Study of the strength properties of modified concrete in tension

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Abstract. The resistance of concrete to axial tension is much less than the resistance to compression and is largely determined by the adhesion of its components. The low tensile strength of ordinary concrete is explained by the heterogeneity of its structure and the discontinuity of concrete, which contributes to the development of stress concentration, especially under the action of tensile forces. To increase the tensile strength of concrete, it is necessary to eliminate, first of all, the heterogeneity of the structure of concrete - one of the main reasons for the large dispersion of the results of mechanical tests of this material, which affects the experimental determination of compressive strength. A significant difference between the compressive strength for ordinary concrete indicates a rather large spread of such values. This scatter is explained by the different influence of factors on tension and compression. For example, for ordinary concretes, it was found that with an increase in W/C, the tensile strength decreases, but to a lesser extent than the compressive strength. With an increase in the grade of concrete, the tensile strength increases. High-strength concretes, as a rule, prepared on concrete mixes with low W/C and on clean conditioned aggregates in the form of crushed stone and sand, have an increased density, therefore, they have less variation in strength readings both in compression and at stretching [1-4].

1 Introduction

To determine the value of the temporary tensile strength R_{st} at one time, Fere proposed dependence in the form:

$$R_{st} = 0.50 \cdot R^{2/3} \qquad (1)$$

At present, this dependence also applies to concrete of grade 600 and more.

Under the action of vibro-impact pressing, the concrete is compacted, which is characterized by a decrease in the thickness (height) of the sample. In all experimental observations, small discrepancies in the relative strain were noted at different heights of the samples, i.e. the dimensions of the samples were taken as 80 x 80, 100 x 100, 150 x 150,

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and the concrete composition was 1 : 1.1 : 2.84 at $(W/C)_{beginning} = 0.35$.

Thus, during vibro-impact pressing of a concrete mixture, preliminary vibro-impact compaction creates favorable conditions for uniform deformation of the mixture. In the process of vibro-impact compaction of the concrete mixture, the aggregate grains begin to move, meeting, repel each other and from the mold walls. As a result, a layer of cement paste appears between them, increasing the homogeneity of the cementing matrix, which contributes to a more compact arrangement of aggregate grains in the concrete mixture. The foregoing is confirmed by the fact that on the surface of samples prepared by vibro-impact pressing without preliminary vibro-impact compaction, individual grains of coarse aggregate were observed that were not covered with cement mortar [6-11].

For samples made by vibro-impact pressing, after preliminary vibration of the mixture, the outer surface consisted mainly of cement stone with a thickness of 0.5 ... 1.0 mm.

2 Methods

As a result of the analysis of modern technologies, it has been established that physical modification is possible by removing excess water added to the concrete mixture to give it the necessary fluidity and workability.

In the process of removing excess water and entrained air, the cement particles will begin to approach each other, which, in turn, will lead to the convergence of grains of coarse and fine aggregates. The normal pressure that is transferred to the water and causes its removal will contribute to the approach of the particles until the external pressure is completely perceived by the dispersed phase.

The removal of free water during the compaction process maximizes the use of the potential properties of cement to increase the density, water resistance and strength of concrete. Currently, in the technology of complex elements, there are several methods for dehydrating a concrete mixture: centrifugation, pressing, vacuuming, vibro-compression, etc. One of the most effective methods should be considered a vibro-peristaltic pressing method, since this can create the necessary conditions for maximum dehydration of a concrete mixture, and concrete.

3 Results and Discussion

The mode of vibrocompression of the concrete mix with dehydration (Table 1) provides the possibility of reducing the water-cement ratio from 0.31...0.40 to 0.263...0.290, i.e. by 14...29.5% of the initial A/C. As a result, the compressive strength of concrete at the age of 28 days increased to 110.7 MPa, the tensile strength reached 16 MPa, and the water resistance increased to 3 MPa. The values of R_{c} and R_{st} for HCMC and conventional concrete are shown in figure 1. At the same time, the value of Rp for ordinary concretes was taken according to the experimental data of O.Y.Berg [6]. It is characteristic that the area of hypercompacted concrete lies above the area of ordinary and even high-strength concretes [19, 20]. A particularly significant difference in the values of R_{st} was observed in extra-strong hyper-compacted concretes.

