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Article

Effect of paraffine wax on the mobility of injection cement mortars

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Abstract. This study investigates the mobility of injection mortar and the influence of a paraffin-based modified additive on its flowability. The research pursues two main objectives: to develop the optimal composition of the additive and to evaluate its effect on mortar mobility at various concentrations. The additive significantly enhances mortar mobility, achieving peak performance at a 0.6% concentration. Further increases beyond 0.6% slightly reduce mobility but maintain an overall positive effect. Additionally, higher concentrations contribute to improved solution stability, as reflected by a reduced coefficient of variation. The additive not only improves the flow characteristics of injection mortar but also ensures its homogeneity and stability. The optimal additive dosage is determined to be within the range of 0.6% to 1.0% by cement weight. The application of digital image analysis in the study demonstrated high measurement accuracy and reproducibility, confirming its suitability for evaluating construction mixtures. The proposed additive shows strong potential for use in construction applications requiring high mortar mobility without compromising structural integrity.
Keywords: modified additive, soil stabilization, cement-sand, paraffin, mechanical properties.

1. Introduction

Injection mortars play a key role in construction and repair works, providing high strength to structures, preventing leaks, and increasing the durability of construction projects [1]. In modern construction, special attention is paid to improving the composition of construction materials to achieve optimal performance characteristics [2]. One of the urgent tasks is to increase the mobility of injection mortars, as it directly affects the quality of casting of structures, their strength, and durability [3]. However, an increase in the mobility of the mixture is often associated with an increase in the water-cement ratio [4], which leads to stratification of the mortar due to removal of active ions by excess water [5], loss of homogeneity [6], and deterioration of strength characteristics [7].

Modern methods of modification of injection mortars include using various chemical additives that change the properties of the mixture [8]. At the same time, there is a demand for additives that not only increase mobility but also provide stability and homogeneity of the mortar [9]. In this regard, using additives based on paraffin components is a promising direction. Such additives have many unique properties, including improving the flowability of the mixture and reducing the probability of its delamination [10], which makes them particularly relevant for use in harsh climatic conditions and with limited resources [11].

A pressing global imperative in the realm of modern construction materials science is to enhance the mobility of injected cement mortars without compromising their strength, homogeneity, and stability. This is of particular significance when working in areas that are difficult to access or in conditions of abrupt climatic changes, where the control of the water-cement ratio at the pouring site is limited or impossible. In conventional methodologies, enhancing mobility is often pursued by increasing the B/C ratio. This approach is frequently accompanied by delamination, washout of active ions, reduction in strength, and diminished water resistance of the mortar.

To address this challenge, a concerted effort has been made in recent years to identify effective modifying additives. A particular focus has been placed on hydrophobizing compounds, with paraffin emulsions (PE) exhibiting particularly promising results. [12] found that PE can form water-repellent films in the capillaries of cement stone, reducing capillary water permeability and increasing corrosion resistance. However, when stearic acid is utilized as an emulsifier within an alkaline cement environment, a series of undesirable outcomes emerge, including dispersion destabilization, coalescence of paraffin globules, an augmentation in porosity, and a deterioration in strength properties.

The subsequent evolution of this approach is elucidated in the studies of [13], who proposed a method for the stabilization of paraffin emulsions through the utilization of acrylic and polycarboxylate plasticizers. These modified paraffin dispersions (MPD) exhibited stability within an alkaline environment, uniform distribution of paraffin within the cement stone structure in the form of mosaic films, and increased frost and water resistance.

The most advanced approach to the problem is posited in the works of [14], in which the utilization of complex additives (CA), including PE, non-ionogenic emulsifiers, and curing gas pedals (urea, calcium nitrate, sodium sulfate) is contemplated. The compositions in question have been demonstrated to produce a synergistic effect, characterized by an increase in cement stone density, an acceleration in strength gain, and an enhancement in resistance to water and salts. The use of urea- and sulfate-containing components yielded particularly favorable results.

Consequently, an analysis of contemporary research, encompassing publications in international journals (MDPI, ScienceDirect, Springer), enables the following conclusions to be drawn:

- Paraffin additives have been shown to promote the formation of hydrophobic films within the cement stone structure.
- Modified paraffin dispersions have demonstrated stability within alkaline environments.
- The incorporation of complex additives with paraffin has been demonstrated to enhance the resistance of cement materials to frost and salt attack.

