

SƏNAYE TULLANTILARI ƏSASINDA DAYANIQLI MODİFİKASIYA OLUNMUŞ POLİPROPİLEN LİFLİ BETON

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Xülasə. Hazırkı tədqiqat işində sıx dağ süxurlarından və müxtəlif mənşəli sənaye tullantılarından sement sistemlərində mineral əlavələr kimi, həmçinin müxtəlif plastikləşdirici əlavələrlə birlikdə istifadə olunmasının mümkünlüyü öyrənilmişdir. Təcrübələrdə Azərbaycan Respublikasında ətraf mühit üçün potensial ekoloji təhlükə yaradan alüminium oksidi istehsalı tullantıları, təbii kvarts süxuru və çınqıl istehsalından alınan sıx daş tozundan istifadə edilmişdir. Müəyyən olunmuşdur ki, ultra incə üyüdülmüş bu komponentlər sement sistemlərində mineral əlavələr kimi tətbiq oluna bilər və bu halda sement daşının sıxılmada möhkəmliyi 4–10% artır. Müəyyən edilmişdir ki, bu incə üyüdülmüş əlavələrin S520 markalı superplastifikator və HP777 markalı hiperplastifikator ilə birlikdə istifadəsi nəticəsində ağır betonun sıxılmada möhkəmliyi 15,5% artmışdır. Belə kompleks əlavələrin polipropilen lifli betonlara təsiri öyrənilmiş və nəticədə alınan lifli betonun möhkəmliyinin 18–40% artdığı müəyyən edilmişdir. Alınmış lifli betonların sıxılmada möhkəmliyi 48,35–58,92 MPa, orta sıxlığı isə 2400–2467 kq/m³ intervalında olmuşdur. Bununla yanaşı, digər əsas istismar göstəriciləri– zərbəyə davamlılıq (12,72%), dinamik dayanıqlıq (4,16%), əyilmədə möhkəmlik (3,03%), əyilmədə dartılma möhkəmliyi (9,09%), sürtünmə müqaviməti (4%) və suya davamlılıq (9,63%) adi polipropilen lifli betonla müqayisədə daha yüksək olmuşdur. Belə betonların maya dəyərinin adi polipropilen lifli betondan 2,23 AZN daha ucuz olduğu müəyyən edilmişdir.

Aparılmış elmi-tədqiqat işləri nəticəsində texniki-iqtisadi, ekoloji və ətraf mühit baxımından səmərəli modifikasiya olunmuş polipropilen lifli beton əldə edilmişdir.

Açar sözlər: lifli beton, ekologiya, dayanıqlı inkişaf, sənaye tullantıları, sement istehsalı, iqtisadi səmərəlilik, effektivlik, məhsuldarlıq, ətraf mühit, qənaət

SUSTAINABLE MODIFIED POLYPROPYLENE FIBER CONCRETE BASED ON INDUSTRIAL WASTE

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Abstract. In the current research, the feasibility of using dense mountain rocks and industrial waste of various origins as mineral additives in cement systems, as well as in combination with various plasticizing additives, was studied. In the experiments, fine powdery aluminum oxide production waste, natural quartz rock and dense stone dust from crushed stone production, which pose a potential ecological threat to the environment in the Republic of Azerbaijan, were used and it was determined that these ultrafinely ground components can be applied as mineral additives in cement systems, and in this case, the compressive strength of cement stone increases by 4-10%. It was determined that by using these finely ground additives in combination with S520 brand superplasticizer and HP777 brand hyperplasticizer, the compressive strength of heavy concrete increased by 15.5%. The effect of such

complex additives on polypropylene fiber fiber concretes was studied and it was determined that the strength of the resulting fiber concrete increased by 18-40%. The compressive strength of the obtained fiber concretes was determined to be 48.35-58.92 MPa, the average density was within the range of 2400-2467 kg/m³, and at the same time, other main operational indicators (impact resistance (12.72%), dynamic stability (4.16%), bending strength (3.03%), bending tensile strength (9.09%), friction (4%) and water resistance (9.63%)) were higher than those of ordinary polypropylene fiber fiber concrete. The cost of such concretes was determined to be 2.23 AZN cheaper than polypropylene fiber concrete. As a result of the conducted scientific research work, a modified polypropylene fiber concrete with technical and economic environmental and ecological effectiveness was obtained.

Keywords: fiber concrete, ecology, sustainable development, industrial waste, cement production, economic efficiency, effectiveness, productivity, environment, savings

Introduction. In the modern era of developing techniques and technologies, the organization of the production of various materials with the application of environmentally friendly, economically efficient, and environmentally friendly raw materials and materials, as well as low-labor-intensive advanced technologies, is one of the important issues facing all industries. This issue is particularly relevant in the context of sustainable development, which involves the rational use of natural resources to reduce environmental impacts and improve the efficiency of cleaner industrial production. Considering that the growing population in all parts of the world requires the expansion of new workplaces, residential areas, recreational facilities, and other construction areas. At the same time, the increasing scale of the construction industry is accompanied by an increase in the consumption of mineral resources and energy, which focuses the attention of researchers on issues of resource conservation and environmental sustainability of building materials. Then we can see that the construction sector is developing rapidly in the world. Currently, concrete and reinforced concrete products and structures made on the basis of concrete mixtures for various purposes are being used in construction. In modern times, in addition to residential and catering buildings, as well as small facilities, the demand for the construction of buildings and structures that require higher responsibility and have architecturally magnificent, unique and individual features has increased significantly. This increases the scale of responsibility of scientists and researchers working in the field of materials science, manufacturing enterprises, as well as engineers participating in the design and implementation process. From this point of view, in recent years, the demand for special-purpose, specific-property concrete mixtures and reinforced concrete products produced on their basis has increased. Considering that the main component that increases the cost of reinforced concrete products is reinforcement and reinforcement products, it is not possible to use large-diameter and high-strength reinforcement products in thinner and bending-requiring structures, or it is necessary to use smaller-diameter and densely placed reinforcement products (nets). This leads to a significant increase in the cost of buildings and structures. Therefore, scientific research shows that the use of various types of fibers in the production of thinner and durable products and structures with special properties gives more effective results. It should also be noted that an additional advantage of using fiber is the ability to partially reduce the material consumption of structures and increase their durability, which meets modern requirements for sustainable construction. Such types of concrete are concretes reinforced with metal, polypropylene, basalt, glass, carbon and other fibers. The application of this type of fiber concrete is expanding today [1-3].

