ISSN 2522-4182

DOI: 10.32347/2522-4182.17.2025.119-130
UDC 624.012.45

INFLUENCE OF MIXING TIME OF CONCRETE MIXTURES ON THE DEFORMATIONAL CHARACTERISTICS OF STRUCTURAL CONCRETES

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Abstract. This scientific work is a continuation of studies [1] related to the determination of the class of structural concretes at different mixing times of the concrete mixture. The influence of the mixing time of the concrete mixture on the strength characteristics of concretes has been established. As a result of strength tests of cube and prism specimens, the classes of concretes by strength under axial compression were determined.

However, in the literature sources there are data on the influence of the deformability of concretes on the determination of their class by strength through the study of the modulus of elasticity of concretes. Therefore, the question arises of studying the deformability characteristics of concretes and their comparison with strength characteristics. Based on the results of these two studies, the final class of concrete can be determined.

The analysis of the current state of development and research of concretes has shown that one of the factors influencing the determination of the class of concrete by strength is the determination of the modulus of elasticity of concretes, which characterizes their deformability characteristics. Under laboratory conditions, studies of the modulus of elasticity and the class of concrete were carried out at mixing times of the concrete mixture of 480, 300, 180, and 90 seconds, respectively. For this purpose, 20 prism specimens with dimensions of 100 × 100 × 400 (height) mm were manufactured and tested. In determining the class of concrete, non-force (volumetric) deformations of concrete and the cost of producing 100 m³ of concrete mixture based on electricity consumption during the mixing time of the mixture were also taken into account.

As a result of the conducted studies, it was determined that to obtain a guaranteed class of structural concrete not less than C16/20 (B20), the optimal mixing time of the concrete mixture is 180 seconds.

The purpose of the study is to investigate the deformational characteristics of structural concretes depending on the mixing time of the concrete mixture and their influence on the determination of the concrete class in terms of compressive strength.

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Keywords: concrete mixture; mixing time; deformation characteristics; modulus of elasticity of concrete; concrete class

PROBLEM STATEMENT

This scientific work is a continuation of studies [1] related to determining the class of structural concrete at the optimal mixing time of the concrete mixture. The influence of mixing time of the concrete mixture on the strength characteristics of concrete has been established. As a result of strength tests of cube and prism specimens, concrete classes were determined according to axial compressive strength.

However, literature sources contain data on the influence of concrete deformability on determining its strength class through the study of the modulus of elasticity of concrete. Therefore, the question arises of studying the deformation characteristics of concrete and comparing them with strength characteristics. Based on the results of these two studies, the final class of concrete can be determined

ANALYSIS OF PREVIOUS RESEARCH

Analysis of the current state of development and research of concrete showed that one of the factors influencing the determination of concrete class by strength is the determination of the modulus of elasticity of concrete, which characterizes its deformation properties. Analysis of publications allows us to state that one of the most successful idealized objects of the general theory of its deformation can be considered the model of a deformed solid body. Such a model made it possible not only to reproduce the elastic–plastic properties of reinforced concrete itself but also to propose their alternative solutions in the form of force, deformation, and improved deformation–force models [2].

Among the deformation characteristics of concrete, two types of deformations can be distinguished: force deformations, which spread in the direction of the applied force, and non-force (volumetric) deformations, which spread in all directions and are mainly caused by shrinkage and swelling of concrete [3,4]. The study by Kongshaug [5] examined how force loading affects expansion and deformation of concrete, and determined that loading acts on concrete synergistically: mechanical characteristics (strength and modulus of elasticity) decrease faster under combined action and change the deformation model of the structure.

The main tool of the deformation calculation model is the actual stress–strain diagram of concrete, which establishes the relationship between its stresses σ and relative deformations ε in the compressed and tensioned zones of the section. Most often such a diagram is obtained by indirect methods, testing standard concrete prisms under eccentric compression [6, 7].

Chinese scientists in [8] proposed a new technology for determining deformability on concrete cubes by simultaneously measuring the modulus of elasticity and Poisson's ratio under a special vibration regime. The authors [9] proposed measuring deformations on porous concrete cylinder specimens by testing these specimens under triaxial compression and tension with significant lateral pressure. At the same time, measuring axial deformation using sensors makes it possible to assess the homogeneity of specimen deformation.

In domestic practice, there are two different approaches to determining the class of concrete by deformability. Authors [3] determine the class of concrete by the initial modulus of elasticity at stresses equal to 20% of ultimate strength, while authors [10] determine the class of concrete by the average value of the initial modulus of elasticity at stresses equal to 30% of ultimate strength. Therefore, two different approaches to determining the class of concrete by deformability require practical studies of both moduli of elasticity, and the class of concrete determined by deformability requires comparison with the class of concrete determined by strength.

It is desirable to supplement the list of Ukrainian studies in which the force loading of prisms was investigated: in [13, 14] the force loading regimes of prisms were studied, analyzing the stress–strain relationship, as well as modeling the stress–strain state of concrete under different loading regimes. The authors [15] conducted tests of prisms under central compression, with emphasis on crack resistance and force deformations.

In the work of the author [16], the modulus of elasticity is considered as the main parameter for stiffness calculations. Examples of determining the initial modulus of elasticity are provided. The study also describes the modulus of elasticity, shrinkage, and creep.

