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EFFECTIVENESS OF ROAD SLABS PRODUCED USING MICROSILICA AND FIBER QUALITY IMPROVEMENT

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ABSTRACT: The physical and mechanical properties of concrete produced for road slabs using bulk fiber reinforcement with polypropylene macro- and microfibers were tested to address challenges in improving road slab performance. The study analyzed the effects of incorporating macrofibers and microfibers into the concrete composition. It was established that low-modulus synthetic fibers significantly influence the strength, density, water resistance, and frost resistance of concrete. Polypropylene macrofibers enhance compressive and bending strength, while polypropylene microfibers improve the cement matrix structure, optimize the pore space, and increase frost and water resistance. Experimental results demonstrated that using fibers of various sizes enables the production of concrete with enhanced strength, density, and durability. Moreover, combining fiber reinforcement with microsilica allowed an increase in bending strength by up to 35%, frost resistance up to F375, and water resistance up to W14. The study's approach included selecting materials compliant with regulations, optimizing C25/30 class heavy concrete compositions with microsilica, and conducting tests to evaluate operational reliability. The findings validate the use of multidimensional polypropylene fibers and microsilica for road slab manufacturing, creating additional crystallization centers and reducing pore space. These results offer insights into enhancing mechanical and durability properties for infrastructure applications, contributing to reduced maintenance costs and extended service life.

Keywords: Fibro-concrete, Low-modulus synthetic fibers, Flexural strength, Frost resistance, Water resistance, Micro-silica.

1. INTRODUCTION

This research was conducted in response to numerous requests from companies utilizing road slabs in their construction projects. These companies aim to develop road slabs with improved strength, density, and frost resistance while simultaneously reducing the thickness and weight of the products. Enhancing road slab performance is critical for increasing infrastructure durability, minimizing maintenance costs, and ensuring safety for vehicles and pedestrians.

This demand has been made feasible by the growing adoption of multicomponent structured concretes with enhanced physical and mechanical properties. Additionally, the use of heavy concrete with volumetric fiber reinforcement has been expanding across various applications. Among the most promising reinforcing materials are polypropylene fibers, which are increasingly utilized in building products and concrete structures [1]. Unlike glass fibers, which are susceptible to corrosion in the alkaline environment of concrete (pH > 7), polymer fibers exhibit superior corrosion resistance.

Detailed studies on the destruction process of fiber-reinforced concrete with polypropylene fibers demonstrate that the behavior of these fibers changes during the later stages of deformation, as illustrated in Figure 1 [2].

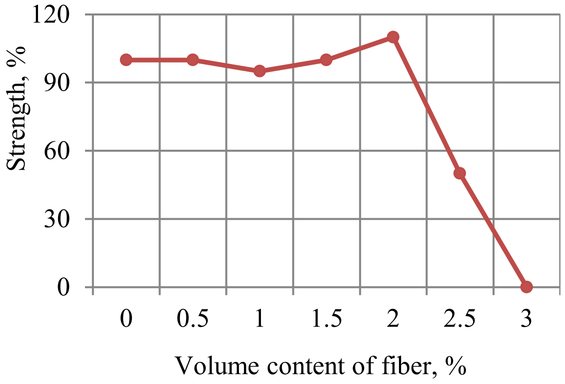

Fig.1 The nature of fiber concrete change in strength depending on low-modulus fiber volume content

Figure 1 illustrates that the composite strength with a low fiber content in the mixture remains relatively stable despite increased fiber consumption. While there is a slight initial decrease in strength, this is compensated by compaction and hardening of the cement stone structure near the fiber surface, ultimately leading to strength gains of up to 17%. However, at higher fiber contents, the strength of the cement matrix may decrease due to defects and delamination caused by technological factors. This ambiguous behavior of low-modulus fibers in the cement matrix highlights the need for further investigation [3,4].

