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THE INFLUENCE OF A MODIFIED ADDITIVE BASED ON A PARAFFIN COMPONENT ON THE WORKABILITY AND SETTING TIME OF AN INJECTION GROUT FOR THE DEEP SOIL CEMENTATION METHOD

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ABSTRACT: The construction industry has seen an increasing reliance on advanced techniques to ensure the stability and durability of structures, particularly in challenging soil conditions. A notable method employed is deep grouting of soils, which necessitates enhanced formulations of injection mortars to augment their mobility and regulate setting time. This study proposes a modified additive comprising paraffin, sulfuric acid, and cement to enhance the rheological and physical-mechanical characteristics of injection mortar. The experimental framework encompassed cone spreading tests and determination of setting time in accordance with GOST standards. The findings indicate that the optimal water-cement ratio (WCR) for mortar mobility of 150 mm is 0.5. The results demonstrate that the additive linearly augments the mobility of the mortar, attaining a maximum value of 187 mm at an additive concentration of 1.0%. However, the optimum concentration in terms of mobility is the range of 0.6-0.8%. The effect of the additive on the setting time exhibited a nonlinear pattern; the greatest increase in setting time was observed at the 0.2% additive concentration (88 minutes increase), while at the 1.0% concentration, the increase was only 12 minutes. Therefore, the optimum additive concentration to balance mobility and setting time is 0.6-0.8%. The outcomes of this study substantiate that the modified additive has the potential to enhance the characteristics of the injection mortar, thereby providing more efficacious solutions for soil consolidation in a range of construction settings.

Keywords: Deep soil cementation, Paraffin, Plasticizing properties, Modified additive

1. INTRODUCTION

The growth of cities, the development of infrastructure, and the increasing load on soils necessitate the use of effective methods to ensure the stability and durability of construction projects. Deep soil cementation has proven to be one of the most effective approaches to addressing these challenges. However, with the advent of new materials and technologies, it has become essential to improve existing methods and develop new solutions for enhancing the properties of cementitious grouts [1]. For skyscraper construction, the use of polymer additives and nanomaterials is recommended to increase soil bearing capacity and structural stability. In subway construction, nanomaterials and chemical additives provide high strength and impermeability of reinforced soils, protecting underground structures from water-saturated layers [2].

Deep soil cementation plays a critical role in modern construction technologies, particularly in urbanization and construction under complex geological conditions. The method effectively strengthens the soil beneath buildings and structures, ensuring their stability and longevity. Its application is especially relevant in seismically active regions where soil reinforcement is necessary to prevent damage during earthquakes [3]. Deep soil cementation is a complex process requiring careful selection and control of injection parameters, grout composition, and soil characteristics. Modern technologies and materials have significantly enhanced the efficiency of this method, ensuring reliable soil reinforcement under various conditions [4].

A key challenge is the lack of data on the long-term effectiveness of modified additives under diverse conditions. Although contemporary studies yield promising results, further research and monitoring are required to confirm the durability and strength of reinforced soils over extended periods [5]. However, existing additives have a number of limitations that hinder their use in demanding applications. The mobility of mortars is limited: Polymeric and mineral additives frequently necessitate a substantial augmentation in the water-cement ratio, leading to mixture delamination and diminished strength of the ultimate material. Poor setting time stability: The additives employed to regulate setting times frequently induce non-linear changes, which can impede their predictability and control over mortar placement processes.

Sensitivity to environmental conditions is another salient issue, as many additives lose effectiveness at low or high temperatures, which limits their use in regions with extreme climates [6]. Consequently, there is an imperative to devise novel solutions that can enhance the critical characteristics of cement-based mortars.

This article presents the results of modifications to injection grouts based on general-purpose ordinary Portland cement. The choice is justified by the high demand for standard M500 cement in the construction market and the engineering-geological conditions of the study region (Central Kazakhstan) [7]. This study focuses on evaluating the impact of a newly developed modified additive on the workability and setting time of the grout, contributing to the enhanced efficiency and reliability of soil reinforcement methods under various conditions.

The enhancement of cement mortar properties, including mobility, setting time, and resistance to external influences, is of paramount importance in ensuring the durability of infrastructure and the seismic resilience of buildings and structures. The incorporation of modified additives enhances the water and chemical resistance of the mortar, a critical consideration in regions characterized by aggressive environmental conditions, such as high salt or acid content in soils [8]. The enhanced strength and stability of the mortar is pivotal in ensuring the reliable operation of the infrastructure throughout its lifespan, thereby reducing the expenses associated with repair and reconstruction.