An analysis of the obtained diagrams in our study was carried out using the work of Fomin et al. [17]. The paper also describes the regularities of deformation changes on the graph and how this affects the load-bearing capacity of structures. An analysis of the obtained diagrams was performed in our study.

In the sections [18] devoted to the calculation of deflections and stiffness, the modulus of elasticity is used as a key parameter. It is explained how its value influences the deformation characteristics of structures.

In the works [19, 20, 21], a common approach to the analysis of concrete deformational characteristics can be observed. All authors emphasize the importance of the modulus of elasticity and shrinkage as key parameters determining the durability of structures. Their studies combine experimental methods (testing of prisms) with theoretical deformation models, which provided the foundation for modern international standards (Eurocode, ACI, RILEM).

The textbook [22] covers the fundamental properties of concrete, including prism testing, modulus of elasticity, and shrinkage.

In the works [23, 24, 25], a common approach to the analysis of the modulus of elasticity and concrete deformability can be observed. The authors demonstrate that these characteristics depend on the microstructure, mixture composition, and concrete class. Using this knowledge helped us to analyze the results obtained after conducting the experiments.

The works in the article [26] are used for predicting concrete deformations is used as a practical tool for engineers. It provides practical methods for forecasting concrete creep and shrinkage, which are widely applied in design practice.

MAIN RESEARCH

Previous studies of cubic and prism strength of structural concretes obtained at mixing times of 90, 180, 300, and 480 seconds showed that the concrete classes determined by cubic strength results, based on calculated coefficients of variation, were identical and corresponded to C16/20 (B20). The concrete classes determined by prism strength results were different; the highest class values, C30/35 (B35) and C25/30 (B30), were observed in mixtures No. 1 and No. 3 at mixing times of 480 and 180 seconds, respectively. The obtained result, where prism strength exceeded cubic strength, is not typical. To confirm or refute the determined concrete classes by strength, studies of the deformative characteristics of concretes were conducted by determining their modulus of elasticity. In addition, linear and volumetric shrinkage of structural concretes, which represent non-strength deformations of concrete, were investigated.

The concrete mixture was prepared in an “Airich” concrete mixer, and specimens for testing were produced by manual compaction in molds and cured for 28 days. The mixing technology and specimen preparation procedure are presented in [1].

In total, 20 prism specimens of dimensions 100 × 100 × 400 mm (height) were produced to determine the modulus of elasticity and concrete class, i.e., 5 specimens of each mixture for the corresponding mixing time. To determine linear and volumetric shrinkage of concretes, 24 cube specimens of dimensions 100 × 100 × 100 mm were produced, i.e., 6 specimens of each mixture.

The relationship between stress and strain of concrete under stepwise loading of prisms was investigated [11]. This relationship characterizes the strength-related deformations of concrete.

For the experiments, dial-type indicators were installed on four opposite faces of the prisms. The prisms were stepwise loaded on a P-125 press with a load of 12.5 kN (Fig. 1). After each loading stage, the indicator readings were recorded, and the average concrete deformations were determined.

Fig 1. Determination of the deformative characteristics of concrete prisms using the P-125 press. Photo by D. Zhuk

Рис 1 Визначення деформативних характеристик бетонних призм на пресі П-125. Автор фото Д. Жук

The load was increased up to failure, and stress–strain diagrams were constructed. On the diagrams, the zones of elastic and elastic–plastic deformations, as well as stresses σ_{02} and σ_{03} and strains ε_{02} and ε_{03}, within which Hooke's law is valid, were identified.

The stresses σ_{02} were taken as equal to 0.2 R_b (ultimate strength). The initial modulus of elasticity E_b for each mixture was calculated as the ratio of stresses σ_{02} to strains ε_{02} [3]. In addition, the mean modulus of elasticity E_{cm} was determined at loads corresponding to 30% of the ultimate strength [10].

The relationship between the initial modulus of elasticity and the mean modulus of elasticity E_{cm} was established. According to [3], this relationship is defined by the coefficient of elastic–plastic deformations of concrete, which is determined by the following formula:

$$v = E_b/E_{cm} \quad (1)$$

To study the structure of concrete, one of the prisms was split in a direction perpendicular to the layers of mixture placement, and the uniformity of aggregate distribution on the internal surface of the concrete as well as the condition of the binder was evaluated.

The prism tests were carried out at an air temperature of 18.6–19.7 °C and a relative humidity of 56–62%.

Table 1 presents the results of determining

Table 1. Results of compressive strength and modulus of elasticity of concrete prisms (mixing time 180 s)

Табл. 1 Результати визначення характеристик бетону призм після випробування на стиск

Specimen labeling	Cross-sectional area $a_{avg} \cdot b_{avg}$ = S, cm²	Ultimate load, P, kN	Prism strength R_b (f_{prism}), MPa	Stresses, σ_{02}, MPa	Strains, $\varepsilon_{02} \cdot 10^5$	Initial modulus of elasticity, $E_b \cdot 10^3$, MPa	Stresses, σ_{03}, MPa	Strain, $\varepsilon_{03} \cdot 10^5$	Mean modulus of elasticity, $E_{cm} \cdot 10^3$, MPa
3_{13}	9,975.9,955 =99,3	206,25	20,77	4,15	13,91	29,86	6,23	21,76	28,63
3_{14}	9,965.10,2 =101,64	225,5	22,19	4,44	13,13	33,79	6,66	21,2	31,4
3_{15}	10,0.10,075 =100,75	225,675	22,4	4,48	14,52	30,85	6,72	21,98	30,57
3_{16}	10,0.10,05 =100,5	204,51	20,35	4,07	14,08	28,91	6,1	21,19	28,81
3_{17}	10,0. 9,975 = 99,75	175,11	17,55	3,51	12,49	28,11	5,27	19,91	26,45

