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ASSESSMENT OF THE INFLUENCE OF A MODIFIED ADDITIVE ON THE STRENGTH CHARACTERISTICS OF INJECTION GROUTS IN THE DEEP CEMENTATION METHOD

Abstract. This study presents the results of research on the influence of a modified additive on the strength characteristics of injection grouts used in the deep cementation method. The primary component of the additive is paraffin, which enhances the plasticity of the mixture and reduces the water-cement ratio, ultimately improving the mechanical properties of the hardened grout. The tests were conducted on beam specimens at different hydration periods to determine the optimal additive concentration that ensures maximum grout strength. The analysis of the results revealed the strength variation dynamics in compression and bending, as well as the most effective additive concentration for further research and practical application. The obtained data may contribute to the improvement of injection-based soil reinforcement technologies and the expansion of deep cementation applications in construction.

Keywords: modified additive, deep cementation method, paraffin, deep cementation.

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Introduction. The proposed deep cementation method has found widespread application in various fields of construction and engineering. In urban environments, deep cementation is used to reinforce the foundations of high-rise buildings, bridges, tunnels, and other infrastructure projects. In rural areas, the method is applied for slope stabilization, landslide prevention, and the reinforcement of shorelines and dams [1]. Given the increasing impact of climate change and rising sea levels, ensuring the reliable protection of shorelines and hydraulic structures has become a priority. Deep cementation enables the creation of strong and durable barriers that prevent erosion and scouring [2].

A notable example of the successful application of this method is the reinforcement of the shoreline in the Netherlands, where high sea levels and frequent storms pose a significant threat. The use of modified cementitious grouts incorporating nanomaterials and polymer additives has allowed for the construction of stable and long-lasting reinforcements capable of withstanding the effects of water and wind [3].

Landslides also present a serious threat to infrastructure and public safety, particularly in mountainous regions and on slopes with unstable soils. Deep cementation is utilized to stabilize slopes, preventing their displacement and collapse. In shoreline reinforcement applications, modified cementitious grouts with nanomaterials and polymer additives provide erosion protection and resistance to climatic impacts. For slope stabilization, the incorporation of polymer additives and nanomaterials helps prevent landslides and enhances resilience against heavy precipitation and earthquakes [4].

The development and application of modified additives in cementitious grouts represent a crucial research area aimed at improving the strength, durability, and stability of reinforced soils [5]. The inclusion of polymer additives, nanomaterials, and chemical compounds in cement mixtures significantly enhances their properties, which is particularly relevant in complex geological conditions and regions with high seismic activity [6].

Despite its numerous advantages, the deep cementation method faces several challenges. One of the main issues is the high cost of modified cementitious grouts, which limits their application in certain projects. Additionally, it is essential to consider the specific conditions of each site and select the optimal grout composition based on the construction requirements and soil type [7].

In recent years, increasing attention has been given to the development of bioactive additives that improve the interaction between cementitious stone and natural soils. Bioactive additives accelerate hydration and enhance the microstructure of the cementitious matrix, leading to increased strength and durability .

This study presents the results of modifications applied to injection grouts based on general-purpose construction cements. The rationale for this approach is that in the construction market and the engineering-geological conditions of the research region (Central Kazakhstan), general-purpose cement of grade M500 is in high demand for injection grouts [8].

The objective of this study was to develop the composition and production technology of a modifying additive for injection grout based on general-purpose construction cement for the deep cementation method. This paper presents the findings of an investigation into the effects of the developed modified additive on the strength of injection grout, with the aim of enhancing the efficiency and reliability of soil reinforcement techniques under various conditions.

Materials and methods. The modified additive for the injection grout consists of the following components: cement, paraffin, sulfuric acid (neutralizer), and water. The primary component of the additive is paraffin, which increases the mobility of the mixture and retains active cement ions within the composition by enhancing its density. Increasing the mobility of the mixture by raising the water-cement ratio in a cement-sand blend can lead to concrete segregation, where active ions are carried to the surface by water.