The addition of ultrafine active silica—specifically, waste from ferrosilicon production—enhances the physical and technical characteristics of concrete by reducing the pore size of the cement matrix [2]. Literature analysis indicates that silica-containing microfillers, when used in quantities of 10–15% of the cement mass, can improve the crack resistance of concrete at 28 days by up to 1.5 times. This enhancement is attributed to increased thixotropic properties of the concrete mix and the formation of a densely packed structure, resulting in improved strength characteristics of the material.

Moreover, the use of dispersed fibers, which have a significantly higher modulus of elasticity than the concrete matrix and are chemically compatible with it, enhances the strength properties of fiber-reinforced concrete compared to ordinary concrete. The most effective approach involves multilevel reinforcement, where high-dispersion fillers, such as microsilica, act as reinforcing elements at the micro-level, while fiber reinforcement provides strength at the macro-level.

This study investigated the physical, mechanical, and operational characteristics of heavy concrete for road slabs by utilizing volumetric fiber reinforcement and modifying the cement matrix with microsilica to improve strength, density, and frost resistance. It specifically addresses gaps in existing research regarding optimal composition and reinforcement strategies for high-performance road slabs, contributing to advancements in concrete technology.

Additionally, the study explores potential cost reductions by minimizing cement and reinforcing metal usage, simplifying the technological process, and automating production [4]. The primary goal of this research was to identify the optimal concrete composition for manufacturing road slabs with high-performance properties.

To achieve this goal, several strategies were implemented:

- Selection of heavy concrete compositions with two-component fiber reinforcement using fibers of various sizes, followed by laboratory testing of their properties.
- Modification of the cement matrix through the addition of microsilica and evaluation of its effects.
- Assessment of the durability of the selected compositions, including frost resistance testing through cycles of freezing and thawing, as well as evaluations of density and water resistance of the final conglomerate [3].

2. RESEARCH SIGNIFICANCE

This research focuses on enhancing the physical and technical characteristics of road slabs through the addition of microsilica and polypropylene fibers. The study demonstrates significant improvements in concrete strength, density, frost resistance, and overall performance. These advancements are essential for extending the service life of road slabs, reducing maintenance costs, and improving reliability. The findings indicate that fiber-reinforced concrete with microsilica can result in stronger and more cost-effective road slabs, offering substantial benefits for the construction industry.

3. MATERIALS AND METHODS

The researchers analyzed and selected raw materials and other components for the concrete mixture based on information provided by the manufacturers, ensuring compliance with international standards [5]. A control composition of C25/30 class heavy concrete, commonly used in road slab production, was then selected for testing [6]. This concrete class is widely adopted in the construction industry due to its balanced strength and durability, making it suitable for various structural applications, including road slabs. Its versatility and reliability make it a preferred choice for projects requiring standard performance levels without excessive material costs.

Subsequently, a theoretical study was conducted to estimate heavy concrete compositions by partially replacing cement with silica, based on previously published research. The results of this theoretical study informed the next stage, which involved adding the optimal amounts of polypropylene fibers of two different sizes to improve the strength, density, frost resistance, and water resistance of the resulting compositions. This research aimed to experimentally validate the theoretical methods, with further industrial application as the ultimate goal.

The research was conducted in six stages, each aimed at addressing specific tasks:

- Stage 1: Selection of basic materials for the study in accordance with regulatory documents.

- Stage 2: Estimation and selection of pilot C25/30 class heavy concrete compositions using the optimal amount of micro-silica, and determination of the main physical and technical indicators [7].

- Stage 3: Step-by-step and combined addition of two widely used types of polypropylene fibers, followed by determination of the main physical and technical parameters of 28-day-old concrete.

- Stage 4: Testing of samples for operational reliability, including assessments of concrete density, frost resistance, and volumetric water absorption.

- Stage 5: Comparison, discussion, and analysis of the results.
- Stage 6: Formulation of main conclusions and recommendations for practical application.