Note. The moduli of elasticity with the lowest values are highlighted in yellow

ISSN 2522-4182

the characteristics of concrete prisms after compression testing, namely the dimensions of the cross-section, applied loads, the results of strength determination, and the modulus of elasticity of concrete produced at a mixing time of 180 seconds. The stress–strain curve of concrete obtained during compression testing of prism P-3_{14} is shown in Fig. 2.

As shown in Table 1, the prism strength of concrete specimens with dimensions of 100 × 100 × 400 mm under axial compression ranged from 17.55 to 22.4 MPa. At the same time, the values of the initial modulus of elasticity were (28.11–33.79) × 10^3 MPa, while the mean modulus of elasticity was (26.45–31.4) × 10^3 MPa.

Figure 3 presents the structure of the internal surface of prism No. 3_{14} after compression testing.

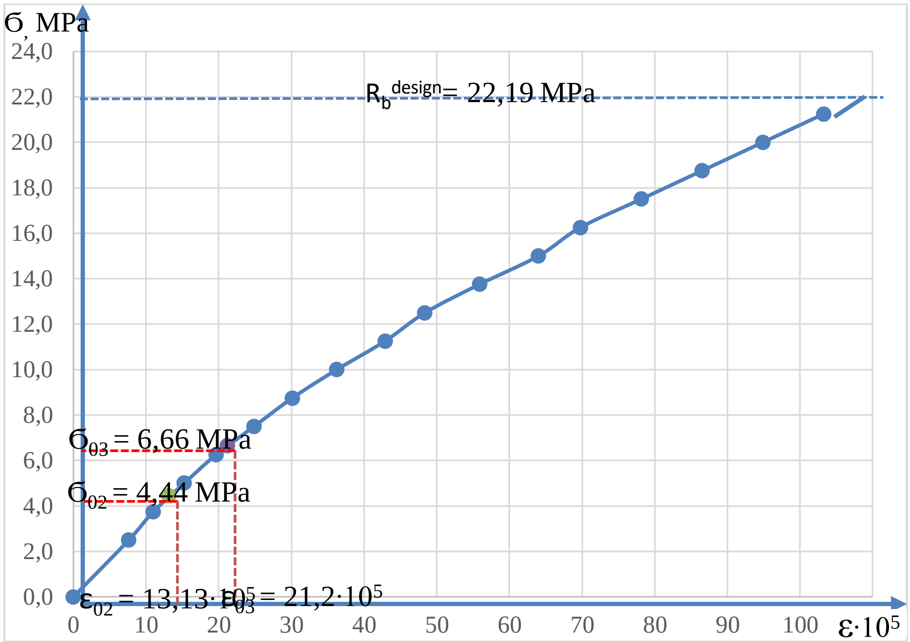

Fig 2. Stress–strain relationship of concrete during compression testing of prism P-3_{14}
Рис 2 Залежність між напруженнями і деформаціями бетону при випробуванні призми П-3_{14} на стиск

Fig 3. Structure of the internal surface of concrete prism P-3_{14} (Photo by D. Zhuk)
Рис 3 Структура внутрішньої поверхні бетону призми П-3_{14} (Автор фото Д. Жук)

As shown in Fig. 3, the binder is uniformly distributed between the aggregate grains, while containing only a small number of open pores. The adhesion of the aggregate grains to the binder is good.

Similarly, prism specimens were tested at mixing times of 480, 300, and 90 seconds.

The results of testing structural concretes allowed us to systematize the dependence of prism strength and modulus of elasticity of concretes obtained at different mixing times of the concrete mixture.

Since there are currently two different approaches in the literature to determining the concrete class, in our opinion it is appropriate to analyze the results according to both approaches. The first approach [3] defines the concrete class B based on prism strength R_b under axial compression and the initial modulus of elasticity E_b, determined at loads equal to 20% of the ultimate load. According to the second approach [10], the concrete class C is defined based on prism strength $f_{cm,prism}$ under axial compression and the mean modulus of elasticity E_{cm}, determined at loads equal to 30% of the ultimate load.

The authors of regulatory document [11, clause 8.6] propose, in our view, a rather ambiguous approach to determining the concrete class, which consists of the following steps:

- when calculating the average values of prism strength and modulus of elasticity within a series of specimens, abnormal (i.e., significantly deviating) test results are preliminarily excluded;
- to justify whether abnormal results should be considered, reference is made to another regulatory document [12, clause 8.8], which requires determining the average intra-series coefficient of variation of compressive strength by testing 30 series of specimens of the same concrete class;
- the obtained intra-series coefficient of variation is then compared with the threshold value [5, Annex A], which should not exceed 8%;
- if the coefficient of variation is greater than 8%, abnormal test results are taken into account;
- if the coefficient of variation is less than 8%, the average prism strength and modulus of elasticity are calculated based on the four specimens with the highest values.