It is known that the discovery and practical application of fiber concrete has a history of more than a century. Thus, the idea of the possibility of producing fiber concrete was put forward by the Russian scientist V.P. Nekrasov in 1909. Therefore, it is V.P. Nekrasov who is considered the author of the production of fiber concrete. However, the large-scale study and application of fiber concrete began in the 60s of the 20th century. Thus, fiber concrete has been studied by researchers from the USA, Great Britain, Canada and other countries. Currently, fiber concrete reinforced with various types of fibers is considered a new generation of high-quality concrete. In modern times, by reinforcing concrete and construction mortars with various fibers, it is possible to improve their physical, mechanical and operational characteristics and increase their durability. Thus, increasing the service life of structures

and reducing the need for their repair and replacement of parts are also considered important factors for the sustainable development of the construction industry. Fiber concrete is considered one of the most promising materials of the 21st century. One of the reasons for such promising and widespread application of fiber concrete is the possibility of applying new fibers in its production and the possibility of applying complex additives for various purposes [4].

Literature review and problem statement. This research aims to develop a sustainable artificial stone material from limestone dust waste through optimization of granulometric composition, binder ratio, and use of hyperplasticizers [5]. Such research is considered an important area of sustainable development of building materials, as it is aimed at utilizing industrial waste and reducing the resource intensity of cement production. The possibility of producing fiber-reinforced concrete with high deformation properties by regulating the microstructure and using it in the design of transport structures was considered. It was found that to create high-performance transport structures, it is necessary to modify fiber mixtures with complex additives, i.e., increase the strength of fiber-reinforced concrete at the micro-level. To obtain a denser structure of the concrete matrix, complex additives were used—ultrafine additive (silica fume) and Master Air 200 B air-entraining additive. It was experimentally proved that using such additives reduces the water-cement ratio and further strengthens the concrete matrix structure [6].

This article discusses the development of modified fiber-reinforced concrete formulations using finely ground mineral additives containing SiO_2 and hyperplasticizers. A comparative analysis of the properties of conventional concrete and its modifications is provided [7].

It should be noted that the use of mineral additives, partially replacing cement, is of particular importance in the context of high volumes of global cement production, accompanied by significant energy costs and greenhouse gas emissions. In the presented paper, concrete resistance to friction was studied. B25 class heavy concrete was selected as an experimental object. Polypropylene and metal fibers were used to increase friction resistance of the selected concrete. The test was carried out on the LKI-3M friction device in accordance with the requirements of ГОСТ 13087. Based on the test results, it was found that the resistance of the polypropylene fiber concrete to the anti-friction resistance of 0.28 g/cm^2 , whereas in the case of metal fiber concrete, this indicator was 0.30 gr/cm^2 . Test results were compared with 112.5% of polypropylene fiber concrete, and 6.25% higher resistance to concrete fibrous concrete compared to B25 grade concrete samples. Based on the results of the experiment, it is possible to say that the application of fiber concrete in the construction of road surfaces is more effective [8].

The crack resistance of fiber-reinforced concrete with and without additives was determined. Based on the test results, it was found that crack resistance was higher for concrete samples containing polypropylene and metal fibers than for standard concrete.

Fiber-reinforced concrete using microsilica has shown improved performance. The effectiveness of using such concrete in road pavement construction has been established [9].

Improving the crack resistance and durability of concrete pavements is considered an important factor in the sustainable development of transport infrastructure, allowing for a reduction in repair and maintenance costs.

In the presented paper, concrete resistance to friction was studied. B25 class heavy concrete was selected as an experimental subject. Polypropylene and metal fibers were used to increase the friction resistance of the selected concrete [10].

Efficiency in the construction, reconstruction, and repair of transport structures can be achieved by using fiber-reinforced concrete with high deformation properties. This article examines the possibility of using complex additives to optimize the composition of fiber-reinforced concrete with high deformation properties. It was found that the use of chemical and ultrafine additives in fiber-reinforced concrete significantly increases compressive and flexural strength. This is due to the fact that the use of steel fibers allows for uniform reinforcement of the concrete throughout the entire volume, which favorably affects the distribution of stresses in the concrete mass and leads to a reduction in stresses in hazardous areas [11]. Taken together, these approaches meet modern sustainable construction requirements aimed at increasing the operational reliability of structures while rationally using material and energy resources.

