comparative analysis of the type of dispersed reinforcement effect with steel fiber produced by «Stalkanat-Silur» (50 mm length, ⌀1 mm) and polypropylene fiber «Baumesh» produced by BAUTECH-Ukraine LLC (36 mm length, ⌀0.68 mm) on physical and mechanical properties and failure mode of fiber-reinforced concrete samples for cement concrete pavements and industrial floors. The indicators of strength and durability as one of the most important concrete properties for pavement structures, that are constantly operate under the influence of high dynamic loads were determined. The possibility of using the studied compositions of concrete with structural fiber of different types is analyzed.

All concrete mixtures had equal workability S4. For fiber-reinforced concrete mix preparation, Portland cement ПЦ II/А-Ш-500 (CEM II/A-S 42.5 R), crushed stone 5-20 mm and sand with a fineness modulus of 2.75 were used. Polycarboxylate superplasticizer MC-PowerFlow 3200 was used to achieve the required workability of fiber concrete mixtures.

It has been established that the use of dispersed reinforcement increases the concrete compressive strength by 13-16%, flexural strength increases by 30-31%, and the abrasion resistance decreases by 31-39%. The use of dispersed reinforcement with «Baumesh» polypropylene fiber in an amount of up to 3 kg/m^3 makes it possible to increase the compressive and flexural concrete strength and also to reduce its abrasion resistance on the same scale as the use of dispersed reinforcement with steel anchor fiber «Stalkanat-Silur» up to 25 kg/m^3. In this case, from an economic point of view, the use of polypropylene fiber is more appropriate.

The optimal content of dispersed reinforcement to increase the strength and abrasion resistance in the fiber-reinforced concrete composition was determined. The fiber-reinforced concrete compositions with steel and polypropylene fibers of compressive strength grade C25/30, and flexural strength grade B_{tb} 3.6, with an increased abrasion resistance were obtained.

Keywords: industrial floors, road pavements, modified fiber concrete, polypropylene fiber, steel fiber.

Introduction. One of the most demanding in terms of physical, mechanical and operational characteristics of building structures are cement-concrete coatings of roads and industrial floors, which operate under conditions of high dynamic loads.

Industrial floor – a building structure operated under different types of loads and influences, which should provide a quality surface for the production process and comfortable, safe human activities. According to [1] the floor should be arranged taking into account the reliability and durability of the accepted structure in accordance with the design and climatic conditions of construction, rational consumption of building materials with the fullest use of their physical and mechanical properties. Concretes of classes C32/40, C25/30, C20/25 and C12/15 can be used for such constructions depending on the intensity of loads.

Cement-concrete pavement is an elastic base slab, which should be made of heavy concrete [2] with high tensile strength, bending resistance, abrasion resistance, frost resistance and corrosion resistance. According to [3] for the preparation of concrete mixtures of road surfaces it is necessary to use local construction materials and new modern road construction materials, in particular different types of fiber [4, 5]. W/C ratio for concrete of the upper layers of two-layer and single-layer pavements should be in the range of 0.4-0.55. As binders it is allowed to use cements of types of CEM I and CEM II (in particular CEM II/A-S). To reduce the amount of water in concrete mixtures, it is recommended to use additives superplasticizers based on polycarboxylates, melamine or naphthalenesulfonate formaldehyde, or lignosulfonates. According to the requirements of [6], road cement concrete can be used in compression classes from C12/15 to C50/60 and tensile classes in bending from B_{tb} 2.0 to B_{tb} 6.0, depending on the category of roads and design requirements. The rate of strength of road cement concrete for the upper layers of two-layer and single-layer coatings on the 7th day of natural hardening should not exceed 80% of the grade strength. The minimum mark on frost resistance of concrete of the top layer of road coverings across all territory of Ukraine makes F200. Water absorption for cement concrete of single-layer and upper layers of two-layer coatings should not exceed 4%. Acceptable marks on abrasion are G1-G3. This is due to the fact that abrasion largely determines the durability of pavements.

