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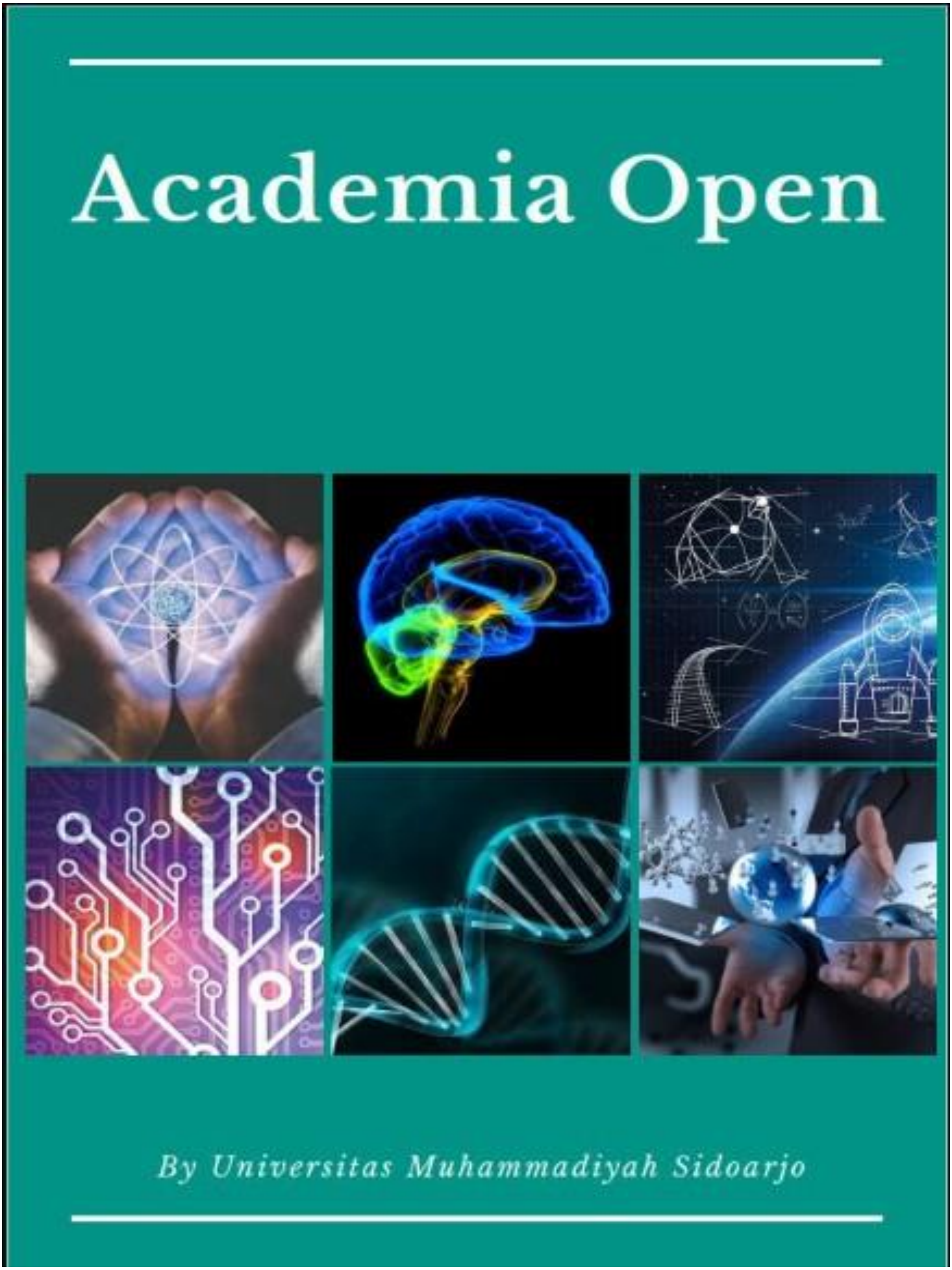

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Kinetics of Compressive Strength Development of B30 Concrete Under the Effect of Chemical Admixtures

Bektosh Botirov, korreys95@gmail.com (*)

Tashkent Architecture and Civil Engineering, Uzbekistan

(*) Corresponding author

Abstract

General Background Compressive strength development defines the load-bearing capacity and structural performance of concrete over curing ages. **Specific Background** Chemical admixtures such as PKAN-55 and BAAS-MIXPLAST 140 W alter cement hydration kinetics and early-age performance. **Knowledge Gap** However, the precise dosage-dependent non-linear strength gain dynamics of B30 concrete modified with these specific admixtures remain insufficiently quantified across long-term ages. **Aims** This study investigates the compressive strength kinetics of B30 concrete incorporating PKAN-55 and BAAS-MIXPLAST 140 W at dosages from 0.6% to 1.0% up to 56 days. **Results** Experimental testing revealed optimum dosages of 0.7% for PKAN-55 and 0.9% for BAAS-MIXPLAST 140 W, yielding 28-day compressive strengths of 43.41 MPa and 41.55 MPa, representing strength increases of 8.47% and 3.82% over control concrete, respectively. **Novelty** A non-linearrelationshipbetweenadmixturedosageandstrengthdevelopmentkineticswasestablished, showing 80–90% 28-day strength gain within 7 days. **Implications** These findings establish critical mix design parameters for accelerating early construction formwork removal and enhancing structural performance.