Furthermore, the implementation of deep grouting techniques, employing enhanced mortars, has been shown to enhance soil cohesion, thereby enabling structures to withstand dynamic loads triggered by seismic events. This is particularly crucial in regions characterized by high seismic activity, a category that includes Central Asia, a region exemplified by the country of Kazakhstan [9].

The stabilization of ground conditions is pivotal in preventing uneven settlement, which can lead to deformation or collapse of structures under seismic action. The enhanced physical and mechanical characteristics of mortars facilitate the absorption of seismic energy, thereby mitigating the adverse effects on structures [10].

The employment of more efficient mortars has the added benefit of reducing the necessity for repair and reinforcement materials, thereby decreasing the environmental impact of construction. Increased structural durability and reduced need for regular maintenance contribute to lower overall operating costs [11].

2. RESEARCH SIGNIFICANCE

The additive for injection cement mortar is composed of the following components: cement, paraffin, sulfuric acid (as a neutralizer), and water. The additive's primary component is paraffin, which enhances the workability of the mixture and retains active cement ions, thereby increasing its density. Increasing the mobility by increasing the water-cement ratio leads to delamination of concrete, with water transporting the active ions to the surface of the concrete. This phenomenon occurs because the water content in the mortar is naturally compelled to the surface, given that the density of the other concrete components exceeds that of water. As a result, the active ions of the dissolved cement batter are carried to the surface in conjunction with water. The incorporation of paraffin-based components in portlandite, as well as the augmentation of the density of the tobermorite gel, does not necessitate an escalation in the water-cement ratio. This phenomenon can be attributed to the plasticizing effect of the paraffin component, which serves to mitigate the risk of ion transport to the surface. Upon dissolution of paraffin in cement, activation occurs within a suspended ionic active medium. The dissolution of hydrophobic paraffin in an aqueous medium necessitates the presence of sulfuric acid.

3. MATERIALS AND METHODS

The preparation of the modified additive involves the complete dissolution of paraffin in the cement mixture while controlling water levels. This control is essential due to the exothermic reaction of neutralizing the alkaline medium of the mixture with sulfuric acid, which causes water evaporation. Through multiple iterations of mixture preparation, an optimal component composition was determined, accounting for water evaporation: 1000 g of cement, 200 g of paraffin, 100 g of sulfuric acid, and 1000 g of water. This proportion provides a balanced, workable mixture that can be easily integrated into the injection grout.

The testing of specimens for cone melting (see Figure 1) was conducted in accordance with the standards outlined in GOST 310.4. The testing procedure involved two distinct stages. In the initial stage, the samples were assessed for their compliance with the standard water-cement ratio and the normative value for cone melting, with a diameter of 15 centimeters. In the subsequent stage, the tests were repeated at the water-cement ratio corresponding to the first stage, but this time for specimens with varying concentrations of modifying admixture.

The composition of the control injection mortar is outlined as follows: 500 g cement, 1500 g sand, and 250 ml water. The variable inclusion of the modifying additive in the control mortar was set at 0.2%, 0.4%, 0.6%, 0.8%, and 1% by weight of the mortar.

For testing purposes, three specimens were prepared for each mixture (Fig. 1), denoted as Mix 1, Mix 2, and Mix 3. To identify the additive content in each mixture, the following labels were used: Mix (R)1-3 for the reference sample and Mix (0.2)1-3, Mix (0.4)1-3, etc., for samples with additive percentages ranging from 0.2% to 1.0%. In total, 18 mixtures were prepared, each comprising three specimens. Table 1 provides the composition of each mixture.

In the second stage, tests were performed at the water-to-cement ratio determined in the first stage for specimens with varying concentrations of the modified additive.

Table 1. Example of Table Formatting.

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 setting time tests for the cement-sand mixture were conducted in accordance with GOST 310.3 Figure 1-4. These tests are fundamental for evaluating the performance of injection grouts. The assessment criteria included the initial setting time, final setting time, and the duration of the setting process. The standard benchmark for evaluating the setting time of injection grouts based on general-purpose cement was established at 3.5–13 hours.

Fig.1 Laboratory testing of specimens, Testing of specimens for cone melting

Fig.2 Laboratory testing of specimens, for cone melting

Fig.3 Laboratory testing of specimens, the setting time tests for the cement-sand mixture

Fig.4 Laboratory testing of specimens. The setting time tests for the cement-sand mixture

The modified additive used in this study consists of cement, paraffin, sulfuric acid (as a neutralizer), and water. The primary component, paraffin, enhances the mixture's workability and retains active cement ions by increasing density. The optimal composition of the additive was determined through iterative experimental adjustments, considering the evaporation of water due to the exothermic reaction of sulfuric acid with the cement mixture. The final formulation used for testing included:

- 1000 g of cement
- 200 g of paraffin
- 100 g of sulfuric acid
- 1000 g of water

The control injection mortar consisted of 500 g of cement, 1500 g of sand, and 250 ml of water. The modified additive was incorporated in concentrations ranging from 0.2% to 1.0% by weight of the mortar.

