MECHANICS

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Research of physicomechanical and design characteristics of vibrated, centrifuged and vibro-centrifuged concretes

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Introduction. Currently, the obtaining of lightweight concrete and reinforced concrete products and structures with the improved structure and characteristics is a challenge. This can be achieved through centrifugation or in a more advanced way — vibro-centrifugation. At the same time, the influence of centrifugal and centripetal forces of inertia in these types of technologies causes differences in the cross-section properties of concrete products and structures. To reflect this in the calculations, it is required to experimentally and analytically investigate the qualitative and quantitative patterns of such differences in the characteristics of concretes obtained through different technologies.

Materials and Methods. The study used the cross-section averaged characteristics of concrete — “integral characteristics of concrete”. The applicable raw materials included portland cement 500, crushed stone fraction 5-20, medium sand. Nine control samples of annular cross-section obtained through vibrating, centrifuging, and vibro-centrifugation were manufactured and tested. The essence of the technique was that each manufactured experimental control sample was used in several types of tests in-parallel. From the total annular section of each sample, three conditional quadrants were distinguished, from which standard samples of small size were cut out. Subsequently, they were tested for axial compression, tension, and flexural tension. The following test equipment was used: electronically controlled mechanical press IPS-10 — for compression testing of prisms, and the breaking machine R-10 — for testing samples for axial tension. Strain sensors and dial indicators were used to measure concrete deformations. Oscilloscopes were also used to obtain the deformative and strength properties of concrete, including full deformation diagrams with descending branches.

Results. We have analyzed the calculation results of the integral design characteristics of the concretes obtained through vibration, centrifugation and vibro-centrifugation. It is established that due to the influence of centrifugal and centripetal forces of inertia under centrifugation and vibration centrifugation, the characteristics of concrete in cross-section become different. In some cases, these differences can be very significant. We have developed and tested the following: a new method for evaluating the dependence of the integral (cross–section averaged) design characteristics of concrete (density, cubic and prismatic axial compressive strength); ultimate deformations under axial compression; axial tensile and flexural tensile strength; ultimate deformations under axial tension; elasticity modulus; diagram of “stress σ_b–strain ε_b” under compression; diagram of “stress σ_{bt}–strain ε_{bt}” under tension on the manufacturing technology (vibrating, centrifuging, vibration centrifugation).

Discussion and Conclusions. Based on the results of the research, conclusions are formulated on the positive effect of the proposed technology of joint vibrating and centrifuging. It consists in improving the integral design characteristics and structure of concrete from vibrating to centrifuging and from centrifuging to vibro-centrifuging.

Keywords*:* vibrating, centrifugation, vibro-centrifugation, column calculation, variatropic structure, integral characteristics of concrete, ultimate deformations, compressive strength, elasticity modulus.

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Introduction. It is known that through vibro-centrifugation[1,2,3] [1–11], it is possible to obtain concretes with improved structure and characteristics compared to those obtained through centrifugation and vibration.

However, in a few works on concrete and reinforced concrete annular structures, the influence of the type of technology on the average (general) cross-section characteristics of concrete was considered [12−15]. At the same time, it is obvious that due to the influence of centrifugal and centripetal forces of inertia under centrifugation and vibration centrifugation, the cross-sectional characteristics of concrete differ [16].

In this paper, we experimentally and analytically investigate the qualitative and quantitative patterns of such differences in the characteristics of concretes obtained through various technologies. Obviously, to account for these differences, it is required to introduce some averaged cross-sectional characteristics of the elements. For this purpose, we introduce the term "integral characteristics of concrete".

Materials and Methods. In total, nine control annular samples made through vibration, centrifugation and vibro-centrifugation were produced and tested. Dimensions of these samples were as follows: outer diameter *D* — 450 mm, inner diameter *d* — 150 mm; total height *H* — 1200 mm.

The equipment and test methods used are described in [8−11].

Crushed stone fraction 5–20 was used as a filler, which brings the properties of the resulting concrete closer to the properties of fine-grained concrete.

In the experiments, the type of manufacturing technology varied, which was recorded in the designations of the samples: vibration — V, centrifugation — C, vibro-centrifugation —VC.