Keywords : B30 Concrete, Chemical Admixture, Compressive Strength, Strength Kinetics, Optimum Dosage

Key Findings Highlights

Optimum dosages of 0.7% PKAN-55 and 0.9% BAAS-MIXPLAST 140 W increase 28-day compressive strength by 8.47% and 3.82%.

Modified mixtures achieve 80% to 90% of their design strength within the first 7 days of curing.

Exceeding optimum chemical admixture dosages causes non-linear strength reduction beyond design thresholds.

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Introduction

The compressive strength of concrete is one of its principal physical and mechanical properties determining the load-bearing capacity, stiffness, durability, and operational reliability of concrete and reinforced concrete structures. Concrete strength is not a constant value; rather, it develops over time as a result of cement hydration, the formation of hydration products, and the progressive densification of the cementitious matrix. Therefore, evaluating only the standard 28-day compressive strength does not provide a complete description of the strength-development process. Investigation of concrete strength at different curing ages is particularly important when assessing the effectiveness of chemical admixtures [1–4].

Modern concrete technology increasingly employs high-range water-reducing chemical admixtures to improve workability, reduce water demand, control the water-to-cement ratio, and enhance the mechanical properties of concrete. Among these admixtures, polycarboxylate-based superplasticizers are of particular interest because of their ability to disperse cement particles effectively. The adsorption of polymer molecules on cement particles and the resulting steric repulsion reduce particle agglomeration and improve the dispersion of the cementitious system. Consequently, a larger effective surface area of cement becomes available for hydration, while reduced water demand contributes to lower capillary porosity and the formation of a denser cement matrix [6, 7, 9, 10, 15–17].

Previous studies have demonstrated that the effectiveness of chemical admixtures depends not only on their chemical structure but also on dosage, cement composition, water-to-cement ratio, and curing conditions. Research on polycarboxylate-based superplasticizers has shown that increasing the admixture dosage does not necessarily result in a proportional increase in compressive strength. Instead, an optimum dosage range generally exists, within which improved cement-particle dispersion and reduced water demand provide the greatest mechanical benefit [6, 9, 15, 16].

Recent studies have also emphasized the importance of evaluating concrete strength development at early ages rather than relying exclusively on the 28-day value. Prediction and experimental assessment of early-age compressive strength have demonstrated that the rate of strength development is strongly associated with cement hydration kinetics and the progressive formation of the hardened cement structure [12–14]. These findings indicate that the strength-development kinetics at 1, 3, 7, and 14 days can provide important additional information regarding the effectiveness of modifying admixtures and their influence on structure formation.

At the same time, the effect of a chemical admixture should be assessed over a sufficiently wide dosage range. An excessive admixture content may alter the interaction between cement particles and the liquid phase and may no longer provide a corresponding improvement in mechanical properties. Therefore, establishing an optimum dosage experimentally is essential for achieving both rapid early-age strength development and adequate long-term compressive strength.

Previous experimental investigations involving PKAN-55 have demonstrated its potential for improving the mechanical properties of concrete [11]. However, a comparative evaluation of the time-dependent compressive-strength development of B30 concrete modified with PKAN-55 and BAAS-MIXPLAST 140 W over a wide dosage range and at several curing ages remains of particular scientific and practical interest. In particular, determining how the dosage of these admixtures affects early-age strength development, standard 28-day strength, subsequent strength gain, and the rate of strength development makes it possible to assess their effectiveness more comprehensively.

Accordingly, the present study experimentally investigates conventional B30 concrete and B30 concrete modified with PKAN-55 and BAAS-MIXPLAST 140 W chemical admixtures. The admixtures were incorporated at dosages of 0.6, 0.7, 0.8, 0.9, and 1.0% by mass of cement. Compressive strength was evaluated at different curing ages in order to characterize the kinetics of strength development and determine the optimum admixture dosage.

The main objective of the study is to establish the relationship between chemical admixture dosage and the time-dependent development of compressive strength of B30 concrete and to determine the optimum dosage of each investigated admixture. Particular attention is given to comparing early-age strength development with the standard 28-day strength and evaluating subsequent strength gain.

The scientific novelty of the study lies in the comparative experimental evaluation of the strength-development kinetics of B30 concrete modified with locally applicable PKAN-55 and BAAS-MIXPLAST 140 W admixtures over the dosage range of 0.6–1.0%, with identification of the dosage-dependent nonlinear response and determination of the optimum contents based on both early-age and 28-day compressive-strength characteristics.

