



EFFECTIVELY MODIFIED HEAVY CONCRETE

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Abstract

This work is devoted to the production of modified high-performance heavy-duty concrete based on materials produced in the Republic of Azerbaijan and industrial waste for various purposes. Fine industrial waste capable of causing environmental pollution and natural quartz sand from Umbaki were used as mineral additives. Ultrafine mineral additives were used in an amount of 10% of cement consumption. With a 10% decrease in cement consumption, the physical and mechanical properties of the proposed modified heavy-duty concrete increased by 2.02% and 2.77%, respectively, compared to conventional heavy-duty concrete. According to the results of the experiments, these fine mineral additives have a positive effect on the physical and mechanical properties of cement, increasing them by 1.92% and 3.62%, respectively. The production of the proposed modified concrete is cost-effective and environmentally friendly, and allows the purchase of modified heavy-duty concrete at a price of 1.78 manat.

Keywords: heavy concrete, modified concrete, ecology, cost-effectiveness, efficiency, productivity, environment

1. INTRODUCTION

The construction materials produced vary depending on their application. This diversity is primarily determined by their properties, which are determined by the specific characteristics of their application, as well as by the economic resources allocated to their production, their environmental impact, their environmentally friendly use, the effectiveness of which depends on the types of raw materials used in production and their effective application, the environmental friendliness of the raw materials, and a number of other factors. Furthermore, the technical and economic performance and efficiency of any product are also determined by its wholesale price. This price can be determined by many factors, including production technology, equipment costs, labor costs, fuel costs, raw materials and supplies, and so on.

Considering that 60% of the cost of manufactured products comes from raw materials and other components, the use of zero-waste technologies in the production process or the use of various polluting industrial wastes instead of natural resources as an efficient source of raw materials further increases the cost-effectiveness of products. Therefore, many researchers are working on using industrial and consumer waste as additives for various purposes, saving materials used in the production of concrete and reinforced concrete. The use of additives to reduce the cost of expensive equipment and specialized production requiring sealing, as well as Portland cement, which is labor- and energy-intensive, is an important area of research with scientific, practical, and economic significance.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

To achieve a denser concrete matrix structure, complex additives were used—an ultrafine additive (silica dust) and the air-entraining admixture Master Air 200 B. Experiments have shown that the use of such additives reduces the water-cement ratio and further compacts the concrete matrix structure [1].

The feasibility of using aluminum oxide production waste from the Ganja Clay and Soil Production Association, located in the Republic of Azerbaijan, as a mineral-active additive was experimentally determined. When using APW at a rate of 10% of the cement consumption, the flexural strength of cement-sand systems increased by 6.2–6.4 MPa after 28 days, and the compressive strength by 39.5–41.4 MPa after 28 days. A comparison of these results with the corresponding parameters of a cement-sandstone mixture without additives showed that the activity of the modified binder increased by 3.2% and 4.8%, respectively. The development of modified concrete compositions was carried out using the method of mathematical statistical analysis of experiments; mathematical models of the ultimate parameter of concrete compressive strength were created, and the optimization of the composition and properties was carried out taking into account the influencing factors through a short lift (replica) [2-3].

The local volcanic rocks used were Tovuz trass and Jeyranchol volcanic ash, while the man-made wastes were waste from the Ganja Alumina Refinery's aluminum oxide production process and open-hearth slag. Microsilica fume was also used for comparison purposes. Mineral additives were introduced into the mixture at a rate of 5–20% of the cement consumption. The impact of mineral additives on the key construction and technological properties of the concrete mix and on the key physical and mechanical properties of hardened concrete was studied. A comparative analysis of the obtained results shows that the use of finely ground additives is feasible when replacing 5–15% of the cement. The use of local additives has the same effectiveness as microsilica fume. For this purpose, local additives were ground to a specific surface area of 250, 370, 470, and 560 m²/kg, after which test specimens were prepared and tested after 28 days of normal curing. An analysis of the test results allows us to draw the following conclusions. It is possible to reduce cement consumption by 5–10% using activated Tovuz trass; to reduce cement consumption by 5–15% using activated Jeyranchol volcanic ash; to reduce cement consumption by 5% using waste from the aluminum oxide production of the Ganja Alumina Refinery; to reduce cement consumption by 5–15% using open-hearth slag. At the same time, the main properties of concrete will be preserved. The dynamics of changes in compressive strength of samples manufactured using finely dispersed waste are presented in comparison with concrete without additives [4–8].