Cement in the additive composition serves as the base in which paraffin is dissolved. As a result, a suspended paraffin-cement mixture is obtained, which is hydrated with water. During the dissolution of paraffin in cement, activation occurs within a suspended ion-active medium. Sulfuric acid is introduced into the additive to facilitate the dissolution of inherently hydrophobic paraffin in an aqueous environment.

The preparation of the modified additive involves the complete dissolution of paraffin in the cement mixture with strict water control. This control is necessary due to the exothermic neutralization reaction between the alkaline cement mixture and sulfuric acid, which causes water evaporation. Through multiple iterations of mixture preparation, the optimal component ratio was established, accounting for water evaporation: Cement – 1000 g, Paraffin – 200 g, Sulfuric acid – 100 g, Water – 1000 g. This proportion provides a balanced, mobile mixture that can be easily incorporated into the injection grout composition. The control injection grout consisted of the following components: Cement – 500 g, Sand – 1500 g, Water – 250 ml, The modified additive was incorporated into the control grout in varying proportions: 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by mass of the mixture.

For strength testing under compression and bending, three specimens of each mixture were prepared (Figure 1), denoted in the results as Mix 1, Mix 2, and Mix 3. To indicate the inclusion of the modified additive, the following labeling system was used: Mix(R)1-3, Mix(0.2)1-3, … Mix(1.0)1-3 (where R represents the reference sample and 0.2–1.0 denotes the percentage of the additive in the specimen composition). A total of 18 mixtures were prepared, each consisting of three beam specimens. Table 1 presents the composition of each mixture.

Table 1

Mixture compositions

Name of samples	Sand, g	Cement, g	Water, g	Additive, g
Reference sample	1500	500	250	0
Mix(0.2)	1500	499	250	1
Mix(0.4)	1500	498	250	2
Mix(0.6)	1500	497	250	3
Mix(0.8)	1500	496	250	4
Mix(1.0)	1500	495	250	5

The strength testing of the specimens under compression and bending was conducted in accordance with GOST 310.4 (Figure 1), which is the standard method for assessing the performance of injection grouts. The comparative analysis of the strength of specimens with varying compositions was performed to determine the optimal composition of the modified additive and evaluate its effectiveness.

Fig. 1. Laboratory strength tests of concrete specimens

By comparing the strength characteristics of specimens with and without the additive, it becomes possible to assess the impact of the additive's components on the modification of the injection grout and its transformation in terms of strength improvement.

Research results and discussion. *Compressive strength tests on specimens.* Figure 2 presents the results of compressive strength testing for specimens with varying compositions of cement grout. The diagrams illustrate the strength development over time at 7, 14, and 28 days, along with the corresponding coefficients of variation.

Figure 2A displays the results for the reference samples (without the additive). Figures 2B–2F show the results for specimens containing the modified additive in different concentrations (ranging from 0.2% to 1.0% by cement mass). These data provide insights into the effectiveness of the additive in enhancing the compressive strength of the injection grout over time.

According to the results of the compressive strength tests, the average strength of the reference samples at different curing ages is as follows:

– 7-day strength: 25.53 MPa (individual values: 24.3–26.4 MPa, coefficient of variation: 4.30%);

– 14-day strength: 33.80 MPa (individual values: 31.9–35.2 MPa, coefficient of variation: 4.95%);

– 28-day strength: 38.70 MPa (individual values: 37.4–39.7 MPa, coefficient of variation: 3.01%).

These values were taken as the baseline for evaluating the effects of the modified additive at different concentrations.

Strength Development with Additive at Different Concentrations.