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Table 1. Influence of molding methods on the strength of concrete

№	Initial W/C	Consumption of materials per 1 m^3 of concrete, kg				Vibro pressing mode	The amount of squeezed water,%	Residual W/C	Compressive strength, MPa, 28 days	$\Delta = \frac{R_c^{vp}}{R_c^{v}}$
		Cement (C)	Sand (S)	Gravel (G)	Water (W)					
1	2	3	4	5	6	7	8	9	10	11
1	0.31	530	495	1272	165	1	$\frac{14.0}{-}$	$\frac{0.268}{0.31}$	$\frac{101.3}{46.7}$	2.17
						2	$\frac{14.5}{-}$	$\frac{0.267}{0.31}$	$\frac{104.6}{46.7}$	2.24
						3	$\frac{15.7}{-}$	$\frac{0.263}{0.31}$	$\frac{110.7}{46.7}$	2.37
2	0.33	490	506	1300	162	1	$\frac{16.7}{-}$	$\frac{0.276}{0.33}$	$\frac{93.6}{45}$	2.08
						2	$\frac{17.9}{-}$	$\frac{0.271}{0.33}$	$\frac{96.3}{45}$	2.14
						3	$\frac{19.1}{-}$	$\frac{0.268}{0.33}$	$\frac{100.4}{45}$	2.23
3	0.35	460	508	1308	161	1	$\frac{19.9}{-}$	$\frac{0.280}{0.35}$	$\frac{85.5}{42.1}$	2.03
						2	$\frac{20.5}{-}$	$\frac{0.275}{0.35}$	$\frac{88.4}{42.1}$	2.10
						3	$\frac{21.7}{-}$	$\frac{0.278}{0.35}$	$\frac{90.5}{42.1}$	2.15
4	0.37	430	512	1316	159	1	$\frac{22.6}{-}$	$\frac{0.287}{0.37}$	$\frac{79.4}{40.3}$	1.97
						2	$\frac{24.5}{-}$	$\frac{0.280}{0.37}$	$\frac{85.4}{40.3}$	2.02
						3	$\frac{24.5}{-}$	$\frac{0.280}{0.37}$	$\frac{85.5}{40.3}$	2.12
5	0.40	397	516	1326	159	1	$\frac{27.3}{-}$	$\frac{0.290}{0.40}$	$\frac{67.1}{34.6}$	1.94
						2	$\frac{28.3}{-}$	$\frac{0.288}{0.40}$	$\frac{69.5}{34.6}$	2.01
						3	$\frac{29.5}{-}$	$\frac{0.283}{0.40}$	$\frac{72.7}{34.6}$	2.10

Note: Above the line - test results of concrete samples, compacted; vibro-impact pressing, under the line - the same, compacted by vibration, where: $R_{st.v-i}$ *- strength of vibro-impact-peristaltically pressed concrete;* $R_{st.v-c}$ *is the strength of vibro-compacted concrete.*

A significant change in the strength of concrete in compression and tension ($R_c\ /\ R_{st}$) is characterized by the fact that this ratio decreases with a decrease in $(W/C)_{beg}$. It can be concluded that with a decrease in the initial W/C, the efficiency of hyperdensification increases [22–24]. The greatest hyper-compaction effect was observed at $(W/C)_{beg}$ = 0.31, when the R_c/R_{st} ratio decreased to 7...8. Therefore, the average tensile strength of hyper-compacted concrete was 109.7/6.9=15.9 MPa. Such tensile strength corresponds to the M150 grade of ordinary concrete in compression. This material is able to withstand significant tensile stresses. For example, it can be reliably used without reinforcement for non-pressure and low-pressure tubular elements. A production review of these provisions confirmed the validity and reliability of these provisions.