Research materials and methods. The current study examined the issue of improving the properties of fiber concrete using local raw materials and materials of the Republic of Azerbaijan. The use of local raw materials reduces transportation costs and promotes the rational use of natural and material resources in construction. For this purpose, the research used CEM II/A-L 42.5 R (Expert) cement produced at the Holcim Azerbaijan Cement Plant, sand from the Bahramtepe deposit (Imishli district), and sand and crushed stone from the Gudiyalchay quarry (Guba district). In order to improve the properties of concrete and also save on Portland cement, mineral additives, plasticizers, and polypropylene fibers, which are currently more widely used in the preparation of fiber concrete mixtures, were used. Reducing the consumption of Portland cement by partially replacing it with mineral additives is considered as one of the ways to reduce the resource intensity of concrete compositions.

As a mineral additive, waste generated during the production of aluminum oxide by the Ganja Gil-Torpaq Production Association operating in the Republic of Azerbaijan, as well as quartz sand from the Umbakı deposit located near Baku and dust generated during the crushing of dense mountain rock, S520 brand superplasticizer, HP 777 brand hyperplasticizer, and SikaFiber T-60s brand polypropylene fibers were used as fibers to improve the rheological properties of the mixture. The inclusion of industrial waste in concrete mixtures allows us to consider the resulting compositions to be oriented towards the principles of rational use of secondary resources.

The chemical (by X-ray spectral method) and mineral (X-ray phase method) compositions of the used mineral additives were studied.

Based on the results of the X-ray spectral analysis, it can be said that the chemical composition of the finely ground aluminum oxide production waste is SiO_2 – 17.44%; Al_2O_3 – 15.60%; Fe_2O_3 – 46.79%; CaO – 1.67%; Na_2O – 2.31%; MgO – 0.28%; P_2O_5 – 0.18%; SO_3 – 0.49%; K_2O – 0.39%; TiO_2 – 3.21%; MnO – 0.43%; Cl – 0.06%, the amount of volatile components at a temperature of 950°C is 10.20%, the mineralogical composition is quartz SiO_2 , magnetite Fe_3O_4 , hematite Fe_2O_3 and feldspar.

The composition of the crushed quartz sand mineral additive is SiO_2 – 97.01%; Al_2O_3 – 0.49%; Fe_2O_3 – 1.16%; CaO – 0.75%; Na_2O – 0.01%; MgO – 0.06%; P_2O_5 – 0.01%; SO_3 – 0.14%; K_2O – 0.09%; TiO_2 – 0.03%; MnO – 0.01%; It was found that Cl – 0.03% and the amount of volatile components at a temperature of 950°C was 0.16%, the main phase of the mineralogical composition was quartz SiO_2 , and a small amount was feldspar.

The granular composition of mineral additives was studied by granulometric analysis. Considering that additives are used to reduce cement consumption, the granular composition of cement was analyzed in parallel in the experiments. The test results were compared. The results of granulometric analysis of the samples are given in Table 1 [12].

Table 1. Granular composition of mineral additives

Particle size, $x_0/\mu\text{m}$	Cumulative distribution, $Q_3/\%$	Particle size, $x_0/\mu\text{m}$	Cumulative distribution, $Q_3/\%$	Particle size, $x_0/\mu\text{m}$	Cumulative distribution, $Q_3/\%$
1	2	3	4	5	6
Waste from the alumina industry					
0,90	7,00	5,00	28,86	30,00	52,05
1,10	9,82	6,00	30,80	36,00	55,02
1,30	12,24	7,50	33,31	43,00	58,26
1,50	14,32	9,00	35,45	51,00	61,82
1,80	16,94	10,50	37,32	61,00	66,09
2,20	19,70	12,50	39,54	73,00	70,86
2,60	21,82	15,00	41,96	87,00	75,74
3,10	23,87	18,00	44,49	103,00	80,46
3,70	25,77	21,00	46,71	123,00	85,78
4,30	27,31	25,00	49,28	147,00	92,22

				175,00	100,00
				S _m =4887,33 cm ² /g	
Natural quartz sand					
0,90	4,57	6,00	22,16	43,00	74,45
1,10	6,41	7,50	25,27	51,00	81,59
1,30	7,98	9,00	28,33	61,00	89,19
1,50	9,33	10,50	31,33	73,00	95,58
1,80	11,03	12,50	35,20	87,00	98,87
2,20	12,85	15,00	39,78	103,00	99,95
2,60	14,29	18,00	44,87	123,00	100,00
3,10	15,77	21,00	49,50	147,00	100,00
3,70	17,25	25,00	55,01	175,00	100,00
4,30	18,59	30,00	61,05	S _m =4100 cm ² /g	
5,00	20,07	36,00	67,54		

The parameters of the S520 superplasticizer and HP777 hyperplasticizer used are given in Table 2, and the parameters of the SikaFiber T-60s polypropylene fibers are given in Table 3.