Analysis of research and publications. The analysis of literature sources shows that to achieve the normative levels of the above physical and mechanical properties of concrete for hard pavements of roads and industrial floors today disperse reinforcement with different types of fiber is actively used [7, 8]. Fiber helps to increase the tensile strength of concrete in bending and wear resistance. At the same time metal fiber is one of the most effective for dispersed reinforcement of concretes which are exposed to dynamic influences. However, due to rising prices for metal products, and hence for the derivative product, such as steel fiber of various types – anchor, corrugated, with flattened ends, etc., the problem of using dispersed fibers from cheaper materials, such as polymers. Depending on the type of polymer fiber, investigations show a generally positive effect on both the strength [9-13] and a number of other characteristics of cement concrete, in particular reducing the penetration of chlorine ions [10] and increasing adhesion to the concrete base [13].

Formulation of the problem. The purpose of this study is a comparative analysis of the strength and abrasion of fiber concrete using different types of structural fiber, namely steel from the Ukrainian manufacturer and polypropylene fiber "Baumesh" from LLC "BAUTECH-Ukraine".

Materials and methods of research. For the preparation of fibrous concrete was used Portland cement CRH CEM II/A-S 42.5 R, as a large aggregate was crushed stone fraction of 5-20 mm, fine aggregate was quartz sand with a modulus of 2.75. Polycarboxylate superplasticizer MC-PowerFlow 3200 was used to achieve the required ease of laying of concrete mixtures. Two types of fiber were used for dispersed reinforcement of the studied concretes: steel anchor fiber produced by Stalkanat-Silur, 50 mm long and 1 mm in diameter; polypropylene fiber "Baumesh" 36 mm long and 0.68 mm in diameter. The grade of ease of laying of all investigated mixtures was S4 (cone draft 17-18 cm) at a constant W/C 0.5. C20/25 concrete without dispersed reinforcement was used as a control composition. Ensuring uniform distribution of fiber in the volume The capacity of the concrete mixture was performed according to [14]. The compositions of the studied fiber concretes are given in Table 1. The amount of steel fiber in the concrete varied from 15 to 25 kg/m^3, polypropylene – from 2 to 3 kg/m^3, which corresponded to the recommendations of the manufacturers of dispersed fibers.

Compressive strength at the age of 7 and 28 days and tensile strength at bending at the age of 28 days were determined for all investigated compositions of concrete and fiber concrete according to [15], and wear resistance tests were performed according to the method [16].

Table 1 – Compositions of the studied fiber concretes

№ s/n	Marking	Cement,	Crushed stone, kg/m³	Sand, kg/m³	Fiber Baumesh 36 mm, kg/m³	Fiber Stalkanat 50 mm, kg/m³	MC-Power Flow 3200, kg/m³	W/C
1	Basic composition C20/25	360	1110	780	–	–	3.40	0.5
2	Composition with Baumesh 2 kg/m³			778	2.0	–	4.08	
3	Composition with Baumesh 2.5 kg/m³				2.5	–		
4	Composition with Baumesh 3.0 kg/m³			777	3.0	–		
5	Composition with steel fiber 15 kg/m³		1105	770	–	15.0	3.64	
6	Composition with steel fiber 20 kg/m³		1103	767	–	20.0		
7	Composition with steel fiber 25 kg/m³		1102	763	–	25.0		

Cube specimens with a rib length of 100 mm were made to study compressive strength, 400 × 100 × 100 mm prisms were made to test tensile bending, and cube specimens with a rib length of 70 were made to determine abrasion indices from these cube specimens mm, as the maximum size of the filler 20 mm did not allow the formation of samples [15] immediately in the form with the appropriate length of the rib.

Research results. During the experimental studies, data were obtained on the physical and mechanical properties of the control composition of concrete and fiber concrete with different types of fiber.