Experimental Methodology

The experimental framework consisted of the following tests:

1. Slump Flow Test: Conducted in accordance with GOST 310.4 standards to evaluate the impact of the additive on mortar workability. The test was performed using different water-cement ratios (WCRs) and additive concentrations. Slump flow diameters were measured for each sample, and correlation coefficients were calculated to determine trends.
2. Setting Time Test: Performed according to GOST 310.3 to assess the impact of the additive on the initial and final setting times of the cement-sand mixture. The benchmark setting time for general-purpose cement was 3.5–13 hours.
3. Analysis of Chemical Interactions: The paraffin-based component interacts with cementitious materials by modifying surface tension and hydration processes. A qualitative analysis of these interactions was conducted to understand the underlying mechanisms affecting setting time and workability.

4. RESULTS AND DISCUSSION

The slump flow test Figure 5-10 illustrates results for the reference samples at varying water-to-cement ratios (WCR). Figures 5 through 9 display the data points and average slump flow values for WCRs ranging from 0.3 to 0.5, respectively. Figure 10 presents the resulting diagrams showing changes in slump flow as a function of water content, along with the correlation coefficients corresponding to each test series.

According to the test results, the average slump flow value for specimens with a WCR of 0.30 is 99 mm, with individual values ranging from 98.5 to 99.5 mm and a coefficient of variation of 4.0%. For specimens with a WCR of 0.35, the average slump flow is 106 mm, with individual values between 104.3 and 107.0 mm and a coefficient of variation of 3.3%. At a WCR of 0.40, the average slump flow is 117 mm, with values ranging from 116.1 to 118.0 mm and a coefficient of variation of 2.6%. For a WCR of 0.45, the average slump flow is 132 mm, with values between 130.0 and 132.6 mm and a coefficient of variation of 2.5%. Finally, for a WCR of 0.50, the average slump flow is 147 mm, with values ranging from 146.9 to 148.5 mm and a coefficient of variation of 2.4%.

The resulting diagram demonstrates that the increase in slump flow is not proportional to the WCR increment. With each additional portion of water, the rate of slump flow increase accelerates. The allowable workability of the injection grout, approximating 150 mm, is achieved at WCR = 0.5. The diagram also indicates that as the WCR increases, the coefficient of variation decreases, suggesting greater stabilization of the mixture's workability as water content rises. Therefore, WCR = 0.5 is selected for the reference grout, and further studies on the mixture's workability with the addition of the modifier will be conducted at this WCR.