In our opinion, it is necessary to consider the coefficient of variation adopted for calculations and design, which equals 13.5%. If the coefficient of variation is lower than 13.5%, the modulus of elasticity should be calculated based on the four specimens with the highest values. Conversely, if the coefficient of variation exceeds 13.5%, abnormal test results must be taken into account.

Thus, when determining the modulus of elasticity of concrete, the coefficient of variation should be established through mathematical processing of the experimental data[13-17].

The summarized results of prism tests at mixing times of 480, 300, 180, and 90 seconds are presented in Table 2.

As shown in Table 2, the highest concrete class determined by the modulus of elasticity is obtained at a mixing time of 480 s. In this case, the final concrete class is taken as the lower of the two values, namely C30/35 (B35). With a reduction in mixing time to 300, 180, and 90 s, concrete of the same class C20/25 (B25) is obtained. The increase in concrete class to C25/30 (B30), determined at a mixing time of 300 s based on the initial elastic modulus, is not considered, since it was obtained with a coefficient of variation of 21.06%, which is significantly higher than the design standard value of 13.5%.

In addition, at a mixing time of 300 s, the elastic–plastic strain coefficient of concrete, equal to 0.909, indicates that under stresses up to 0.2 of the ultimate load, the deformation of concrete remains elastic, while under stresses above 0.2 of the ultimate load, elastic–plastic deformation occurs.

Table 2. Results of Determining the Modulus of Elasticity and the Class of Structural Concrete
Табл. 2 Результати визначення модуля пружності та класу конструкційного бетону

No.	Metrics	Mix No. Mixing Time of Concrete, s			
		1 480	2 300	3 180	4 90
1	Initial Modulus of Elasticity $E_b = 0{,}2 \cdot f_{ck,prism}$, MPa	36,16	32,445	30,85	31,94
2	Average Initial Modulus of Elasticity $E_{cm} = 0{,}3 \cdot f_{ck,prism}$, MPa	35,55	29,48	29,85	30,72
3	Coefficient of Elastic–Plastic Deformations of Concrete, ν	0,983	0,909	0,968	0,962
4	Determined Coefficient of Variation for the Initial Elastic Modulus, V_m,%	2,8	21,06	7,26	2,97
5	Determined Coefficient of Variation for the Average Initial Elastic Modulus, V_m,%	2,44	9,91	13,16	5,19
6	Concrete Class by Initial Elastic Modulus C(B)	C32/40 (B40)	C25/30 (B30)	C20/25 (B25)	C20/25 (B25)
7	Concrete Grade Based on the Average Initial Elastic Modulus, C(B)	C30/35 (B35)	C20/25 (B25)	C20/25 (B25)	C20/25 (B25)

Note. The values of the initial elastic modulus and the average initial elastic modulus of concrete should be multiplied by 10^3.

Non-load (volumetric) deformations of concrete were also investigated. For this purpose, both linear and volumetric shrinkage were determined [19-22].

Linear shrinkage of concrete, expressed as a percentage, was determined on six cube specimens of dimensions 100 × 100 × 100 mm as follows. After demolding, four lines parallel to the central axis were marked on four opposite faces (along the specimen height). The initial length of these lines was taken as the reference dimension. Measurements were performed using a caliper.

After curing the specimens for 28 days, the dimensions were measured again, and the linear shrinkage of concrete was calculated according to the following formula:

$$\varepsilon = \frac{l_2 - l_1}{l_1} \times 100 \qquad (2)$$

where:

- l_1 — the initial specimen dimension after demolding;
- l_2 — the specimen dimension after 28 days of curing.

The volumetric shrinkage of concrete, expressed as a percentage, was determined by recording the change in specimen volume according to the following formula:

$$\varepsilon_v = \frac{V_2 - V_1}{V_1} \times 100 \qquad (3)$$

where:

- V_1 — the initial specimen volume after demolding;
- V_2 — the specimen volume after 28 days of curing.

Figure 4 presents the graph of the dependence of linear and volumetric shrinkage of concrete on the mixing time of the concrete mixture [19-22].

As shown in Figure 4, the highest linear shrinkage, equal to 0.11%, is observed in concrete produced with a mixing time of 300 s. Overall, the linear shrinkage of concrete changes insignificantly and, in the graph of Figure 4, appears as a straight line with a slight increase in shrinkage values when the mixing time increases from 90 to 300 s. With an increase in mixing time to 480 s, the linear shrinkage of concrete decreases to 0.07%, which practically does not differ from the shrinkage value of concrete produced with a mixing time of 90 s.