The problem of estimating the dependence of the integral (averaged over the cross–section) structural characteristics of concrete (density, axial compressive strength (cube and prism); ultimate deformations under axial compression; axial tension strength and flexural tension; ultimate deformations under axial tension; elasticity modulus; diagram of "stress σ_b– strain ε_b" under compression; diagram of "stress σ_{bt}–strain ε_{bt}" under tension) on the manufacturing technology (vibration, centrifugation, vibro-centrifugation) was considered.

Research Results. The test procedure differed in that each manufactured experimental control sample was used in several types of tests in-parallel. Control samples in a single copy were selected and tested on the 7th, 28th and 180th days.

From the total annular section of each sample, 3 conditional quadrants *A, B* and *C* were allocated, from which small-size samples were cut out. Subsequently, they were tested for axial compression, tension, and flexural tension (Fig. 1, 2).

Four cube samples with an edge of 15 cm were cut out of the quadrant *A* for compression and tension tests (levels 1–4), one prism (15×15×60 cm) — for flexural tension tests (level 5). For the axial compression tests, two prisms (15×15×60 cm) were cut out of the quadrant *B* (levels 1–2). Next, three prisms (15×15×60 cm) were cut out of the quadrant *C* for axial tension tests (levels 1–2).

After testing the cubes for axial compression, we obtained values $R_{b,cub}$, after testing the prisms for axial compression — values R_b, ε_{bR}, R_{bt}, ε_{btR}, E_b=E_{bt} and the deformation diagram "σ_b–ε_b"; after testing the prisms for axial tension — values R_{bt} and the deformation diagram "σ_{bt}–ε_{bt}"; and after testing the prisms for flexural tension — values R_{btb}.

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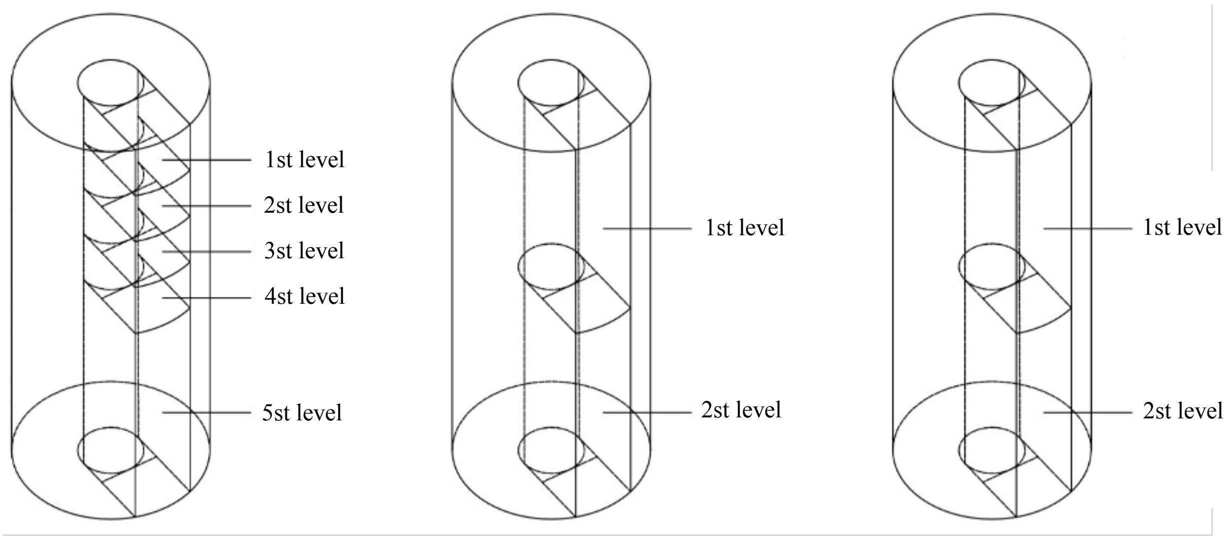
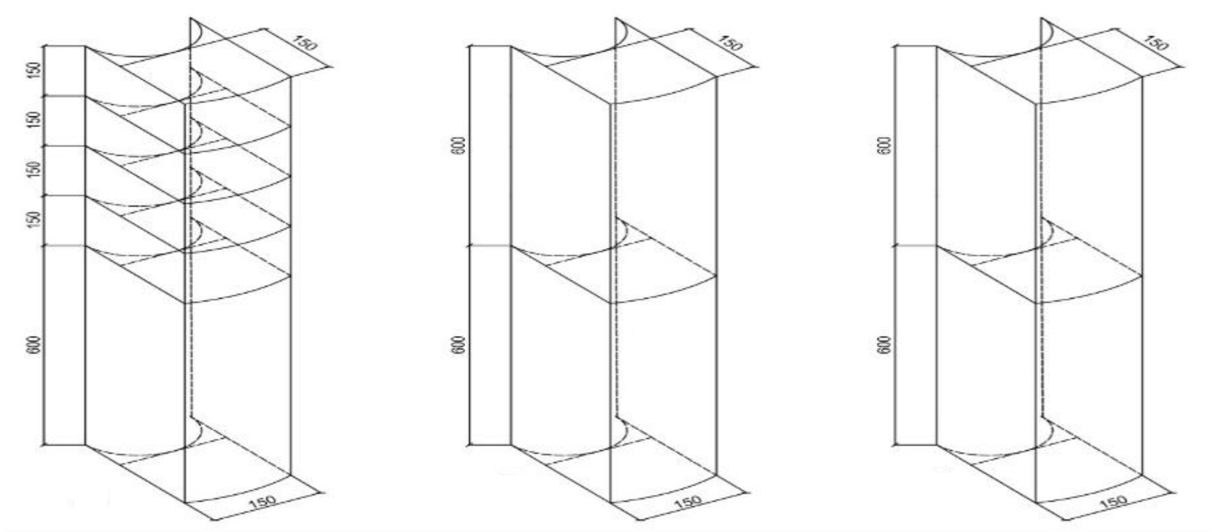