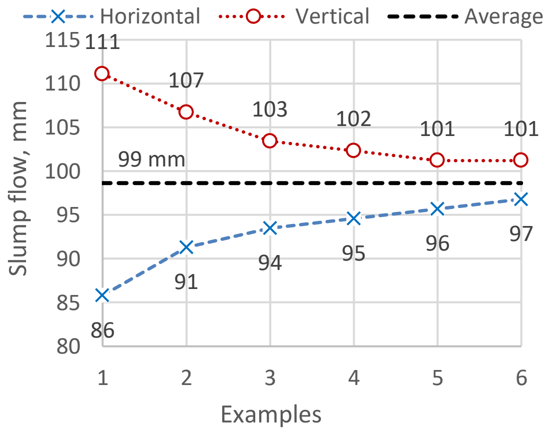

Fig. 5 Slump Flow Test Outcomes for Various Water-Cement Ratios: WCR=0.30

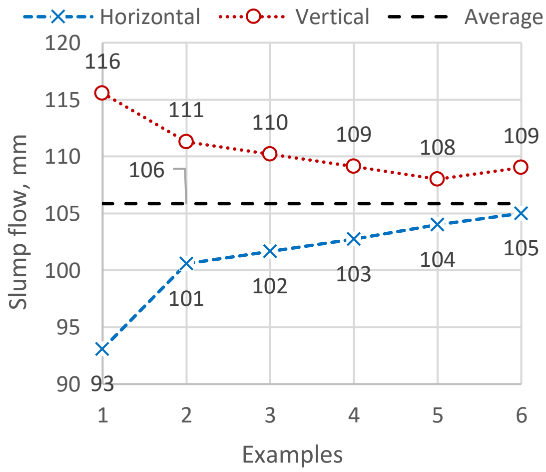

Fig. 6 Slump Flow Test Outcomes for Various Water-Cement Ratios: WCR=0.35

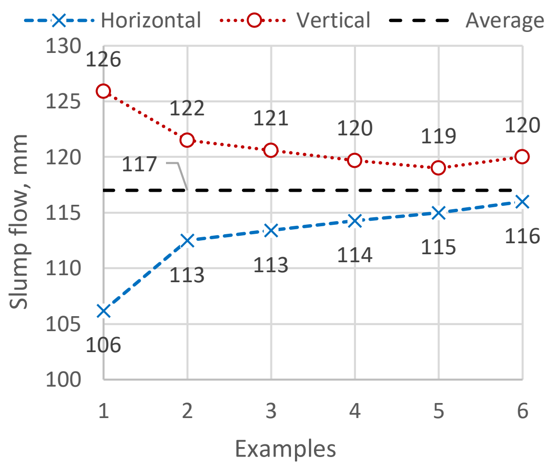

Fig. 7 Slump Flow Test Outcomes for Various Water-Cement Ratios: WCR=0.40

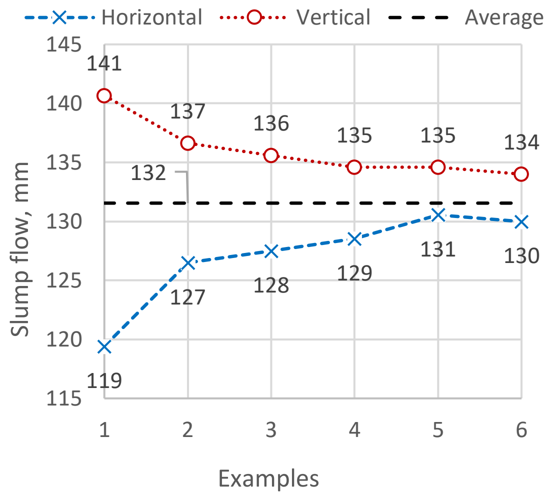

Fig. 8 Slump Flow Test Outcomes for Various Water-Cement Ratios: WCR=0.45

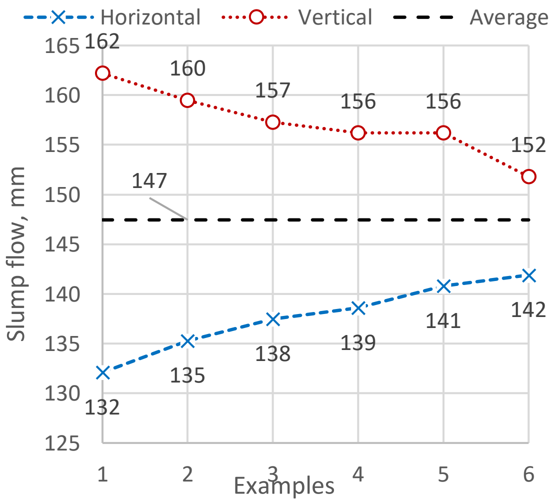

Fig. 9 Slump Flow Test Outcomes for Various Water-Cement Ratios: WCR=0.50

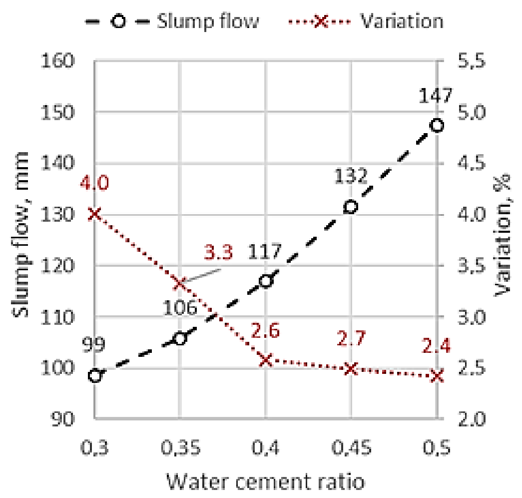

Fig. 10 Slum Flow Test Outcomes for Various Water-Cement Ratios 2F – Resultant diagrams

Figure 11-16presents the slump flow test results for specimes with varying concentrations of the modified addtive. Figures 11 through 15 show the data points nd average slump flow values for additive concentrations ranging from 0.2% to 1.0% (by cement mass). Figure 17 provides the resulting diagrams shwing the changes in slump flow as a function of the additive concentration, along with the correlation coefficients for each test series.