As can be seen from table 1, at a constant value of W/C 0.5 to achieve the required grade of easy-laying concrete mixture S4 control composition (№1), fiberglass dispersion-reinforced polypropylene fiber (№2-№4) and compositions with steel fiber reinforcement (№5-№7) the required amount of superplasticizer was 3.4 kg/m^3 (0.944% by weight of cement), 4.08 kg/m^3 (1.133% by weight of cement) and 3.64 kg/m^3 (1.011% of mass of cement). The increased consumption of superplasticizer in fiber concrete mixes with use of polypropylene fiber is explained by the fact that on unit of volume of concrete mix much more polypropylene fibers, than steel are necessary. This hindered the achievement of the design workability and required an increase in the dosage of the superplasticizer.

Table 2 shows the obtained strength characteristics of the studied concretes and fiber concretes.

The average density of the studied concretes and fiber concretes was in the range of 2410-2440 kg/m^3, the concrete of the control composition corresponded to the design class for compression C20/25.

At the age of 7 days (Fig. 1), the control composition (№1) had a compressive strength of 28.9 MPa, which for an early age corresponds to the concrete class C16/20. Samples of fiber concrete (№2) and (№3) with polypropylene fiber had a compressive strength of 29.5 and 31.4 MPa, respectively, which also corresponds to the concrete class C16/20. Fiber concrete samples (№4) also with polypropylene fiber reached a compressive strength of 32.2 MPa. So at the age of 7 days samples fiber concrete (№4) corresponded to the design class C20/25. In turn, the samples fiber concrete (№5) with a steel fiber content on the 7th day of hardening had a compressive strength of 30.9 MPa, i.e. conditionally belonged to class C16/20. Samples of fiber concrete (№6) and (№7) with steel fiber for 7 days reached a compressive strength of 32.1 MPa and 33.3 MPa, respectively, and already at this age correspond to the design class of concrete C20/25.

Table 2 – Compressive and tensile strength in bending of the studied fiber concrete

№ s/n	Marking	Strength in compression at the age of 7 days fcm.7, MPa	Strength in compression at the age of 28 days fcm, MPa	Strength tensile when bending at the age of 28 days fc.tf, MPa	Average density ρ, kg/m^3
1	Basic composition C20/25	28.9	35.6	3.53	2415
2	Composition with Baumesh 2 kg/m^3	29.5	38.8	4.49	2425
3	Composition with Baumesh 2.5 kg/m^3	31.4	39.8	4.58	2420
4	Composition with Baumesh 3.0 kg/m^3	32.2	41.8	4.72	2415
5	Composition with steel fiber 15 kg/m^3	30.9	39.4	4.47	2435
6	Composition with steel fiber 20 kg/m^3	32.1	42.0	4.59	2410
7	Composition with steel fiber 25 kg/m^3	33.3	43.1	4.75	2440

After 28 days of curing (Fig. 1) control the composition (№1) corresponded to the design class C20/25 and had a compressive strength of 35.6 MPa. In turn, all fiber concretes with polypropylene fiber for 28 days had a strength corresponding to the concrete class C25/30 and depending on the amount of fiber had a compressive strength in the range of 38-41 MPa. Fiberglass reinforced with steel fiber also reached the concrete class C25/30 at the design age and, depending on the amount of fiber, their compressive strength was in the range of 39-43 MPa. The consumption of cement per 1 m^3 of fiber concrete was similar in composition (№1).

The obtained research results allow us to note that the use of different types of fiber has a positive effect on the compressive strength of fiber concrete. All studied fiber concretes at the design age had a strength that provides one class higher compared to the control composition. The use of polypropylene fiber on average increased the compressive strength of fiber concrete compared to the control composition by 7.6% at the age of 7 days and by 12.6% at the age of 28 days. The strength of fiber concrete with steel fiber at the age of 7 days exceeded the compressive strength of the control composition by an average of 11.3%, and at the age of 28 days – by 16.4%. In Fig. 2 shows the difference in the nature of the destruction of samples of concrete and fiber concrete.