a) *b)* *c)*

Fig. 1. Scheme of manufacturing small-size concrete samples from quadrants along the height of experimental control full-scale samples of annular cross-section for calculating integral characteristics: *a*) quadrant *A*; *b*) quadrant *B*; *c*) quadrant *C*



a) *b)* *c)*

Fig. 2. Experimental small-size concrete samples from quadrants *A, B, C* of experimental control samples of full-scale annular cross-section for the analysis of integral structural characteristics *a*) quadrant *A*; *b*) quadrant *B*; *c*) quadrant *C*

The test procedure according to GOST 10 180 was applied. The following test equipment was used: IPS-10 — for testing prisms for compression, and P-10 — for testing samples for axial tension.

To measure concrete deformations, strain sensors with a measurement base of 50 mm and dial indicators with graduation 0.001 mm were used.

To obtain the deformative and strength properties of concrete, including complete deformation diagrams with descending branches, experiments were carried out using a constant deformation rate.

For this purpose, in addition to strain gauges, oscilloscopes were also used.

For tests with the same load feed rate, a loading step of $0.1R$ was selected, and the deformations of the prisms increased with a step of $0.1\varepsilon_R$ (Fig. 3).

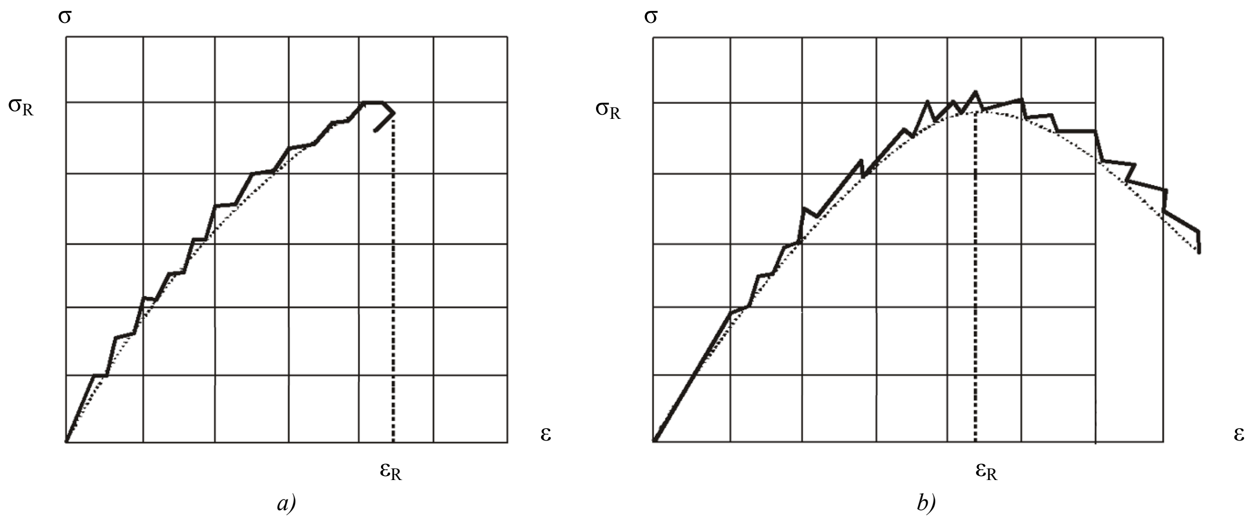


Fig. 3. Test modes of experimental small-size samples:
a) — step-by-step, with constant loading rate (Δσ=const);
b) — step-by-step, with constant deformation rate (Δε=const)

The final test mode consisted in increasing the load to the maximum and its subsequent decrease in the process of increasing deformation. Thus, during the tests, the descending branch of the concrete diagrams "σ – ε" was fixed, which has a fairly clear outline up to about the value of σ = 0.8 R, both under compression and tension. Subsequently, the dependence acquired a very unstable character

After analyzing the results obtained, we can draw conclusions about the influence of the sample manufacturing technology. The results of experimental studies of changes in the integral characteristics of experimental concrete samples, depending on the manufacturing technology, are shown in Fig. 4–10.

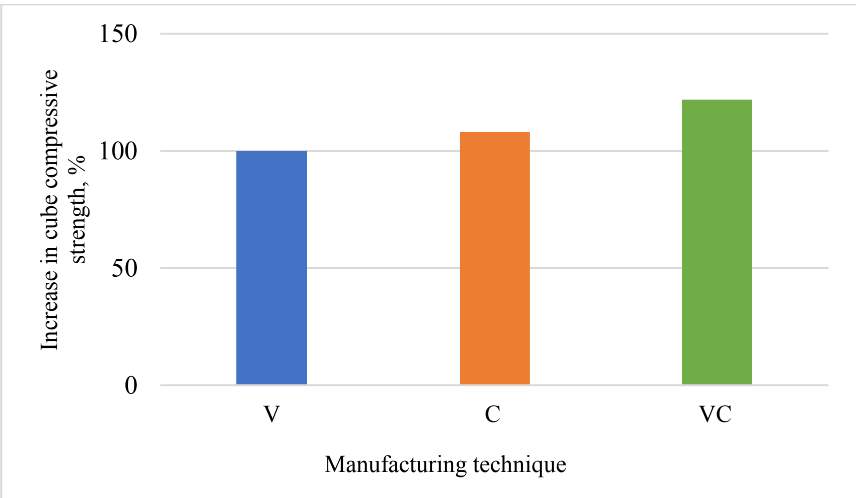


Fig. 4. Influence of manufacturing technique on increase in cube strength of concrete under compression

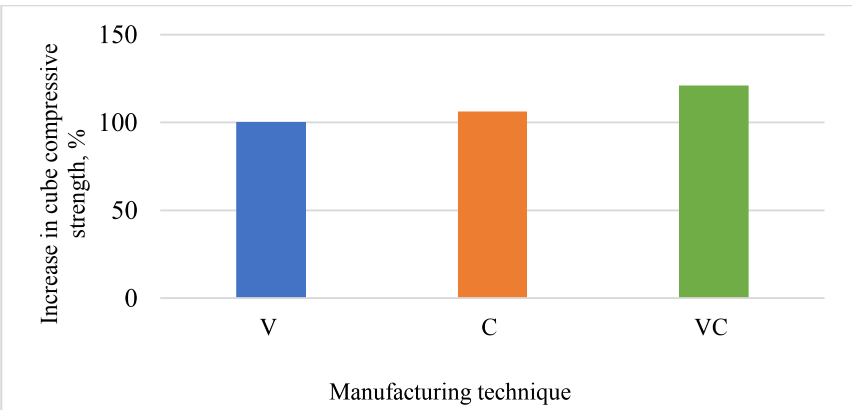


Fig. 5. Influence of manufacturing technology on increase in prism strength of concrete under axial compression

