Obtaining High-strength Concrete Using Local Microdispersed Additives

Aleksandre Peikrishvili
Technical University of Georgia, M.Kostava st 77, Tbilisi 0175, Georgia
aleksandre.peikrishvili@gau.edu.ge
DOI: https://doi.org/10.52340/building.2025.72.02.10

Abstract. The article discusses modern approaches to producing high-strength concrete using local microdispersed additives. It examines the principles of modifying the composite structure of concrete and the influence of microsilica, microclay, and metakaolin on the rheological and physical properties of the mixture. The research subject is the effectiveness of silicomanganese dust from the Zestafoni Ferroalloy Plant as a micro-additive on concrete strength. Results of chemical and physical-technical analysis confirm that this residue contains a low amount of active SiO2 and does not provide the required concrete strength. Comparative analysis shows that foreign microsilica with high silicon content significantly increases concrete density, strength, and corrosion resistance. Additionally, the study explores the possibility of using cement kiln dust which, in combination with superplasticizers, contributes to raising the concrete class and alleviating ecological problems.

Keywords: Microsilica; silicomanganese dust; micro-additives; concrete modification; local raw materials.

Introduction.

One of the most decisive and influential factors in the ongoing development of modern concrete technology is the meticulous processing and application of the scientific foundations regarding concrete modification. Currently, one of the most prevalent and effective methods for modifying the internal structure of composite building materials involves the strategic introduction of highly active additives into their basic composition to enhance performance. These mineral additives can be derived from either natural or artificial origins and typically contain various silicate minerals. Depending on their source and processing, these minerals may exist in several physical states, including crystalline, fine-crystalline, colloidal, or amorphous states. Within this category of transformative materials, microsilica, microclay, and metakaolin stand out as the primary and most significant types of additives used to achieve these structural improvements.

The inclusion of these specific mineral additives in a concrete composition significantly helps to maintain the flowability of the mixture for a critical period during the construction process. This retention of flow is exceptionally important in contemporary concrete technology, particularly for the successful implementation of self-compacting concretes that require high mobility. Furthermore, these materials are characterized by distinct rheological properties that ensure the concrete mixture does not undergo segregation, which would otherwise compromise the structural integrity of the material. By using these additives, engineers can ensure that an optimal level of viscosity is maintained for a specific and necessary duration, allowing for proper placement and finishing of the concrete in various architectural and industrial applications.

On a global scale, microsilica has become a staple in the international construction industry, where it is utilized extensively in the production of heavy concretes, foam concretes, and specialized dry construction mixtures. The widespread adoption of this material is explained by its unique and highly desirable physical and chemical properties. Its remarkably high pozzolanic activity is fundamentally determined by its extreme degree of dispersity and the substantial abundance of amorphous silicon dioxide (SiO_2) within its structure. Physically, microsilica presents as a super-dispersed powder that possesses an exceptionally large specific surface area, which allows it to react more efficiently within the cementitious matrix than standard materials.

From a technical perspective, microsilica exhibits a fascinating contrast between its bulk and true density; while its bulk density is relatively low, ranging from 120 to 450 kg/m3, its true density is often ten times higher or more, measured between 2200 and 2300 kg/m3. Chemically, it is characterized by an extremely high content of SiO_2 (98%), which exists almost entirely in an active amorphous form. The physical scale of these particles is also extraordinary, with an average size of only 0.1 to 0.2 μm, making them approximately 50 to 100 times finer than standard cement particles. This microscopic size contributes to a massive specific surface area that typically ranges between 13,000 and 35,000 m2/kg, facilitating the dense and high-strength microstructures required for modern infrastructure.

The profound influence of microsilica on the complex process of structure formation within cementitious systems is fundamentally governed by the intricate relationship between two primary mechanisms, which researchers and material scientists categorize as the physical and chemical factors. These factors do not operate in isolation but rather work in a highly synergistic manner to transform the internal architecture of the concrete from the moment water is first introduced until the material reaches its final, fully hardened state. By understanding and manipulating this dual-action modification, engineers can precisely tailor the rheological and mechanical properties of the composite material, ensuring that the resulting building substance meets the increasingly rigorous demands of modern high-performance infrastructure projects.

The physical factor is intrinsically linked to the exceptional ultra-dispersity of microsilica particles, which significantly dictates the behavior of the cement system during its initial coagulation stage. While the mixture is still in its plastic and workable state, these incredibly fine microsilica particles—which are significantly smaller than the cement grains themselves—serve as a strategic micro-filler by occupying the microscopic interstitial spaces and voids that naturally exist between the much coarser grains of cement. This "filler effect" facilitates the creation of a vast and dense network of coagulation contacts between the various solid-phase components, effectively stabilizing the suspension and reducing the likelihood of water bleeding. As the hydration process progresses into the subsequent crystallization stage, this dense packing continues to pay dividends by physically blocking the development of large capillary pores, thereby dramatically increasing the overall density and structural homogeneity of the hardening stone.