Table 2. Main indicators of S520 superplasticizer and HP777 hyperplasticizer

Plasticizer type and brand	Chemical composition	Density, g/cm^3 (at 20°C)	pH values
Superplasticizer S520	Aqueous solutions of modified polycarboxylate esters and lignosulfonates	1.14-1.16	5.0 – 7.0
Hyperplasticizer HP777	Polycarboxylate	1.30-1.35	5.0 – 6.0

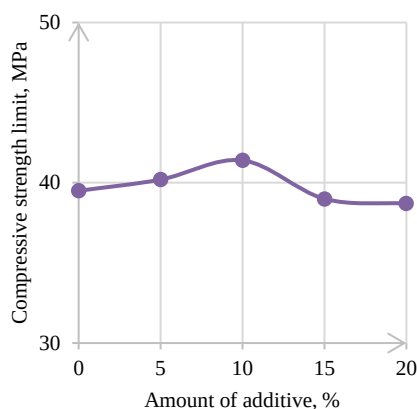
Table 3. Characteristics of SikaFiber T-60s polypropylene fiber

Brand	Sika
Country of manufacture	Swiss
Color	black
Length	60 mm
Diameter	0.9 mm
Tensile strength	>500 MPa
Density	0.91 kg/dm^3
Adsorption	none
Chemical resistance	high
Melting temperature	+280°C
Resistance to molds	high
Modulus of elasticity	20 MPa
Weight	0.90 g/cm^3
Maximum elongation	25%

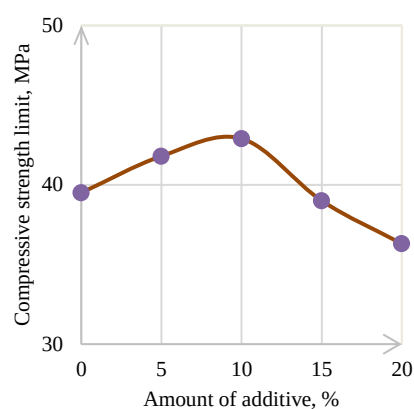
The tests were carried out in accordance with the requirements of the International Standards Documents in force in the Republic of Azerbaijan. The performance of cement was studied in accordance with the technical requirements of the State Standard AZS EN 197.1-2021 [13] according to the test methods and rules EN 196-2-2013 [14].

The properties of the concrete mixture were determined in accordance with the standard EN 206-1:2000 [15]. The compressive strength of concrete was studied according to EN 12390-2 [16], crack resistance tests according to ISO 29167-2021 [17], dynamic stability of concrete, tensile and flexural strength according to ISO 10180-2012 [18], abrasion tests according to ISO 13087-2018 [19], and water resistance according to ISO 12730.5-2018 [20].

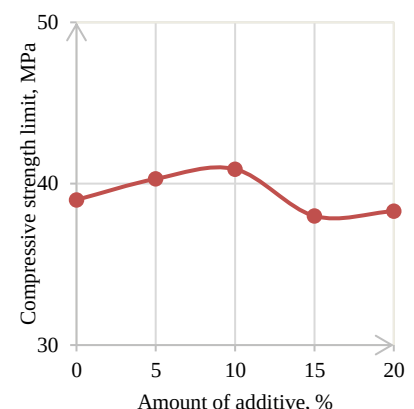
Work conduct. The research was carried out in stages. At the initial stage, the possibility of using ultrafine ground alumina production waste, quartz sand and slag stone powder as mineral additives was studied, and their effect on cement-sand systems was determined. The use of these materials was considered not only from the standpoint of improving the properties of cement systems, but also from the point of view of involving secondary resources in construction production. The samples were prepared in standard sizes in the ratio cement: sand = 1:3. The ultrafine ground mineral additives used were used in an amount of 5-20% of the cement consumption, and their effect on the rheological properties and mechanical properties of the cement mortar was studied. The results were analyzed in comparison with samples prepared without additives in parallel. The normal density and setting time of the prepared mortar were determined in the Vika device, and standard 40x40x160 mm bars were prepared from the prepared mixtures. The samples were tested after hardening by the standard method. The test results are given in graphs 1-3.



Graph 1. Dependence of cement stone strength on the amount of finely ground alumina production waste



Graph 2. Dependence of cement stone strength on the amount of finely ground quartz sand



Graph 3. Dependence of cement stone strength on the amount of finely ground dense stone dust

As can be seen from Graph 1-3, when finely ground mineral components (aluminum oxide production waste, quartz sand, dense stone dust) were used in an amount of 10% of the cement consumption, the strength of the tested cement stone increased by 4.87%, 10%, 6.15%, respectively. Thus, partial replacement of Portland cement with mineral additives allows for simultaneous improvement of strength characteristics and reduction of binder consumption. The effect of the additives used on the structure formation process of cement stone was studied (Figure 1).

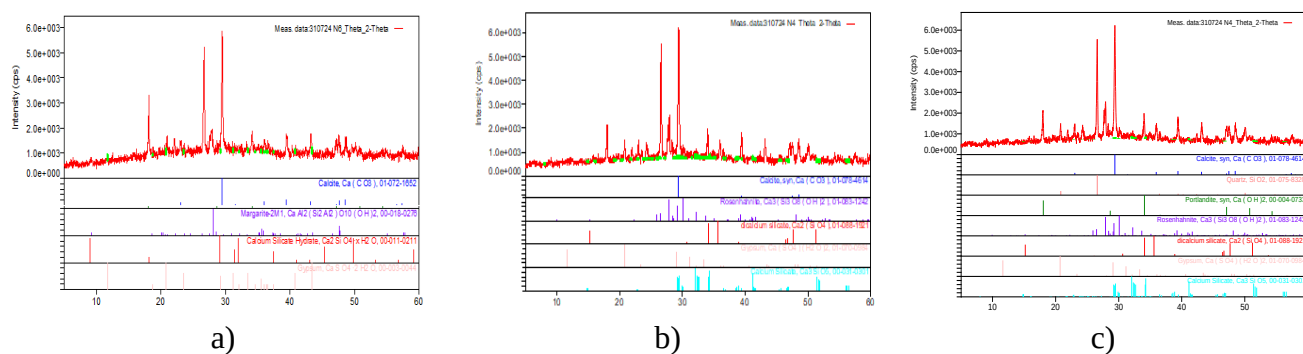


Figure 1. Diffractogram of cement stone samples with mineral additives: a) aluminum oxide production waste-based sample; b) quartz sand sample; c) stone waste dust-based sample