To provide a comprehensive assessment of strength development, the obtained results were analyzed for different curing ages, allowing the early-age strength, the design 28-day strength, and the subsequent development of strength to be compared. The results also provide a basis for assessing the suitability of the investigated modified concrete compositions for reinforced concrete applications.

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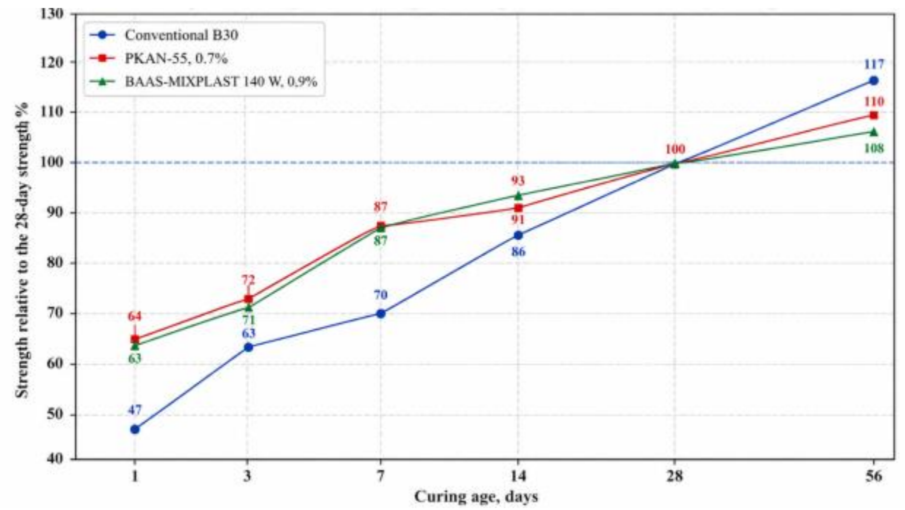

Fig. 1. Degree of compressive strength development of conventional and modified B30 concrete relative to the 28-day strength

Materials And Methods

A. Raw Materials

The experimental investigation was carried out using locally available raw materials selected for the production of B30 heavy concrete. Portland cement, natural fine aggregate, crushed coarse aggregate, water, and the chemical admixtures PKAN-55 and BAAS-MIXPLAST 140 W were used as the principal constituents.

Two locally manufactured Portland cements were initially evaluated: CEM II/A-I 32.5 N produced by HUAXIN SEMENT JIZZAKH LLC and CEM II/A-I 32.5 N produced by JIZZAX SEMENT PLANT LLC. Their chemical, mineralogical, and physical-mechanical characteristics were experimentally assessed before selecting the binder for the main concrete investigation.

The mineralogical analysis showed that the HUAXIN cement contained approximately 53.72% C_3S, 22.40% C_2S, 7.83% C_3A, and 8.53% C_4AF, whereas the corresponding values for JIZZAX SEMENT PLANT cement were 51.40, 24.10, 7.10, and 9.20%, respectively.

The 28-day compressive strength of the HUAXIN cement reached 41.4 MPa, compared with 36.9 MPa for the JIZZAX SEMENT PLANT cement. On the basis of the chemical, mineralogical, and mechanical test results, HUAXIN SEMENT JIZZAKH CEM II/A-I 32.5 N was selected as the principal binder for the subsequent experimental investigation.

The aggregates consisted of medium-sized Class II construction sand and fractionated crushed stone. The coarse aggregate fractions considered in the experimental program were 5–10, 10–20, and 20–40 mm. The aggregates were supplied by SAYXAN ORIENT LLC and satisfied the applicable requirements for aggregates used in heavy concrete.

B. Chemical Admixtures

Two polycarboxylate-based chemical admixtures were investigated.

The first admixture, PKAN-55, is a polycarboxylate-based superplasticizer synthesized by free-radical copolymerization. NPEG-2400 was used as the macromonomer, acrylic acid as the monomer, 2-mercaptopropionic acid as the chain-transfer agent, and potassium persulfate as the initiator.

The synthesis parameters were optimized experimentally. A reaction temperature of approximately 70°C, division of the reagents into four portions, and an interval of approximately 25 min between additions provided the most favorable conditions. The chemical structure of the resulting product was verified by IR spectroscopy, while gel-filtration chromatography indicated that the principal molecular-weight fraction was approximately 6.3 kDa.

The second admixture, BAAS-MIXPLAST 140 W, manufactured by BAAS CHEMICALS LLC, is also a polycarboxylate-based high-range water-reducing superplasticizer. According to the experimental and technical data reported in the dissertation, its relative density was approximately 1.091 g/cm³, pH 4.6, and chloride content below 0.1%.