The description and characteristics of the materials used in this research are provided below.

Table 1 presents the properties of the binder (cement) selected for the study in accordance with [8].

Cement Characteristics:

The cement used in this study is grade CEM I 42.5 N, manufactured by Heidelberg LLP, Shymkent, Kazakhstan. According to the specification provided in [9]: I indicates the first type of cement based on gypsum content (SO_3), which should range between 1.5% and 3.5–4.0% for high-strength, non-additive cements; 42.5 represents the strength class corresponding to the minimum normative value of compressive strength; N denotes normal strength at early age.

A series of tests were conducted to verify the selected binder's compliance with the specified norms and requirements [8]. The methods outlined in the standards [9] were used to determine the parameters presented in Table 1. The obtained results are consistent with the standards outlined in [10,11].

Table 1 Test results of Portland cement grade CEM I 42.5N

Parameter	Actual Values	Values According to GOST 31108-2016
Residual on a 45 µm sieve, %	3,0	-
Residue on the 80 µm sieve, %	0,6	-
Normal density, %	27,4	-
Grinding fineness, %	92,9	-
Specific surface area (Blaine), cm^2/g	3500	-
Test for uniformity of volume change (Le Chatelier Ring)	Withstands	Withstands
Setting time, min	180	No earlier than 60
Compressive strength at 28 days, MPa	53,7	No earlier than 42,5
Compressive strength at 2 days, MPa	21,3	No earlier than 10
True density, kg/m^3	3130	-
Bulk density, kg/m^3	1240	-
Consumption per 1 m^3 of heavy concrete, kg	350-450	-

Table 2 Mass fraction content of CEM I 42,5 N, %

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Other imp.
20.30	5.75	5.36	63.18	3.07	0.77	0.78	0.48	0.36

Table 2 presents the chemical composition of CEM I 42.5 N, which complies with [8].

Sand supplied by Mark LLP (Almaty region, Kazakhstan) was used for testing. This filler meets the standard requirements. The characteristics of the fine aggregate (sand) are provided in Table 3.

Table 3 Sand characteristics

Group of sand	Manufacturer	Grain size, mm	Total residue on sieve No. 063, %	Content of dust and clay inclusions, %	Consumption per 1 m^3 of heavy concrete, kg
Coarse	Mark LLP	2.6	62.5	1.08	800-1000

The sand used belongs to the coarse group and is supplied by Mark LLP (Almaty, Kazakhstan). Its grain size is 2.6 mm, with a total residue on the No. 063 sieve of 62.5%, and a dust and clay inclusions content of 1.08%. The consumption of sand per 1 m^3 of heavy concrete ranges from 800 to 1000 kg.

To achieve satisfactory characteristics of the concrete mixture, sand with dust-like inclusions not exceeding 1.5% is required. The tested sand contains 1.03% pulverized and clay inclusions, and its size modulus is 2.55. These indicators comply with the requirements for sand used in heavy concrete aggregates, as outlined in [12].

For the large aggregate (crushed stone and gravel), achieving satisfactory characteristics of the concrete mixture requires that the total residues on control sieves during sieving of fractions 5–10 mm, 10–15 mm, 10–20 mm, 15–20 mm, 20–40 mm, 40–80 mm, and mixtures of fractions 5–20 mm correspond to the specifications provided in Table 4. Here, d and D denote the smallest and largest nominal grain sizes in millimeters.

Table 4 Recommended indicators of large aggregate sieving*

Diameter of holes of control sieves, mm	Total residues on the control sieves, % by weight
d	From 90 to 100
0.5(d+D)	From 30 to 60
D	Up to 10
1.25D	Up to 0.5

** For 5-10 mm crushed stone and gravel fractions, and mixtures of 5-20 mm fractions, lower sieves of 2.5 mm (or 1.25 mm) should retain 95-100%. By agreement, a total residue of 30-80% on a 0.5 (d+D) sieve is allowed [13].*

Crushed stone fractions of 5–10 mm and 10–20 mm, produced by Baltabay LLP (Almaty, Kazakhstan), were used as large aggregates. These aggregates comply with standard requirements. Table 5 presents the characteristics of the large aggregate (crushed stone) used in this study.