The economic aspect of the proposed material efficiency is presented and the role of public policy in providing market incentives for more efficient material use is discussed. In addition, the engineering approach to material efficiency presented by Allwood et al. (2011) in the previous issue of Resources, Conservation and Recycling is commented on. We argue that concerns about potential future resource shortages are not a compelling reason to introduce policies aimed at improving material efficiency, as opposed to various environmental externalities and lack of information in the relevant material markets. Moreover, in such cases, decision makers should choose policies that target the relevant market failures (e.g., environmental damage) as closely as possible. This usually means avoiding policies that directly promote specific material efficiency options. Policies that address specific environmental concerns and eliminate informational externalities will improve material efficiency more effectively. This is because it is difficult for decision makers to know in advance how and by how much they will need to change the production and use of materials [9].

2. RESEARCH MATERIALS AND METHODS

In the research work, Holcim Azerbaijan Cement Plant CEM II/A-L 42.5 R (Expert) brand cements, sand from the Bahramtepe deposit located in the territory of the Republic of Azerbaijan, aggregate sand and crushed stone from the Gudiyalchay quarry located in the Guba region, and superplasticizer (S520) were used as a plasticizer. As a mineral additive, aluminum oxide production waste from the Ganja Clay-Soil Production Union located in the territory of the Republic of Azerbaijan, quartz sand from the Umbaki deposit in Baku and aggregate sand production dust were used. The technical parameters of the cement and the strength of the cement stone were tested according to the test methods and rules of the AZS EN 197.1-2021 State standard, in accordance with the relevant technical requirements of EN 196-2-2013.

The properties of the concrete mixture were determined according to the standard EN 206-1:2000 (GOST 7473-2010).

The compressive strength of concrete was determined according to EN 12390-2, crack resistance tests were carried out in accordance with the requirements of the International standards and documents in force in our country according to GOST 29167-2021, dynamic stability of concrete, tensile and bending strength were determined according to GOST 10180-2012, abrasion tests were carried out according to GOST 13087-2018, and water resistance was determined according to GOST 12730.5-2018.

3. WORK CONDUCT

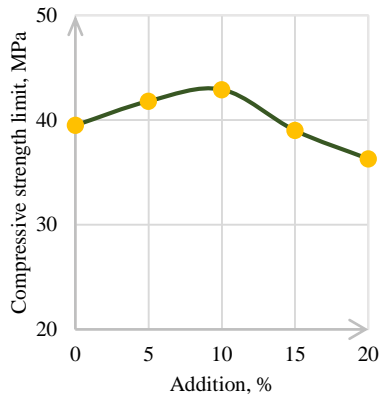
The experiments were conducted in several stages. In the first stage, ultrafine alumina production waste, quartz sand, and sand dust were used as mineral additives, and their effect on cement-sand systems was studied. The cement-sand mixture was prepared in a ratio of 1:3. To study the effect of ultrafine mineral additives on the properties of the cement-sand mixture, standard samples were prepared using a 5-20% cement ratio. In addition, samples without additives were prepared to study the effect of the additive on the mechanical properties of the cement-sandstone mixture. The cement-water ratio remained constant throughout the experiments. The normal density and setting time of the prepared mortar were determined using a Vika device, and three columns measuring 40x40x160 mm were prepared from each composition. The samples were tested after hardening using the standard method. The test results are presented in Table 1 and in Graphs 1, 2, and 3.