ISSN 2522-4182

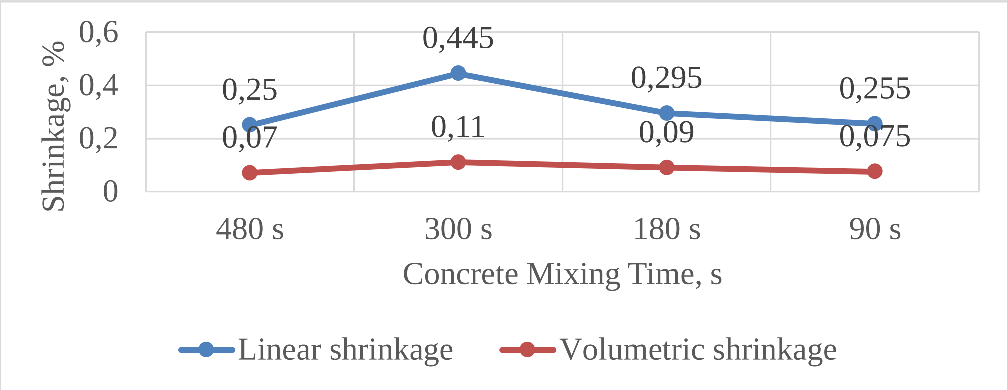

Fig 4. Dependence of Linear and Volumetric Shrinkage of Concrete on Mixing Time
Рис 4 Залежність лінійної та об'ємної усадки бетону від часу перемішування бетонної суміші

The volumetric shrinkage of concrete produced with a mixing time of 300 s increases significantly and reaches 0.445%. This increase on the volumetric shrinkage curve is characterized as a "peak." The volumetric shrinkage of concrete produced with mixing times of 90 and 480 s is practically the same, amounting to 0.255% and 0.25%, respectively.

The elevated values of linear and volumetric shrinkage of concrete produced with a mixing time of 300 s are directly related to the reduction in compressive strength and bulk density of concrete [1].

Studies of concrete deformability at different mixing times showed that, according to the determined values of the elastic modulus and the indicators of linear and volumetric shrinkage, the deformability characteristics of concrete can be distinguished at mixing times of 480 s and 180 s, when the concrete class corresponds to C30/35 (B35) and C20/25 (B25), respectively. However, according to the previously determined prism strength values [1], at mixing times of 480 s and 180 s the concrete class corresponds to C30/35 (B35) and C25/30 (B30), respectively, while according to cube strength values the concrete class is the same and corresponds to C16/20 (B20).

Therefore, the conducted studies demonstrated a significant difference in determining the concrete class based on strength and deformability of specimens.

In the final determination of the optimal mixing time of the concrete mixture with respect to concrete class, the following factors were considered:

1. The cost of producing 100 m³ of concrete mixture at mixing times of 480 s and 180 s in an "Ayrich" concrete mixer, based on electricity consumption of 3.3 kWh and the cost of 1 kWh of electricity for industrial enterprises (6.9 UAH):
   - at a mixing time of 180 s:
     277.8 h×3.3 kWh×6.9 UAH=6325.5 UAH
   - at a mixing time of 480 s:
     740.7 h×3.3 kWh×6.9 UAH=16865.7
2. The concrete class in terms of axial compressive strength is determined by the temporary resistance to compression of concrete cubes with an edge length of 150 mm [2].
3. In this case, the final concrete class is rationally taken as the lower of the obtained values.

Considering the above, it should be concluded that, in order to obtain a guaranteed class of structural concrete not less than C16/20 (B20), the optimal mixing time of the concrete mixture is 180 s.

CONCLUSIONS

The conducted studies of concrete deformability at different mixing times of 480, 300, 180, and 90 s showed that, according to the determined values of the elastic modulus of concrete and the indicators of its linear and volumetric shrinkage, the deformability characteristics of concrete can be distinguished at mixing times of 480 s and 180 s, when the concrete class corresponds to C30/35 (B35) and C20/25 (B25), respectively. However, according to the previously determined prism strength values [1], at mixing times of 480 s and 180 s the concrete class corresponds to C30/35 (B35) and C25/30 (B30), respectively, while according to cube strength values the concrete class is the same and corresponds to C16/20 (B20).

In the final determination of the optimal mixing time of the concrete mixture with respect to concrete class, the following factors were taken into account: the cost of producing 100 m³ of concrete mixture in an "Ayrich" concrete mixer; the determination of concrete class by axial compressive strength based on the temporary resistance of concrete cubes; and the rational acceptance of the final concrete class as the lower of the obtained values.

As a result of the conducted studies, it was determined that, in order to obtain a guaranteed class of structural concrete not less than C16/20 (B20), the optimal mixing time of the concrete mixture is 180 s.