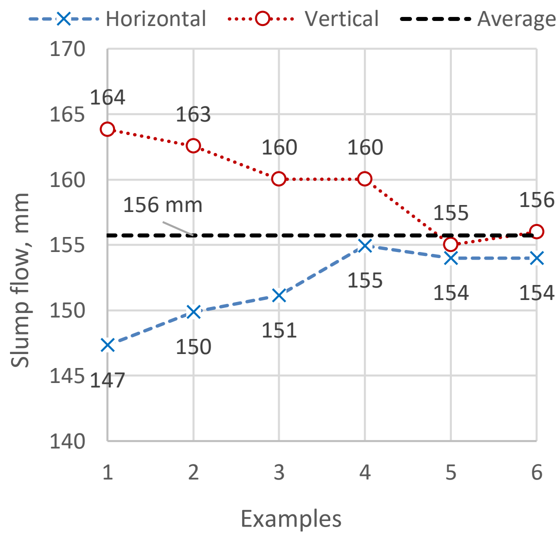

Fig. 11 Slump Flow Test Outcomes for Various Additive Concentrations: Mix (0.2)

According to the test results, the average slump flow value for specimens with Mix(0.2) is 156 mm, with individual values ranging from 154.5 to 157.5 mm and a coefficient of variation of 2.1%. For Mix(0.4), the average slump flow is 165 mm, with values between 164.2 and 166.6 mm and a coefficient of variation of 2.1%.

The average slump flow for Mix(0.6) is 175 mm, with values ranging from 172.9 to 175.5 mm and a coefficient of variation of 2.2%. For Mix(0.8), the average slump flow is 182 mm, with values between 180.8 and 182.7 mm and a coefficient of variation of 1.7%. Finally, for Mix(1.0), the average slump flow is 187 mm, with values ranging from 186.0 to 188.0 mm and a coefficient of variation of 2.3%.

The resulting diagram demonstrates that the increase in slump flow is not proportional to the increase in additive concentration. With each subsequent addition of the additive (in increments of 0.2%), the rate of slump flow increase diminishes, indicating a decreasing influence of the additive on workability. The comparable coefficients of variation across all test series indicate high stability of the data points and consistent workability across all mixture compositions.

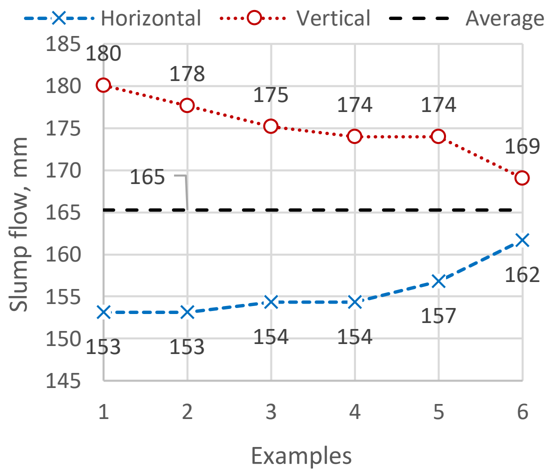

Fig. 12 Slump Flow Test Outcomes for Various Additive Concentrations: Mix (0.4)

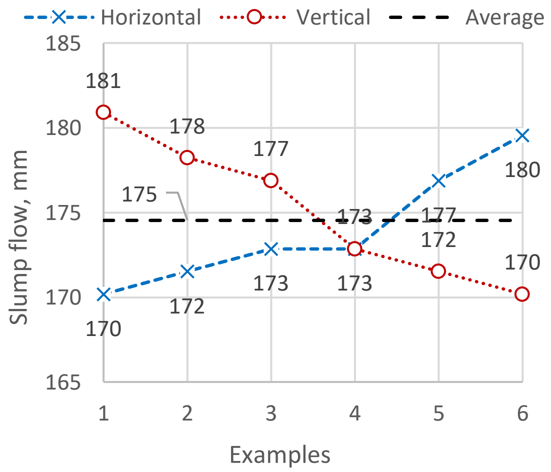

Fig. 13 Slump Flow Test Outcomes for Various Additive Concentrations: – Mix (0.6)

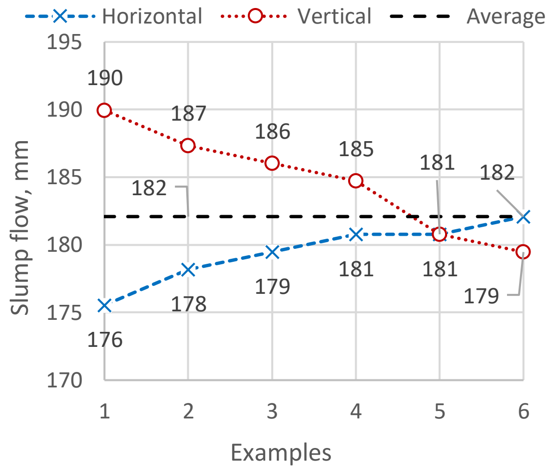

Fig. 14 Slump Flow Test Outcomes for Various Additive Concentrations:– Mix (0.8)