Table 5 Large filler characteristics

Grain size, mm	Manufacturer	Complete residues on sieves 0,5(d+D), % (norm 30-60)	Complete residues on the sieve 1,25 D, % (norm no more than 0.5)	Consumption per 1 m^3 of heavy concrete, kg
5-10	Baltabay, LLP (Almaty, Kazakhstan)	56,22	0,37	200-400
10-20		58,97	0,45	500-700

Table 6 shows the characteristics of the modifying additive (microsilica) accepted according to [13,14].

Table 6. Microsilica characteristics

Type	Manufacturer	Mass fraction of active SiO$_2$, % by weight, not less than 95	Consumption per 1 m^3 of heavy concrete, kg
MK-95	Tau-Ken Temir LLP, Karaganda, RoK	95,9	Up to 50

Microsilica consists of spherical particles with a diameter of approximately 0.1 microns and a specific surface area ranging from 15 to 25 m^2/g or higher. Its bulk density varies between 150 and 250 kg/m^3. Chemically, microsilica is primarily composed of non-crystalline silica, with a typical content exceeding 85% and reaching up to 98%. According to data provided by Tau Kun Temir LLP, Karaganda, Kazakhstan, the specific surface area of the microsilica used in this study is 0.398 m^2/g [14].

Table 7 presents the chemical composition of the microsilica, as specified in [15].

Table 7 Chemical composition of microsilica 95, %

SiO$_2$	C	Mois.	Fe$_2$O$_3$	Al$_2$O$_3$	CaO	pH	ρ, g/cm^3	LOI
95.9	1.3	1.07	0.07	0.2	0.46	7.89	0.44	2.68

Based on the chemical composition provided by the manufacturer and its comparison with microsilica quality standards [16], it can be concluded that the oxide content in the microsilica is sufficient to meet the set objectives.

Table 8 presents the characteristics of the chemical additive (polycarboxylate PCE hyperplasticizer) as specified in [17].

Table 8 Polycarboxylate PCE hyperplasticizer characteristics

Type	Manufacturer	Additive efficiency criteria	Consumption per 1 m^3 of heavy concrete, kg
AR 122	«ARPG» LLP Astana, Kazakhstan	from П1 to П5	from 5 to 8

Based on differences in geometric characteristics, reinforcing fibers are conditionally classified into microfibers (with diameters measured in tens of micrometers and lengths typically up to 25 mm) and macrofibers (with diameters reaching several millimeters and lengths extending to tens of millimeters). The selection of polypropylene fibers in this study was driven by their superior corrosion resistance and ability to enhance the toughness and crack resistance of concrete. Previous studies have shown that an optimal proportion of fibers, uniformly distributed within the mix, improves mechanical performance without significantly affecting workability. This balance ensures that the concrete achieves increased durability while remaining workable during application.

Microsilica was incorporated at levels designed to enhance the concrete's microstructure and reduce permeability. Literature supports this approach, demonstrating its ability to improve compressive strength and durability. In addition to enhancing frost resistance, the inclusion of microsilica optimizes the overall performance of concrete in demanding environments.

For the experimental studies, two types of synthetic reinforcing fibers were used: FibroLux macrofibers and Fibrin microfibers, both manufactured by Fibrolux LLC, St. Petersburg. Their characteristics, as specified by the manufacturer, are presented in Table 8.