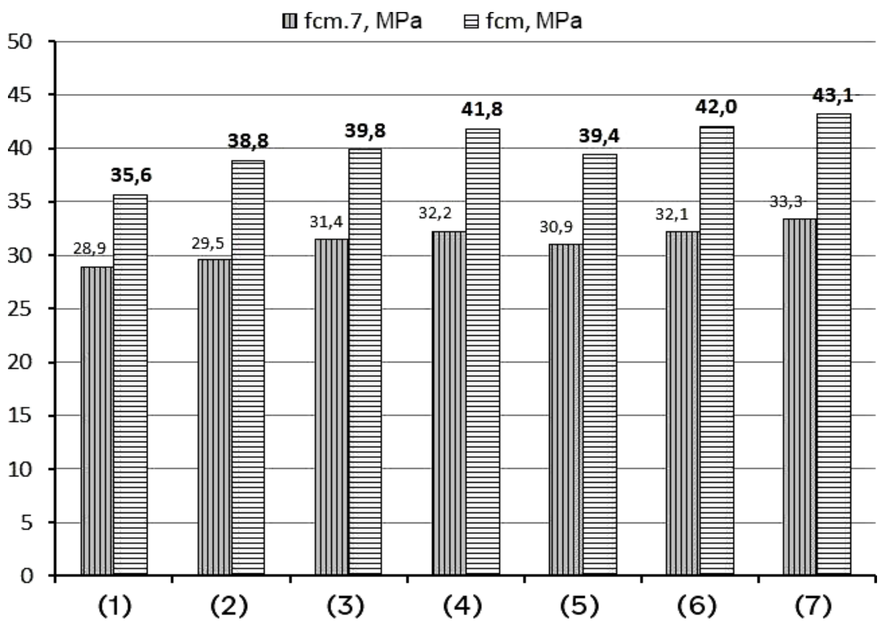

Fig. 1. Compressive strength of concrete at the age of 7 and 28 days

Fig. 2. The nature of the destruction of samples of classical and dispersed reinforced concrete:
a – concrete without dispersed reinforcement; b – fiber concrete using fiber "Baumesh";
c – fiber concrete using steel fiber

The obtained fiber concretes are effective when used for the installation of cement concrete pavements and industrial floors, depending on their design requirements.

Tests of fibrous concrete for tensile strength in bending were carried out at the age of 28 days (Fig. 3). Strength of control concrete composition (№1) was 3.53 MPa, which corresponds to the class B_{tb} 2.8. Fiber concretes with polypropylene fiber (№2-№4) had a tensile strength in bending from 4.49 MPa to 4.72 MPa (class B_{tb} 3.6), i.e. were characterized by tensile strength in bending on average 30.2% higher strength of the control composition. Fiber concretes with steel fiber (№5-№7) achieved tensile strength in bending from 4.47 MPa to 4.75 MPa (class B_{tb} 3.6), which is on average 30.4% higher than the concrete of the control composition.

In Fig. 4 shows the difference in the nature of the destruction of samples of concrete and fiber concrete in the tensile test under bending. Analyzing the image, it can be noted that the control sample of concrete without fiber has a fragile type of fracture, while the disperse-reinforced sample is not completely destroyed in the compressed cross-sectional area.