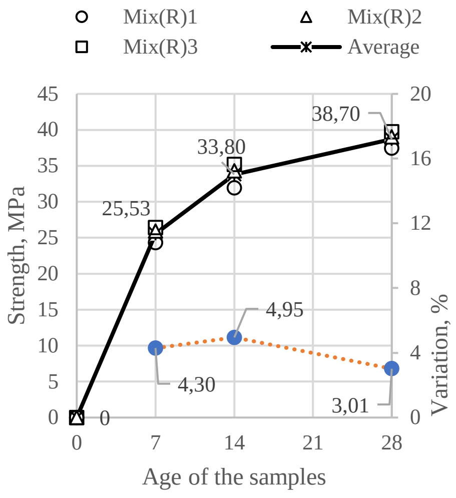
0.2% additive: 7-day strength: 25.7 MPa (range: 24.4–26.8 MPa, coefficient of variation: 4.59%), 14-day strength: 34.5 MPa (range: 32.7–35.8 MPa, coefficient of variation: 4.74%), 28-day strength: 39.1 MPa (range: 38.0–39.9 MPa, coefficient of variation: 2.53%).

0.4% additive: 7-day strength: 26.1 MPa (range: 24.9–27.1 MPa, coefficient of variation: 4.13%), 14-day strength: 34.5 MPa (range: 33.4–36.3 MPa, coefficient of variation: 4.55%), 28-day strength: 39.3 MPa (range: 38.1–40.9 MPa, coefficient of variation: 2.77%).

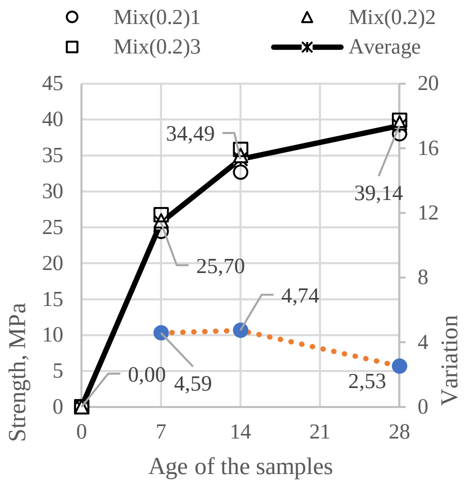
0.6% additive: 7-day strength: 26.1 MPa (range: 24.9–26.4 MPa, coefficient of variation: 4.17%), 14-day strength: 34.8 MPa (range: 33.9–35.9 MPa, coefficient of variation: 2.80%), 28-day strength: 40.3 MPa (range: 39.6–41.2 MPa, coefficient of variation: 2.10%).

0.8% additive: 7-day strength: 26.8 MPa (range: 25.5–28.1 MPa, coefficient of variation: 4.97%), 14-day strength: 36.2 MPa (range: 35.3–36.9 MPa, coefficient of variation: 2.30%), 28-day strength: 41.9 MPa (range: 41.2–42.5 MPa, coefficient of variation: 1.57%).

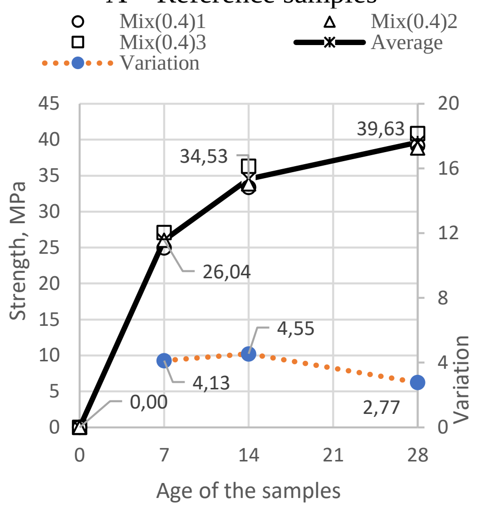
1.0% additive: 7-day strength: 27.1 MPa (range: 25.7–28.2 MPa, coefficient of variation: 4.75%), 14-day strength: 36.4 MPa (range: 35.2–37.2 MPa, coefficient of variation: 3.00%), 28-day strength: 42.1 MPa (range: 41.3–43.1 MPa, coefficient of variation: 2.15%).



