High-Strength Concrete Composition Design: Current Trends

Aleksandre Peikrishvili
Georgian Technical University, Tbilisi, Georgia, 77 M. Kostava st, 0160
aleksandre.peikrishvili@gau.edu.ge

DOI: https://doi.org/10.52340/building.2025.71.17

Abstract A rational proportioning of the main components of high-strength concrete—cement, aggregates, water, and additives—has been determined, ensuring minimal cement consumption while maintaining optimal technical and technological performance characteristics required for concrete mix design. The concrete composition has been selected using an analytical-experimental method, optimizing the preparation of mixtures within permissible limits. The following factors must be considered: concrete strength at compression (class), ease of placement, compaction coefficient (Kg > 0.98), cement activity, actual and overall porosity, granulometric composition of sand and gravel, as well as the type and quantity of modifiers.

Key words: Concrete, hyperplasticizer, microfiller, granulometry, dispersion, aggregate, fine-grained, cement stone, modifier.

Introduction.

High-strength concrete (80-150 MPa) is achieved through the combined use of high-activity cements, calcined and finely ground sand, coarse aggregates with strengths exceeding 120-150 MPa, plasticizing chemical modifiers, and various micro- and ultradispersed additives (such as silica fume, metakaolin, fly ash, limestone powder, microquartz, etc.). The water-cement ratio (w/c) in such concretes is relatively low, typically in the range of 0.3-0.35 or even lower. High-strength concretes are characterized by increased density, durability, and resistance to atmospheric and other aggressive influences. A key feature of high-strength concrete technology is the ability to achieve higher-grade concrete using cement of a given grade. This is not only accomplished by using materials with enhanced properties but also by designing a concrete structure where the performance characteristics of its components are effectively optimized.

the main part

The modern requirements for the design of high-strength concrete structures involve meeting the following conditions:

1. Incorporation of hyperplasticizers in the concrete mix, which allows for a reduction in the water-cement ratio, significantly increasing the strength of the concrete.
2. Optimization of aggregate consumption, ensuring a granulometric composition that closely aligns with the ideal distribution—from micron-sized fine particles (such as microfillers) to coarse aggregates measuring several centimeters. This approach enhances the efficiency of mineral fillers, reducing the amount of coarse aggregates. Research indicates that the maximum aggregate size should not exceed 20 mm. The optimal granulometry of aggregates and dispersed materials ensures the formation of a dense, strong structure, where fine particles fill the voids between coarser grains.

High-strength concrete exhibits superior physical and mechanical properties. Its low porosity minimizes the penetration of aggressive substances into its Matrix.

Currently, ultra-high-strength concretes (120-150 MPa) are divided into two categories: fine-grained (maximum aggregate size up to 16 mm) and ultra-fine-grained (maximum aggregate size up to 0.5 mm). In both cases, the use of microfillers and finely ground mineral additives is recommended. To improve compressive strength and crack resistance, metallic, synthetic, or polymer fibers are used. The properties of high-strength concrete are significantly influenced by the structure of the cement paste. The main factors affecting

cement paste properties are the crystalline phase structure and porosity.
The accurate calculation and selection of concrete mix proportions ensure a rational balance between cement, aggregates, water, and additives, leading to minimal cement consumption while maintaining the necessary technical and technological characteristics. Concrete mix designs are selected using analytical-experimental methods within feasible composition limits. The following factors must be considered: concrete compressive strength (class), workability of the concrete mix, compaction coefficient (Kg > 0.98), cement activity, actual and total porosity, granulometric composition of sand and gravel, type and quantity of modifiers, etc. (pic. 1).