Table 9 Fibers technical characteristics

Characteristics	Value	
Fiber name	FibroLux	Fibrin
Type of fiber	Macrofiber	Microfiber
Material	Mod. polyp.	Mod. polyp.
Average density, kg/m^3	920	907
Length, mm	50	15
Equivalent diameter, mm	0,75	0,02
Tension strength, MPa	415	385
Resistance to chemical attack	-	-
Melting point, °C	170	170
Burning point, °C	> 350	> 350
Modulus of elasticity, MPa	-	-
Conducting power	-	-

Table 10 presents the composition of C25/30 class concrete produced using a cement binder, which is utilized in the production of PD 1-6 and PD 2-6 road slabs [18]. This composition was adopted as the control mix for further experiments.

Table 10 Control composition of C25/30 class concrete

Cement		Sand		Crushed stone (5-10 mm)		Crushed stone (10-20 mm)		PCE - AR 122		Water		Density
kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg /m^3
400	16.1	971	39.2	287	11.6	667	26.9	5.9	0.24	148	6	2382,3

To test the hypothesis, compositions were prepared, and experimental studies were conducted to evaluate the physical and technical parameters of fiber-reinforced concrete simultaneously reinforced with low-modulus macro- and microfibers in various ratios. These compositions were designed based on the available factors and tested using the methods outlined below.

3.1 Bending, Compressive and Tensile Strength Determination

As part of the compression and tensile bending tests, samples were prepared in 100×100×100 mm and 100×100×400 mm molds according to [19] using the pilot composition mixture and, subsequently, each test composition. Once the samples reached 28 days of age, the tests were conducted.

The processing and evaluation of the test results were performed using the following formula:

$$R = \alpha \frac{F}{A} K_W \tag{1}$$

where: F is the destructive load, N; A is the working cross–sectional area of the sample, mm^2; α is the scale coefficients for reducing the strength of concrete to the strength of concrete in samples of 100x100x100 mm size; Kw - correction factor for cellular concrete, assuming moisture content of the samples at the time of testing (not applicable for heavy, fine-grained and SCC).

Concrete compressive strength (R, Mpa) was calculated with an accuracy of 0.01 MPa according to the formula.

Concrete tensile strength in bending was calculated with an accuracy of 0.01 MPa according to the formula.

$$R_{bt} = \delta \frac{Fl}{ab^2} K_W \tag{2}$$

where: F is the destructive load, N; a, b, l, - the width, height of prism cross-section and the distance between the supports, respectively, when testing samples for tensile bending, mm; δ - scale coefficients for bringing the concrete strength to the concrete strength in basic size and shape samples; Kw - correction factor for cellular concrete, taking into account the moisture content of the samples at the time of testing (not applicable for heavy, fine-grained and SCC).

3.2 Determination of Concrete Water Resistance

Tests to determine concrete water resistance were conducted according to [18]. During the determination of the concrete grade for waterproofness, the water pressure was increased in 0.2 MPa increments every 1–5 minutes and maintained at the same level for a specified time period at each stage. The test continued until signs of water filtration, such as droplets or a wet spot, appeared on the upper end surface of the sample. The concrete waterproofness grade W is defined as the maximum water pressure (0.1 MPa) at which no water filtration is observed through the sample, as determined by the wet spot method based on visual assessment.

Fig.2 Method for determining water permeability in concrete

The waterproofness of each sample is determined by the maximum water pressure at which no filtration through the sample is observed. The water resistance of a set of samples is evaluated based on the maximum water pressure at which at least four out of six samples show no signs of filtration. The concrete grade for water resistance is assigned according to Table 11.

Table 11 Waterproofness of concrete

Water res., MPa	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Grade (W)	W2	W4	W6	W8	W10	W12	W14	W16	W18	W20

After obtaining the water resistance data (Tables 12 and 13 below), we determined the dependence of fiber reinforcement with polypropylene fibers of different sizes and the simultaneous poly-reinforcement effect on the average concrete density.

3.3 Determination of Concrete Average Density

Tests to determine the average density of concrete were conducted by calculating the volume of correctly shaped samples based on their geometric dimensions. The dimensions of the samples were measured using a ruler or caliper with an error not exceeding 1%. The mass of the samples was determined by weighing, with an error not exceeding 0.1%.