Nevertheless, a number of significant issues remain to be adequately studied. A paucity of studies exists that systematically analyze the effect of paraffin additives on the mobility and stability of injection solutions at reduced W/C. Secondly, the influence of different dosages on the uniformity of paraffin distribution and homogeneity of the solution is evaluated fragmentarily. Thirdly, the extant works did not employ contemporary methodologies for digital image processing in the context of objective mobility assessment, a factor that has the potential to enhance the accuracy and reproducibility of measurements.

The objective of the present study is to develop a paraffin-modifying additive based on paraffin-cement suspension and to conduct a comprehensive study of its effect on the mobility, stability, and homogeneity of injected cement mortars at different water-cement ratios. The study will utilize digital imaging to analyze the results.

2. Methods

Table 1 below shows the content of the paraffin-based modifying additive (i.e., paraffin-cement suspension, hereinafter – PCS) and the reference mortar (cement-sand) used to mix the modified injection mortar compositions.

Table 1 – Composition of PCS and reference mortar

Component	Content, kg	
	PCS	Reference mortar
Portland cement [15]	1.0	0.5

Paraffin wax [16]	0.2	-
Sulfuric acid [17]	0.1	-
Tape water	1.0	0.3
Sand [18]	-	1.5

The composition of PCS included cement, paraffin wax, sulfuric acid (as a neutralizer), and water. The primary active component was paraffin wax, which was dissolved in the cement mixture to enhance the mobility and stability of the injection mortar. The sulfuric acid was necessary to facilitate the dispersion of hydrophobic paraffin in the aqueous medium via an exothermic neutralization reaction. The composition of reference mortar included cement, sand, and water.

Table 2 below shows the compositions of the injection mortar prepared for the study.

Table 2 – Studied compositions of injection mortar

No.	Content, kg			PCS, % by weight of reference mortar
	Water	Portland cement	Sand	
1*	0.15	0.5	1.5	-
2	0.15	0.5	1.5	0.2
3	0.15	0.5	1.5	0.4
4	0.15	0.5	1.5	0.6
5	0.15	0.5	1.5	0.8
6	0.15	0.5	1.5	1.0

*Reference composition of injection mortar

PCS was added to the reference mortar in varying concentrations from 0.2 to 1.0 % by weight of reference mortar (i.e., 2.15 kg). A total of 6 compositions were prepared, with three samples for each composition (to take an average). Then the water-cement ratio (W/C) of the compositions was modified from 0.3 to 0.6 by adding water in increments of 0.05 kg to each subsequent series.

Mobility testing was carried out for each series by the slump flow test according to [19] with some differences. Thus, to improve measurement precision, a digital image analysis was applied so that the photographs of each sample's spread were taken from a fixed height and angle, and processed in AutoCAD software to determine the spread area in cm² (Figure 1).