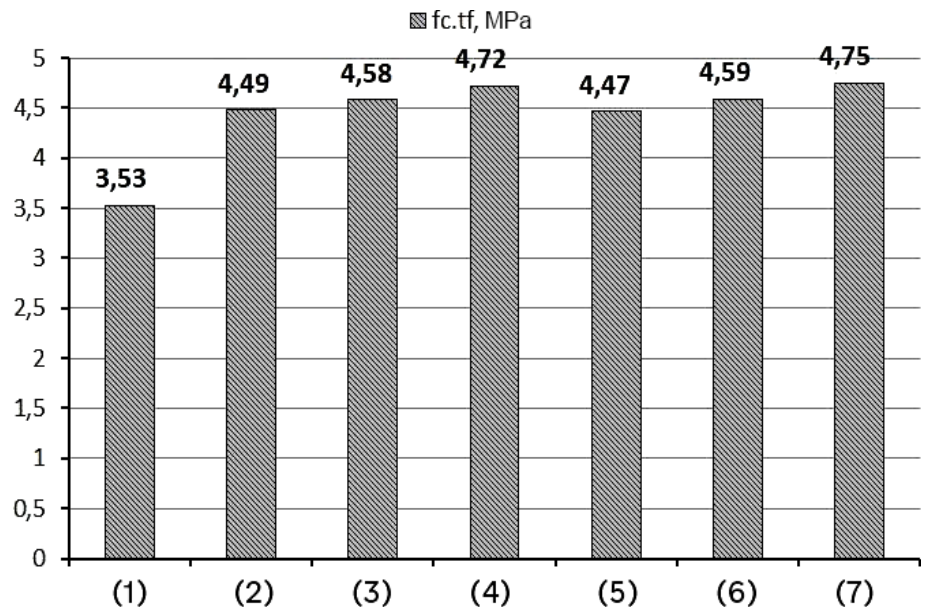

Fig. 3. Tensile strength of bending concrete

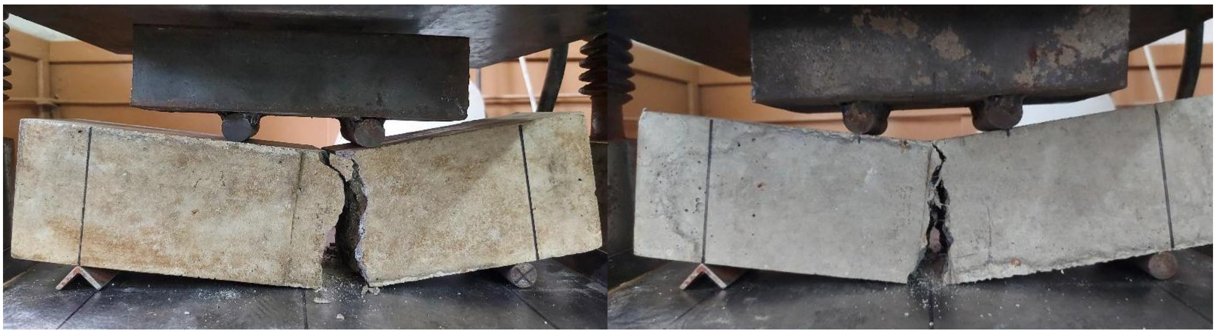

Fig. 4. The nature of the destruction of samples not modified (left)
and dispersed reinforced concrete (right) after tensile bending test

In fact, the compressive and tensile strength in bending of concretes with steel fiber (№5-№7) did not differ from the strength of concretes with propylene fiber (№2-№4). The difference in strength did not exceed 4%. However, it should be taken into account that fiber concretes with significantly different fiber contents are compared: up to 3 kg/m^3 for Baumesh polypropylene fiber and up to 25 kg/m^3 for steel anchor fiber. Given the rising prices for steel products, the use of polypropylene fibers may be more appropriate.

Wear resistance or abrasion is an important indicator of concrete, especially for pavements and industrial floor slabs, which are constantly under the influence of external forces from cars, forklifts, etc. In Fig. 5 shows the manufactured samples for testing. Table 3 shows the data on wear resistance (abrasion) of the studied compositions of concrete and fiber concrete.

Analyzing the obtained data (Fig. 6), we can note the positive effect of dispersed reinforcement on the wear resistance of fiber concrete. The control composition (№1) according to the current DSTU 8858:2019 is not allowed for the installation of cement-concrete pavements, as its abrasion is 0.52 g/cm^2 with a permissible 0.5 g/cm^2 [2].