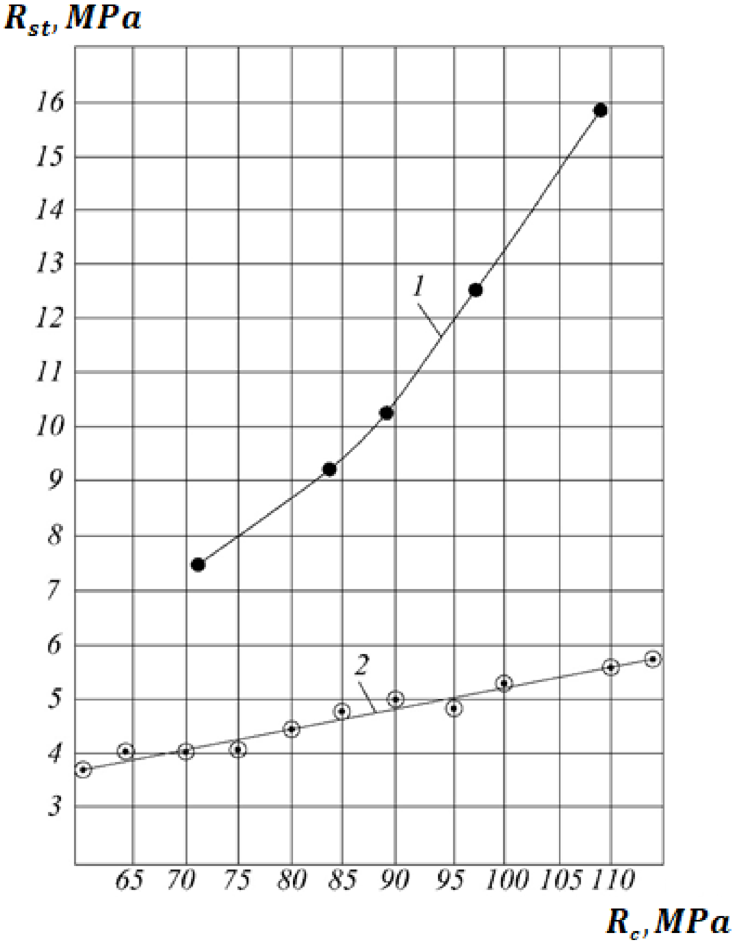

Fig. 1. The dependence of the strength of concrete in axial tension R_{st} on its cylindrical strength R_c: 1 – vibro-peristaltic hyper compacted concrete (R_{st}); 2 - data of O.Ya. Berg [11].

The ratio of the strength of concrete in tension and compression, given in table 2 are also reflected in the graph, figure 2.

An analysis of the experimental data for determining the tensile strength of hyper-compacted concrete leads to the conclusion that the use of the Fere formula is impossible. As follows from dependence (1), the coefficient 0.5 is a constant value. This may be true for vibro-compacted concrete. During hyper consolidation and modification of concrete, the coefficient in the Fere formula becomes variable and depends on the value of the compressive strength of concrete, Fig. 3. From experimental data it follows that when the strength of concrete changes from 70 to 110 MPa, the coefficient increases from 0.55 to 0.70. One can accept the linear dependence of K_r on K_b. In this case, Fere's formula for hyper- compacted modified concrete takes the form:

$$R_{st} = K \cdot R_c \sqrt[3]{R_c^2} \qquad (2)$$

Table 2. The ratio of the strength of concrete in tension and compression

Strength characteristic of concrete, MPa, at the age of 28 days	Designation	$(W/C)_{beg}/(W/C)_{res.av}$				
		$\frac{0.31}{0.265}$	$\frac{0.33}{0.270}$	$\frac{0.35}{0.276}$	$\frac{0.37}{0.281}$	$\frac{0.40}{0.285}$
Vibrocompacted	R_c	46.3	45.1	42.0	41.2	34.9
	R_{st}	5.1	4.9	4.5	4.0	3.4
	R_c/R_{st}	9.1	4.9	4.5	4.0	3.4
Vibro-impact-pressed	R_c	109.7	97.4	89.1	84.9	71.3
	R_{st}	15.9	12.5	10.2	9.1	7.4
	R_c/R_{st}	6.9	7.8	8.7	9.3	9.6