Simultaneously, **the chemical factor**, which is deeply rooted in the specific chemical-mineralogical composition of the microsilica, initiates a transformative reaction that fundamentally alters the balance of the cement stone's hydrated phases. The high concentration of active amorphous silicon dioxide within the microsilica reacts chemically with calcium hydroxide—a relatively weak and soluble byproduct of cement hydration—to produce additional volumes of calcium hydrosilicates, commonly known as the C-S-H gel. This chemical metamorphosis is crucial because these secondary hydrosilicates are significantly stronger, more stable, and more adhesive than the initial hydration products. By converting weaker, crystalline components into a robust and dense binder, the chemical presence of microsilica ensures a superior bond between the cement paste and the aggregate, reinforcing the entire matrix at a molecular and microscopic level.

Consequently, the harmonious integration of **high-dispersity microsilica** into a mixture allows for the industrial production of advanced concretes that are characterized by extraordinary compressive strength and remarkably low permeability. Because the internal pore structure is so refined through the filler effect and the chemical bond is made so resilient through the pozzolanic reaction, the resulting material exhibits a significantly increased resistance to aggressive environmental factors. This effectively prevents the ingress of moisture, salts, and harmful ions that typically lead to the corrosion of reinforcement steel and general material degradation. Ultimately, this comprehensive structural modification translates into a construction material with vastly improved durability and a significantly longer service life, making it an indispensable component for modern engineering challenges.

Tables 1 and 2 present the chemical composition and physical-technical indicators of silicomanganese dust from the Zestafoni Ferroalloy Plant alongside data from similar plants in the former Soviet Union. The data shows that Zestafoni silicomanganese dust is characterized by the lowest content of active SiO2.

Table 1

Chemical composition of some microfillers

Origin of Micro-filler	Name of Micro-reinforcer	Chemical Composition of Micro-fillers							
		SiO2	Fe2O3	Al2O3	CaO	MgO	K2O+Na2O	MnO	SO3
Novoselovskoye	Ferrosilicon	89.7	**2**	**1.7**	**2.5**	**1.76**	**1.89**	**-**	**0.3**
Chelyabinsk	Ferrosilicon	89.2	**2.84**	**1.68**	**2.1**	**1.75**	**1.43**	**-**	**0.5**
Ermak	Ferrosilicon	70.1	**3.43**	**2.03**	**11.4**	**0.9**	**0.9**	**-**	**0.4**
Aktyubinsk	Ferrosilicochromium	66.1	**2.2**	**1.3**	**0.44**	**14.65**	**1.8**	**-**	**4.2**
Zestafoni	Silicomanganese	**25.2**	**2.64**	**4.27**	**18.6**	**4**	**2.1**	**35.8**	**4.2**
Zestafoni	Silicomanganese	**35.4**	**2.3**	**3.86**	**4.58**	**4.2**	**2.4**	**39.1**	**3.4**

Table 2

Some physical and technical ndicators of ultrafine waste from ferroalloy production

Manufacturing Plant	Novokuznetsk	Chelyabinsk	Ermak	Aktyubinsk	Zestafoni	Zestafoni
Type of Ultrafine Waste	Ferrosilicon	Ferrosilicon	Ferrosilicon	Ferrosilicochromium	Silicomanganese	Silicomanganese
SiO2 Content, %	89.7	89.2	70.1	66.1	25.2	35.4
Hydraulic Activity	98	94	58	40	14.2	25
Water Demand	40	33	137	43	26	33

Experimental studies utilized silicomanganese dust collected from filters at the Zestafoni plant, which chemical analysis showed contains no more than 20% SiO2, and a Norwegian-produced additive called "Microsilica". According to international standards, the SiO2 content in Microsilica should exceed 85%, a requirement met by the foreign additive. The study considered the high cost of the foreign additive versus the need to utilize Zestafoni silicomanganese dust and the possibility of enriching it with SiO2 by reducing manganese content.

Results in **Tables 3 and 4** show that Zestafoni silicomanganese dust has the lowest active SiO2 content, and experiments demonstrated that its use as a micro-additive in concrete mixtures does not yield adequate results.

Table №3

Composition of Concrete Mixes Modified with Zestafoni Silicomanganese and Norwegian Microsilica

Mix Series No.	Cement (kg/m3)	Khrami River Crushed Stone (5-20 mm) (kg/m3)	Khrami River Sand (0-2.5 mm) (kg/m3)	Khrami River Sand (2.5-5 mm) (kg/m3)	Water (l/m3)	Admixture Type and Dosage (%)	Zestafoni Silicomanganese (kg/m3)	Water/ Cement Ratio
1	400	905	510	275	180	ViscoCrete SF 18 (1.0%)	80	0.45
2	420	855	540	290	170	ViscoCrete SF 18 (1.0%)	84	0.4
Mix Series No.	Cement (kg/m3)	Khrami Crushed Stone (5-10 mm) (kg/m3)	Khrami Crushed Stone (10-20 mm) (kg/m3)	Khrami Sand (0-2.5 mm) (kg/m3)	Quartz Sand (2.5-5 mm) (kg/m3)	Water (l/m3)	Admixture Type and Dosage (%)	Foreign Production Microsilica (kg/m3)
1	400	305	565	490	325	180	ViscoCrete SF 18 (1.0%)	80
2	420	315	585	470	290	170	ViscoCrete SF 18 (1.0%)	84