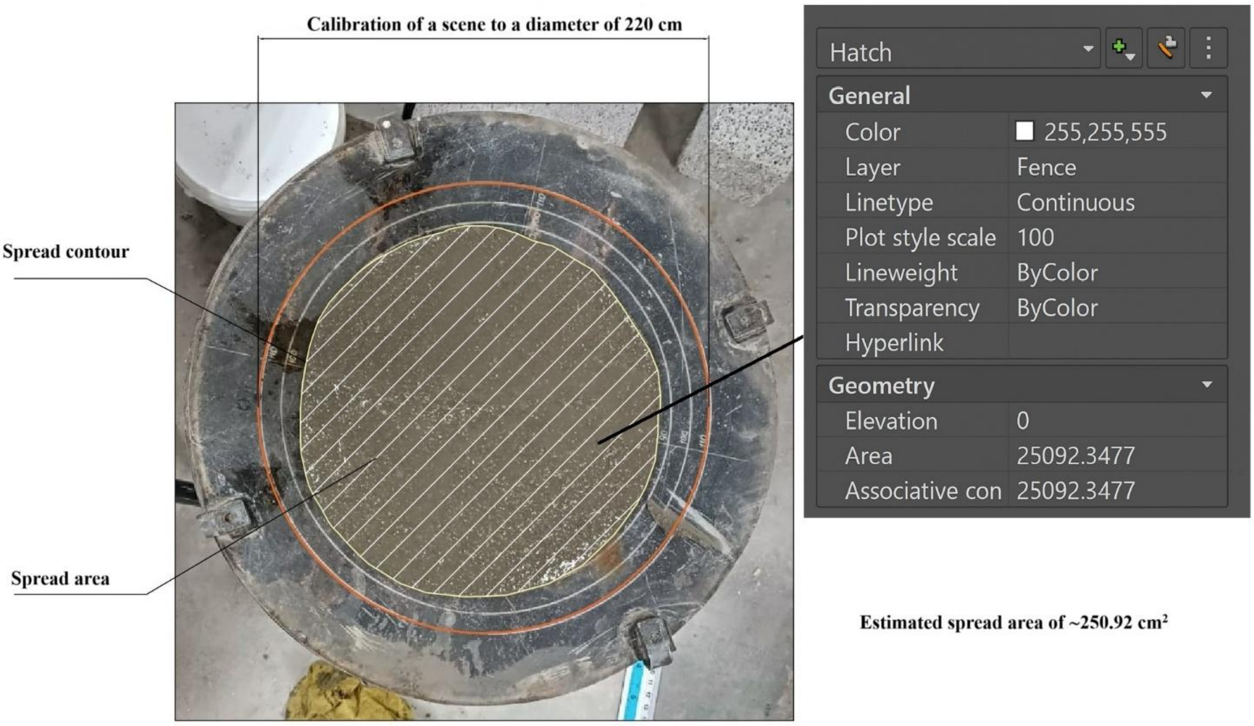

Figure 1 – Slump flow testing procedure

Tests on the viscosity of the injection solution were carried out following the modified method outlined in [19], entitled "Cements." The objective of this study is to determine the most effective methods for determining mobility. The primary approach involves the use of digital image processing to enhance the precision of measurements. The [20] method was utilized as an international analog.

The test equipment included the following: The standard Abrams cone is characterized by specific dimensions: its height is 300 millimeters, its base diameter is 200 millimeters, and its top base diameter is 100 millimeters.

The digital camera was mounted at a fixed height. The software known as AutoCAD has been utilized for the purpose of conducting spreading analysis.

Test Procedure: The mixture was subsequently poured into a cone without undergoing compaction. The cone was elevated in a vertical direction, thereby enabling the mortar to flow unimpeded on a horizontal surface. A photograph was obtained from an elevated vantage point, subsequently digitized in AutoCAD to ascertain the spreading area (in cm²). The mortar samples were measured on three separate occasions, and the mean of these measurements was calculated. The experimental tests were conducted at water-cement ratios ranging from 0.3 to 0.6 and at additive concentrations ranging from 0.2% to 1.0% by weight of the control formulation.

The strength of modified mortars was evaluated by means of a compression method following [21] (or alternatively, [22]). The international analog is the method [23].

Test equipment: The apparatus under consideration is a hydraulic press with a maximum capacity of 2000 kN. The dimensions of the metal mold are 70.7 millimeters in length, width, and height, with each dimension measuring 70.7 millimeters. The vibration table is utilized for the purpose of compacting the specimens during the molding process. The following test procedure was employed: Control cubes were fabricated from each composition. The specimens were maintained under standard conditions (temperature 20 ± 2 °C, humidity not less than 90%) for a period of 28 days. The experimental tests were conducted using a press machine, with the load applied uniformly until the specimen fractured [23].

3. Results and Discussion

Figure 2 below shows the results of the slum flow tests of the sample.