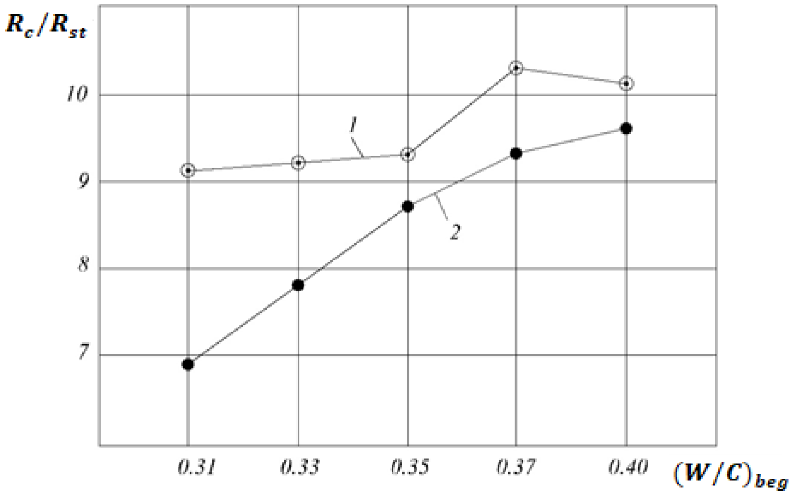

Fig. 2. The ratio of the strength of concrete in tension and compression: 1 - concrete, compacted by vibration; 2 - concrete compacted by vibro-impact pressing.

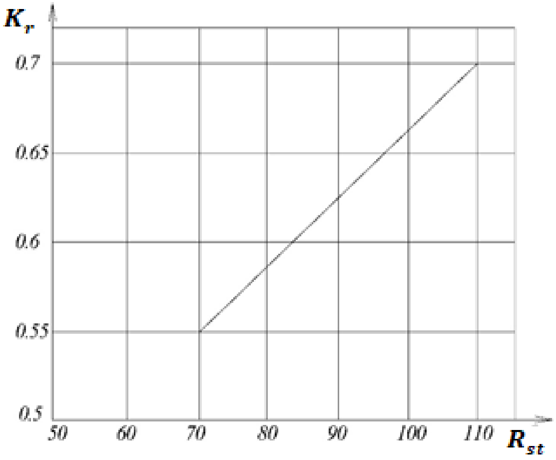

Fig. 3 The dependence of the stretching coefficient in the refined Fere formula for hyper-compacted modified concrete (HCMC)

It is more rational to bring this formula to the form:

$$R_{st} = \frac{K \cdot \sqrt[3]{R_c^5}}{100}. \qquad (3)$$

As shown by the experiments, this dependence makes it possible to reliably predict the tensile strength of hyper compacted concrete. It should be noted that for HCMC with a strength above 90 MPa, the R_c/R_{st} ratio decreases to 7...8. Consequently, high-intensity compaction and modification of concrete also leads to an increase in the homogeneity of the material, and, consequently, an additional increase in tensile strength.

4 Conclusions

1. The developed complex method of hyper-consolidation and modification of the concrete mixture makes it possible to increase the strength of experimental concrete by 2...2.2 times compared to the strength of vibro-compacted concrete with the same initial W/C value

2. The ratio between the strength of hyper-compacted concrete and $(W/C)_{res}$ is linear, however, the tangent of the slope of the dependence $R_c = (W/C)_{res}$ is 2 times greater than the analogous parameter of vibrocompacted concrete.

3. The functional dependence of the strength of hyper compacted concrete on its structural components, strength, elasticity and deformability of the corresponding cement stone and mortar part of concrete has been established, while the dependence of R_c on R_{st} and K_{dis} is approximately linear.

4. Experiments have shown that hyper consolidation, together with the modification of the concrete mixture, has a greater effect on the tensile strength of concrete, while the ratio R_c / R_{st} decreases to 7 ... 8 compared to the same indicator of high-strength concrete, equal to 9 ...10. A refined dependence is proposed for determining R_{st} by grade strength R_c obtained from the Fere formula.