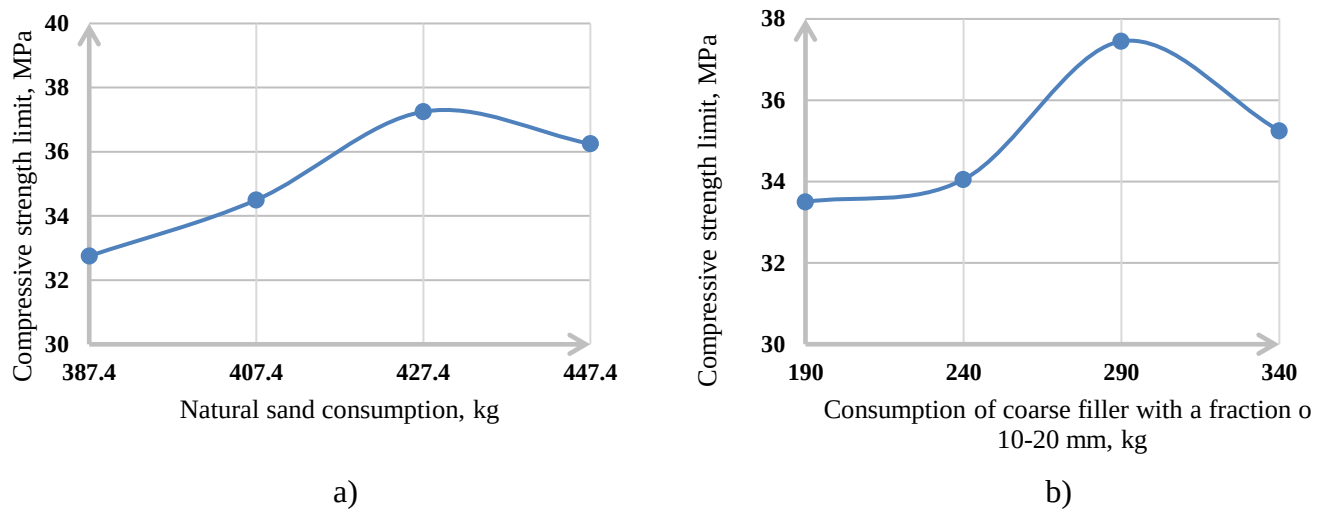
As can be seen from the diffractogram (Figure 1. a), when ultrafine ground alumina production waste was used, the mineralogical composition of the cement stone was α -quartz SiO_2 , calcite CaCO_3 , calcium hydroxide $\text{Ca}(\text{OH})_2$, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, $\text{CaAl}_2(\text{Si}_2\text{Al}_2)\text{O}_{10}(\text{OH})_2$, when ultrafine ground quartz sand was used (Figure 1. b), the mineralogical composition of the cement stone was α -quartz SiO_2 , calcite CaCO_3 , calcium hydroxide $\text{Ca}(\text{OH})_2$, $\text{Ca}_3(\text{SiO}_8)(\text{OH})_2$, Ca_3SiO_5 , belite Ca_2SiO_4 , $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, and in the samples using ultrafine ground dense stone powder (Figure 1. c), the mineralogical composition of the cement stone was α -quartz SiO_2 , calcite CaCO_3 , portlandite $\text{Ca}(\text{OH})_2$, $\text{Ca}_3(\text{SiO}_8)(\text{OH})_2$, belite Ca_2SiO_4 , Ca_3SiO_5 minerals form. The main structural, dense and high strength properties of cement systems with hardened mineral additives are formed due to the $\text{Ca}_2\text{SiO}_4 \cdot x\text{H}_2\text{O}$ mineral (table 4).

Table 4. Mineralogical composition of mineral additives used, %

No	Mineral additive name	SiO ₂ (α-	CaCO ₃	Ca(OH) ₂	Ca ₃ (SiO ₈)(OH)	Ca ₃ SiO ₅	Ca ₂ SiO ₄ x0.5H ₂ O	Ca ₂ SiO ₄ (belite)	Ca ₅ (SiO ₄) ₂ (OH	CaSO ₄ x2H ₂ O (gypsum)	CaAl ₂ (Si ₂ Al ₂)O ₁₀ (OH) ₂	Magnetite	Fe ₂ O ₃	Amorphous
1	Aluminum oxide production waste	15	25	20	-	-	-	-	-	5	25	-	-	10
2	Quartz sand	13	29	17	14	6	-	6		4	-	-	-	11
3	Dense stone dust	10	14	48	6	-	10	-	2	4	-	-	-	4

The second stage was devoted to determining the share of coarse and fine aggregates used in the single system. Since the main part of the concrete composition is made up of fillers (85%), the effect of fine (sand) and coarse aggregates (crushed stone) was studied, taking into account the significant effect of the location and distribution level of fillers in a single volume on the operational characteristics of concrete. Optimization of grain composition was considered as a way to increase the density of the structure and rational use of mineral resources. After studying the relative consumption share of local coarse and fine aggregates in a single volume, fiber concrete mixtures were prepared taking into account this share share. After standard samples were hardened for 28 days, the compressive strength limit was determined by testing them in a UTEST UTC-4320 hydraulic press. In all cases, 3 standard-sized 150x150x150 mm samples were prepared based on concrete mixtures. In the experiments, water, cement and one type of filler were kept constant, the consumption of other fillers was changed by 20 kg and

samples were prepared. The compressive strength limit of the hardened samples (graph 4) was determined [21].