For both chemical admixtures, the dosage was varied from 0.6 to 1.0% by mass of cement to determine the effect of dosage on the kinetics of compressive-strength development and to identify the optimum dosage.

C. Concrete Mix Proportioning

The concrete mixture was designed using an experimental mix-design approach with consideration of the water-to-cement ratio, aggregate packing, workability, and required B30 strength class. The selection and adjustment of the concrete composition were performed in accordance with the principles of GOST 27006–2019, while the workability of the fresh concrete mixture was evaluated by the standard slump-cone method according to GOST 10181–2014.

The reference B30 concrete had a workability class corresponding to P3 (slump 10–15 cm). The composition of 1 m³ of conventional B30 concrete used as the basis of the experimental investigation is presented in Table 1.

Tabel 1. Composition of Conventional B30 Concrete per 1 m³

Constituent	**Quantity**
HUAXIN CEM II/A-I 32.5 N cement	450 kg
Fine aggregate	743 kg
Crushed stone (10–20 mm)	970 kg
Water	234 L
Concrete class	B30 (M400)
Workability	P3 (10–15 cm)

For the modified mixtures, the dosage of PKAN-55 and BAAS-MIXPLAST 140 W was varied from 0.6 to 1.0% of cement mass. The admixture dosage was therefore treated as one of the principal experimental variables.

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For the BAAS-MIXPLAST 140 W series, the dissertation gives a working composition of 330 kg cement, 826 kg fine aggregate and 1116 kg crushed stone per 1 m³. Increasing the admixture dosage from 0.6 to 1.0% reduced the required mixing water from 170 to 162 L, corresponding to a reduction in the water-to-cement ratio from approximately 0.51 to 0.48.

Tabel 2. Working Compositions of B30 Concrete with BAAS-MIXPLAST 140 W

Admixture dosage	Cement, kg/m³	Fine aggregate, kg/m³	Crushed stone, kg/m³	BAAS-MIXPLAST 140 W, kg/m³	Water, L/m³	W/C
0.6%	330	826	1116	1.98	170	0.51
0.7%	330	826	1116	2.31	168	0.50
0.8%	330	826	1116	2.64	166	0.50
0.9%	330	826	1116	2.97	164	0.49
1.0%	330	826	1116	3.30	162	0.48

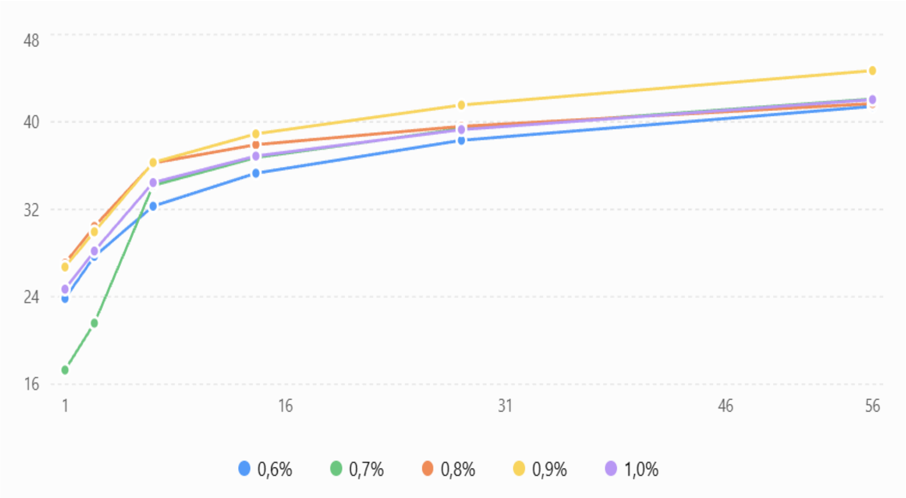

Fig. 2. Compressive Strength Development Kinetics of B30 Concrete Modified with BAAS-MIXPLAST 140 W Chemical Admixture

D. Preparation and Curing of Concrete Specimens

After optimization of the concrete compositions, the mixtures were prepared, placed into molds, and compacted under controlled laboratory conditions. The preparation and testing procedures followed the requirements of GOST 10180–2012, GOST 10181–2014, GOST 18105–2018, and GOST 7473–2010.

Concrete specimens used for compressive-strength testing were cubes with dimensions of 100 × 100 × 100 mm.

Before testing, the specimens were stored under laboratory conditions at a temperature of (20 ± 5)°C and a relative humidity of at least 55%. Each specimen was visually inspected before testing. Specimens exhibiting cracks, damaged edges, visible voids, delamination, or other defects capable of influencing the test result were excluded.

The geometric dimensions and external condition of the specimens were also checked prior to testing.

E. Compressive Strength Testing

Before the compressive-strength tests, the average density of the concrete specimens was determined from their measured mass and geometric dimensions in accordance with GOST 12730.1. This parameter was used as an additional indicator of the homogeneity and quality of the concrete structure.

