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A novel approach of introducing crystalline protection material and curing agent in fresh concrete for enhancing hydrophobicity

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HIGHLIGHTS

- Enhance the performance of concrete under harsh curing conditions.
- Treating fresh concrete with crystallising material and curing agents.
- Tests include water absorption, compressive strength, and microscopic analysis.
- Crystallising material followed by wax-based curing agent improved the strength.
- Applying liquid curing agent with a high w/c ratio increased internal cracks.

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ABSTRACT

A new line of research to enhance the performance of concrete under adverse (harsh) and normal (air cured) curing conditions is presented. A crystallising hydrophobic admixture and curing agents were added to fresh concrete to improve its resistance against severe environmental conditions. A two-stage approach was pursued by adding the crystallising admixture to fresh concrete followed by curing agents, in a wax and liquid forms, in a separate application process, followed by exposing concrete to normal and adverse curing conditions. Results obtained suggests that protecting concrete with the crystallising admixture followed by applying wax based curing agent improves concrete strength and its resistance to water ingress than concrete cured with the liquid curing agent. When following the crystallising-wax treating system under adverse curing conditions, a more conserved strength was noticed compared to that produced by the crystallising-liquid system. Using the liquid curing agent in concrete with high water to cement ratio (w/c) has increased the cracks in the internal structure, while water permeability has decreased, either under normal curing conditions or adverse conditions. Following this protection-curing system in industry would resolve the problem of applying protection on wet surfaces and increase concrete's resistance to deterioration. A microscopic study of the crystallising material was attained with a Scanning Electron Microscope (SEM) to check crystal growth with time.

1. Introduction

In the UK, there are more than 61,000 highways and bridges constructed in reinforcement concrete [1–3]. Although these structures were designed and built to withstand deterioration, they have proven to demand substantial repair and maintenance, mostly because climatic conditions and winter salting [4,5]. The presence of excess moisture in the concrete leads to winter cycles of freezing and thawing that cause severe damage [5].

In recent years, there has been much research on protecting and waterproofing concrete by hydrophobic impregnant materials [6,7]. Silanes and siloxanes materials were the most widespread option for protecting concrete and its reinforcement, as they act sufficiently in reducing water ingress and harmful chemicals carried by water [7–10]. However, the performance of silane and siloxane impregnants has been brought into question [10]. The inadequate performance of these commonly applied, high-build waterproofing systems on bridge decks, and their failure to effectively protect concrete drove researchers to look for some alternative treatments [2]. Adding to that, solvent-based forms of these materials, which have a high level of organic solvents, have a negative effect on the environment and are subjected to restrictions [7,11]. Furthermore, research with these materials indicates that

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adequate dosage and good penetration in concrete requires unrealistically low moisture content when they are applied to concrete [7]. This refers to pores occupied by water at time of application; when pores are saturated, the penetration of such materials would be difficult due to repellency and lack of available place. Finally, the existence of excess moisture in concrete at the time of applying these materials reduces their performance and efficiency against chloride penetration. Accordingly, alternative hydrophobic materials, that comply with the British Standard BS EN 1504-2 [12], were brought to light to cover the disadvantages of silane and siloxane solvent-based materials. In contrast, water-based materials and others with crystallising mineral components are aimed to function well in the presence of high moisture content in concrete.

Limited researches are available of Crystallising materials. Cementitious crystallising coatings were applied to concrete structures, which are in a direct contact with water like swimming pools and water tanks, in order to protect them from water ingress [13]. This type of coating materials has significantly improved concrete resistance to absorb water, in addition to its innocuous effect on the quality of water. Reiterman and Pazderka [14] tested the efficacy of another type of crystallising coatings, in terms of water absorption and its ability to protect concrete at a thorough depth. They were successful in reducing the absorbed amount of water at depths between 180 and 190 mm from the surface compared to untreated concrete. In a following research, Pazderka and Hajkova [15] studied the effect of adding a crystallising admixture to concrete, at the mixing stage, on reducing its water permeability. Results showed an early interaction between concrete and the added material, where a full waterproofing effect was reached after 12 days of casting. The only dilemma in this kind of admixtures is its negative effect on the compressive strength of concrete which was observed, on a small-scale and negligible level, in the aforementioned research.