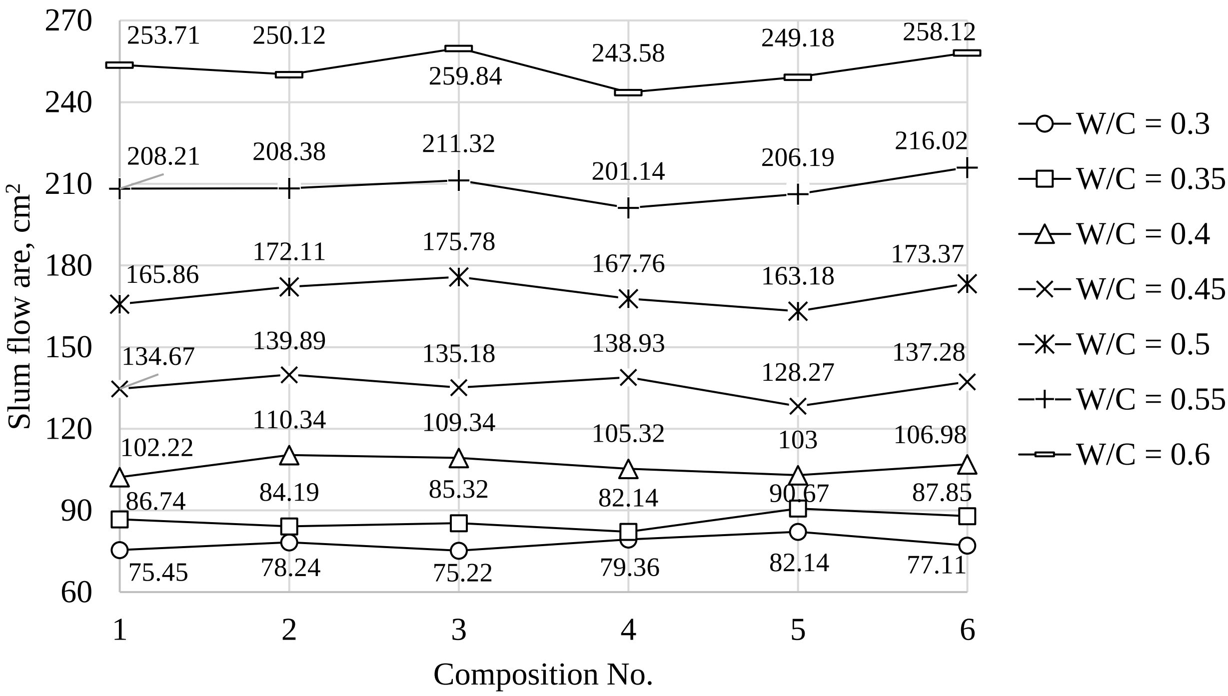

Figure 2 – Slump flow test results

Figure 2 shows the results of injection mortar slump tests as a function of the amount of Paraffin Cement Suspension (PCS) added. It can be seen that as the PCS content increases from 0.2% to 0.6%, there is a sharp increase in the spread area, indicating an improvement in the flowability of the mixture. As the PCS content is further increased up to 0.8-1.0%, the increase in flowability slows down, and at 1.0%, a slight decrease is observed, which may be due to excessive paraffin content increasing the viscosity of the system.

The main trend: the fluidity of the solution increases with the addition of PCS up to the optimum point (0.6%), after which a plateau or slight deterioration of the index is observed. This indicates that there is a critical level of additive above which the performance stabilizes or decreases.

Figure 3 below presents the sum of slump flow values, visually demonstrating the level of mobility stability of the compositions.

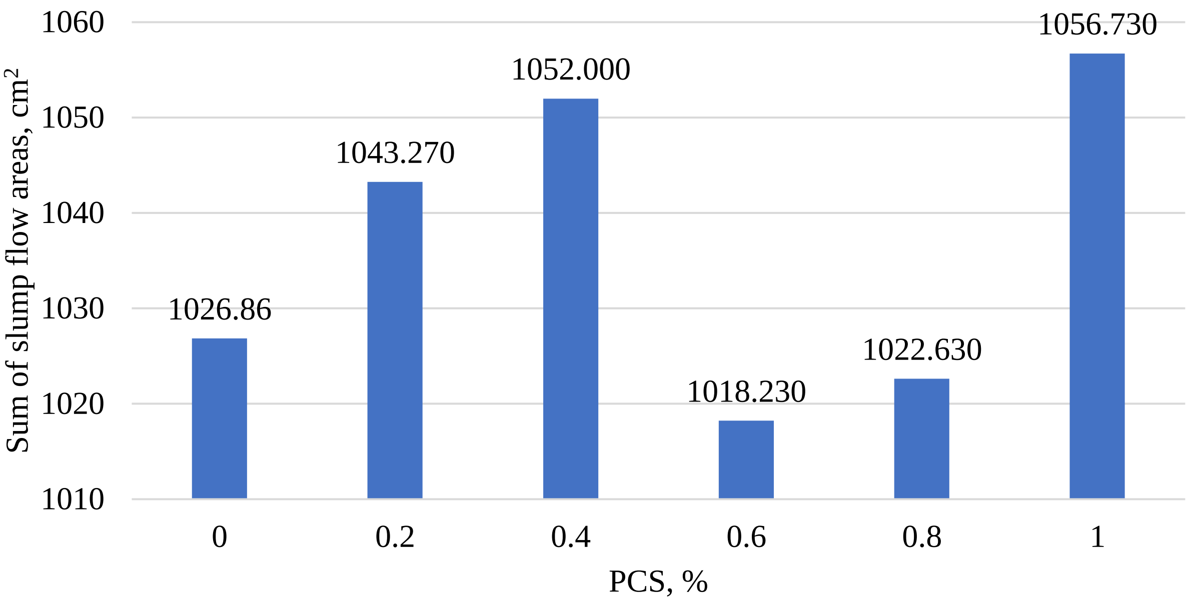

Figure 3 – Mortar mobility stability matrix

Figure 3 shows the mortar mobility stability matrix for different PCS contents and variation of the water-cement ratio. The maximum value of the total spreading area (1057 cm²) is achieved at a PCS content of 1.0%, indicating the highest mobility stability at this concentration. This confirms that higher PCS content helps to reduce the sensitivity of the formulation to changes in water-cement ratio.