Compressive-strength testing was performed in accordance with GOST 10180–2012 using a PGM-100MG4 hydraulic testing press.

The specimens were centered between the loading platens of the testing machine, and the compressive load was increased continuously at a rate of 0,6±0,2 MPa/s

The maximum load recorded at specimen failure was taken as the ultimate failure load and was subsequently used to calculate the compressive strength.

For an individual specimen, the compressive strength was determined from:

$$R_i = \frac{F_i}{A_i}$$

where R_i is the compressive strength of the individual specimen, MPa; F_i is the maximum failure load, N; and A_i is the loaded cross-sectional area, mm².

For each series, the mean compressive strength was calculated as:

$$R_m = \frac{\sum_{i=1}^{n} R_i}{n}$$

where n is the number of specimens in the corresponding series.

F. Evaluation of Strength Development Kinetics

To quantitatively characterize the development of concrete strength with curing age, the compressive strength at a given age was related to the corresponding 28-day strength:

$$K_t = \frac{R_t}{R_{28}} \cdot 100\%$$

where K_t is the degree of strength development at age (t), R_t is the compressive strength at age (t), and R_{28} is the 28-day compressive strength.

The average rate of compressive-strength development between two testing ages was determined as:

$$V_R = \frac{R_{t2} - R_{t1}}{t_2 - t_1}$$

where V_R is the average strength-development rate, MPa/day.

These parameters were used to compare conventional B30 concrete with concrete modified using different dosages of PKAN-55 and BAAS-MIXPLAST 140 W and to identify the dosage providing the most favorable strength-development characteristics.

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Results And Discussion

The experimental results demonstrated that the compressive strength of all investigated B30 concrete compositions increased with curing age. However, both the rate of strength development and the ultimate strength level depended considerably on the type and dosage of the chemical admixture.

A. Effect of PKAN-55 Dosage on Compressive Strength

The effect of PKAN-55 dosage was investigated over the range of 0.6–1.0% by mass of cement. The obtained results revealed a nonlinear relationship between admixture dosage and compressive strength.

For conventional B30 concrete, the compressive strength reached 25.11 MPa at 3 days, 28.07 MPa at 7 days, and 40.02 MPa at 28 days.

The addition of PKAN-55 accelerated strength development, particularly during the early curing period. Among the investigated compositions, concrete containing 0.7% PKAN-55 showed the most favorable overall performance. Its compressive strength reached 31.00 MPa at 3 days, 37.80 MPa at 7 days, and 43.41 MPa at 28 days.

Thus, the increase in 28-day compressive strength relative to conventional B30 concrete was:

$$\Delta R = \frac{43.41 - 40.02}{40.02} \cdot 100 = 8.47\%$$

The 0.8% PKAN-55 composition exhibited a particularly high early-age strength, reaching 38.50 MPa at 7 days. However, its 28-day compressive strength was 42.56 MPa, slightly lower than the 43.41 MPa obtained at a dosage of 0.7%.

A further increase in admixture dosage resulted in a reduction in strength: the 28-day compressive strength decreased to 40.76 MPa at 0.9% and 38.43 MPa at 1.0%. Therefore, the optimum dosage of PKAN-55 was established as 0.7% by mass of cement. The dissertation likewise identifies 0.7% as the composition providing the highest overall compressive-strength result.

B. Microstructural Analysis of PKAN-55-Modified Concrete by X-Ray Diffraction

To explain the observed strength-development behavior at the physicochemical level, X-ray diffraction analysis was performed on PKAN-55-modified B30 concrete at 3, 7, and 28 days.

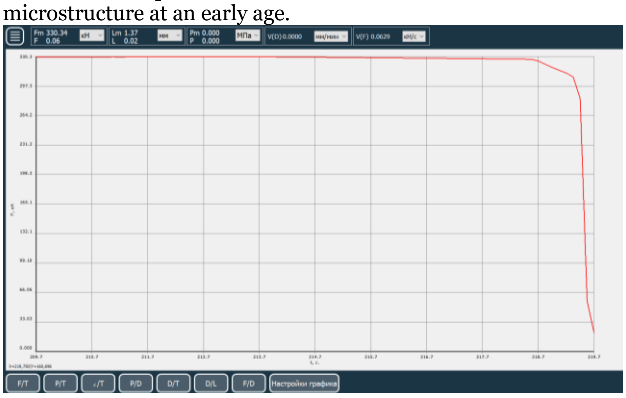
1. Three-Day Curing Period

At 3 days, the highest-intensity diffraction peak was observed at approximately:

$$2\theta \approx 29.4°$$

corresponding to the alite (C_3S) phase. Additional peaks at approximately 32°, 34°, 41°, 50°, 59°, 62°, and 66° were associated with belite (C_2S), tricalcium aluminate (C_3A), tetracalcium aluminoferrite (C_4AF), and portlandite [$Ca(OH)_2$].