The average density (ρ_w, kg/m³) of concrete for each sample in the set was calculated with an error of up to 1 kg/m³ using the following formula:

$$\rho w = m / V * 1000 \qquad (3)$$

where m – is sample mass, kg; V — sample volume, m3. The concrete average density is calculated as the arithmetic mean of the test results of all samples in set.

4. RESULTS AND DISCUSSION

The physical and mechanical characteristics of the samples obtained during laboratory tests are presented in Table 12, which includes the detailed compositions of concrete containing microsilica per 1 m³ and their corresponding compressive strength data at 7 and 28 days. These results provide insight into the performance of concrete mixes with varying microsilica content compared to the reference mix.

The average compressive strength of 32.7 MPa, observed for the pilot C25/30 class concrete composition, was established as the baseline value (100%) for comparative analysis. Table 12 highlights a clear and consistent trend in strength enhancement at early curing stages when a portion of the cement is replaced with MK-95 microsilica. This improvement becomes increasingly significant as the microsilica content rises.

The strength gain can be attributed to the pozzolanic activity of microsilica, which introduces active SiO_2 into the mix. This active silica reacts with calcium hydroxide released during cement hydration, forming a tightly packed crystal structure composed predominantly of low-base calcium hydrosilicates (Calcium Silicate Hydroxide Hydrate) $Ca_5\,(OH)_2\,Si_6O_{16} * 4H_2O * CaO\,/\,SiO_2 < 1{,}5$. The resulting microstructure is denser, more homogeneous, and contributes to enhanced mechanical properties. These findings corroborate the theoretical framework outlined by the authors in [2], demonstrating the practical implications of their hypothesis.

Furthermore, Figure 3 vividly illustrates the effect of substituting up to 50 kg of MK-95 microsilica per cubic meter of concrete. This adjustment leads to a measurable increase in compressive strength, with a 12% improvement at 7 days and a remarkable 25% enhancement at 28 days. Importantly, this substitution enables a reduction in CEM I 42.5 N cement consumption from 400 kg to 360 kg per cubic meter, without compromising the specified rheological properties or the targeted compressive strength outlined in [18]. This optimization not only enhances the mechanical performance of the concrete but also aligns with sustainable construction practices by reducing the overall cement content, thereby minimizing the environmental footprint associated with cement production.