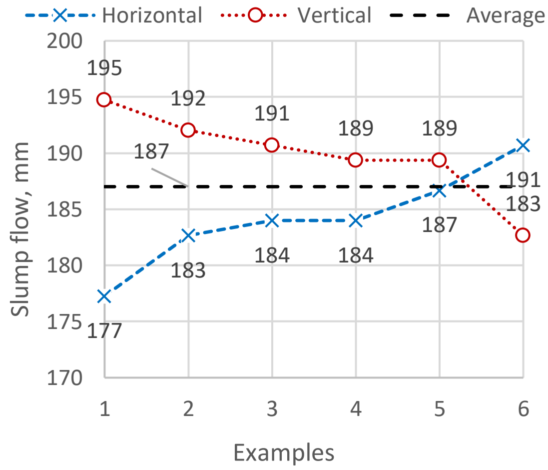

Fig. 15 Slump Flow Test Outcomes for Various Additive Concentrations: Mix (1.0)

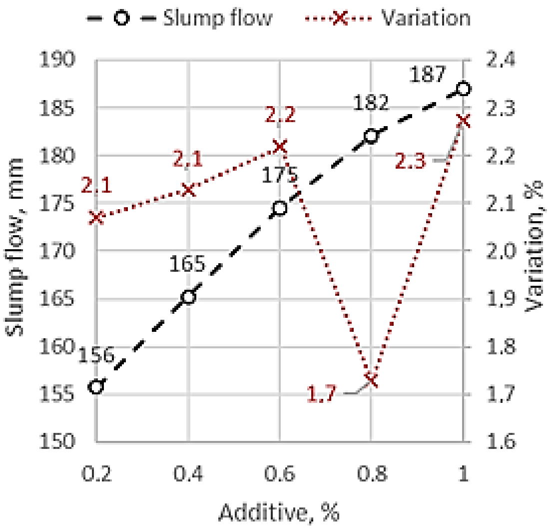

Fig. 16 Slump Flow Test Outcomes for Various Additive Concentrations: Resultant diagrams

5. SETTING TIME RESULTS

The results of setting time tests presents in Figure 18-21.

Figure 21 displays the data points and average initial setting times for the different compositions. Figure 20 shows the average final setting times. Figure 21 illustrates the duration of the setting process. Figure 4D highlights the dynamics of setting time changes as a function of additive concentration.

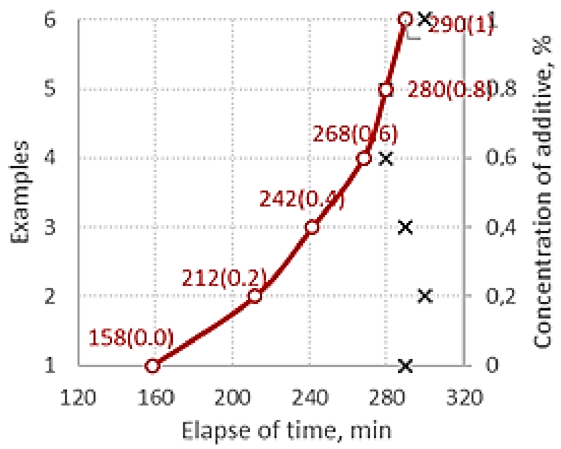

Fig.18 Setting Time Measurement Results. The beginning of setting

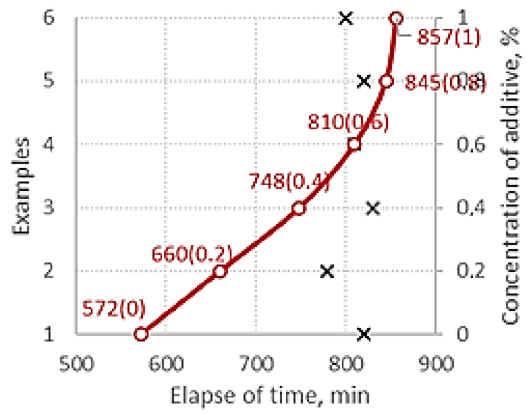

Fig.19 Setting Time Measurement Results. End of the setting

The detailed analysis of these results demonstrates the influence of the modified additive on the setting times, providing critical insights into its performance and applicability for injection grouts in various scenarios. The results indicate that the minimum average initial setting time was observed in the reference sample, with an average value of 158 minutes. The individual data points ranged from 150 to 170 minutes, with a coefficient of variation of 4.8%. The maximum average initial setting time was found in samples with the highest concentration of the modified additive (1.0%), with an average value of 290 minutes. The data points for these samples ranged from 280 to 300 minutes, with a coefficient of variation of 3.1%.