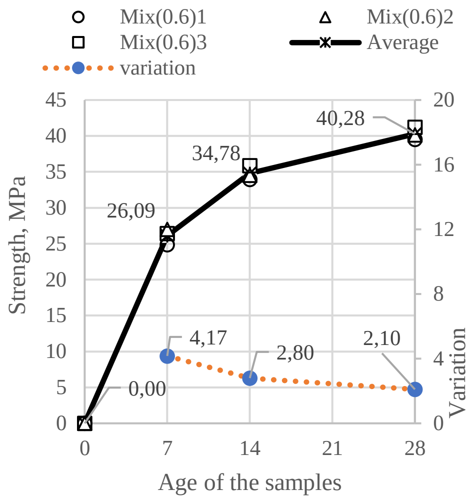
A – Reference samples



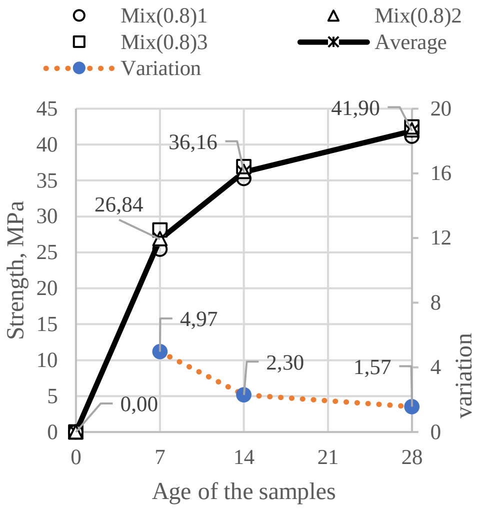
B – Mixture 0.2% additive



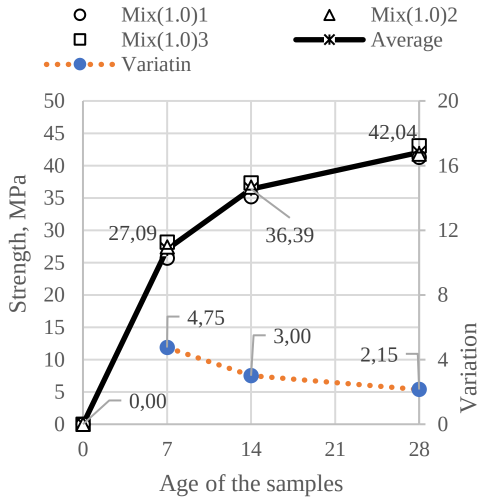
C – Mixture 0.4% additive



D – Mixture 0.6% additive



E – Mixture 0.8% additive



F – Mixture 1.0% additive

Fig. 2. Results of determining the compressive strength of the samples

Analysis of Strength Variations. The changes in the coefficients of variation over time indicate that as the full curing period progresses, the results become more stable, and the scatter of individual values decreases. This suggests that the specimens are approaching full structural strength.

Early-stage curing: Structural strength is less stable, with variation coefficients exceeding 4.17% in all cases. End of the curing period: The variation coefficients decrease significantly, reaching a 30–50% reduction, indicating greater uniformity in structural formation.

These findings confirm that the addition of the modified additive positively influences strength development and consistency, particularly in the later stages of hydration.

Tensile strength testing of specimens. Figure 3 presents the results of flexural strength testing for specimens with varying compositions of cement grout. The diagrams illustrate the strength development over time at 7, 14, and 28 days, along with the corresponding coefficients of variation.

Figure 3A displays the results for the reference samples (without the additive). Figures 3B–3F show the results for specimens containing the modified additive in different concentrations (ranging from 0.2% to 1.0% by cement mass).

These data provide insights into the effectiveness of the additive in enhancing the flexural strength of the injection grout over time.