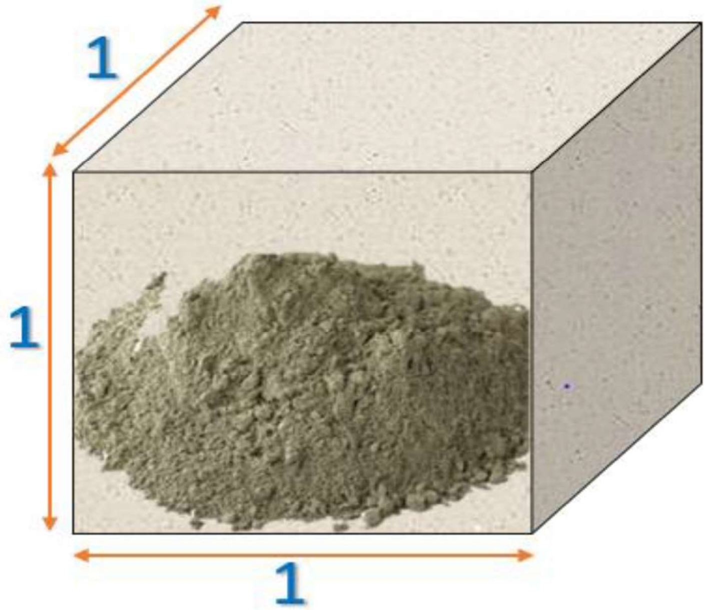

Fig. 1. The water-cement ratio (w/c) is estimated using the formula:
w/c = 0.43Rc / (Rb - 0.215Rc)

where Rc is the cement grade or activity (MPa), and Rb is the target concrete strength (MPa).
To determine the water demand per cubic meter of concrete, experimental data based on known bulk density and maximum aggregate size is used.
Cement consumption is calculated using the formula:
c = w / (w/c)
The feasibility of achieving high-strength concrete with a specific cement type is determined based on experimental results. For 1 m³ of concrete, cement consumption should not exceed 550-600 kg.
Mix proportions are determined using the absolute volume method, ensuring that the total absolute volume of all materials equals 1000 liters.
Optimal aggregate proportions are selected based on the following principles:
1. The highest overall strength of the mix is achieved by properly balancing fine and coarse sand fractions.
2. The highest overall strength of the mix is achieved by properly balancing fine and coarse gravel fractions.
3. The optimal sand-to-gravel ratio is determined to ensure the best workability while maintaining cement and water consumption within acceptable limits.
If the designed mix does not meet the project requirements, adjustments are made by increasing or decreasing the cement content,

which subsequently affects the w/c ratio.
The optimal amount of sand and gravel in 1 m³ of concrete is calculated using the formulas:
$R = (s + g) / (1 + r)$, and $S = (s + g)-g$;
The final mix proportions are tested through laboratory trial batches, ensuring that the calculated w/c ratio is maintained. Bulk density remains unchanged, and only water and cement adjustments are made when necessary.
Each batch of concrete is used to prepare a set of control specimens for quality assessment. The number of specimens per batch is determined according to the specific requirements of the construction technology being utilized. These specimens are subjected to rigorous compressive strength testing after a curing period of 28 days. The results from these tests are used to develop graphs that illustrate the relationship between compressive strength and the water-cement ratio, providing valuable insights for optimizing mix design. Currently, achieving concrete strengths exceeding 100 MPa remains a significant challenge due to material limitations. Despite advancements in mix design methods and the availability of high-quality materials, the primary obstacle is the crushing strength of granite aggregates. Granite originates from natural rock formations with an average compressive strength of approximately 180 MPa. However, during the crushing process, microcracks inevitably form within the aggregate particles. These microcracks substantially reduce the effective strength of the aggregates to around 90-100 MPa, limiting the potential strength of the concrete. Efforts to enhance concrete performance have led to the incorporation of chemical modifiers, which can improve the strength of the cement matrix up to 120 MPa. While these additives strengthen the binding material, the reduced strength of the aggregates remains a critical limiting factor. Without stronger aggregates, further increases in concrete strength are difficult to achieve. To overcome this issue, research is needed to explore alternative aggregates with higher crushing strength or to develop advanced processing techniques that minimize microcracking. Additionally, innovations in nanotechnology and supplementary cementitious materials could help optimize the structural integrity of high-strength concrete. Until such advancements are realized, the maximum achievable concrete strength will continue to be constrained by the inherent properties of available aggregates.

Fig. 2 . Granite gravel

In the process of selecting the composition of high-strength concrete, some of our colleagues opted for maximizing the consumption of cement and modifiers while minimizing the amount of fine aggregates. As a result, the obtained concrete primarily relied on the durable cement matrix, while the coarse aggregate functioned merely as a casing. The composition of this type of concrete is reflected in Table 1.