Table 1

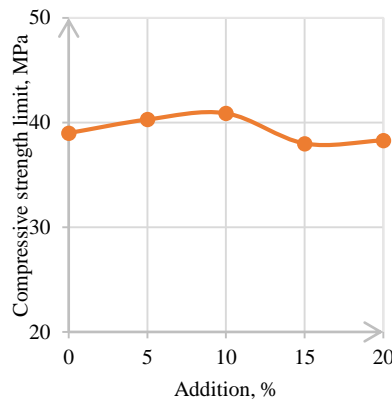
The effect of waste on the properties of cement-sand systems

Type of material	Composition, % by mass		Test results					
	Cement	Addition, %	Normal density, %	Holding period		Average density, kg/m ³	Strength index, MPa	
				beginning, minute	end, hour		28 day	
	CEM II/A-L 42,5 R (Expert)							
Cement	100	-	29	190	4.1	2.1	6.0	39.0
Alumina production waste	95	5	28	191	4.5	2.07	6.23	40.2
	90	10	28	191	4.6	2.08	6.40	41.4
	85	15	27	191	4.4	2.03	6.0	39.0
	80	20	25	191	4.7	1.95	5.9	38.7
Quartz sand	95	5	29	192	4.7	2.09	6.3	41.8
	90	10	28	191	4.5	2.12	6.47	42.9

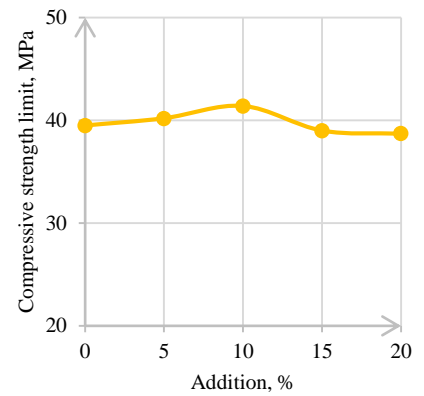
	85	15	27	199	4.9	2.05	5.76	39.0
	80	20	25	198	4.8	2.03	4.9	36.3
Sand dust	95	5	27	190	4.0	2.2	6.1	40.3
	90	10	28	192	4.3	2.0	6.2	40.9
	85	15	26	190	4.0	2.01	6.1	38.0
	80	20	25	191	4.1	1.90	5.7	38.3



Graph 1. Dependence of the strength of cement stone on the amount of mineral additive in the form of fine quartz sand



Graph 2. Dependence of the strength of cement stone on the amount of finely ground dense stone dust



Graph 3. Dependence of cement stone strength on the amount of mineral additive obtained from fine industrial waste

As can be seen from the table and graph, when finely ground mineral components (quartz sand, dense stone dust waste, industrial waste) were used in an amount of 10% of the cement consumption, the strength of the tested cement stone increased by 8.60%, 4.87% and 4.81%, respectively. The effect of the additives used on the structure formation process of cement stone was studied (Figure 1).