REFERENCE

1. **Konoplyanyk, O. Yu., & Zhuk, D. V.** (2025). Influence of mixing time of concrete mixtures on strength characteristics of structural concretes. *Ukrainian Journal of Construction and Architecture,* 3(027), 81–91. [in Ukrainian] https://doi.org/10.30838/UJCEA.2312.270425.81.1164
2. **Romashko, V. M.** (2020). General fundamentals of reinforced concrete elements and structures deformation mechanics. *Collection of Scientific Works of the Ukrainian State University of Railway Transport* (191), 45–52. [in Ukrainian] https://doi.org/10.18664/1994-7852.191.2020.217288
3. **Dzyuba, A. P., Dzyuba, A. A., & Levitina, L. D**. (2022). Optimal design of shell constructions taking into account the evolution of corrosion damage. *Strenggth of materials and theory of structures*, (108), 17-34. [in English] https://doi.org/10.32347/2410-2547.2022.108.17-34
4. **Neville, A. M., & Brooks, J. J.** (2010). *Concrete Technology* (2nd ed.). 442 p. [in English] ISBN: 9788-131-7294-23
5. **Kongshaug, S. S., Oseland, O., Kanstad, T., Hendriks, M. A. N., Rodum, E., & Markeset, G.** (2020). Experimental investigation of ASR-affected concrete – The influence of uniaxial loading on the evolution of mechanical properties, expansion and damage indices. *Construction and Building Materials*, (245), 118384. **[**in English] https://doi.org/10.1016/j.conbuildmat.2020.118384
6. **EN 1992-1-1.** (2004). Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. *European Commission*. [in English] ISBN: 978-058-0420-82-8
7. **Solodei, I. I., Ruvin, O. H., Kolyakova, V. M., & Kulikov, O. P.** (2024). Formulation of the problem of interaction between a structure and a soil plastic medium under dynamic evolutionary processes. *Strength of materials and theory of structures*, (112), 83–92. [in Ukrainian] https://doi.org/10.32347/2410-2547.2024.112.83-92
8. **Sha, X., & Zhu, S.** (2025). Joint measurement of modulus of elasticity and Poisson's ratio of concrete cubes by actuating special vibration modes: A novel baseline-free technique. *Journal of Sound and Vibration*, 618, 119288[in English] https://doi.org/10.1016/j.jsv.2025.119288
9. **Vu, X. H., Malecot, Y., & Daudeville, L.** (2009). Strain measurements on porous concrete samples for triaxial compression and extension tests under very high confinement. *The Journal of Strain Analysis for Engineering Design*, 44(8), 633–657. [in English] https://doi.org/10.1243/03093247JSA547
10. **DBN V.2.6-98:2009.** (2011). Konstruktsii budynkiv i sporud. Betonni ta zalizobetonni konstruktsii. Osnovni polozhennia [Buildings and structures. Concrete and reinforced concrete structures. Basic provisions]. *[Chynni vid 01.06.2011] Kyiv: Minrehionbud Ukrainy. 2011. – 71 s.* . [in Ukrainian]
11. **DSTU B V.2.7-217:2009.** (2010). Betony. Metody vyznachennia pryzmovoi mitsnosti, modulia pruzhnosti i koefitsiienta Puassona [Concretes. Methods for determining prism strength, modulus of elasticity and Poisson's ratio]. *[Chynni vid 22.12.2009]. Kyiv: Minrehionbud Ukrainy. 2010. – 16 s.* [in Ukrainian]

12. **DSTU B V.2.7-214:2009.** (2010). Betony. Metody vyznachennia mitsnosti za kontrolnymy zrazkamy [Concretes. Methods for determining strength by control specimens]. *[Chynni vid 22.12.2009]. Kyiv: Minrehionbud Ukrainy 2010. – 43 s.* . [in Ukrainian]
13. **Krus, Yu. O.** (2022). Connection between stresses and strains of concrete under different force modes of short-term axial compression. *Technical Sciences and Technologies*, (1(27), 184–198. [in Ukrainian] https://doi.org/10.25140/2411-5363-2022-1(27)-184-198
14. **Koliakova, V., & Bozhynskyi, M. (2017).** Settlement and theoretical studies of the temperature distribution in the cross section of concrete staircase folds**.** *Building Constructions. Theory and Practice*, *1*(1), 149–157. [in Ukrainian] https://doi.org/10.32347/2522-4182.1.2017.149-157
15. **Fesenko, O., & Koliakova, V.** (2022). Fire resistance analysis of bending timber structures according to Eurocode 5. *Building Constructions. Theory and Practice*, (10), 94–107. [in Ukrainian] https://doi.org/10.32347/2522-4182.10.2022.94-107
16. **Barashykov, A.**, & **Koliakova V**. *Building Structures: Textbook. VD Slovo, 2011. – 256 s* [in Ukrainian]
17. **Koliakova, V. M., Bozhynskyi, M. O., & Fesenko, O. A. (2016).** Temperature distribution in the cross-section of a reinforced concrete slab. *Modern Technologies and Methods of Calculations in Construction*, (5), 232–239. Lutsk: LNTU. [in Ukrainian]
18. **Pavlikov, A. M.** (2017). Reinforced Concrete Structures: Buildings, Facilities, and Their Parts. *Kyiv: Osnova Publishing House*. 512 p. [in Ukrainian] ISBN: 978-617-6076-88-9
19. **Neville, A. M.** (2011). Properties of Concrete (5th ed.). *Harlow: Pearson Education Limited*. 846 p. [in English] ISBN: 978-027-3755-80-7
20. **Bažant, Z. P., & Jirásek, M**. (2002). Creep and Shrinkage in Concrete Structures. *Berlin: Springer*. 357 p. [in English] ISBN: 978-079-2374-34-0
21. **Lizunov, P. P., Pogorelova, O. S., & Postnikova, T. G.** (2023). Influence of stiffness parameters on vibro-impact damper dynamics. *Strength of materials and theory of structures.*, (110), 21-35. [in English] https://doi.org/10.32347/2410-2547.2023.110.21-35
22. **Bažant, Z. P., & Baweja, S**. (2000). Creep and shrinkage prediction model for analysis and design of concrete structures: Model B3. *Materials and Structures*, 33(6), 357–365. [in English] https://doi.org/10.1007/BF02473152
23. **Zhou, F., Li, Y., Wang, J., et al.** (2022). Concrete elastic modulus experimental research based on theory of capillary tension. *Materials*, 15(3), 1123–1138. [in English] https://doi.org/10.3390/ma15103734
24. **Mehta, P. K., & Monteiro, P. J. M.** (2006). Concrete: Microstructure, properties, and materials — updated perspectives. *Cement and Concrete Composites*, 28(6), 481–489 [in English] https://doi.org/10.1016/j.cemconcomp.2006.02.010
25. **Aïtcin, P. C.** (1998). High-Performance Concrete. *London: E & FN Spon*. 600 p. [in English] https://doi.org/10.4324/9780203475034
26. **Bažant, Z. P., & Li, G. H.** (2008). Comprehensive analytical model for creep and shrinkage of concrete. *Cement and Concrete Research*, 38(6), 751–765. [in English] https://doi.org/10.1016/j.cemconres.2008.01.002