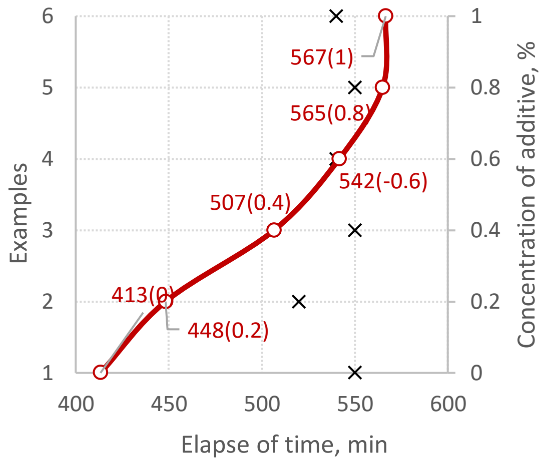

Fig.20 Setting Time Measurement Results. Duration of the setting time

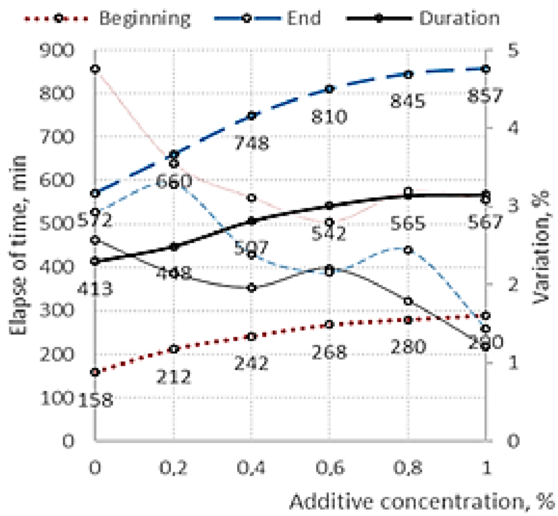

Fig.21 Setting Time Measurement Results. Resulting values

A similar trend was observed for the final setting times: The minimum average final setting time for the reference sample was 572 minutes, with data points ranging from 550 to 590 minutes and a coefficient of variation of 2.6%.

The maximum average final setting time was recorded for samples with 1.0% additive concentration, averaging 857 minutes, with data points between 830 and 890 minutes and a coefficient of variation of 1.2%. All data points showed high consistency and strong correlation, as indicated by the relatively low coefficients of variation, which did not exceed 5% in any test series. Additionally, an increase in additive concentration was associated with a reduction in the coefficients of variation, suggesting improved stability in the setting times due to the plasticizing effect of the additive.

Figure 22-23 provides a visual representation of the additive's influence compared to the reference sample: Figure 22 shows the absolute increments in setting times as a function of additive concentration. Figure 23 illustrates the percentage increase in setting times relative to the reference sample.

These results highlight the additive's significant impact on extending the setting times, with the effect becoming more pronounced at higher concentrations. The findings underline the potential of the additive to enhance grout performance, particularly in applications requiring extended workability and setting times.

The diagrams in Figure 23 reveal a nonlinear increase in setting times with the additive concentration. The underlying cause of the observed non-linearity can be attributed to the exhaustion of the plasticizing effect of the paraffin-containing component as a surfactant. This occurs when the surfactant reaches or approaches its limit of solubility, at which point the addition of further surfactant ceases to have a plasticizing effect. It is important to note that as the concentration of the additive increases, the plasticizing effect concomitantly rises.

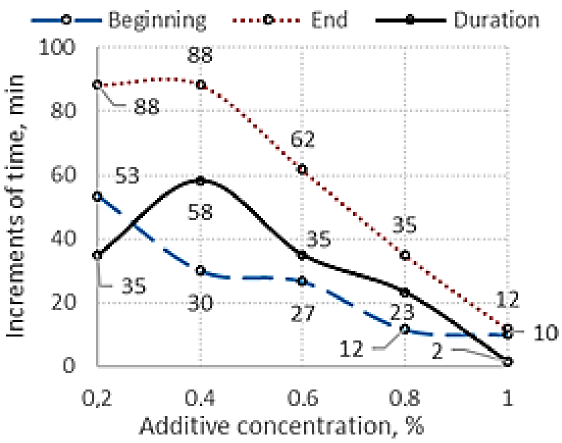

Fig. 22 Influence of Additive on Setting Time: Diagrammatic Representation. Duration of setting

Consequently, this results in a decrease in surface tension, which in turn leads to an increase in setting time. While the additive maintains its influence, its effectiveness diminishes significantly with each subsequent increment. For instance, at an additive concentration of 0.2%, the initial setting time increases by 88 minutes, whereas at 1.0%, the increase is only 12 minutes. Similarly, for the final setting time, the increment at 1.0% additive concentration is merely 2 minutes.