Compared with conventional concrete of the same age, the PKAN-55-modified specimen exhibited sharper and more intense diffraction peaks, while the amorphous fraction was lower. This indicates more active cement hydration and more intensive formation of the cement-stone microstructure at an early age.



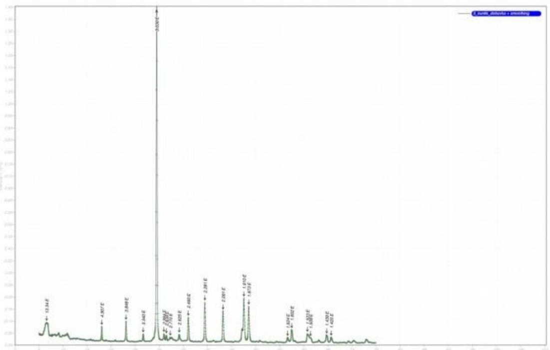


Fig. 3. B30 concrete containing PKAN-55 at 3 days:
(a) compressive-strength test result (b) XRD pattern

The microstructural results are consistent with the mechanical behavior of PKAN-55-modified concrete. The appearance of distinct crystalline peaks at an early age indicates active hydration and explains the accelerated development of compressive strength.

2. Seven-Day Curing Period

At 7 days, the dominant diffraction peak remained at:

$$2\theta \approx 29.4°$$

corresponding to C_3S. Peaks characteristic of C_2S, C_4AF, C_3A, and $Ca(OH)_2$ were also observed at approximately:

$$2\theta \approx 32 - 33°, 41°, 50°, 59°, 62°$$

Compared with the 3-day specimen, the diffraction peaks became more clearly defined and more intense, while the amorphous fraction decreased. This indicates an increase in hydration products and further densification of the cement matrix.

For the optimum 0.7% PKAN-55 composition, the 7-day strength reached 37.80 MPa, corresponding to:

$$K_7 = \frac{37.80}{43.41} \cdot 100 \approx 87.1\%$$

This confirms that a substantial proportion of the final 28-day strength developed during the first week.

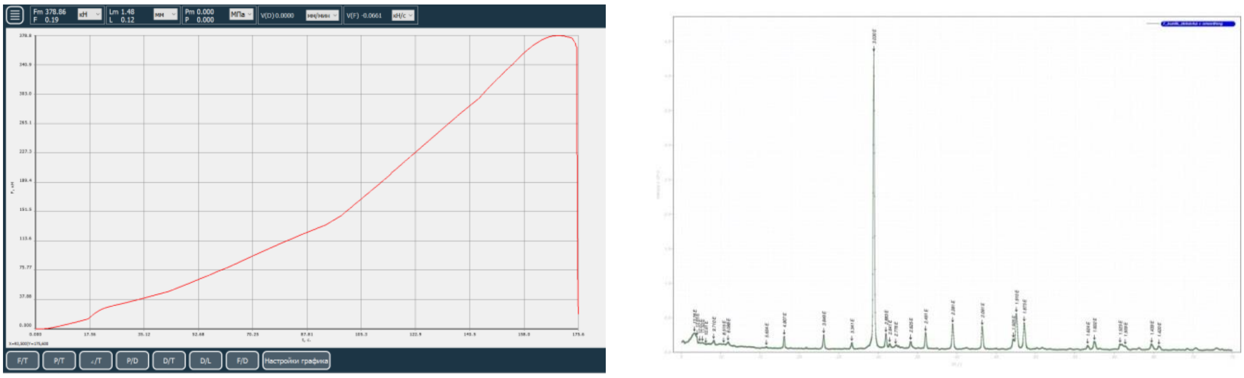


Fig. 4. B30 concrete containing PKAN-55 at 7 days:
(a) compressive-strength test result; (b) XRD pattern

The increased peak intensity at 7 days demonstrates that the hydration products continued to develop actively. The reduction of the amorphous phase and the increase in crystallinity are consistent with the more rapid development of compressive strength in PKAN-55-modified concrete.

3. Twenty-Eight-Day Curing Period

At 28 days, the XRD pattern indicated the formation of more stable crystalline phases within the hardened cement matrix. The dominant diffraction peak remained at:

$$2\theta \approx 29.4°$$

corresponding to the C_3S phase.

Additional diffraction peaks were observed at approximately:

$$2\theta \approx 32 - 34°, 47 - 49°, 62°$$

associated with C_2S, $Ca(OH)_2$, C_4AF, and C_3A.

The diffraction peaks at 28 days were sharper and more intense than those observed at earlier curing ages, indicating a high degree of crystallization and structural densification. The development of portlandite and belite phases provides additional evidence of continued cement hydration and the formation of a stable hardened matrix.