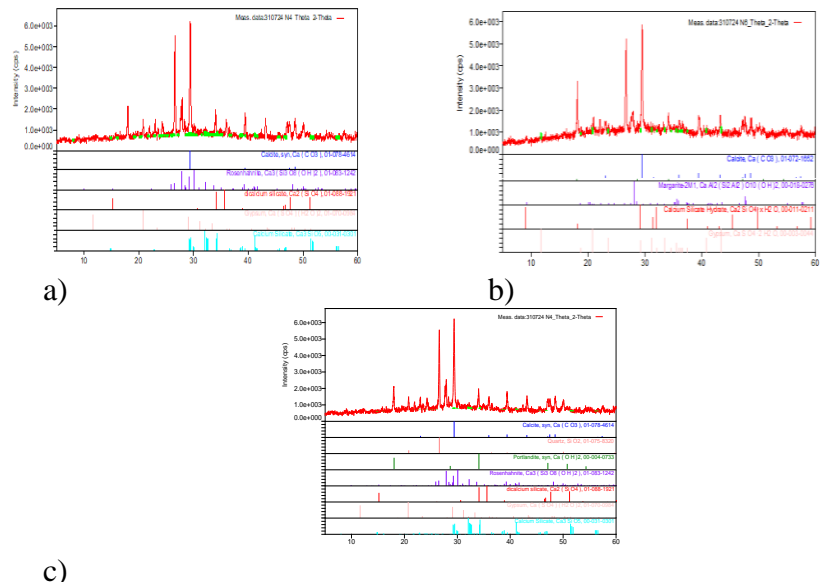


Figure 1. Diffraction patterns of cement stone samples with mineral additives
a) quartz sand sample
b) aluminum oxide production waste-based sample
c) stone waste dust-based sample

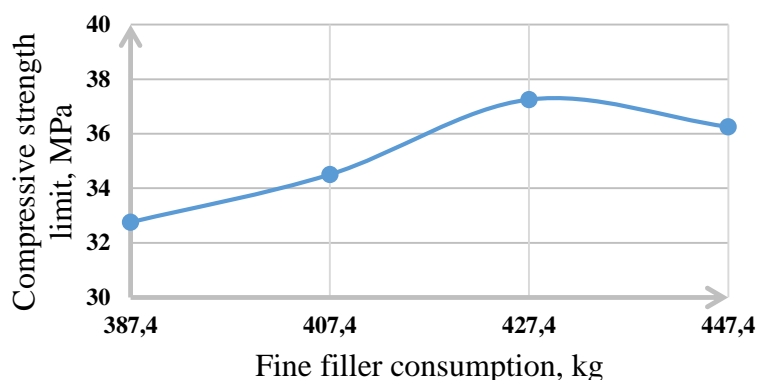
As can be seen from the diffraction pattern (figure 1. a), when quartz sand is used, the mineralogical composition of the stone is calcium hydroxides of various bases, while in the samples using calcite, aluminum-oxide production waste (figure 1. b) and crushed stone dust

(figure 1. c), the mineralogical composition of the stone is calcium hydrosilicates. The main structure of cement systems with hardened mineral additives, dense and high strength are formed due to this mineral.

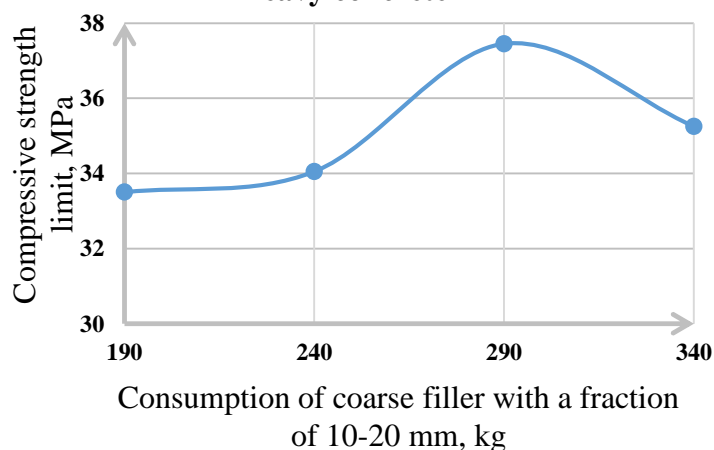
The second stage is devoted to the development of optimally modified heavy concrete compositions based on locally produced materials (portland cement, sand, crushed stone).

Standard samples were determined by testing in a UTEST UTC-4320 hydraulic press after 28 days of hardening. For the purpose of testing, 3 samples of each composition were prepared with dimensions of 150 x 150 x 150 mm. The samples were tested after 28 days of hardening.

Since the main part of the concrete composition is made up of fillers (85%), the effect of small (sand) and large fillers (crushed stone) was studied, taking into account the significant effect of the placement and distribution level of fillers in a uniform volume on the operational characteristics of concrete. In the experiments, water, cement and 1 type of filler were kept constant, while the other filler was changed by 20 kg and samples were prepared. The compressive strength limit of the samples hardened under normal hardening conditions (28 days) was determined (graphs 4, 5) [10].



