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**ENVIRONMENTAL AND ECONOMIC CHALLENGES OF THE CEMENT
INDUSTRY AND THE PATH TO SUSTAINABLE DEVELOPMENT**Doctor of Technical Sciences, Prof. **Adilkhodjaev A.I.**

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Abstract: This article examines the key problems of the modern cement industry related to high energy intensity and significant carbon footprint. The necessity of transitioning to resource-saving technologies is substantiated. It has been shown that partial replacement of cement clinker with finely dispersed mineral fillers is a strategically important solution for reducing the environmental burden and product cost.

The cement industry - one of the pillars of the modern construction industry - is also one of the largest sources of anthropogenic impact on the environment. Portland cement production is associated with enormous energy costs and greenhouse gas emissions, which poses serious environmental and economic challenges for the industry. The solution to this situation is the implementation of a sustainable development concept, the key element of which is the modification of cement systems using finely dispersed mineral fillers.

The main problem in the cement industry is a huge carbon footprint. The production of one ton of cement is accompanied by the emission of 0.8-0.9 tons of CO₂. The cement industry accounts for approximately 8% of global anthropogenic carbon dioxide emissions. The main sources of emissions are the decarbonization process of limestone (CaCO₃→CaO+CO₂) and the combustion of fuel for clinker firing. In parallel with environmental problems, there is a depletion of non-renewable natural resources - limestone, clay, gypsum [1]. At the same time, industrial sectors face the problem of utilizing a huge amount of finely dispersed waste (ashes, slag), which is placed in landfills occupied by fertile lands.

The most effective strategy that meets the principles of a "green" economy is to partially replace cement clinker with affordable mineral materials. Such materials can be technogenic wastes (silt ash, microsilica, granulated blast furnace slag) or natural materials (metakaolin, limestone flour). This approach allows achieving a triple positive effect: economic (reducing the cost of construction materials), environmental (reducing CO₂ emissions and utilizing industrial waste), and technical (improving the physical and mechanical properties of cement stone and concrete, including strength, durability, and density) [2].

The modern technology of cement systems has undergone significant evolution, going beyond the traditional component system. Currently, designing cement composite compositions is a complex scientific and technical process aimed at creating multicomponent systems containing two or more functional additives. This transition is due to the need to improve the operational characteristics of concrete, as well as the solution of environmental and economic problems [3].

A promising scientific direction is the integrated use of finely dispersed mineral fillers in cement systems. Composition design technologies have transitioned from mono- to binary, as well as triple and more multi-component systems, which allows achieving a synergistic effect exceeding the sum of individual contributions of each component [4]. Combining two or more fillers with different mechanisms of action allows you to eliminate the shortcomings of each of them and strengthen the positive aspects.

The combined use of finely ground carbonate and other types of active additives can contribute to creating the most favorable conditions for the formation of the necessary complex of properties. For example, the use of limestone provides early strength gain due to the filling effect and acceleration of hydration of the aluminates phases, which is especially important in the first 24 hours. At the same time, the active additive in the form of microsilica enters into an intensive pozzolanic reaction with the formation of secondary C-S-H phases. As a result, high strength and durability are ensured in later hardening periods.

Based on the presented theoretical provisions, the following statement can be put forward as a scientific hypothesis (Figure 1):

The development of highly effective cement composites should be based on the principles of targeted microstructure management, implemented through the combination of finely dispersed mineral fillers with varying surface activity and nature. We assume that the synergistic effect is achieved when using binary or multicomponent systems, where fillers play two complementary roles, according to the postulates of V.I. Salomatov's theory [5] (Fig. 1):

1. Creating crystallization centers and accelerating hydration To accelerate structure formation processes in the early stages of hardening, it is necessary to use fillers whose surface activity is equal to or higher than the binding activity ($F_n \geq F_v$). Particles of such fillers (e.g., microsilica, metacaolin) act as active nucleation centers, intensifying hydration and forming a strong matrix.
2. Structure ordering and deformation reduction: To optimize mechanical characteristics and increase durability in later stages, it is necessary to introduce fillers with surface activity lower than that of the binder ($F_n < F_v$). These particles (e.g., finely ground limestone, crushed sand) contribute to the reduction of inter-particle deformations at the interface, resulting in a more ordered, dense, and stable structure, minimizing the risk of microcrack formation.