References

1. Zhao Y., Liu Y., Shi T., Gu Y., Zheng B., Zhang K., and Shi S. Study of mechanical properties and early-stage deformation properties of graphene-modified cement-based materials. Construction and Building Materials, **257**, 119498 (2020)
2. Hany N. F., Hantouche E. G., and Harajli M. H. Finite element modeling of FRP-confined concrete using modified concrete damaged plasticity. Engineering Structures, **125**, pp.1-14. (2016)
3. Chen X., Wu S., and Zhou J. Experimental and modeling study of dynamic mechanical properties of cement paste, mortar and concrete. Construction and Building Materials, **47**, pp.419-430 (2013)
4. Sukmak G., Sukmak P., Horpibulsuk S., Yaowarat T., Kunchariyakun K., Patarapaiboolchai O., and Arulrajah A. Physical and mechanical properties of natural rubber modified cement paste. Construction and Building Materials, **244**, 118319 (2020)
5. B. Khasanov and T. Mirzaev, Production of extra-strong concrete axisymmetric products. In E3S Web of Conferences, **97**, (2019) doi:10.1051/e3sconf/20199706011
6. Berg O. Y., Rozhkov A. I. Issledovaniya neuprugikh deformatsiy i strukturnykh izmeneniy vysokoprochnogo betona pri dlitel'nom deystvii szhimayushchikh

napryazheniy, **70**, Moscow (1969)

7. Pisanko G. N. Issledovaniye prochnostnykh i deformativnykh svoystv vysokoprochnykh betonov, **36**, pp. 88-91, Moscow (1960)
8. B. Khasanov, R. Choriev, N. Vatin and T. Mirzaev. The extraction of the water-air phase through a single filtration hole. In IOP Conf. Series: Materials Science and Engineering **883** (2020), doi:10.1088/1757-899X/883/1/01220
9. Rokach V. S., Kochetkov Yu.I. Prochnost i deformativnost' betona na osobo bystrotverdeyushchem tsemente. Beton i zhelezobeton, 12, pp. 21-22 (1968)
10. Fernández Canteli A. C., Castañón L., Nieto B., Lozano García M., Holušová T., and Seitl S. Determining fracture energy parameters of concrete from the modified compact tension test. Frattura ed Integrita Strutturale, **30,** (2014)
11. Sytnik V. I., Ivanov Yu.A. Rezultaty eksperimentalnykh issledovaniy prochnostnykh i deformativnykh kharakteristik betonov markov 600-1000, p. 128, Kiyev (1966)
12. Cifuentes H., Lozano M., Holušová T., Medina F., Seitl S., and Fernandez-Canteli A. Modified disk-shaped compact tension test for measuring concrete fracture properties. International Journal of Concrete Structures and Materials, **11**(2), pp.215-228 (2017)
13. B. Khasanov, N. Vatin, T. Mirzaev, A. Suyunov and M. Radjabov. Physicochemical fundamentals of modifying concrete mix and concrete. In IOP Conf. Series: Materials Science and Engineering **1030**, (2021) doi:10.1088/1757-899X/1030/1/012022.
14. Chun B., Kim S., and Yoo D. Y. Reinforcing effect of surface-modified steel fibers in ultra-high-performance concrete under tension. Case Studies in Construction Materials, **16**, e01125. (2022)
15. B. Khasanov, N. Vatin, T. Mirzaev, A. Suyunov and M. Radjabov. Analysis of the mode of squeezing out excess water for mixing concrete mixture in the process of peristaltic compaction. In IOP Conf. Series: Materials Science and Engineering **1030**, (2021) doi:10.1088/1757-899X/1030/1/012021
16. Kaklauskas G., Gribniak V., Bacinskas D., and Vainiunas P. Shrinkage influence on tension stiffening in concrete members. Engineering structures, **31**(6), 1305-1312 (2009)
17. B. Khasanov L. Irmuhamedova, G. Firlina, T. Mirzaev. Theoretical foundations of the structure formation of cement stone and concrete. In IOP Conf. Series: Materials Science and Engineering **869** (2020) doi:10.1088/1757-899X/869/3/032032
18. Carreira D. J., and Chu K. H. Stress-strain relationship for reinforced concrete in tension. In Journal Proceedings, 83(1), pp. 21-28 (1986)
19. B. Khasanov, N. Vatin, Z. Ismailova and T. Mirzaev. Physical modification of concrete mix and concrete. Materials Science and Engineering **883**, (2020) doi:10.1088/1757-899X/883/1/012205
20. Stramandinoli R. S., and La Rovere H. L. An efficient tension-stiffening model for nonlinear analysis of reinforced concrete members. Engineering Structures, **30**(7), 2069-2080 (2008)