Graph 4. Effect of natural sand and aggregate consumption on the compressive strength of heavy concrete



Graph 5. Effect of 10-20 mm fractional crushed stone consumption on the compressive strength of heavy concrete

Based on the experimental results (graph 4), it was determined that the use of a fine aggregate mixture in the concrete mixture, natural sand : fine sand = 42.65% : 57.35%, is more effective both economically and technologically. The obtained results increased by 13.74% [10]. The use of a coarse aggregate mixture based on two fractions of crushed stone in the ratio (5-10 mm) : (10-20 mm) = 74.5% : 25.5% is expedient and allows obtaining a more dense concrete structure (37.45 MPa). The results were confirmed by calculation (graph 5) [10].

The optimal compositions of ordinary heavy concrete and modified heavy concrete, including raw materials and materials used, taking into account the ratio of fillers, were determined

by the method of mathematical statistical planning of experiments. In the experiments, the water/cement ratio (water/cement=0.38) was kept constant, 3 influencing factors (cement, sand, crushed stone) were adopted, and a 23-type experimental plan was developed. Based on the initial experiments, the levels of influencing factors were prepared in laboratory conditions in accordance with the adopted plan, and samples were tested after hardening under normal conditions. The obtained test results were statistically analyzed using a computer program, and mathematical models (regression equations) of the compressive strength limit parameter of concrete were developed [10].

For ordinary heavy concrete [10]:

$$R_{str.} = 39.73 + 0.39X_1 - 1.23X_2 + 0.53X_3 + 0.85X_1X_2 - 1.7X_1X_3 + 1.07X_2X_3 - 0.68X_1X_2X_3$$

For heavy concrete with complex additives containing superplasticizer alumina production waste [3]:

$$R_{a.sp.}^{28} = 41.21 + 0.48X_1 - 1.59X_2 + 0.71X_3 + 1.15X_1X_2 - 2.18X_1X_3 + 1.38X_2X_3 - 0.94X_1X_2X_3$$

For heavy concrete with complex additives containing superplasticizer quartz sand [11]:

$$R_{q.sp.}^{28} = 42.75 + 0.53X_1 - 1.71X_2 + 0.79X_3 + 1.31X_1X_2 - 2.32X_1X_3 + 1.56X_2X_3 - 0.99X_1X_2X_3$$

In accordance with the research plan, the operational characteristics of the proposed modified concretes were studied in the third stage. Experimentally, the crack resistance, dynamic stability, tensile strength during bending, friction and water resistance of the proposed concretes were determined.

Taking these into account, it is considered satisfactory to determine the economic efficiency of the proposed modified concrete according to the costs incurred on the materials used.

Considering the locality of the materials, the economic efficiency of the modified concrete was accepted in accordance with wholesale prices in Azerbaijan. The economic efficiency of the proposed modified concrete was determined in comparison with the cost of heavy concrete (table 2).

Table 2.

Cost and economic efficiency of 1 m³ of heavy concrete and the proposed modified concrete made from local raw materials and materials

Name of raw materials and materials	Unit of measurement	Consumption per 1 m ³ of fiber concrete mixture	Wholesale price of materials	Total cost, manat	Economic efficiency, manat
Ordinary heavy concrete					
Cement	tone	0.375	142	53.25	
Natural sand	m ³	0.14	18	2.52	
Sand dust	m ³	0.19	17	3.23	
Crushed stone (5-10)	m ³	0.65	17	11.05	
Crushed stone (10-20)	m ³	0.22	17	3.74	
Water	m ³	0.14	2	0.28	
Total cost:				74.07	
Modified ordinary heavy concrete					
Cement	tone	0.36	142	51.12	
Natural sand	m ³	0.14	18	2.52	
Sand dust	m ³	0.19	17	3.23	
Crushed stone (5-10)	m ³	0.65	17	11.05	
Crushed stone (10-20)	m ³	0.22	17	3.74	
Mineral supplement	m ³	0.03	12	0.36	
Water	m ³	0.137	2	0.27	
Total cost:				72.29	1.78

