Specific Features Of The Properties Of High-Strength Concrete

[1] Yusupov R.R.
[2] Khujaev D.Kh.
[3] Khikmatkhujaev I.Sh.
[4] Salomov A.A.
[1] Candidate of technical sciences, professor, Tashkent University of Architecture and Construction, The Republic of Uzbekistan, Uzbekistan
[2] PhD, associate professor, Tashkent University of Architecture and Construction, The Republic of Uzbekistan, Uzbekistan
[3] Master's student, Tashkent University of Architecture and Construction, The Republic of Uzbekistan, Uzbekistan
[4] Tashkent University of Architecture and Construction, The Republic of Uzbekistan, Uzbekistan

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Abstract

The application of high-strength concrete reduces the self-weight of reinforced concrete structures, decreases cross-sectional dimensions, and enables the creation of rational structural forms of elements, which is important for improving their operational performance.

This article summarizes the properties of high-strength concrete based on the results of several studies conducted to investigate their main characteristics. According to the research results, the specific features of such concrete are determined by the quality of the materials used, concrete production technology, and operating conditions under load.

At present, new experimental and theoretical studies are planned in order to further expand research in this field and introduce high-strength concrete into construction practice. One of the main objectives is the application of high-strength concrete in multi-storey reinforced concrete frame residential and public buildings.

Keywords: High-strength concrete, properties, reinforced concrete, results, testing, strength, deformation.

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1. Introduction

As is known, concrete is an artificial stone with a complex structure, and its specific properties are determined by the materials included in its composition and the compounds formed as a result.

Among concretes, high-strength concretes and reinforced concrete structures based on them are becoming increasingly widespread due to their special properties and expanding fields of application. These properties are widely used in the construction of modern multi-storey and high-rise buildings. Such buildings are being built using monolithic reinforced concrete construction technologies. Recently, extensive research has been carried out to develop and implement economically efficient and reliable construction methods. As a clear example, it is appropriate to cite the increasing use of high-strength concretes, as the demand for them arises from their unique properties.

Properties and advantages. According to the current standard [1], high-strength concretes are concretes with a compressive strength class of B60 and above, for which specific requirements are established. For their production, Portland cement clinker-based cements, clean and dry fractionated aggregates, and of course supplements must be used. Special attention is paid to the quality of materials and production technology [2,3].

Currently, the use of such concretes is mainly widespread in industrial construction; using their special properties, unique and high-rise buildings with heights of 300 m and above are also being constructed. An example of this is load-bearing structures (columns, walls, foundations, etc.) with high application efficiency. This allows for a reduction in geometric dimensions and reinforcement consumption of reinforced concrete structures, resulting in a decrease in the overall weight of the building. In addition, high-strength concrete is increasingly used in the construction of special engineering structures.

Like other construction materials, high-strength concrete has both advantages and disadvantages.

Advantages:

– high compressive, tensile, and flexural strength;

– high resistance to deformation and crack formation;

– good frost resistance and resistance to temperature variations;

– impermeability to high water pressure;

– high chemical resistance;

– savings in concrete and reinforcement due to reduced geometric parameters and reinforcement requirements.

Disadvantages:

– high cost due to the need for special components (supplements);

– the necessity of specialized equipment (high-speed concrete mixers) to ensure proper mixing technology.

2. Results

The strength of high-strength concrete, like that of ordinary concrete, depends on the water–cement ratio and cement strength. In addition, it depends on the activity of supplements and the cleanliness of aggregates. By fulfilling technological requirements, compressive strength can reach 150–170 MPa and tensile strength 6.0–7.0 MPa [3].

Considering these factors, current design standards for concrete and reinforced concrete structures [4,5,6] limit the maximum compressive strength class of heavy concrete to 105 MPa according to EN 1992-1-1, and to B100 MPa according to the Russian standard SP 63.13330.2012 and QMQ 2.03.01-21. In all three documents, concrete strength classes are based on testing at 28 days of age.

According to EN 206-1 [7] and GOST 10180-2012 [8], the compressive strength of heavy concrete, including high-strength concrete, is determined using standard cube specimens measuring 150×150×150 mm. The prism strength, modulus of elasticity, and Poisson's ratio of high-strength concrete are determined in accordance with GOST 24552 [9].

The tensile strength of concrete is determined by the maximum stress generated under axial tensile loading. If tensile strength is determined by splitting, the axial tensile strength is taken as 90% of the splitting tensile strength.

The addition of silica fume, fly ash, and polycarboxylate superplasticizers to heavy concrete accelerates cement hydration, increases the density and strength of cement stone, and ensures high strength (R = 60–80 MPa) of self-compacting concrete [2]. The prism strength coefficient varied between 0.79 and 0.91, while tensile strength ranged from 6.3 to 7.6 MPa, which are characteristic values for high-strength concrete.

