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Application of crystallising hydrophobic mineral and curing agent to fresh concrete

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HIGHLIGHTS

- Novel method to optimise concrete hydration by crystallising hydrophobic treatment at curing stage.
- Combination of crystallising hydrophobic and curing agent treatments provided the highest strength preservation.
- Combined treatment is effective in preventing increased permeability despite adverse curing.
- Combined treatments safeguard the strength and permeability against the negative effects of substandard curing.

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ABSTRACT

Whilst the use of curing agents is common practice in the production of reinforced concrete, it is not normal to apply protective treatments to freshly cast concrete. Such treatments, which are generally hydrophobic in nature, are commonly applied to matured concrete, as protection against chloride and water absorption and associated cyclic freeze thaw attack. One gateway issue in respect to the application of such surface treatments to fresh concrete, is its unavoidably high moisture content, which is known to substantially downgrade the effectiveness of silane and siloxane hydrophobic treatments. The possibility of protectively treating fresh concrete is interesting from the logistic and economic standpoints, in the matter of early completion of on-site works. Towards this advantageous position, it is interesting to observe that early surface treatment with a crystallising hydrophobic mineral solution, immediately followed by a curing agent application, safeguards the 28 day strength of concrete in an extremely adverse curing environment. Added to this, the treated concrete sorptivity values with protected curing and the adverse curing regime, are similar, indicating that concrete durability may also be protected by the combined surface treatment, applied as early as 3 h following casting.

1. Introduction

The UK has more than 61,000 highway and local road bridges, the vast majority of which are constructed in reinforced concrete, demanding an annual maintenance expenditure in excess of £4bn in 2012–2013, for example [1]. Structures in many UK regions suffer recurring adverse weather conditions, with instances of the highest recorded use of winter de-icing salts in Europe [2]. The UK also has one of the highest annual rainfalls in Europe, recorded at 1120 cm in 2014 [3]. To make matters worse, the correspondence between zones with overlapping wet and freezing conditions is strong, the West Highlands of Scotland being one example. Furthermore, predictions for towards the end of the 21st century, indicate that increasingly adverse weather will become more frequent and wider spread [4].

Whilst the need for effective concrete protection is of growing importance, there is, in parallel, increasing probability of high moisture content existing at the time of protective treatment application. Unfortunately, even modest increases in concrete moisture content above laboratory testing requirements, substantially downgrades the performance of silane and siloxane treatments against chloride penetration [5]. For this reason, the main driver in the ongoing research is 'alternative protective treatment materials', ones that are application moisture tolerate (AMT). In this reported investigation, Patented [6] crystallising hydrophobic

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mineral technology is employed that uses moisture in its curing process and, in this sense it is AMT, significantly contrasting with the dry conditions specified for other material treatments. A further characteristic of this crystallisation material, is its extremely low toxicity [7]. Contrastingly, a substantially water diluted silane has been proved to be toxic in nature [8].

In this reported investigation, the crystallisation treatment has been applied to fresh concrete, this directly followed by the application of a non-permanent curing compound. The performance of this innovative combination is tested by comparing the 28 day strength and permeability outcomes for concrete subjected to normal or adverse curing conditions.

2. Background

Two well established strategies for safeguarding the 'whole life' strength and durability of structural concrete are the application of a curing agent to fresh concrete, and a hydrophobic pore lining material to mature concrete. The main purpose of the former is to prevent loss of hydration water during concrete curing, thus avoiding associated effects such as surface shrinkage, cracking and reduced strength. Since 1986, in the UK [9], the latter has been applied with the intention of controlling moisture movement and ingress of chloride ions that cause active corrosion of steel reinforcement. In this reported study, early application of a combination of hydrophobic impregnation followed by a curing agent is investigated.