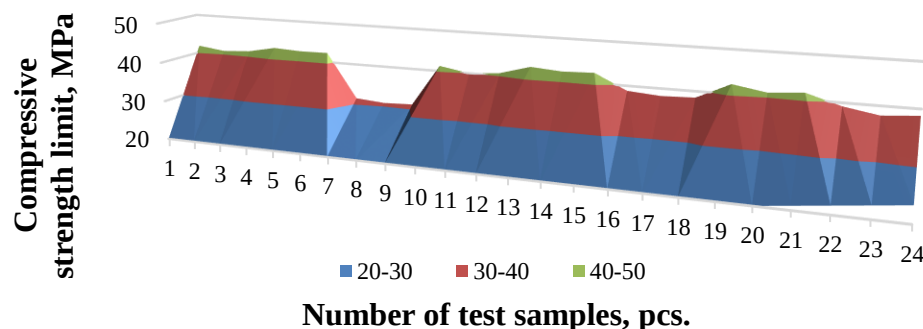


Graph 4. a) The effect of natural sand consumption on the compressive strength of heavy concrete; b) The effect of 10-20 mm crushed stone consumption on the compressive strength of heavy concrete

Based on the experimental results (graph 4. a), it was determined that the use of a fine aggregate mixture in the concrete mixture, natural sand: fine sand = 42.65%: 57.35% ratio, is more effective both economically and technologically. According to the obtained results, the compressive strength of concrete increased by 13.74% [21].

It was considered more efficient to prepare a coarse aggregate mixture based on two fractions of crushed stone (5-10 mm) : (10-20 mm) = 74.5%: 25.5%. The test results showed that a denser concrete structure was obtained in this ratio, and therefore, the compressive strength of the obtained concrete was 37.45 MPa (graph 4. b), which increased the compressive strength of the concrete prepared on the basis of the initial mixture by 6.24% [21]. This gives grounds to say that the small filler grains in a single volume at the specified filler ratio fill the gaps between the large fillers more densely, and it is possible to obtain dense structural concrete.

Taking into account the initial experimental results, polypropylene fiber-reinforced concrete and modified fiber-reinforced concrete compositions were developed. The experiments were conducted not by the traditional classical method, but by a more progressive method applied in the science of concrete science - the method of mathematical statistical planning of experiments. In the experiments, the water/cement ratio was kept constant, 3 influencing factors (cement, mineral additives, fiber) were selected and a 23-type experimental plan was developed. The experiments were carried out according to the plan and the test results are given in graphs 5-7. The results obtained in the experiments were analyzed comparatively with the indicators of heavy concrete samples with optimal composition prepared in parallel.

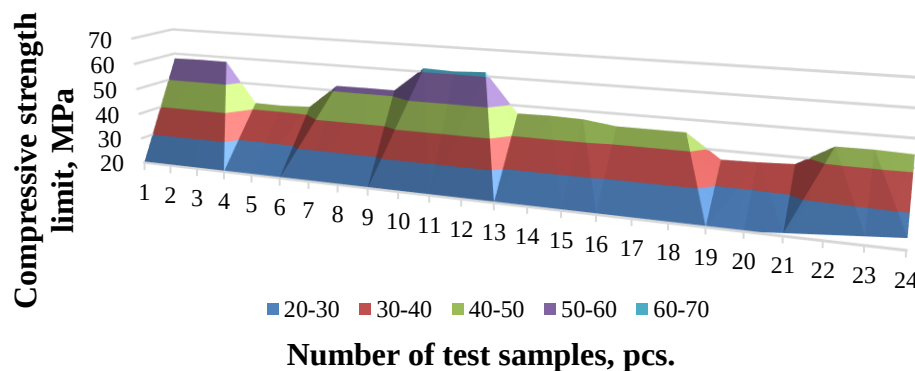


Graph 5. Test results of ordinary heavy concrete

The test results of ordinary heavy concrete were statistically analyzed using a computer program, and a mathematical model of the compressive strength parameter, the main indicator of concrete, was constructed taking into account the obtained regression coefficients.

$$R_{str} = 39,73 + 0,39X_1 - 1,23X_2 + 0,53X_3 + 0,85X_1X_2 - 1,7X_1X_3 + \\ + 1,07X_2X_3 - 0,68X_1X_2X_3$$

Taking into account statistical analysis and the influence levels of variable factors, the optimal composition of ordinary heavy concrete was determined by the short rise method, both computationally and experimentally. The compressive strength of the obtained ordinary heavy concrete with the optimal composition was 41.84 MPa.