According to the results of the flexural strength tests, the average strength of the reference samples at different curing ages is as follows:

– 7-day strength: 3.23 MPa (individual values: 3.03–3.46 MPa, coefficient of variation: 6.74%);

– 14-day strength: 4.26 MPa (individual values: 4.04–4.49 MPa, coefficient of variation: 5.29%);

– 28-day strength: 5.11 MPa (individual values: 4.92–5.23 MPa, coefficient of variation: 3.30%)

These values were taken as baseline indicators for assessing the effect of the modified additive at different concentrations.

Strength Development with Additive at Different Concentrations.

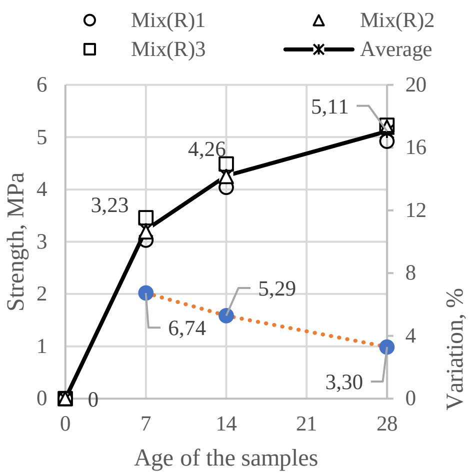
0.2% additive: 7-day strength: 3.30 MPa (range: 3.12–3.55 MPa, coefficient of variation: 6.77%), 14-day strength: 4.34 MPa (range: 4.14–4.58 MPa, coefficient of variation: 5.16%), 28-day strength: 5.21 MPa (range: 5.07–5.39 MPa, coefficient of variation: 3.14%).

0.4% additive: 7-day strength: 3.37 MPa (range: 3.28–3.55 MPa, coefficient of variation: 4.54%), 14-day strength: 4.41 MPa (range: 4.21–4.67 MPa, coefficient of variation: 5.38%), 28-day strength: 5.28 MPa (range: 5.11–5.45 MPa, coefficient of variation: 3.22%).

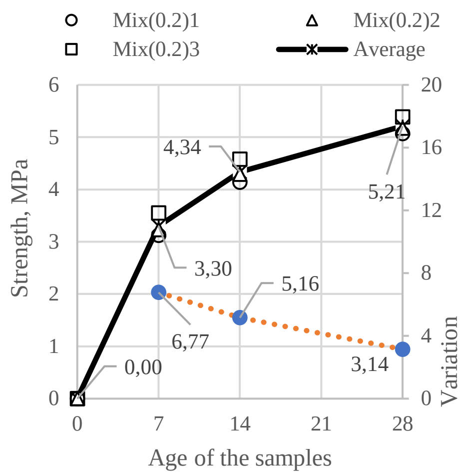
0.6% additive: 7-day strength: 3.41 MPa (range: 3.29–3.62 MPa, coefficient of variation: 3.41%), 14-day strength: 4.45 MPa (range: 4.26–4.74 MPa, coefficient of variation: 5.69%), 28-day strength: 5.33 MPa (range: 5.14–5.53 MPa, coefficient of variation: 3.67%).

0.8% additive: 7-day strength: 3.43 MPa (range: 3.29–3.56 MPa, coefficient of variation: 3.95%), 14-day strength: 4.48 MPa (range: 4.28–4.69 MPa, coefficient of variation: 4.58%), 28-day strength: 5.45 MPa (range: 5.23–5.66 MPa, coefficient of variation: 3.95%).

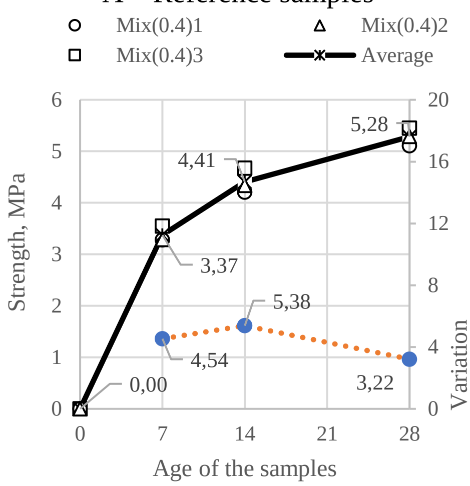
1.0% additive: 7-day strength: 3.48 MPa (range: 3.30–3.65 MPa, coefficient of variation: 5.03%), 14-day strength: 4.53 MPa (range: 4.34–4.72 MPa, coefficient of variation: 4.20%), 28-day strength: 5.49 MPa (range: 5.29–5.61 MPa, coefficient of variation: 3.22%).