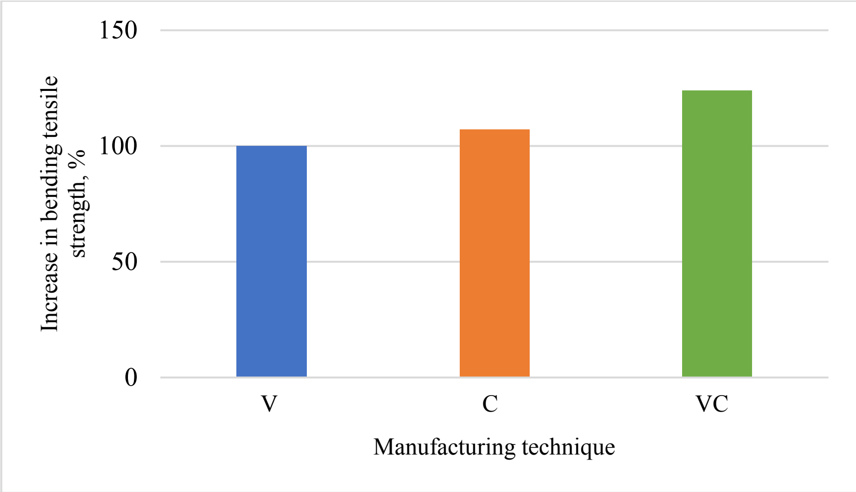


Fig. 6. Dependence of increase in bending tensile strength of concrete on manufacturing technique

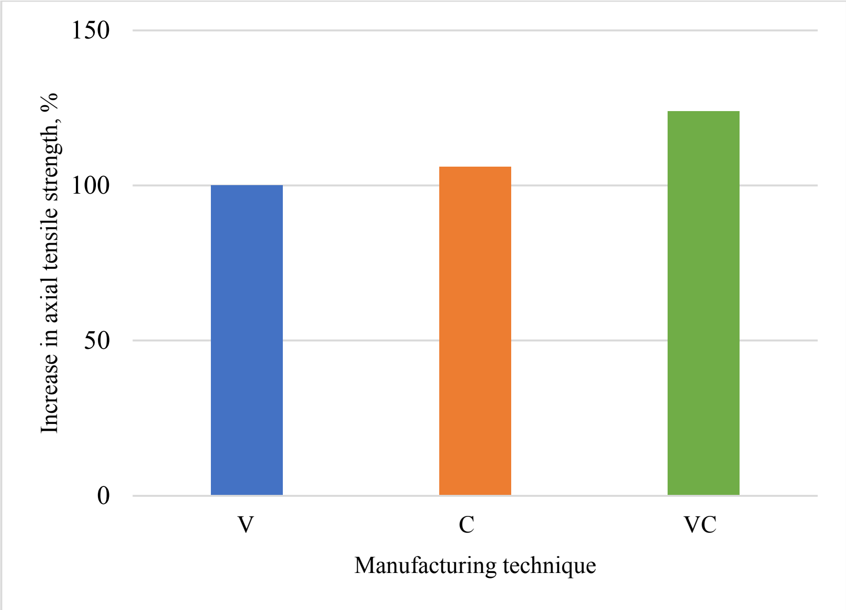


Fig. 7. Dependence of increase in axial tensile strength of concrete on manufacturing technique