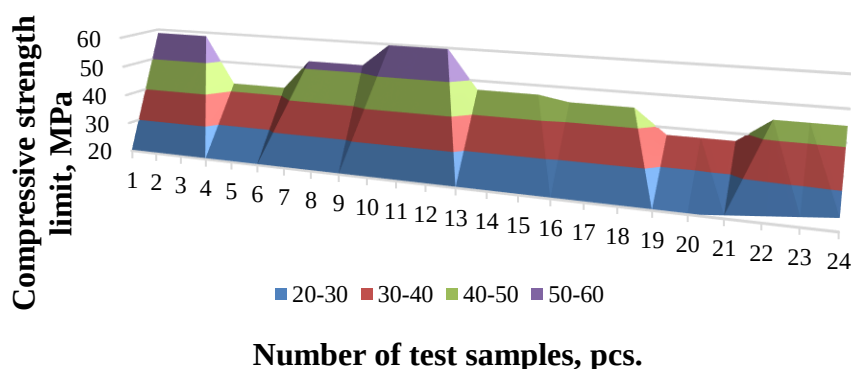


Graph 6. Test results of finely ground alumina production waste and polypropylene fiber concrete with HP – 777 hyperplasticizing additive

The test results of ultrafine ground aluminum oxide production waste, polypropylene fiber fiber concrete with complex additives containing HP777 brand hyperplasticizer were statistically analyzed using a computer program, and a mathematical model of the compressive strength parameter, the main indicator of concrete, was constructed taking into account the obtained regression coefficients.

$$R_{a.hp.f.s.}^{28} = 48,49 + 0,306X_2 - 4,91X_3 + 1,57X_1X_3 - 2,92X_2X_3 - 1,98X_1X_2X_3$$

Taking into account the statistical analysis and the influence levels of variable factors, the optimal composition of modified polypropylene fiber fiber concrete with complex additives (hyperplasticizer, finely ground aluminum oxide production waste) was determined computationally and experimentally by the short rise method. The compressive strength of the modified polypropylene fiber fiber concrete with the optimal composition obtained was 48.35 MPa, which increased by 6.51 MPa (15.5%) compared to heavy concrete.



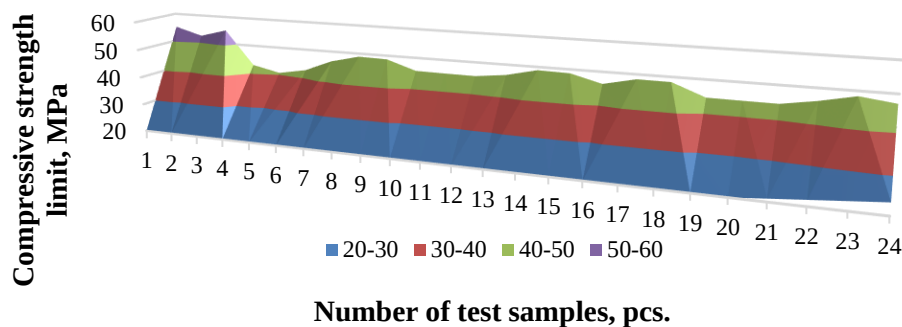
Graph 7. Test results of polypropylene fiber concrete containing finely ground quartz sand and a hyperplasticizing additive of the HP – 777 brand

The test results were statistically analyzed using a computer program and a mathematical model (regression equation) of the compressive strength limit parameter of fiber concrete was developed [21].

The optimal composition of the modified polypropylene fiber concrete with complex additives containing HP777 hyperplasticizing ultrafine ground quartz sand was established according to the experimental results (compressive strength limit parameter) carried out in accordance with the levels of the variable factors, taking into account the regression coefficients determined as a result of statistical analysis and the influencing factors.

$$R_{g.hp.f.s.}^{28} = 48,78 - 0,219X_1 + 0,44X_2 - 4,97X_3 + 4,42X_1X_2 + 1,54X_1X_3 - 2,77X_2X_3 - 1,97X_1X_2X_3$$

Taking into account the levels of variable factors, the optimal composition of polypropylene fiber-reinforced concrete with a complex additive of hyperplasticizer, ultrafinely ground quartz sand was developed and it was determined that the compressive strength of the modified fiber-reinforced concrete is 58.92 MPa, which is 17.08 MPa (40.82%) higher than that of conventional heavy concrete.



Graph 8. Test results of polypropylene fiber reinforced concrete with finely ground quartz sand and S520 superplasticizer additive

Based on the results of the conducted experimental tests of polypropylene fiber-reinforced concrete with complex additives containing S520 brand superplasticizer, ultrafine ground quartz sand, and a computer program analysis, the mathematical model of the parameter $R_{g.sp.f.s.}^{28}$ was obtained as follows:

$$R_{g.sp.f.s.}^{28} = 47,05 - 1,55X_1 - 0,87X_2 + 1,61X_1X_2 + 2,18X_1X_3 - 0,77X_1X_2X_3$$

Statistical analysis of the results, calculation of influencing factors, compliance with the influence limit and experimentally verified, determined the compressive strength of the modified polypropylene fiber concrete with an optimal composition (finely ground quartz sand, S520 brand superplasticizer) as 49.70 MPa. This indicator was 7.86 MPa (18.78%) higher than the corresponding indicators of heavy concrete with an optimal composition. Based on the results of the conducted experiment, it can be said that the properties of polypropylene fiber concrete can be improved by using complex additives of various compositions.