Similar results characterizing the properties of high-strength concrete have been reported in other studies [3].

In these studies, three heavy concrete compositions were tested: one with superplasticizer and two with organo-mineral modifiers. The modifier consumption was 96–98 kg/m³, and cement content ranged from 465–475 kg/m³. The sand-to-crushed stone ratio was kept constant at 0.79. The compressive strength results were 76.3 MPa for the first mix and 89.2 and 88.2 MPa for the second and third mixes, respectively. Corresponding prism strength coefficients were 0.95, 0.93, and 0.95. These results indicate that high-strength heavy concretes have high prism strength and an extended elastic deformation stage.

It is known that deformations of high-strength concrete under short-term increasing loads, similar to ordinary concrete, consist of two components: elastic and pseudoplastic deformations, associated with the formation of microcracks. Such tests aim to determine the modulus of elasticity and ultimate strains. The obtained values depend on concrete strength, material proportions, loading regime, stress gradient, scale effect, and other factors.

With increasing strength of high-strength concrete, the modulus of elasticity also increases. For example, when prism strength increased from 72.4 MPa to 83.8 MPa, the modulus of elasticity increased by about 30%. Similar relationships were observed in other studies and largely determine the shape of the stress–strain diagram. For high-strength concrete, this relationship is predominantly linear.

Stress–strain diagrams adopted in design standards of different countries differ. These diagrams are curved, with ultimate strains corresponding to maximum stress ranging from 150×10^{5} to 220×10^{5}. In high-strength concrete, the linear stage of the stress–strain diagram extends up to 0.6 Rb [10].

The stress–strain diagrams under compression are shown in the figure.

a. b.

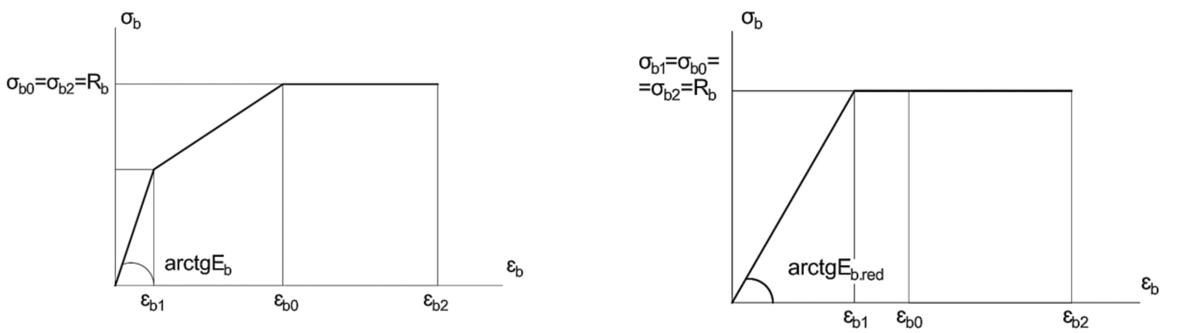

Figure. Stress–strain relationships of concrete under compression:

a – trilinear diagram;

b – bilinear diagram.

The modulus of elasticity values of high-strength concrete are given in the table.

Regulatory document	Concrete compressive strength class					
EN 1992-1-1	60	67	75	85	95	105
$E_b \times 10^{-3}, MPa$	37.5	38.0	39.0	41.0	42.0	44.0

QMQ 2.03.01-24	55	60	70	80	90	100
$E_b \times 10^{-3}, MPa$	39.5	40	41	42	42.5	43
СП 63.13330.2012	55	60	70	80	90	100
$E_b \times 10^{-3}, MPa$	39.0	39.5	41	42	42.5	43

The values presented in the table are very close across all three standards, with differences not exceeding 3–5%, mainly due to variability in concrete composition. According to the standards of Uzbekistan and the Russian Federation, the modulus of elasticity values are the same.

The ultimate strain values for high-strength concrete according to EN 1992-1-1 range from 245×10^{-5} to 280×10^{-5}. In this standard, failure of compressed concrete is assessed based on limiting deformation, with different approaches to ultimate limit state consideration.

3. Conclusion

The specific properties of high-strength concrete presented in this article determine its application areas. Due to its dense structure, such concrete is resistant to aggressive environments. Depending on porosity, high-strength concrete can also exhibit high frost resistance, water impermeability, and resistance to deterioration.

The use of high-strength concrete in buildings and structures can reduce the weight of compressed elements by up to 25% and reinforcement consumption by up to 20%.

High-strength concrete enables new efficient structural solutions, allowing large spans to be covered with reinforced concrete structures while reducing overall weight. This is particularly important for ensuring seismic resistance of buildings and structures in earthquake-prone regions.

Currently, further experimental and theoretical studies are planned to expand research and implement high-strength concrete in construction practice, particularly in multi-storey reinforced concrete frame residential and public buildings.

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