Moisture-retaining film-forming compounds for cement concrete pavements in arid climates

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Abstract. In hot and arid climates, rapid moisture loss from freshly placed cement concrete pavements disrupts hydration, leading to reduced strength and durability. This study evaluates novel film-forming compositions based on secondary industrial resources (GACH-3 and spent mineral oils). The research establishes the physicochemical mechanisms of pore colmatation achieved through the synergistic interaction of paraffin-based components and technical oleic acid. Experimental results demonstrate that the optimized composition increases compressive strength by up to 35.1 % and reduces moisture evaporation twofold. Long-term observations (12 months) confirmed significantly reduced porosity and microcrack sizes.

Keywords: concrete care, composition based on GACH-3, film-forming material, cement-concrete coating, water evaporation.

1. Introduction

In hot and arid climates, rapid moisture loss from fresh cement concrete pavements disrupts hydration, reducing strength and durability. Film-forming curing compounds are used to limit evaporation; however, existing solutions often suffer from low efficiency, high viscosity, or high cost. This study develops and evaluates a novel film-forming composition based on locally available materials to reduce moisture loss and improve the physico-mechanical properties of concrete under severe climatic conditions.

The novelty of this research lies in the utilization of secondary industrial resources – specifically GACH-3 (a petroleum refining by-product) and spent mineral oils - to create a high-performance moisture barrier. Unlike traditional latex-based compounds, the proposed GACH-3-based system is specifically optimized for high thermal radiation (surface temperatures exceeding 50 °C) and low humidity (below 15 %) characteristic of Uzbekistan. By transforming industrial waste into a high-value engineering material, this approach not only ensures pavement reliability but also directly aligns with "circular economy" principles, significantly reducing the carbon footprint and reliance on expensive imported polymers.

2. Material and method

This section describes the development of a novel film-forming composition and the characteristics of the reference materials used for comparative analysis.

2.1. Reference curing compounds

To evaluate the effectiveness of the proposed approach, three existing formulations were analyzed:

– T1: A latex-based compound comprising styrene-butadiene (divinylstyrene) latex, solid hydrocarbons, lanolin production waste, and calcined soda. Experimental evaluation revealed its insufficient efficiency in preventing surface microcracks under extreme plastic shrinkage [10, 13].

– T2: An improved conventional compound incorporating oil dewaxing by-products and plasticizers. Despite better performance, T2 exhibits high viscosity at lower temperatures, complicating field application in spring and autumn.

– T3 (Prototype): A multi-component analogue based on latex and solid paraffin (Patent RU 2455265) [12]. While functional, its high cost and insufficient film-formation speed under arid conditions limit its practical use.

2.2. Development of the optimized GACH-3 based composition

The proposed composition was designed to eliminate the shortcomings of the prototype by utilizing secondary industrial resources. The optimized formulation, designated as Composition 2, is detailed in Table 1.

Table 1. Optimized formulation of the proposed GACH-3 based curing compound

Component	Mass fraction, wt. %
Petroleum GACH (GACH-3)	20.0
Used I-20 mineral oil	2.5
Hydrolyzed polyacrylonitrile (Hypan-0.7)	0.5
Silicon dioxide	1.0
Technical oleic acid	1.0
Water	75.0

The rationale for the selected components is as follows:

– GACH-3: A petroleum refining by-product used as the primary paraffin-based hydrophobic agent. It reduces film formation time and enhances reflectivity.

– Mineral oil I-20: Acts as a solvent to ensure the complete dissolution of GACH-3 and promotes penetration into the concrete matrix. Increasing the concentration above 2.5 % is avoided due to a decrease in the solubility parameter.

– Hypan-0.7: A polymer component introduced to improve the mechanical resistance and elasticity of the protective layer.

– Silicon dioxide: Regulates viscosity and stabilizes the system; contents above 1 % may lead to agglomeration.

– Technical oleic acid: Functions as an emulsifier that promotes pore colmatation and stabilizes the system.