Table №4

Dependence of concrete compressive strength on the age of the material

Concrete Mix	Admixture	Concrete	Concrete	Concrete	Concrete	Concrete
1	ViscoCrete SF 18 (1.0%)	10.6	21.5	32.3	37.5	45.3
2	ViscoCrete SF 18 (1.0%)	12.8	25.5	34.4	41.8	50.4
Concrete Mix Series No.	Admixture Type and Dosage	Concrete Strength at 1 Day (MPa)	Concrete Strength at 3 Days (MPa)	Concrete Strength at 7 Days (MPa)	Concrete Strength at 14 Days (MPa)	Concrete Strength at 28 Days (MPa)
1	ViscoCrete SF 18 (1%)	18.1	30.8	54.3	73.5	84.6
2	ViscoCrete SF 18 (1%)	21.4	34.5	63.5	80.8	95.7

Testing of Cement Kiln Dust

During the testing of cement kiln dust, Sika Viscocrete SF-18 was used as a plasticizer. One series of samples was prepared without additives or plasticizers, while another series (Series 2) used only Viscocrete SF-18. Samples were tested at 7 and 28 days, with results shown in Table 5.

Table №5

Testing of concrete made with cement Dustmicrofiller

№	Type of Micro-filler	Concrete Composition (kg/m3)						Cone Slump (cm)	Bulk Density (kg/dm3)		Compressive Strength (MPa)	
		Cement	Sand	Crushed Stone	Micro-filler	Plast.	Water		7 Days	28 Days	7 Days	28 Days
1	-	450	800	860	-	-	250	10	2.29	2.33	33.1	52.3
2	-	450	820	880	-	4.5	180	15	2.32	2.34	51.3	73.6
3	Cement Dust	450	785	845	72	4.5	205	15	2.37	2.37	58.4	82

Kiln dust as a potential mineral modifier, a specialized high-performance superplasticizer known as Sika Viscocrete SF-18 was integrated into the mixture to optimize its rheological and mechanical performance. The experimental methodology involved preparing distinct series of samples to ensure a rigorous comparative analysis; specifically, one control series was manufactured without any additives or plasticizers to serve as a baseline, while a second series utilized only the Viscocrete SF-18 plasticizer to evaluate its independent impact on the cementitious system. To evaluate the development of physical-technical properties and the evolution of the material's structure over time, these samples underwent rigorous strength testing at two critical curing intervals: 7 days and 28 days. The precise composition of the modified concrete involved a superplasticizer dosage fixed at 1% relative to the total cement mass, whereas the mineral micro-filler—the cement kiln dust—constituted approximately 16% of the cement mass, ensuring a significant presence of ultra-dispersed particles within the composite mix.

The subsequent analysis of the experimental results demonstrates that the strategic integration of micro-fillers in tandem with a superplasticizer significantly enhances the compressive strength of the concrete compared to the baseline additive-free versions. This improvement is primarily driven by physical and chemical factors where the ultra-dispersed mineral particles effectively fill the microscopic pores within the hardening stone structure, thereby increasing overall density and the number of coagulation contacts. Furthermore, this process facilitates the modification of the composite structure by potentially altering the balance of hydrated phases, leading to an increased volume of more stable and durable calcium hydrosilicates. Consequently, these findings validate that such modifications effectively enable the elevation of the concrete's functional class, proving that high-performance materials can be successfully achieved using locally sourced additives. Beyond these technical advantages, this research directly addresses the critical industrial challenge of cement kiln dust utilization; by repurposing this residue as a functional component in concrete production, the industry can resolve persistent ecological problems and promote sustainable waste management practices within the construction sector.

References

1. 1. V.V. Malhotra. Innovative Applications of Superplasticizers in Concrete – A Review// CANMET/ACI Symposium on Advantes in Concrete Science Tech. Rome, okt. 7-10, 2007, Proceedings, p.p. 271-314.
2. V. Batrakov, S. Kaprielov. Durabiliti of Concretes Modified bi Silicoorganoc Compounds// CANMET/ACI int. Sump. On Advances in Concr. Technology. LasVegas June, 2005, Supplementari papers, p.p. 609-624.
3. B. Pecur, N. Stirmer. Compatibility of polycarboxylate superplasticizers with cement. of 8th CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete. Suppl. volume. P. 213-226.
4. m. turZelaZe, g. TaTaraSvili, i. giorgaZe. TviTSemWidroebadi betoni – dRevandeli samSeneblo amocanebis gadawyvetis efeqturi instrumenti. Jurnali „energia", №2 (58), 2011, გვ. 77-79.
5. Д.М. Поляков, С.В. Коваль. Самоуплотняющийся бетон с использованием карбонатного наполнителя. Ж. «Вестник», Киев, 2010 1(81), стр. 107-112.