As can be seen from the table, the total cost of 1 m³ of ordinary heavy concrete is 74.07 manat, and modified ordinary heavy concrete is 72.29 manat. Compared to ordinary heavy concrete, the economic efficiency of modified ordinary heavy concrete is 1.78 manat per 1 m³ of concrete. The conducted economic efficiency reports show that the proposed modified heavy concrete is an economically efficient type of concrete compared to traditional concretes of the same composition.

Result: Based on the results of the conducted experiments, it was determined that various industrial production wastes - waste from aluminum oxide production and crushed stone or aggregate waste from the production of sand based on dense stone, as well as Umbaki quartz sand, can be used as finely ground mineral additives. These finely ground mineral additives increase the physical and mechanical properties of cement systems and heavy concrete prepared on their basis by 2.02% and 2.77%, respectively. The possibility of adding these additives in the amount of 10% of the cement consumption leads to high hermeticity, saving on cement produced with expensive equipment, high energy and labor costs, and the use of dust and fine-grained natural rocks, which cause environmental pollution, is of special scientific and practical importance. The fact that the cost of modified concrete prepared with these additives is 1.78 manat cheaper in terms of material costs will allow increasing production productivity and concrete production volume. These, in turn, determine both the economic and environmental efficiency of the proposed modified concrete.

REFERENCES

1. N.M.Ahmadov, I.N.Shirinzade, "Development of effective fiber-reinforced concrete compositions used in transportation structures", Eastern-European Journal of Enterprise Technologies, No. 2/1(110), pp. 6-11, September 2021.
2. T.A. Hagverdiyeva, K.B. Jamalova, "Artificial SiO₂-containing mineral-active adhesive material and concrete purchase research", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 60, Vol. 16, No. 3, pp. 213-219, September 2024.
3. T.A. Hagverdiyeva, K.B. Jamalova, "Friction resistant fibro concrete", Scientific works, No. 2, pp. 22-24, 2017.
4. T.A. Akhverdieva, R. Jafarov, "Influence of fine-ground mineral additives on concrete properties", Building materials, Issue 3, No. 3, pp. 73-76, March 2019.
5. T.A. Hagverdiyeva, R.Jafarov. "Impact of Fine Ground Mineral Additives on Properties of Concrete", Waste in production of building materials, pp. 73-75, 2019.
6. T.A. Akhverdieva. "Interaction of the Tauz trace rock with liquid glass (sodium metasilicate)", Journal - Graduate student and applicant, Publisher: Society with Online Limitation Publishing House Sput, No. 5, pp. 144-145, 2008.
7. T.A. Akhverdieva. "Study of the processes of hardening and structure formation of alkali-mineral binders and concrete", Journal of Natural and Technical Sciences, No. 1, pp. 369-377, 2010.
8. T.A. Akhverdieva. "Alkali-mineral binders and concretes based on alumina production waste", Current problems of modern science, pp. 218-223, 2019.
9. Patrik Söderholm, John E. Tilton, "Material efficiency: An economic perspective", Resources, Conservation and Recycling, Vol. 61, pp. 75-82, April 2012.
10. Jamalova, K.B., Hagverdiyeva, T.A., Gurbanova, R.A., Ganiyeva, S.A. Optimizing concrete performance: Influence of granular structure and filler distribution on strength characteristics // - Denmark: International Journal on "Technical and Physical Problems of Engineering", - 2025. №1, p. 247-252.
11. Jamalova, K.B., Hagverdiyeva, T.A. Study of production of adhesive material and concrete modified with natural component containing SiO₂. PLMO 2024: 3rd International Conference on Problems of Logistics, Management and Operation in the East-West Transport Corridor, Baku, 15-17 may, 2024. p. 1-7.