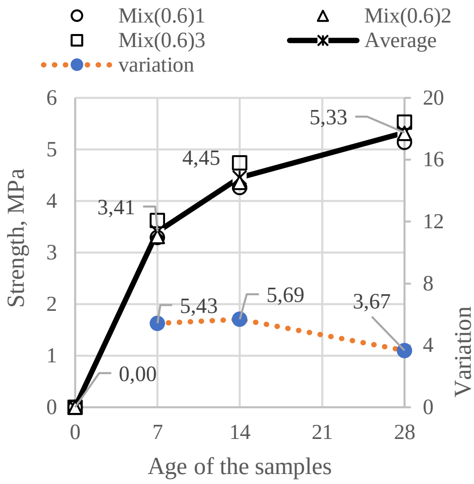
A – Reference samples



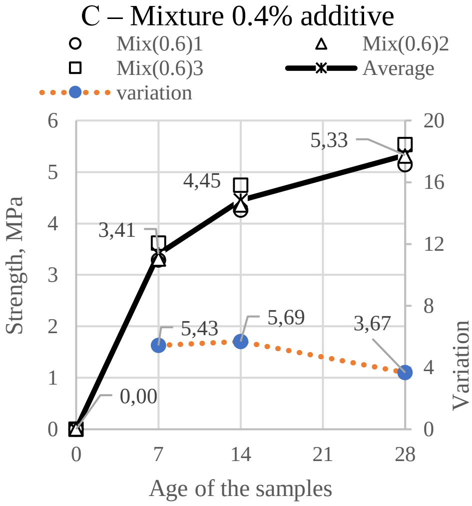
B – Mixture 0.2% additive



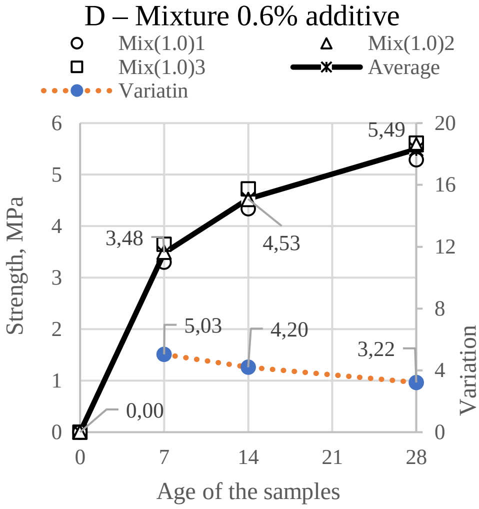
C – Mixture 0.4% additive



D – Mixture 0.6% additive



E – Mixture 0.8% additive



F – Mixture 1.0% additive

Fig. 3 Results of flexural strength of the samples

Analysis of Strength Variations. The changes in the coefficients of variation over time indicate that as the full curing period progresses, the results become more stable, and the scatter of individual values decreases. This suggests that the specimens are approaching full structural strength.

Early-stage curing: Structural strength is less stable, with variation coefficients exceeding 5% in most cases. End of the curing period (28 days): The variation coefficients decrease significantly, showing a 20–30% reduction, indicating improved uniformity in structural formation.