Under laboratory test conditions for 28 day concrete, hydrophobic impregnation materials of different chemistry have been found to comply with EN1504-2, the European Standard addressing concrete protection measures [10]. The prescriptive testing for this compliance, incorporates the test method defined in Appendix 2 of UK Highway Agency's Design Manual for Road and Bridges [11]. Whilst this design manual points to high purity monomeric alkyl (isobutyl)–trialkoxy silane as a suitable hydrophobic material for concrete impregnation, it recognises the possibility of complaint alternatives. To date, such alternatives include siloxanes, aqueous silanes and siloxanes, silane emulsions and creams and crystallising solutions, all held complaint with EN1504-2. However, investigations show that achievable dosage, penetration and resistance to chloride ion penetration with silane and siloxane derived treatments, depend on the existence of low moisture content at their application time [12]. Of the complaint material types, only crystallisation materials are intended to work with the concrete moisture content.

A range of curing material and methods are applied in structural concrete production including membrane curing compounds, self-curing and accelerating concrete mix additives, concrete wrapping and waterproofing compounds [13]. In terms of chemistry, curing materials include silicate solutions, polyurethanes, acrylic polymer coatings, film forming polymetric compounds, durable resins, low viscosity acrylic solutions, emulsions, aqueous biodegradables and liquid waxes. Depending on the material type, these work on a permanent or temporary basis, the former intended to provide long term protection. To the best knowledge of the authors, there is no curing agent for which compliance with EN1504-2 is claimed.

3. Objective

The objective of this investigation is to determine the effect that a combination of a crystallising hydrophobic mineral and wax based curing agent, applied sequentially to fresh concrete, have on its 28 day strength and permeability, under normal and adverse curing conditions.

4. Investigation method

4.1. Concrete mix design

For the purposes the investigation, C40 Concrete used, this was designed in accordance with BS EN 206-1/BS 8500 [14] for a characteristics strength of 40 MPa (5801 psi) at 28 days, with water to cement ratio of 0.45 and slump value, according BS EN 12350-2 [15] in the 30–60 mm (1.18–2.36 ins) range. A number of trial mixes were investigated for this, with the adopted mix proportions given in Table 1.

A control mix was prepared according to the constituent proportions given in Table 1, for which compressive strength testing outcomes for 3 days, 7 days and 28 days are given in Table 2. The slump value was 49 mm.

4.2. Surface treatments

Both the crystallising hydrophobic and the following wax based curing agent, were brush applied, uniformly to all cube faces, according to the manufacturer's specified dosages. The crystallisation material uses moisture to from tightly adhering hydrophobic mineral crystals within the pores of the concrete, thus combating absorption of water and chlorides, which lead to corrosion of the embedded reinforcement. A wax based, bio-degradable curing agent was employed. The chemical formulation is not currently available for publication.

To determine the influence of the crystallisation and curing agent on strength and permeability, cases were run for concrete with separate and combined surface treatments, each with its own untreated controls. Table 3 gives the treatment schedule for both the normal and adverse curing regime cases. In the cases where the curing agent was applied, this was removed immediately prior to permeability testing.

4.3. Treatment age

Wishing to apply the surface treatments as early as possible to the fresh concrete, it was decided to monitor the internal moisture content of the concrete, commencing from the time of mould filling. The intention of this is to determine approximately at what time the water demand for the hydration process commenced in the central region of the concrete ie the concrete mix passing from plastic to solid state. Whilst the surface would predictably reach this stage earlier, we did not wish to disturb the still solidifying interior, possibly weakening the concrete overall.

An electrical resistance method [16] was used to monitor the moisture environment within the curing concrete, with discreet moisture detection sensors located at the centre, half depth and surface of the cube (see Fig. 1). Fig. 2 plots typical data sets for a 100 mm (4″) cube, this indicating distinct separation between commencement of moisture reduction at the surface and internal locations, the former at approximately 28 min and the latter 27 min after casting. From the same graph, it is also apparent throughout the full depth, that the initially fast reduction in

Table 1
Adopted concrete mix design.

Ingredient	kg/m^3 (lb/ft^3)
Cement (42.5 N)	457 (28.5)
Water	210 (13.1)
Fine aggregate	660 (41.2)
Course aggregate	1073 (67.0)
Total	2400 (149.8)