Fig. 5. Made cube samples with a rib length of 70 mm for abrasion test

Table 3 – Indicators of abrasion of the studied concrete and fiber concrete

№ investigated concrete/fiber concrete composition	1	2	3	4	5	6	7
Abrasion, g/cm^2	0.52	0.42	0.37	0.34	0.44	0.40	0.36

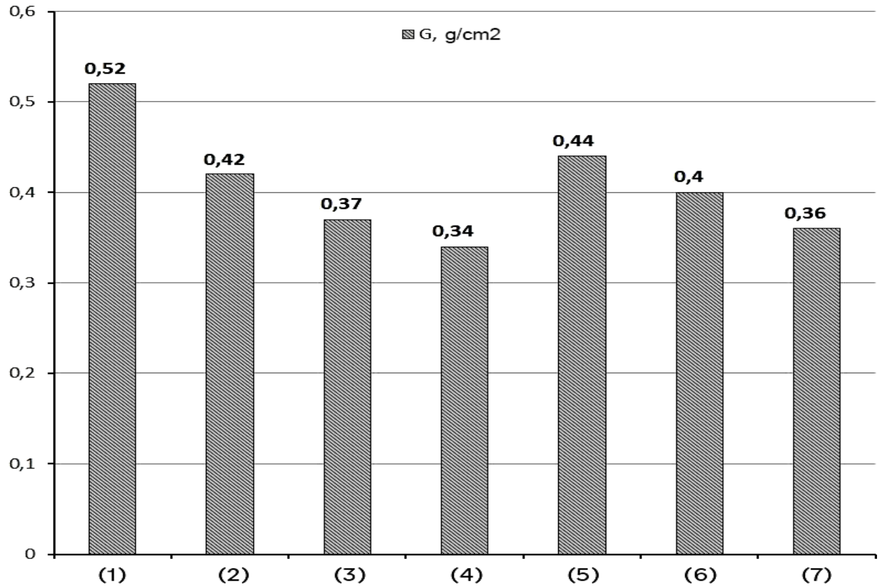

Fig. 6. The abrasion index of the studied samples of concrete and fiber concrete

As the number of fiber fibers of both types increases, the wear resistance of concrete increases, i.e. abrasion decreases. Thus, it decreases by an average of 39% when using polypropylene fiber produced by Baumesh, depending on its quantity, and by 31% when using steel fiber produced by Stalkanat-Silur. Consumption of polypropylene fiber in the amount of 2 kg/m^3, steel fiber 15 kg/m^3 and 20 kg/m^3 allows to obtain fiber concrete with abrasion grade G3, and consumption of polypropylene fiber 2.5 and 3 kg/m^3 or steel fiber 25 kg/m^3 allows to receive fiber concrete with the G2 abrasion mark.

The best wear resistance of fiber concrete with the use of polypropylene fiber is due to its better adhesion to the concrete matrix, which was observed in tests of flexural strength. Due to the lower adhesion of steel fiber to the concrete matrix under abrasion loads, steel fibers are "released" from the concrete mass, while polypropylene remains in it and gives greater resistance to wear of the composite [17-19].

Conclusions. Disperse reinforcement using both Stalkanat-Silur steel anchor fiber and Baumesh polypropylene fiber has a positive effect on compressive strength, tensile strength in bending and wear resistance of the studied concretes.

Compared with the control composition when used in the composition of steel fiber compressive strength of concrete at the age of 7 days increases by 11.3%, when using polypropylene fiber – by 7.6%. On the 28th day, the increase in compressive strength of fiber concrete with dispersed reinforcement with steel anchor fiber is 16.4%, and with polypropylene fibers – by 12.6%. The use of steel fiber increases the tensile strength in bending at the age of 28 days by 30.4%, and fiber concrete composites with polypropylene fiber – by 30.2%. Thus, the studied physical and mechanical properties of fiber concrete with polypropylene fiber do not differ significantly from similar indicators for fiber concrete with steel fiber.

Compared with control samples of concrete when used in steel fiber abrasion of concrete decreased by 0.08-0.16 g/cm^2 (31%), when using polypropylene fiber – by 0.1-0.18 g/cm^2 (39%).

In general, the use of dispersed reinforcement with polypropylene fiber "Baumesh" in the amount of up to 3 kg/m^3 can increase the compressive and tensile strength of concrete in bending, as well as its wear resistance on the same scale as the use of dispersed reinforcement with steel anchor fiber "Stalkanat-Silur "in the amount of up to 25 kg/m^3. In this case, from an economic point of view, the use of polypropylene fiber, which has a much lower cost compared to steel, is more appropriate.