Conclusion. Based on the test results, the highest compressive strength (at all curing ages) was observed in specimens with the maximum additive concentration of 1.0%, showing a 6–9% increase compared to the reference sample, depending on the curing age. A notable increase in strength was observed up to an additive concentration of 0.8%, after which the influence of the additive on strength diminished. The strength gain at 1.0% concentration compared to 0.8% was only 0.3–0.9%, indicating that for optimal strength improvement, an additive concentration of 0.8–1.0% can be considered. From a statistical perspective, a significant strength increase was first recorded at 0.6% concentration. If other performance parameters (beyond compressive strength) are taken into account, the optimal additive concentration may be considered within the 0.6–1.0% range by cement mass.

Flexural Strength: The highest flexural strength (at all curing ages) was also observed in specimens with the maximum additive concentration of 1.0%, showing a 6–8% increase compared to the reference sample, depending on the curing age. A steady increase in flexural strength was recorded up to an additive concentration of 1.0%. Thus, for optimal enhancement of flexural strength, an additive concentration of 1.0% is recommended. From a statistical perspective, a noticeable strength gain was observed at 1.0% concentration. If strength preservation is prioritized while optimizing other performance parameters, the recommended additive range may be 0.2–1.0% by cement mass.

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ТЕРЕҢ ЦЕМЕНТТЕУ ӘДІСІНІҢ ИНЪЕКЦИЯЛЫҚ ЕРІТІНДІЛЕРІНІҢ БЕРІКТІК СИПАТТАМАЛАРЫНА МОДИФИКАЦИЯЛАНҒАН ҚОСПАНЫҢ ӘСЕРІН БАҒАЛАУ

Аңдатпа. Бұл мақалада терең цементтеу әдісінде қолданылатын инъекциялық ерітінділердің беріктік сипаттамаларына модификацияланған қоспаның әсерін зерттеу нәтижелері берілген. Қоспаның негізгі құрамдас бөлігі парафин болып табылады, ол қоспаның икемділігін жақсартуға және су-цемент қатынасын азайтуға көмектеседі, бұл ақыр соңында шыңдалған ерітіндінің механикалық қасиеттерін жақсартады. Ерітіндінің максималды беріктігін қамтамасыз ететін қоспаның оңтайлы концентрациясын анықтау үшін әртүрлі гидратация уақытында сәулелік үлгілерде сынақтар жүргізілді. Нәтижелерді талдау қысу және иілу беріктігінің өзгеру динамикасын анықтауға, сонымен қатар кейінгі зерттеулер мен практикалық қолдану үшін қоспаның ең тиімді концентрациясын анықтауға мүмкіндік берді. Алынған мәліметтер топырақты айдау технологиясын жетілдіруге және құрылыста терең цементтеуді қолдану аясын кеңейтуге ықпал ете алады.

Тірек сөздер: модификацияланған қоспа, терең цементтеу әдісі, парафин, терең цементтеу.

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ОЦЕНКА ВЛИЯНИЯ МОДИФИЦИРОВАННОЙ ДОБАВКИ НА ПРОЧНОСТНЫЕ ХАРАКТЕРИСТИКИ ИНЪЕКЦИОННЫХ РАСТВОРОВ МЕТОДА ГЛУБИННОЙ ЦЕМЕНТАЦИИ

Аннотация. В данной статье представлены результаты исследования влияния модифицированной добавки на прочностные характеристики инъекционных растворов, применяемых в методе глубинной цементации. Основным компонентом добавки является парафин, который способствует улучшению пластичности смеси и снижению водоцементного отношения, что в конечном итоге повышает механические свойства затвердевшего раствора. Испытания проводились на балочных образцах в разные сроки гидратации с целью определения оптимальной концентрации добавки, обеспечивающей максимальную прочность раствора. Анализ результатов позволил выявить динамику изменения прочности при сжатии и изгибе, а также определить наиболее эффективную концентрацию добавки для последующих исследований и практического применения. Полученные данные могут способствовать совершенствованию технологий инъекционного упрочнения грунтов и расширению области применения глубинной цементации в строительстве.

Ключевые слова: модифицированная добавка, метод глубокой цементации, парафин, глубинная цементация.