Moreover, compared with the 3- and 7-day specimens, the amorphous fraction was almost absent, while the diffraction peaks became more distinct and intense. This confirms that PKAN-55 contributed to the densification of the cement matrix and the stable formation of hydration products.

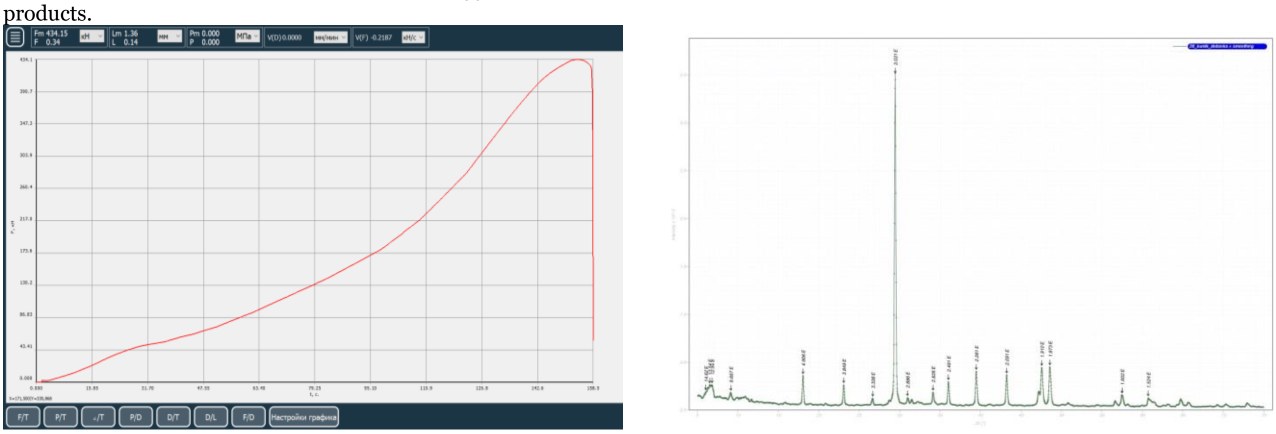


Fig. 5. B30 concrete containing PKAN-55 at 28 days:
(a) compressive-strength test result; (b) XRD pattern

C. Relationship Between Strength Development and Microstructural Evolution

The mechanical and XRD results show a consistent relationship between concrete strength development and the evolution of the cementitious microstructure.

At 3 days, hydration was already active, but the amorphous component was still relatively significant. By 7 days, the intensity and clarity of the diffraction peaks increased, while the amorphous fraction decreased. At 28 days, stable crystalline phases became predominant and the cement matrix showed the highest degree of structural densification.

The observed process can be represented schematically as:

cement hydration→formation of hydration products→increase in crystallinity→reduction of amorphous phase→densification of cement matrix→increase in compressive strength

These results provide the microstructural evidence requested by the reviewer and support the conclusion that the enhanced mechanical performance of PKAN-55-modified B30 concrete is related to accelerated hydration and progressive densification of the cement matrix.

D. Effect of BAAS-MIXPLAST 140 W Dosage

The effect of BAAS-MIXPLAST 140 W was also investigated over a dosage range of 0.6–1.0% by mass of cement.

The 28-day compressive strength increased with admixture dosage up to an optimum level of 0.9%, at which a maximum value of:

$$R_{28} = 41{,}55 MPa$$

was obtained.

Compared with conventional B30 concrete:

$$\Delta R = \frac{41{,}55 - 40{,}02}{40{,}02} \cdot 100 = 3{,}82\%$$

When the BAAS-MIXPLAST 140 W dosage was increased to 1.0%, the 28-day strength decreased to approximately 39.30 MPa, confirming the

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existence of an optimum dosage.

The experimental BAAS-MIXPLAST 140 W results therefore follow a similar nonlinear dosage–strength relationship to PKAN-55: an increase in dosage improves performance only up to a specific optimum level.

Since the dissertation material used for the present paper does not contain a corresponding 3-, 7-, and 28-day XRD series for BAAS-MIXPLAST 140 W, no separate XRD figure should be artificially added for this admixture. Its interpretation should remain based on the measured mechanical and technological results.

E. Comparative Evaluation of the Optimum Compositions

Tabel 3. Time-Dependent Variation in the Compressive Strength of Conventional B30 Concrete and B30 Concrete with PKAN-55 Admixture

Concrete composition	Optimum dosage	28-day strength, MPa	Increase relative to conventional B30
Conventional B30	—	40.02	—
PKAN-55-modified B30	0.7%	43.41	8.47%
BAAS-MIXPLAST 140 W-modified B30	0.9%	41.55	3.82%

The results indicate that both superplasticizers improved the compressive-strength characteristics of B30 concrete, while PKAN-55 at 0.7% provided the highest 28-day compressive strength. In addition, the XRD investigation provides direct microstructural support for the enhanced performance of the PKAN-55-modified concrete.