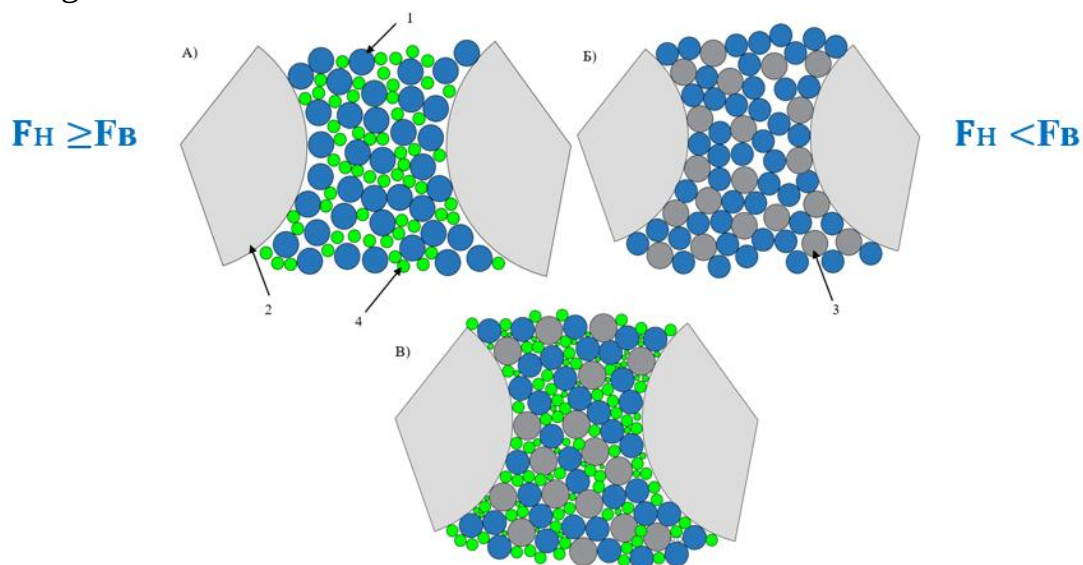


Figure 1. Spatial-structural topology of a binder

- A - Dispersity of mineral filler higher than cement dispersity; B - The dispersity of the mineral filler is significantly lower than the dispersity of the cement; B - The dispersity of binary mineral filler is greater than and less than the dispersity of cement (optimal packaging).

Conclusion. Thus, the introduction of binary finely dispersed mineral fillers is not just a technical improvement, but a strategic necessity for the cement industry to transition to sustainable development. The greatest effectiveness is achieved when using binary (two-component) fillers (e.g., a combination of microsilica and limestone flour), which provide a synergistic effect:

1. Microstructure optimization: The combination of particles of different dispersity contributes to the multi-scale compaction of cement stone.

2. Reduce porosity: Effective filling of the intergranular space leads to a sharp decrease in permeability and total porosity.
3. Improving durability: The compacted structure achieved through binary fillers ensures increased strength and durability of the material.
4. Economic: Reducing the cost of construction materials by replacing expensive clinker with cheaper fillers.
5. Ecological: Reducing CO₂ emissions by reducing clinker production volumes and utilizing industrial waste.
6. Technical: Improving the physical and mechanical properties of cement stone and concrete (strength, durability, density).

References

1. Worrell, E., Price, L., Martin, N., Hendriks, C., & Meida, L. O. Carbon dioxide emissions from the global cement industry. *Annual Review of Energy and the Environment*, 2001, 26 (1), 303-329.
2. Mehta, P. K., & Monteiro, P. J. M. *Concrete: Microstructure, Properties, and Materials*. 4th ed. McGraw-Hill Education, 2014.
3. Scrivener, K. L., Juilland, P., & Monteiro, P. J. M. Advances in Understanding the Hydration of Calcium Carbonate-Portland Cement Systems. *Cement and Concrete Research*, 2015, 73, 1-17.
4. Kalashnikov, V. I., & Klyushnikov, I. V. *High-strength concrete based on nanotechnology*. Science, 2010.
5. Salomatov, V. I. *Theory of Composite Building Materials*. Higher School, 1989.