In this study, a crystallisation hydrophobic material was applied to fresh concrete, followed by the application of a permanent curing compound. The efficiency of this novel blend is tested in terms of strength and permeability under adverse (harsh) curing regimes. Interest in water activated materials, such as crystallising solutions, acknowledges the improbable occurrence of those ideal low-moisture conditions that favor the established hydrophobic treatments.

The main approach followed by the authors is to protect and extend the service life of concrete by the application of a crystallising hydrophobic solution to the fresh concrete, followed by a curing compound. The hypothesis is that treating concrete with these materials will increase resistance against cracking whilst maintaining strength by controlling excessive hydration during the curing process. Hydrophobic treatments were considered, earlier, by researchers to provide additional protection to reinforcement embedded within concrete from aggressive materials, especially for concrete with high permeability [8,16].

With regard to curing processes and materials, many curing methods and compounds are available and applied in industry to promote hydration and provide protection to concrete [17]. These compounds function as temporary or permanent protection compounds depending on the nature of materials used to produce them. So called permanent curing agents are intended to deliver long duration protection. The influence of these different curing compounds and techniques has been always under study to reduce the negative effect of adverse curing conditions on concrete, as they restrain water movement through concrete pores during its early life [18,19]. Nevertheless, results regarding their effect on concrete properties under adverse conditions are not always beneficial [19].

This paper investigates the early application of a crystallising material followed by a curing compound on fresh concrete and their influence on its properties under adverse curing conditions. It is an extension of an earlier study conducted by the authors [3] to assess the influence of adverse and normal curing conditions on the performance of the same protective material used here with a wax-based curing agent. The wax-based curing agent is formed from a stable mix of different types of waxes in water.

The objectives of this research are:

1) To determine the influence of a successive application of a crystallising protection material followed by a water-based curing compound to fresh concrete, in terms of strength, water absorption, and permeability, when subjected to favorable (normal) and adverse (harsh) curing regimes. The adverse curing consisted of constant high speed air circulation on the specimens to accelerate hydration process.
2) To study the effect of applying the protection-curing combination on concrete in respect of potential crack's formation.
3) To assess the performance of the protection material and relate its performance to previous research, but with different associated variables; different curing agent and water to cement ratio.

Early application of protection materials to fresh concrete in the presence of a high moisture content has been under investigation by the authors, with promising results [2,3]. Results from a previous study [3] are be used to compare outcomes.

2. Experimental work

2.1. Specimen manufacture

C40 concrete was chosen for this study because this type of concrete is generally used for pavement construction and in other structural applications [2,20]. The design mix, as shown in Table 1, was made in agreement with the British Standard BS 1881-125 [21]. A w/c ratio of 0.48 was used which was marginally higher than the previous studies [2,3]. The high-water cement ratio resulted in a slump 65 mm, but no segregation was noted in the compacted specimens.

2.2. Surface applied protection material

The protective material used in this research is a patented material, KLD-1 is an aqueous crystallising waterproofing material applied to concrete with an amount of 2% of cement mass, followed by a wax-based and water-based curing agent. Both materials conform to BS EN 1504-2 [12], and have been tested under the first objective to assess their performance against water absorption. KLD-1 as a dual functioning system works to absorb water to form crystals that reduce moisture movement by closing concrete capillaries, and then form another type of crystals that repel excess water and prevent its penetration through concrete pores.

Table 1
Adopted mixture proportions.

Component	Quantity (kg/m^3)
Cement (CEM II/32.5 N; Sulphates < 3.5%, Chlorides < 0.10%, and initial setting time around 1.25 h)	480
Water	230
Fine aggregate	650
Coarse aggregate	1040
Total	2400
Water/Cement ratio	0.48