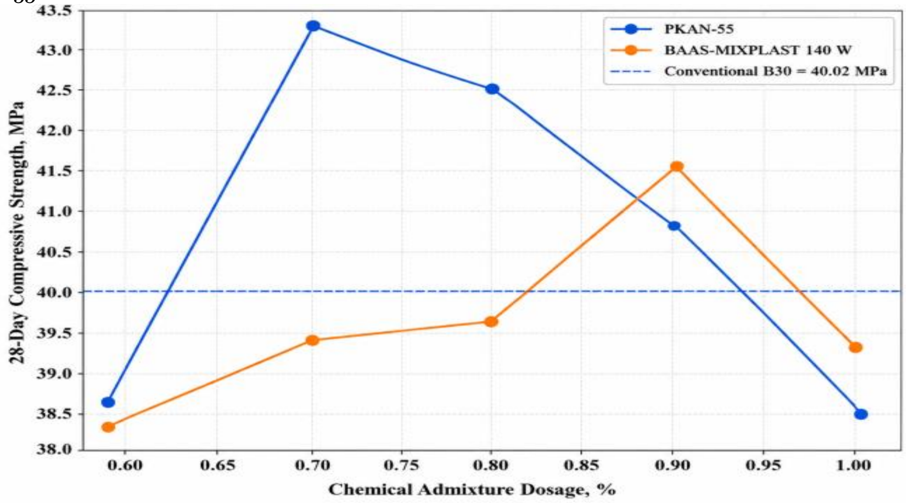

Fig. 6. Effect of Chemical Admixture Dosage on 28-Day Compressive Strength

Conclusion

The experimental investigation confirmed that the compressive strength development of B30 concrete is significantly influenced by both the type and dosage of the chemical admixture. The results obtained for conventional concrete and concrete modified with PKAN-55 and BAAS-MIXPLAST 140 W showed that strength increased progressively with curing age, while the rate and magnitude of this increase depended on the selected admixture content.

For conventional B30 concrete, the 28-day compressive strength was 40.02 MPa. The highest 28-day compressive strength among the PKAN-55-modified compositions was obtained at a dosage of 0.7% by mass of cement, reaching 43.41 MPa. This corresponds to an increase of approximately:

$$\frac{43{,}41 - 40{,}02}{40{,}02} \cdot 100 = 8{,}47\%$$

Thus, 0.7% PKAN-55 was established as the optimum dosage within the investigated range. Increasing the dosage above this level did not provide a further improvement in strength and resulted in a gradual decrease in the 28-day compressive strength.

For concrete modified with BAAS-MIXPLAST 140 W, the most effective dosage was 0.9% by mass of cement. At this dosage, the 28-day compressive strength reached 41.55 MPa, which was approximately 3.82% higher than that of conventional B30 concrete. A further increase in the admixture content to 1.0% resulted in a reduction in compressive strength, which confirmed the existence of an optimum dosage for this superplasticizer as well.

The strength-development kinetics also demonstrated that the chemical admixtures were particularly effective during the early curing period. For the optimum 0.7% PKAN-55 composition, the compressive strength reached 37.80 MPa at 7 days, corresponding to approximately 87.1% of its 28-day strength. This result indicates accelerated early-age structure formation compared with conventional B30 concrete.

The X-ray diffraction results provided additional physicochemical evidence supporting the mechanical test results. In PKAN-55-modified concrete, diffraction peaks associated with C_3S, C_2S, C_3A, C_4AF, and $Ca(OH)_2$ were identified at 3, 7, and 28 days. With increasing curing age, the diffraction peaks became sharper and more intense, while the amorphous fraction gradually decreased. At 28 days, the cement matrix exhibited the highest degree of crystallinity and structural densification.

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This microstructural evolution confirms that the improved compressive strength of PKAN-55-modified concrete is associated with more intensive hydration, stable formation of crystalline hydration products, and progressive densification of the cementitious matrix. The comparative XRD analysis also showed that the amorphous fraction decreased from the early curing stage and was practically absent by 28 days.

Overall, the experimental results established that the optimum dosages were 0.7% for PKAN-55 and 0.9% for BAAS-MIXPLAST 140 W. These dosages provided the most favorable combination of early-age strength development and 28-day compressive strength.

The obtained results demonstrate that the use of the investigated polycarboxylate-based superplasticizers can improve the mechanical performance of B30 concrete when applied at an appropriate dosage. In particular, PKAN-55 at 0.7% showed the highest efficiency among the investigated compositions and can be considered a promising modifying admixture for the production of reinforced concrete elements requiring accelerated strength development and improved compressive-strength characteristics.

Thus, the findings provide an experimental and microstructural basis for the practical application of locally applicable chemical admixtures in B30 concrete and support their use in reinforced concrete production under controlled mix-design and curing conditions.

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