Table 1: Concrete Mix Composition (kg/m³)

Cement (kg)	Modifier MB10-01 (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Hyperplasticizer (kg)	Slump (cm)	w/c Ratio	Concrete Density (kg/m³)	Concrete Strength (MPa)
550	110	697	902	152	2	20	0.28	2413	102.9
550	110	660	930	164	4	27	0.3	2436	98.7
550	110	650	950	135	-	19	0.25	2421	92.5

The compressive strength of gravel is a critical factor influencing the overall performance and durability of concrete. It is widely recommended that the compressive strength of gravel should be at least 1.5 times greater than that of the concrete it is used in. This ensures the structural integrity and longevity of concrete structures. However, in our opinion, for specific types of concrete, the strength of the gravel should at the very least match the compressive strength of the concrete itself. When the aggregate strength aligns with or exceeds that of the concrete, it enhances bonding, reduces the risk of failure, and improves the long-term durability of the structure.

Georgia possesses significant reserves of both crushed and natural rock quarries, making it a valuable source of high-quality aggregates for concrete production. These abundant reserves provide a reliable raw material base for manufacturing high-strength concrete, which is essential for constructing durable and resilient infrastructure. The availability of strong aggregates enables engineers to design and build structures that can withstand heavy loads and harsh environmental conditions while maintaining structural stability over time. In addition to its structural benefits, using

locally sourced gravel offers economic and environmental advantages. By utilizing

Fig. 3 . Mineral resources of Georgia

domestic aggregate resources, construction costs related to material transportation are significantly reduced. This not only makes concrete production more cost-effective but also contributes to sustainable construction practices by minimizing carbon emissions associated with long-distance transportation. Locally available, high-quality gravel ensures that infrastructure projects maintain high performance while being economically and environmentally responsible.

The role of aggregate strength in achieving high-performance concrete is especially critical in large-scale projects and load-bearing structures, such as bridges, high-rise buildings, and industrial facilities. The mechanical properties of gravel directly impact the compressive strength and durability of the concrete mix. By optimizing the selection of high-strength gravel, construction professionals can ensure that concrete structures meet modern engineering standards and remain resilient for years to come.

Given Georgia's rich quarry resources, the country has the potential to continue developing high-performance concrete for a wide range of construction applications. Careful selection of strong aggregates is essential to maximizing the structural efficiency of concrete. As construction demands increase, the use of high-quality gravel will remain a key factor in ensuring the durability, strength, and sustainability of infrastructure projects.

Conclusion.

Currently, the existing methods for designing high-strength concrete and the quality of available raw materials do not allow for the production of concrete with a compressive strength exceeding 100 MPa. One of the main limitations is the quality of the coarse aggregate used in concrete mixtures. Most coarse aggregates are derived from crushed river ballast, which, while containing some high-strength fragments, also includes particles with relatively low compressive strength. These weaker particles reduce the overall structural integrity of the concrete, preventing the achievement of ultra-high-strength compositions. To produce concrete with a compressive strength of 150 MPa, monomineral crushed rock aggregates from igneous formations such as granite, diorite, and gabbro are required. These rocks possess compressive strengths of up to 250 MPa, making them suitable for high-performance concrete. Additionally, the incorporation of chemical modifiers can enhance the strength of the cement matrix, potentially increasing it to 150 MPa. However, despite improvements in cement matrix strength, the limiting factor remains the low strength of coarse aggregates derived from river ballast. The presence of weaker particles in river ballast significantly impacts the structural performance of concrete, making it difficult to achieve ultra-high compressive strengths in practical applications. To overcome this limitation, alternative aggregates with higher crushing strengths need to be explored. The use of carefully selected, high-strength aggregates could enable the production of stronger, more durable concrete. Further research is essential to identify new aggregate sources and processing techniques that minimize microcracking and enhance aggregate strength. Until then, the development of ultra-high-strength concrete remains constrained by the limitations of available coarse aggregates, making advancements in material selection crucial for future high-performance concrete applications.

REFERENCES

1. V. Mechtcherine, M. Haist, A. Heveren, H. Miller. Self-Compacting Lightweigt concrete a new highperformance building material. The first fib Congress, Conference proceedings, Osaka, Japan 2015

2. Т.М. Петрова, Н.А. Джаши, О.М. Смирнова, Э.Ю. Чистяков. Современные подходы к проектированию составов высокопрочных бетонов. Ж. «Строительный тендер», 2009, №42, стр. 32-36.

3. V.V. Malhotra. Innovative Applications of Superplasticizers in Concrete – A Review// CANMET/ACI Symposium on Advantes in Concrete Science Tech. Rome, okt. 7-10, 2017, Proceedings, p.p. 271-314.

4. J. Hamada. Influence of Superplasticizers on the hydration of cement and the pore structure of hardened cement. Cement and Concrete Research, 2002, 45, N2, 128-134.