The obtained compositions of fiber concrete can be used for the installation of rigid cement concrete coatings and concrete industrial floors.

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ПОРІВНЯННЯ ВЛАСТИВОСТЕЙ ФІБРОБЕТОНІВ ДЛЯ ПРОМИСЛОВИХ ПІДЛОГ І ДОРОЖНІХ ПОКРИТТІВ ЗІ СТАЛЕВОЮ ТА ПОЛІПРОПІЛЕНОВОЮ ФІБРОЮ

[1]**Кровяков С.О.**, д.т.н., доцент,
skrovyakov@ukr.net, ORCID: 0000-0002-0800-0123
[1]**Гедулян Д.Ю.**, аспірант,
hedulian@ogasa.org.ua, ORCID: 0000-0003-1754-6854
[1]**Крижановський В.О.**, аспірант,
vitolloscience@gmail.com, ORCID: 0000-0003-1332-1922
[1]**Заволока М.В.**, к.т.н., професор,
mvzavoloka@ukr.net, ORCID: 0000-0002-2080-1230
[2]**Єлькін О.В.**, к.т.н., доцент,
elkin-alex@ukr.net, ORCID: 0000-0002-3043-5107
[1]*Одеська державна академія будівництва та архітектури*
вул. Дідріхсона, 4, м. Одеса, 65029, Україна
[2]*КП «БУДОВА»*
вул. Осипова, 25, м. Одеса, 65012, Україна

Анотація. В статті наведений порівняльний аналіз впливу типу дисперсного армування сталевою та поліпропіленовою фіброю на фізико-механічні властивості та характер руйнування зразків фібробетонів для влаштування цементобетонних дорожніх покриттів та покриттів промислових підлог. Використовувалася сталева фібра виробництва «Стальканат-Сілур» (довжина 50 мм, діаметр 1 мм) та поліпропіленова фібра «Baumesh» від ТОВ «БАУТЄХ-Україна» (довжина 36 мм, діаметр 0,68 мм). Визначалася міцність на стиск і на розтяг при згині, а також стиранність бетону, як одні з важливіших показників якості для матеріалу зазначених конструкцій, що постійно знаходяться під впливом високих динамічних навантажень. Проаналізована можливість використання досліджуваних складів бетонів з використанням конструктивної фібри різного типу.

Всі бетонні суміші мали рівну легкоукладальність S4. Для приготування фібробетонів використовувався портландцемент CRH ПЦ II/А-Ш 500 Р-Н, щебінь фракції 5-20 мм і пісок з модулем крупності 2,75. Полікарбоксилатний суперпластифікатор MC-PowerFlow 3200 використовувався для досягнення необхідної легкоукладальності фібробетонних сумішей.

Встановлено, що за рахунок дисперсного армування міцність бетону на стиск зростає на 13..16%, міцність на розтяг при згині на 30..31%, а стиранність знижується на 31..39%. Використання дисперсного армування поліпропіленовою фіброю «Baumesh» у кількості до 3 кг/м^3 дозволяє підвищити міцність бетону на стиск та на розтяг при згині, а також його зносостійкість у тому ж масштабі, як і використання дисперсного армування сталевою анкерною фіброю «Стальканат-Сілур» у кількості до 25 кг/м^3. При цьому з економічної точки зору використання поліпропіленової фібри є більш доцільним.

Визначено оптимальний вміст дисперсного армування у складі фібробетонів для підвищення показників міцності та зносостійкості. Отримано склади фібробетонів зі сталевою та поліпропіленовою фіброю класу С25/30 за міцністю на стиск, та B_{tb} 3,6 за міцністю на розтяг при згині, з підвищеним показником зносостійкості.

Ключові слова: покриття автомобільних доріг, промислові підлоги, модифікований фібробетон, поліпропіленова фібра, сталева фібра.

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