2.3. Physicochemical interaction mechanism

The high moisture-retention capacity of the proposed system is achieved through a synergistic “barrier and seal” effect. The GACH-3 component forms a continuous hydrophobic surface film that physically blocks the evaporation path. Simultaneously, the technical oleic acid interacts with the Ca^{2+} ions in the fresh cement concrete pore solution to form insoluble calcium soaps. These soaps, acting in tandem with silicon dioxide micro-fillers, effectively colmate (seal) the capillary pores. This multi-level barrier ensures that the internal moisture remains available for continuous cement hydration [5, 6] even under extreme thermal radiation [11].

2.4. Preparation and application procedure

The preparation process involves heating the water to 60 °C, followed by the sequential addition of GACH-3, used mineral oil I-20, technical oleic acid, and Hypan-0.7 under continuous stirring. Silicon dioxide is then introduced to adjust the viscosity and stabilize the emulsion. The resulting homogeneous emulsion is applied by spraying at a recommended rate of 300-350 g/m^2 [3, 4, 14]. Film formation begins within 30 minutes and is fully completed within 3 hours at (20±2) °C. The recommended application temperature range for the concrete surface is from +2°C to +45°C. All concrete specimens were cast and tested in accordance with GOST 10180-2012 [1] and GOST 12730.3-2020 [2].

3. Results and discussion

The experimental evaluation of the film-forming properties of the proposed composition was conducted on concrete specimens prepared in accordance with GOST 10180-2012 [1]. To ensure statistical reliability, all tests were performed in triplicate, and the results are presented as the arithmetic mean ± standard deviation (SD), providing a confidence interval of 95 %.

3.1. Optimization of the composition

Initially, six formulations were tested to determine the optimal component ratio. The physical and mechanical properties of the treated specimens are summarized in Table 2.

Table 2. Physical and mechanical properties of concrete specimens treated with various experimental curing formulations.

	Compressive strength, MPa		Water absorption, %		Bending tensile strength, MPa		Amount of evaporated water, %	
	1st layer	2nd layer	1st layer	2nd layer	1st layer	2nd layer	1st layer	2nd layer
Comp. 1	47.9	42.5	10.9	10.8	5.7	5.2	5.0	4.8
Comp. 2	54.7	51.4	10.7	10.6	6.4	6.1	4.3	4.1
Comp. 3	45.7	42.3	11.0	10.9	5.4	5.2	5.5	5.3
Comp. 4	39.8	37.2	11.5	11.3	4.8	4.4	7.9	7.4
Comp. 5	36.1	35.9	11.5	11.2	4.1	3.9	7.9	7.6
Comp. 6	33.4	33.1	11.7	11.2	3.8	3.6	8.5	7.9

Analysis of Table 2 indicates that Composition 2 (20.0 % GACH-3) achieves the highest performance metrics. To address the requirement for experimental analysis, these data were visualized to establish variable correlations.

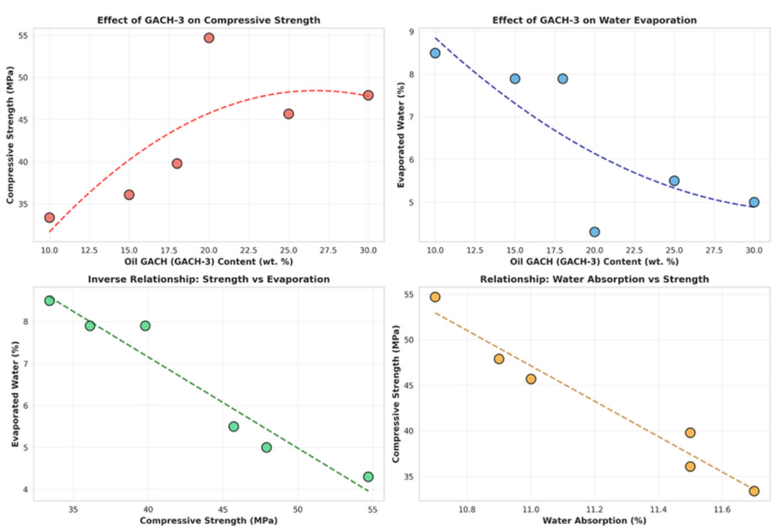

Fig. 1. Correlation analysis between GACH-3 content, compressive strength, and moisture evaporation