LITERATURE

1. **Konoplyanyk, O. Yu., & Zhuk, D. V.** (2025). Vplyv chasu peremishuvannia betonnykh sumishei na mitsnisni kharakterystyky konstruktsiinykh betoniv *Ukrainian Journal of Construction and Architecture*, 3(027), 81–91. [in Ukrainian] https://doi.org/10.30838/UJCEA.2312.270425.81.1164

2. **Romashko, V. M. (2020).** Zahalni osnovy mekhaniky deformuvannia zalizobetonnykh elementiv I konstruktsii. *Zbirnyk naukovykh prats Ukra-yinskoho derzhavnoho universytetu zaliz-nychnoho transportu, (191), 45–52.* https://doi.org/10.18664/1994-7852.191.2020.217288
3. **Dzyuba, A. P., Dzyuba, A. A., & Levitina, L. D**. (2022). Optimal design of shell constructions taking into account the evolution of corrosion damage. *Strenggth of materials and theory of structures*, (108), 17-34.

https://doi.org/10.32347/2410-2547.2022.108.17-34
4. **Neville, A. M., & Brooks, J. J.** (2010). *Concrete Technology* (2nd ed.). 442 p. [in English] ISBN: 9788-131-7294-23
5. **Kongshaug, S. S., Oseland, O., Kanstad, T., Hendriks, M. A. N., Rodum, E., & Markeset, G.** (2020). Experimental investigation of ASR-affected concrete – The influence of uniaxial loading on the evolution of mechanical properties, expansion and damage indices. *Construction and Building Materials*, (245), 118384. https://doi.org/10.1016/j.conbuildmat.2020.118384
6. **EN 1992-1-1.** (2004). Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. *European Commission*. [in English] ISBN: 978-058-0420-82-8
7. **Solodei, I. I., Ruvin, O. H., Kolyakova, V. M., & Kulikov, O. P.** (2024). Postanovka zadachi vzaiemodii sporudy i hruntovoho plastychnoho seredovyshcha v umovakh dynamichnykh evoliutsiinykh protsesiv *Strength of materials and theory of structures*, (112), 83–92. [in Ukrainian] https://doi.org/10.32347/2410-2547.2024.112.83-92
8. **Sha, X., & Zhu, S.** (2025). Joint measurement of modulus of elasticity and Poisson's ratio of concrete cubes by actuating special vibration modes: A novel baseline-free technique. *Journal of Sound and Vibration*, 618, 119288[in English] https://doi.org/10.1016/j.jsv.2025.119288
9. **Vu, X. H., Malecot, Y., & Daudeville, L.** (2009). Strain measurements on porous concrete samples for triaxial compression and extension tests under very high confinement. *The Journal of Strain Analysis for Engineering Design*, 44(8), 633–657. [in English] https://doi.org/10.1243/03093247JSA547
10. **DBN V.2.6-98:2009.** (2011). Konstruktsii budynkiv i sporud. Betonni ta zalizobetonni konstruktsii. Osnovni polozhennia [Buildings and structures. Concrete and reinforced concrete structures. Basic provisions]. *Kyiv: Minrehionbud Ukrainy*.. [in Ukrainian]
11. **DSTU B V.2.7-217:2009.** (2010). Betony. Metody vyznachennia pryzmovoi mitsnosti, modulia pruzhnosti i koefitsiienta Puassona [Concretes. Methods for determining prism strength, modulus of elasticity and Poisson's ratio]. *Kyiv: Minrehionbud Ukrainy*.. [in Ukrainian]
12. **DSTU B V.2.7-214:2009.** (2010). Betony. Metody vyznachennia mitsnosti za kontrolnymy zrazkamy [Concretes. Methods for determining strength by control specimens]. *Kyiv: Minrehionbud Ukrainy*. [in Ukrainian] https://doi.org/10.25140/2411-5363-2022-1(27)-184-198
13. **Krus, Yu. O.** (2022). Zviazok mizh napruzhennyamy i deformat¬siiamy betonu za riznykh sylovykh rezhymiv korotkochasnoho osiovoho stysku [Relationship between stresses and deformations of concrete under different force regimes of short-term axial compression]. *Tekhnichni nauky ta tekhnolohii*, (1), 45–53. [in Ukrainian] https://doi.org/10.25140/2411-5363-2022-1(27)-184-198
14. **Koliakova, V., & Bozhynskyi, M. (2017).** (2017). Rozrakhunkovo-teoretychni - rozpodilu temperatury v pererizi zalizobetonnoi konstruktsii skhidchastykh skladok. *Budivelni konstruktsii. Teoriia i praktyka, 1(1), 149–157.* https://doi.org/10.32347/2522-4182.1.2017.149-157
15. **Fesenko, O., & Koliakova, V.** (2022). (2022). Rozrakhunok na vohnestiikist derevianykh zhynalnykh konstruktsii za metodykoiu Yevrokodu 5. *Budivelni konstruktsii. Teoriia i praktyka, (10), 94–107.* https://doi.org/10.32347/2522-4182.10.2022.94-107
16. **Barashykov, A.**, & **Koliakova V**. Budivelni konstryctsii: Pidrychnyk. *VD Slovo, 2011. – 256*
17. **Koliakova, V. M., Bozhynskyi, M. O., & Fesenko, O. A. (2016).** Temperature distribution in the cross-section of a reinforced concrete slab. *Modern Technologies and Methods of Calculations in Construction*, (5), 232–239. Lutsk: LNTU. [in Ukrainian]
18. **Pavlikov, A. M.** (2017). Zalizobetonni konstruktsii: budivli, sporudy ta yikh chastyny *Kyiv: Osnova Publishing House*. 512 ISBN: 978-617-6076-88-9
19. **Neville, A. M.** (2011). Properties of Concrete (5th ed.). *Harlow: Pearson Education Limited*. 846 p. [in English] ISBN: 978-027-3755-80-7
20. **Bažant, Z. P., & Jirásek, M**. (2002). Creep and Shrinkage in Concrete Structures. *Berlin: Springer*. 357 p. ISBN: 978-079-2374-34-0
21. **Lizunov, P. P., Pogorelova, O. S., & Postnikova, T. G.** (2023). Influence of stiffness parameters on vibro-impact damper dynamics. *Strength of materials and theory of structures.*