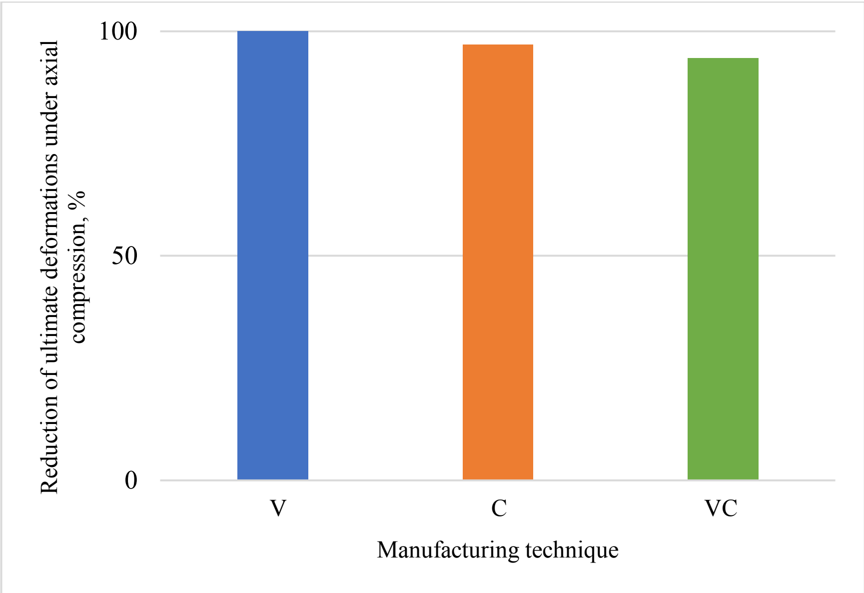


Fig. 8. Dependence of reduction of ultimate deformations under axial compression of concrete on manufacturing technique

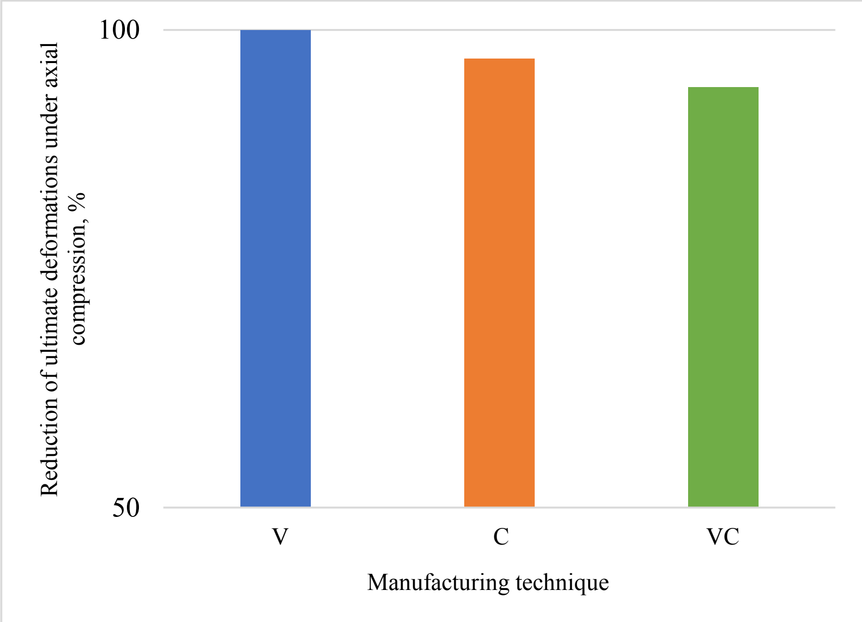


Fig. 9. Dependence of reduction of ultimate deformationsunder axial tension of concrete on manufacturing technique