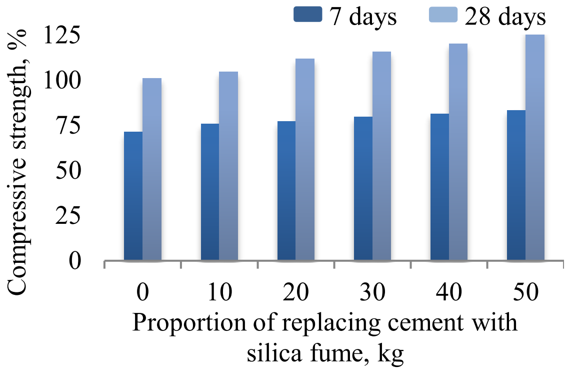

Fig.3 Compressive strength of samples with microsilica

Table 12 C25/30 class concrete composition with microsilica 95

No.	W/C	Cement		Sand		Crushed stone (5-10 mm)		Crushed stone (10-20 mm)		AR-122		Microsilica 95		Water		Compressive strength at the age of 2 days [1]		Compressive strength at the age of 7 days [1]	
		kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	MPa	%	MPa	%
1*	0.37	400	16.1	971	39.2	287	11.6	667	26.9	5.9	0.24	-	-	148	6.0	23.3	71,3	33.1	101,1
2	0.37	400	16.0	971	38.5	287	11.5	667	26.8	5.9	0.24	10	0.4	152	6.1	24.8	75,7	34.2	104.6
3	0.36	390	15.7	971	39.0	287	11.5	667	26.8	5.9	0.24	20	0.8	147	5.9	25.2	77,1	36.6	111.9
4	0.36	380	15.3	971	39.0	287	11.5	667	26.8	5.9	0.24	30	1.2	147	5.9	26.0	79,6	37.9	115.8
5	0.35	370	14.9	971	39.1	287	11.6	667	26.8	5.9	0.24	40	1.6	144	5.8	26.6	81,4	39.3	120.2
6	0.35	360	14.5	971	39.1	287	11.6	667	26.8	5.9	0.24	50	2.0	144	5.8	27.2	83,3	41.8	127.7

* *pilot composition*

Table 13 Test results of concrete reinforced with polypropylene fibers

№	Indicators	The value of indicators when using fibers				
		Concrete without fibers	Fibrin microfiber (0.1%)	Fibrin microfiber (0.2%)	FibroLux microfiber (0.8%)	FibroLux microfiber (1.1%)
		1	2	3	4	5
1	Average density $\rho_{average}$, kg/m^3	2346	2371	2368	2379	2400
2	Compression strength R_{compr}, MPa	33.9	37.2	36.9	40.7	43,2
3	Bending strength R_{prod}, MPa	5.44	5,47	5.52	6.61	7.23
4	Frost resistance F, cycle	220	280	340	225	230
5	Water resistance grade , W	W8	W14	W14	W8	W10
6	Abrasion capacity G, g/sm^2	0.77	0.58	0.56	0.72	0.74

Table 14 Physical and mechanical characteristics of samples reinforced with various sized fibers

№	Indicators	The value of indicators when using fibers				
		Concrete without fibers	Fibrin microfiber (0.1%)+ FibroLux macrofiber (0.8%)	Fibrin microfiber (0.2%)+ FibroLux macrofiber (0.8%)	Fibrin microfiber (0.1%)+ FibroLux macrofiber (1.1%)	Fibrin microfiber (0.2%)+ FibroLux macrofiber (1.1%)
		1	2	3	4	5
1	Average density ρ $_{average}$, kg/m^3	2346	2365	2341	2381	2372
2	Compression strength R_{compr}, MPa	33.9	41.3	41.0	42.6	41.3
3	Bending strength R_{prod}, MPa	5.44	6.83	7.03	7.31	7.11
4	Frost resistance F, cycle	220	330	355	360	375
5	Water resistance grade , W	W8	W12	W14	W14	W12
6	Abrasion capacity G, g/sm^2	0.77	0.51	0.51	0.46	0.44

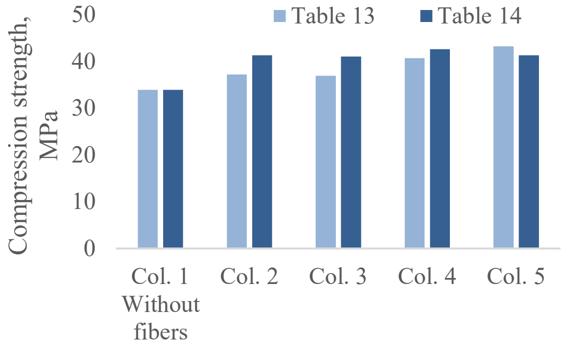

Fig.4 Impact of fiber types on compressive strength. (Data from Tables 13 and 14)

A summary of the physical and technical characteristics of fiber concrete compositions, with varying contents of 9 mm and 50 mm polypropylene fibers, experimentally confirmed during laboratory tests, is presented in Table 13.

Analysis of the experimental data in Table 13 indicates that certain types of fibers enhance specific properties of the initial concrete, while other properties remain virtually unchanged. For instance, as previously demonstrated by the author in [5], polypropylene microfibers improve compressive and bending strength by an average of 27% but have a negligible effect on the durability characteristics of fiber-reinforced concrete. Conversely, the use of macrofibers leads to improvements in frost resistance, water resistance, and abrasion resistance, while the increase in strength does not exceed 10%, consistent with earlier published studies.