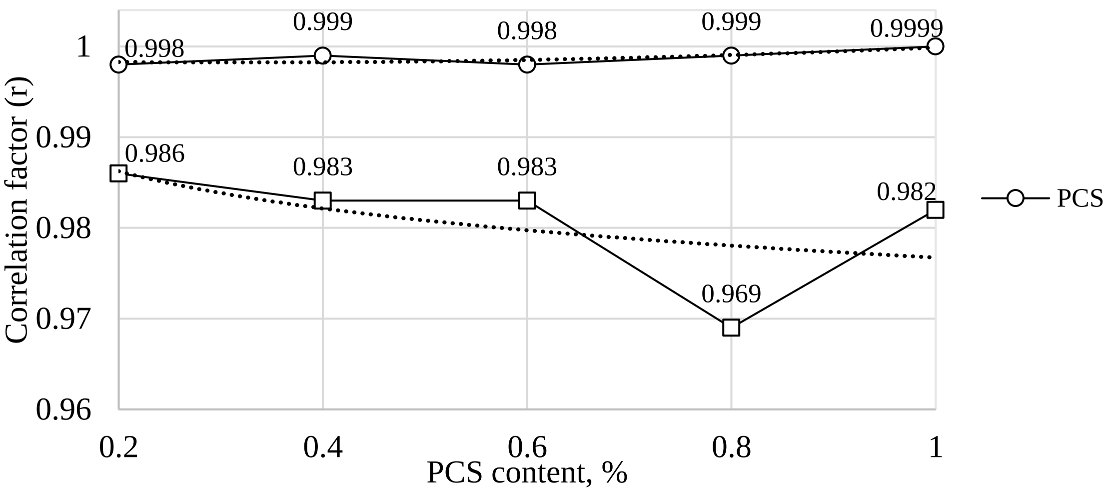

Figure 4 – Correlation analysis

Figure 4 illustrates the correlation between PCS content and the water-cement ratio. A strong positive correlation has been demonstrated between increasing PCS dosage and enhancing mortar flow stability. This phenomenon is attributed to the hydrophobic effect of paraffin, which mitigates the impact of excess water on the dispersed structure of the mortar.

The findings of the present study demonstrate a strong correlation with the results obtained in the study of [12], [13], [14], which demonstrated that modified paraffin emulsions promote the formation of hydrophobic films in the pores of cement stone, thereby increasing its stability and reducing capillary water permeability. In the work of [9], it was also noted that the incorporation of paraffin additives into mortar enhances its resistance to shrinkage deformations. This improvement is directly related to enhanced flowability and distribution uniformity.

[3] and [4] emphasize in their studies that an increase in flowability is possible at higher water-cement ratios. However, this increase is accompanied by a deterioration in strength properties. In contrast, the utilization of PCS in our study attained high flowability at low W/C, a critical aspect for injection mortars in hard-to-reach areas.

4. Conclusions

1) The modified paraffin-based additive presented in the study enhances the mobility of the injection mortar without increasing the water-cement ratio. This results in the maintenance of homogeneity and an increase in the stability of the composition.

2) The extant research has demonstrated that the additive, composed of paraffin-cement suspension (PCS), exerts a favorable influence on the flowability of injected cement mortar. The optimal effect is attained at the PCS dosage of 0.6% of the mass of the control mortar, at which the maximum spreading area and high mobility stability are observed.

3) Increasing the PCS concentration to 1.0% enhances mobility stability with changing water-cement ratios, rendering this additive particularly effective in variable humidity and temperature conditions.

4) The employment of digital image analysis in AutoCAD to estimate the spreading area of the mortar enhanced the precision of the measurements and the reproducibility of the results, thereby substantiating the method's applicability in laboratory settings.

5) A comparison with existing studies confirmed that the modified paraffin emulsions form hydrophobic films that reduce water absorption and increase the durability of cement stone without reducing the strength characteristics.

6) The developed paraffin-based additive is recommended for use in injection works, particularly in hard-to-reach and climatically unstable areas where high mobility and homogeneity are essential without increasing the water-cement ratio.

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Denis Tsygulyov – data collection, visualization, testing.
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