(110), 21-35. https://doi.org/10.32347/2410-2547.2023.110.21-35

22. **Bažant, Z. P., & Baweja, S**. (2000). Creep and shrinkage prediction model for analysis and design of concrete structures: Model B3. *Materials and Structures*, 33(6), 357–365. https://doi.org/10.1007/BF02473152

23. **Zhou, F., Li, Y., Wang, J., et al.** (2022). Concrete elastic modulus experimental research based on theory of capillary tension. *Materials*, 15(3), 1123–1138. https://doi.org/10.3390/ma15103734

24. **Mehta, P. K., & Monteiro, P. J. M.** (2006). Concrete: Microstructure, properties, and materials — updated perspectives. *Cement and Concrete Composites*, 28(6), 481–489 https://doi.org/10.1016/j.cemconcomp.2006.02.010

25. **Aïtcin, P. C.** (1998). High-Performance Concrete. *London: E & FN Spon*. 600 ISBN: 041-919-2700 https://doi.org/10.4324/9780203475034

26. **Bažant, Z. P., & Li, G. H.** (2008). Comprehensive analytical model for creep and shrinkage of concrete. *Cement and Concrete Research*, 38(6), 751–765. https://doi.org/10.1016/j.cemconres.2008.01.002

ВПЛИВ ЧАСУ ПЕРЕМІШУВАННЯ БЕТОННИХ СУМІШЕЙ НА ДЕФОРМАТИВНІ ХАРАКТЕРИСТИКИ КОНСТРУКЦІЙНИХ БЕТОНІВ

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Анотація. Дана наукова робота є продовженням досліджень [1], які пов'язані з визначенням класу конструкційних бетонів при різних часах перемішування бетонної суміші. Встановлений вплив часу перемішування бетонної суміші на міцністні характеристики бетонів. В результаті випробувань міцності зразків-кубів та призм встановлені класи бетонів за міцністю на вісьовий стиск.

Однак в літературних джерелах присутні данні про вплив деформативності бетонів на визначення їх класу за міцністю шляхом дослідження модуля пружності бетонів. Тому постає питання дослідження деформативних характеристик бетонів та їх порівняння з міцністними характеристиками. За результатами цих двох досліджень може бути визначений остаточний клас бетону.

Аналіз сучасного стану розробки та дослідження бетонів показав, що одним з факторів, які впливають на визначення класу бетону за міцністю - є визначення модуля пружності бетонів, який характеризує його деформативні характеристики.

В лабораторних умовах були проведені дослідження модуля пружності і класу бетону при часі перемішування бетонної суміші 480, 300, 180 і 90 секунд відповідно. Для цього виготовлювали та випробували 20 зразків-призм розмірами 100х100х400 (висота) мм. При визначенні класу бетону враховували також несилові (об'ємні) деформації бетону та вартість виготовлення 100 м^3 бетонної суміші виходячи з витрат електроенергії за час перемішування суміші.

В результаті проведення досліджень визначено, що для отримання гарантованого класу конструкційного бетону не менш С16/20 (В20) оптимальний час перемішування бетонної суміші складає 180с.

Мета роботи полягає в дослідженні деформативних характеристик конструкційних бетонів в залежності від часу перемішування бетонної суміші та їх впливу на визначення класу бетону по міцності на стиск.

Ключові слова: бетонна суміш; час перемішування суміші; конструкційний бетон; деформаційні характеристики, модуль пружності бетону; клас бетону

Received: November 03, 2025.
Accepted: December 05, 2025.