Table 14 presents the test results of fiber concrete compositions with the simultaneous use of fibers of different sizes in varying proportions within the same composition.

Concrete reinforcement with low-modulus fibers represents a promising approach for improving the quality of heavy concrete. By combining fibers of various sizes in optimal quantities, it is possible to produce concrete that exhibits both the enhanced strength characteristics typically associated with macrofiber reinforcement and the high durability achieved through polypropylene microfiber reinforcement. This aligns with the findings of authors described in [20].

The compositions showed an average 25% increase in compressive strength and 30% in bending strength compared to the control composition. Water resistance improved by three grades (W8 to W14), frost resistance by 61%, and abrasion resistance by 40% [21-23]. Synthetic fiber reinforcement enhances durability, extends repair intervals, and reduces operational costs. The results confirm the feasibility of using low-modulus synthetic fibers for volumetric road slab reinforcement, particularly with various fiber sizes [24].

An example of replacing conventional concrete with fiber-reinforced concrete in prestressed products already exists. For instance, [22] describes the use of steel wire fibers in ribbed coating slabs, where stressed reinforcement is retained in the longitudinal ribs and non-stressed reinforcement in the transverse ribs, while the grid is eliminated. This approach reduced the shelf thickness by 10 mm without compromising load-bearing capacity, resulting in a lighter structure and lower concrete consumption.

5. CONCLUSION

Based on numerous laboratory and industrial tests, it can be concluded that replacing part of the cement with silica in concrete is both economically and scientifically justified. Unlike conventional concrete compositions, modified concretes achieve up to 20% cement savings while enhancing density, frost resistance, and volumetric water absorption, resulting in improved performance characteristics. The results align with previous research on concretes with microsilica and theoretical assumptions about the formation of additional crystallization centers and the reduction of pore space due to reactive pozzolanic additives (active silica SiO_2). This reaction occurs as $Ca(OH)_2$ binds with active silica to form calcium hydrosilicate: $Ca(OH)_2 + SiO_2 + mH_2O = CaO{*}SiO_2{*}nH_2O$.

Microcracks in hardening concrete arise due to early forced stresses and self-stresses caused by shrinkage or heat release during cement hydration. These cracks primarily form in the porous "cement stone/aggregate grain" contact zone. When a crack encounters a fiber, its propagation is temporarily halted as the fiber absorbs tensile forces, stabilizing the crack. Numerous small-diameter fibers are critical for preventing microcracks, as their length becomes less significant at this stage due to the absence of relative movement between the fibers and the cement matrix. Research indicates that increasing fiber size and content reduces shrinkage deformations and the probability of cracking, thereby enhancing resistance to shrinkage and reducing cracking risk.

Experiments confirm that volumetric fiber reinforcement with polypropylene fibers is highly effective for road slabs, improving concrete strength and deformation characteristics. Polypropylene macrofibers enhance strength, while microfibers modify the cement matrix, improving durability characteristics such as frost resistance, water resistance, and abrasion resistance. Combining fibers of various sizes in optimal proportions produces fiber-reinforced concrete with significantly increased strength and durability. These characteristics are particularly beneficial for producing high-strength, frost-resistant road slabs.

The findings of this study address the research objectives by demonstrating the effectiveness of fiber reinforcement and microsilica in enhancing the mechanical properties of concrete road slabs. Experimental data show up to a 25% increase in compressive strength, a 35% increase in bending strength, frost resistance of up to F375, and water resistance of up to W14. These compositions are recommended for crack-resistant road slabs with reduced cross-sections and 10–20% less weight. This research provides valuable insights for the construction industry, highlighting the benefits of incorporating advanced materials to improve performance and sustainability.

6. ACKNOWLEDGMENTS

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