As shown in Fig. 1, a parabolic relationship exists between GACH-3 content and compressive strength, with a clear optimum at 20 wt. %. Beyond this point, the increase in hydrophobic components leads to a slowdown in strength gain. The inverse linear correlation between strength and evaporation rates confirms the "barrier and seal" hypothesis: by minimizing moisture loss (4.3 %), the composition ensures the necessary hydration degree for the cement matrix.

3.2. Comparative performance

Based on the optimization, Composition 2 was compared against water curing (control) and the T3 prototype [12].

As demonstrated in Table 3, the proposed composition increased compressive strength by 35.1 % and flexural tensile strength by 72.9 % compared to water-cured samples. Moisture evaporation was reduced twofold relative to the T3 prototype, which was developed based on the existing multi-component technology. This significant improvement is attributed to the physicochemical mechanism described in Section 2.3: the formation of insoluble calcium soaps, which effectively colmates the pores [10, 13].

Table 3. Comparative performance analysis of the optimized composition versus water-cured and T3-protected benchmarks

Indicators	Test results				
	Water	Composition from T3		Proposed composition	
		1st layer	2nd layer	1st layer	2nd layer
Compressive strength, MPa	40.5	43.2	44.8	54.7	51.4
Bending tensile strength, MPa	3.7	4.9	5.0	6.4	6.1
Water absorption, %	14.2	12.6	11.1	10.7	10.6
Amount of evaporated water, %	122.0	87.0	77.0	43.0	41.0

3.3. Long-term durability and microstructure

To assess long-term reliability, specimens were analyzed 12 months after application [14].

The data in Table 4 show that the treatment leads to a significantly denser microstructure [5, 6]. Porosity was reduced to 1.5-2 %, and microcrack sizes were minimized to 1.5-2 μm. These results confirm that early-age moisture conservation promotes a more refined and dense C-S-H gel structure, significantly enhancing durability under arid climatic conditions [11].

Table 4. Long-term microstructural parameters and porosity of concrete specimens 12 months after application of various curing treatments

Indicators	Concrete hardening under various conditions		
	Uncovered	Coated with T3 composition	Covered with the proposed composition
Porosity, %	6.0	3.0	1.5-2
Pore size, μm	80-120	60-90	45-65
Micro-crack width, μm	10-12	7-8	1.5-2

4. Conclusions

The research successfully developed and validated an innovative film-forming composition based on GACH-3 petroleum residue, specifically tailored for cement concrete curing in hot and arid climatic conditions characteristic of the Uzbekistan region. The scientific foundation of this study establishes a synergistic "barrier and seal" mechanism, where the hydrophobic paraffin film is reinforced by pore colmatation through the interaction of technical oleic acid with ions in the fresh concrete matrix.

Experimental evaluations established that Composition 2 is the optimal formulation, effectively reducing moisture evaporation twofold and enhancing compressive strength by 35.1 %

and flexural tensile strength by 72.9 % relative to standard water curing. Comparative analysis with the T3 prototype confirmed the superior engineering efficiency and cost-effectiveness of the proposed GACH-3-based system.

Furthermore, long-term microstructural observations conducted 12 months after application demonstrated a significant refinement of the concrete structure. Porosity was reduced to 1.5-2 %, and microcrack sizes were minimized to 1.5-2 μm, proving that early-age moisture conservation promotes a more refined C-S-H gel structure and ensures enhanced operational durability.

From a sustainability perspective, the utilization of secondary industrial resources such as GACH-3 and spent mineral oils directly supports "circular economy" principles by reducing the carbon footprint and the dependence on expensive imported polymers. Consequently, the developed composition is highly recommended for large-scale practical application in the construction and maintenance of cement concrete road and airfield pavements in regions with severe climatic conditions.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

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