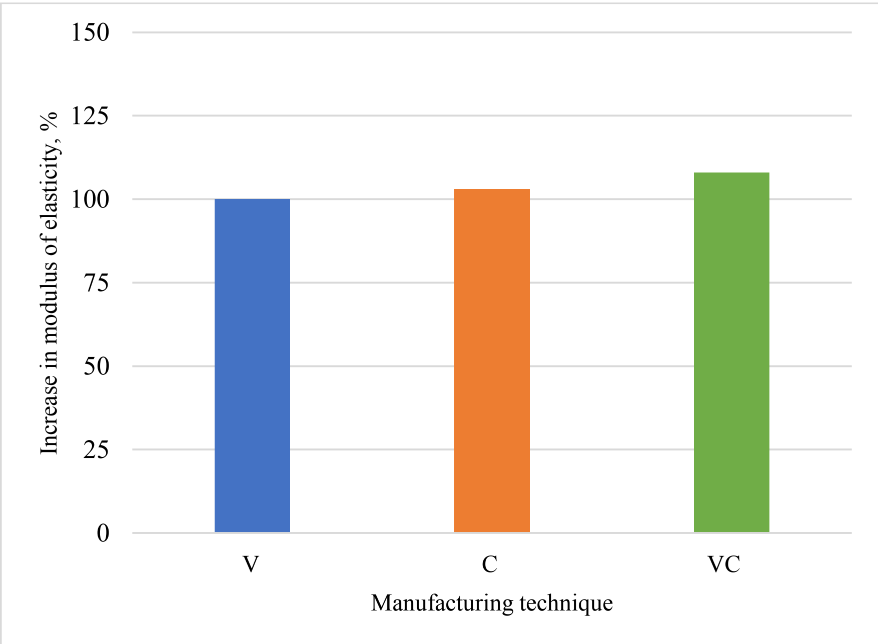


Fig. 10. Influence of manufacturing technique on increase in the concrete modulus of elasticity

Discussion and Conclusions. The influence of the sample manufacturing technology on the density at all ages was minimal (about 2 %), therefore, when calculating, the indicator "density" can be neglected.

Vibro-centrifugated concretes showed higher values in terms of "compressive strength" and "tensile strength" than vibrated and centrifuged concretes, namely: prism and cube compressive strength — up to 22.0 %, axial and flexural tensile strength — up to 27.0%.

Due to the ordering of the ongoing processes of hydration of cement stone, an increase in the compressive and tensile strengths of concrete with simultaneous vibration and centrifugation, in comparison with centrifuged and vibrated samples, with age occurs in the studied range of concrete age (7-180 days) and is practically within the same limits in all ages.

For vibro-centrifuged samples, there is a slight decrease (up to 6 %) in the ultimate deformations under axial compression and tension. This corresponds to the maximum strength of the concretes under study.

Vibro-centrifugated concretes, in comparison with vibrated and centrifuged concretes, showed the lowest ultimate deformations at any age.

The values of “compressive modulus E_b” and “tensile modulus E_{bt}” at all ages of concrete were up to 8.0 % higher in vibro-centrifuged concretes than in vibro-centrifuged and centrifuged concretes.

An increase in strength, with a parallel decrease in the ultimate deformations, was the reason for an increase in E_b and E_{bt} in concretes with simultaneous vibration and centrifugation, rather than in concretes with one of the types of compaction. This fact affected the “stress-strain” diagram — the maximum shifted up and to the left.

Differences in the stress-strain diagrams under compression and tension, characteristic of concretes with simultaneous centrifugation and vibration, at all ages are as follows:

— increase in strength and decrease in ultimate deformations (maximum shifts up and to the left);

— increase in the initial modulus of elasticity (increase at the ascending angle origin).

At all ages of concretes, the following tendency was characteristic: an increase in the lifting capacity of the ascending branch of the diagrams, a decrease in the descending branch in centrifuged and vibro-centrifuged concretes compared to vibrated ones.

According to this study, it is appropriate to draw the following conclusions.

1. Studies of the integral design characteristics under compression and tension of the considered types of concrete of various manufacturing techniques at the ages of 7, 28 and 180 days showed:

— concrete performance is improved from vibrating to centrifuging and from centrifuging to vibro-centrifuging;

— increase at all ages of compressive and tensile strengths (up to 23 %);

— reduction of all ultimate deformations (up to 8 %);

— increase in elastic modulus under various types of loading (up to 10 %).

2. For all integral diagrams of the “stress-strain” deformation of concrete with simultaneous vibration and centrifugation, the following is characteristic:

— moving the maximum up and to the left;

— increasing at the ascending angle origin;

— increasing the chart lift in the ascending branch.

3. Through numerous experimental studies, it has been established that simultaneous vibration and centrifugation contributes to the production of concretes with improved structure and characteristics, rather than concretes obtained by only one type of impact — centrifugation or on.

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Claimed contributorship

L. R. Mailyan: basic concept formulation; approval of the final version of the paper before submitting it for publication. E. M. Shcherban': collection, analysis and interpretation of the material for the paper. S. A. Stel'makh: computational analysis; text preparation; formulation of conclusions. Yu. V. Zherebtsov: plotting graphs and tables for the paper. M. M. Al-Tulaikhi: translation of the abstract and keywords into English, review of foreign literature sources.

All authors have read and approved the final manuscript.