The operational characteristics of the modified fiber concrete optimized in terms of composition and properties were studied. Experimentally, the following properties of the proposed modified fiber concrete were determined: Crack resistance (12.72%), dynamic stability (4.16%), bending strength (3.03%), tensile strength during bending (9.09%), friction (4%) and water resistance (9.63%). The obtained results were determined to be higher than those of conventional polypropylene fiber reinforced concrete. Improving operational characteristics helps to increase the service life of structures and reduce repair and maintenance costs. The economic efficiency of modified fiber reinforced concrete, which is more effective in terms of technological and operational aspects, more effective in terms of ecological and environmental protection (waste management) due to the use of raw materials (saving cement, efficient filler consumption per unit volume), and effective in terms of traditional classical concrete, has been studied. Thus, the obtained results demonstrate a combination of technological, economic, and environmental efficiency, which corresponds to modern principles of sustainable development of

building materials. It is known that the economic efficiency of the product depends on many factors. Considering that the largest expense in the construction of buildings and structures, as well as in the production of products, is the cost of materials. For this reason, the economic efficiency of the proposed modified fiber reinforced concrete was determined taking into account the costs incurred on materials. The report on the economic efficiency of modified fiber reinforced concrete was carried out in accordance with wholesale prices in Azerbaijan, taking into account the locality of the materials. The results are given in Table 5.

Table 5. Cost and economic efficiency of modified fiber concrete

Name of raw materials and materials	Unit of measurement	Consumption per 1 m ³ of fiber concrete mixture	Wholesale price of materials, AZN	Total cost, AZN	Economic efficiency, AZN
Polypropylene fiber reinforced concrete					
Cement	tone	0.375	142	53.25	
Natural sand	m ³	0.14	18	2.52	
Alanti sand	m ³	0.19	17	3.23	
Crushed stone (5-10)	m ³	0.59	17	11.03	
Crushed stone (10-20)	m ³	0.22	17	3.74	
Superplasticizer	kg	10.4	1,5	15.6	
Polypropylene fiber	kg	6.35	5.73	36.38	
Water	m ³	0.137	2	0.27	
Total cost:				125.02	
Modified polypropylene fiber reinforced concrete					
Cement	tone	0.359	142	50.9	
Natural sand	m ³	0.14	18	2.52	
Alanti sand	m ³	0.19	17	3.23	
Crushed stone (5-10)	m ³	0.59	17	10.03	
Crushed stone (10-20)	m ³	0.22	17	3.74	
Mineral additive	m ³	0.01	12	0.12	
Superplasticizer	kg	10.4	1,5	15.6	
Polypropylene fiber	kg	6.35	5.73	36.38	
Water	m ³	0.137	2	0.27	
Total cost:				122.79	2.23

As can be seen from Table 4, the total cost of materials for 1 m³ of polypropylene fiber reinforced concrete is 125.02 AZN, while for modified fiber reinforced concrete this cost is 122.79 AZN. The economic efficiency of 1 m³ of modified fiber reinforced concrete is 2.23 AZN. The economic calculations performed show that the proposed modified fiber reinforced concrete can be considered an economically efficient type of concrete.

Result. The possibility of applying finely ground raw materials of various origins (aluminum oxide production waste, quartz sand, dense stone dust) to cement systems has been determined. It has been established that the inclusion of these materials allows for the rational use of secondary resources in the composition of cement compositions. It has been experimentally determined that when these additives of various origins are used in an amount of 10% of the cement consumption, it allows to increase the compressive strength of cement stone by 4.87-10%.

By taking a mixture of fine fillers (natural sand - fine sand consumption) in a ratio of natural sand: fine sand = 42.65% : 57.35% in a unit volume, it was possible to obtain an economically and technologically effective dense-structured concrete with a compressive strength of 13.74%. By effectively selecting a large filler fraction in a unit volume ((5-10 mm) : (10-20 mm) = 74.5% : 25.5%),

an increase in the compressive strength of concrete by 6.24% was achieved. Optimization of the grain composition contributed to the formation of a denser concrete structure and increased efficiency in the use of mineral resources.

The preparation of modified polypropylene fiber-reinforced concrete with a hyperplasticizer HP777 brand, finely ground aluminum-oxide production waste, with a compressive strength of 48.35 MPa, optimized in terms of composition and properties, was determined by calculation and experimental methods. It was determined that the compressive strength of this type of modified fiber-reinforced concrete is 15.5% higher than that of conventional heavy concrete with an optimal composition.

Through calculations and laboratory experiments, a modified polypropylene fiber-reinforced concrete with a hyperplasticizer HP777 brand, finely ground quartz sand, with a compressive strength of 58.92 MPa, optimized in terms of composition and properties, was obtained. It was determined that the compressive strength of this type of modified fiber-reinforced concrete is 40.82% higher than that of conventional heavy concrete with an optimal composition.

Experimentally, a modified polypropylene fiber-reinforced concrete with a compressive strength of 49.70 MPa was obtained with a hyperplasticizer of the S520 brand, finely ground quartz sand, a complex additive optimized in terms of composition and properties. It was determined that the compressive strength of this type of modified fiber-reinforced concrete is 18.78% higher than that of conventional heavy concrete with an optimal composition.

Modified fiber-reinforced concrete with a crack resistance (12.72%), dynamic stability (4.16%), bending strength (3.03%), bending tensile strength (9.09%), friction (4%) and water resistance (9.63%) was obtained by applying complex additives of various origins. The improvement in the specified performance indicators indicates a potential increase in the service life of structures and a reduction in operating costs.

Taking into account the cost of materials used in the preparation of 1 m³ of concrete mixture, a modified polypropylene fiber-reinforced concrete composition was developed, which was obtained economically cheaper. Based on the results of the conducted calculations and experimental tests, an economically and technologically efficient, environmentally and ecologically effective modified polypropylene fiber reinforced concrete was obtained. The obtained results demonstrate the combination of strength, performance, and resource efficiency characteristics of the developed material, making it a promising material for the sustainable development of the construction industry. The developed approach can be adapted to various regions, taking into account national regulatory requirements and environmental standards.

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