The maximum efficiency of the additive is observed in its influence on the initial setting time. Although its effect relative to the reference sample decreases with higher concentrations, it remains noticeable. In contrast, the final setting time shows no significant changes with additive concentrations exceeding 0.8%. At these levels, further increases in concentration do not impact this parameter.

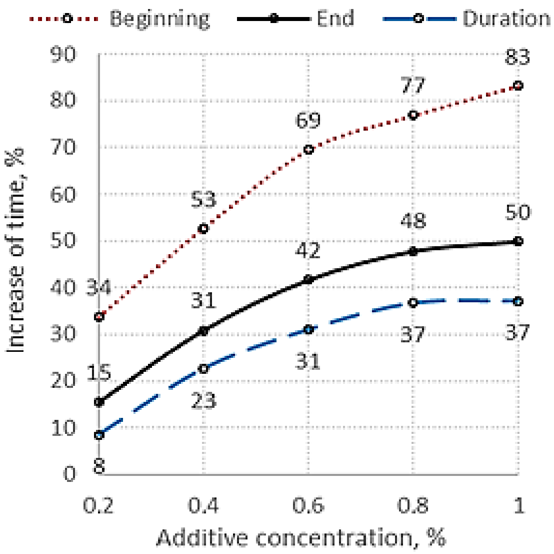

Fig. 23 Influence of Additive on Setting Time: Diagrammatic Representation. Coefficients of variation

This plateau effect is reflected in the duration of the setting process, where the values for 0.8% and 1.0% additive concentrations are almost identical—565 and 567 minutes, respectively. This indicates that the additive has reached its maximum potential to extend setting times at these concentrations.

Based on these findings, the optimal concentration of the additive in terms of its influence on setting times is 0.8%. However, a concentration range between 0.4% and 1.0% could also be considered optimal, depending on the behavior of other physical and mechanical properties of the mixture in subsequent studies. This flexibility allows for adjustments based on specific application requirements and performance criteria.

The research results obtained in this study are consistent with those from earlier studies [12], which found that the addition of surfactant to concrete increases its mobility by 7% and its strength by 78%. In another study [13], analogous outcomes were observed for the impact of surfactant, as represented by the multifunctional cleaning agent "L.O. C.," on the performance characteristics of concrete. The incorporation of 1% of "L.O. C." by weight of cement led to a 28% increase in both plasticity and strength.

6. CONCLUSIONS

The study evaluated the effects of varying additive concentrations on the workability and setting behavior of injection mortars, using a water-to-cement ratio (WCR) of 0.5. The slump flow test results confirm that the target workability—defined as a cone spread diameter of 150 mm—is closely achieved at this WCR, with actual values ranging from 146 to 149 mm. This indicates that the chosen WCR provides sufficient baseline fluidity for further experimentation with additive concentrations.

Subsequent tests conducted at a constant WCR of 0.5 revealed a clear, nearly linear relationship between additive concentration and slump flow values. As the additive dosage increased, so did the spread diameter, reaching its maximum at 1.0% concentration. However, this increase was not directly proportional. The rate of improvement in slump flow diminished at higher concentrations, suggesting diminishing returns beyond a certain point. From a practical standpoint, an additive concentration between 0.6% and 0.8% offers an optimal balance between improved workability and material efficiency. This range ensures enhanced flowability without the need for excessive additive use, which could have cost, environmental, or performance implications.

In terms of setting behavior, the additive's impact was also measurable across all tested concentrations. The study found that each increase in additive dosage delayed the initial and final setting times, as well as extended the overall setting duration. However, unlike the relatively linear trend observed in slump flow, the influence on setting times was nonlinear. The most significant delays occurred at the lower concentration increments, indicating that the additive's effect on setting time plateaus as its concentration increases. At the maximum tested concentration of 1.0%, the setting duration stabilized, with values of 565 and 567 minutes, suggesting that further increases would yield negligible change.

From these findings, an optimal additive concentration of 0.8% is recommended for achieving the peak influence on setting times. Nevertheless, a broader range of 0.4% to 1.0% may be considered viable depending on other factors such as strength, durability, cost, and environmental impact. This range provides flexibility in designing mixtures tailored to specific site or project requirements.

Future research will extend this investigation by evaluating the mechanical strength of hardened concrete samples containing varying additive dosages. Additional studies will also focus on the long-term performance and durability of these mixtures in field conditions. Environmental assessments will be conducted to determine the ecological footprint of the additive and to ensure the sustainable use of the material in real-world applications. These continued investigations aim to provide comprehensive guidance for the practical use of this additive in injection mortar formulations.

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