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Performance evaluation of curing compounds using durability parameters

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HIGHLIGHTS

- Effectiveness of five curing compounds at 25 °C and 45 °C was evaluated using three durability index tests and compressive strength test.
- Durability parameters were found to be more sensitive than compressive strength.
- Oxygen permeability index (OPI) test showed most consistent results.

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ABSTRACT

With the world facing a huge shortage of water and labourer, the use of curing compounds in place of conventional and prolonged wet curing is inevitable. However, hot weather conditions and the quality control issues in many countries necessitate diligence in the selection of curing compounds. However, the ASTM C156 standard (water loss test) – the only standard method available – exhibits large variability in results and cannot be used to reliably assess the effectiveness and qualify curing compounds. Also, the compressive strength test is not sensitive enough to assess the quality of curing compounds. Given this scenario, there is a need for an alternate test method to assess the effectiveness of curing compounds. This paper presents an experimental investigation on the suitability of tests on various durability parameters to assess the effectiveness of curing compounds. The oxygen permeability index (OPI), water sorptivity index (WSI), non-steady-state migration coefficient for chloride penetration (D_{nssm}), total porosity, and compressive strength were used as test parameters. These parameters of mortar specimens prepared using Ordinary Portland Cement and cured using wet curing, air drying, and five curing compounds were evaluated. The mortar specimens were kept in the following two controlled environments: (i) mild (25 °C, 65% RH) and (ii) hot (45 °C, 55% RH). The study found that the OPI, WSI, and D_{nssm} are suitable and more sensitive than the compressive strength in assessing the effectiveness of curing compounds. Amongst these three, OPI test showed more consistent results and can be recommended as a test for qualifying curing compounds.

1. Introduction

Curing compounds are membrane-forming chemicals that help in preventing the loss of water from the surface of concrete and thus, facilitate curing of concrete during the early stages of the hydration process [1]. The use of curing compounds not only eliminates the need for additional potable water and frequent supervision for the entire period of curing but also provides a viable solution where the conventional wet curing methods become impractical. Some of the examples are high-rise buildings, tunnel linings, and large pavement slabs. However, despite their relevance in the fast-paced construction industry of present times, which is struggling to meet its water requirements, there have been very limited attempts to investigate performance of curing compounds and the factors affecting it.

ASTM C156 provides a water loss test for the qualification of curing compounds [2]. Although ASTM C156 appears to be a fairly simple test, it has met with acute criticism worldwide because of its extremely low precision. ASTM C156 itself has reported a single-operator standard deviation of 0.13 kg/m^2 and a multi-laboratory standard deviation of 0.30 kg/m^2. Considering the limit of 0.55 kg/m^2 on water loss prescribed by ASTM C309 [3], these standard deviation values would reach to a minimum of 24 and 55% respectively. With this level of precision, it would be impossible to decide whether to pass or fail a particular curing compound

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let alone differentiating between the performances of different curing compounds [4].

Conventionally, the influence of curing on the quality of concrete in the field has been evaluated by its effect on the compressive strength of concrete and have also been studied well [5–10]. However, it has been observed that the properties of the cover concrete or the near-surface concrete can vary substantially from those of the interior concrete. These variations in the properties of concrete can extend to more than 40 mm beneath the surface, out of which the outer 20 mm exhibits the major variations [11]. These variations can result from the segregation of concrete as a result of bleeding, over working of the concrete by excessive consolidation/finishing, and the loss of water due to poor curing practices. It was observed in the studies on cement paste and mortar that drying due to poor curing practices can adversely affect the porosity, diffusivity, and water sorptivity up to a depth of 50 mm [12,13].

As the effect of curing extends only to the near-surface region, the use of a bulk property such as compressive strength appears to be an ineffective way of evaluating the curing efficiency. In fact, Fattuhi, in a study on 16 different curing compounds, found that although the water retention efficiencies of curing compounds with respect to air-dried specimens varied widely between 25% and 89%, the resultant 28-day compressive strength for all the cases were above 80% of that of the water cured specimens [14]. This practice also results in the underestimation of the role that curing plays in enhancing the durability of RC structures. Also, transport parameters have been observed to yield much better sensitivity to the effects of curing than compressive and flexural strength [15–17]. These parameters include air permeability, water sorptivity, resistance to carbonation, and chloride permeability.

Studies have shown the benefits of adopting wet curing during the early age on the durability of concrete. Seven days of wet curing has been observed to reduce the water absorption of concrete exposed to harsh environment for 360 days by 22% [18]. Through a study on Ground Granulated Blast Furnace Slag (GGBFS) concrete cured in simulated arid climate, Austin et al. have shown that the lack of wet curing could significantly increase the air permeability and water sorptivity [19]. Similarly, the water sorptivity of fly ash concretes has been observed to demonstrate greater sensitivity to deficient curing in arid climates than that of Ordinary Portland Cement (OPC) concretes [15,20]. Zhang et al. reported that the influence of curing on the chloride resistance of OPC concretes increases with increase in the water-to-cement ratio [21]. The findings of a limited number of studies on curing compounds generally highlight their inferior performance in comparison to wet curing and in some cases, marginal or even no improvement over air curing [17,19,21,22]. However, their potential in reducing the differences between the transport properties of near-surface concrete and the interior concrete has also been realized [23,24]. Curing compounds also help in mitigating plastic and drying shrinkage, although wide variations exist in the performance [25,26].

Tests on transport properties, also commonly referred to as durability tests, can serve as a rational and effective approach to characterize curing methods. However, the lack of standardization and the use of different test methods across the world render it very difficult to conclusively assess the sensitivity of these tests to curing from the existing literature. Moreover, contradictions between the results of different test methods have also been observed [27,28]. For instance, Tan and Gjorv concluded that elevated temperatures reduced the chloride resistance of concrete; however, the resistance to water penetration showed no corresponding variation with temperature [27]. In general, water sorptivity appears to be the most widely used parameter for evaluating curing efficiencies and has been observed to demonstrate great sensitivity to curing [23,29]. However, instance where surface tests such as water sorptivity, air permeability, pull-off strength, and accelerated carbonation test showed limited sensitivity to curing has also been reported [28]. Taking into account the above mentioned gaps and contradictions present in the existing literature, this study focuses on the following two objectives: (1) to evaluate and compare the performance of curing compounds (CC) with respect to conventional curing methods in different exposure conditions, and (2) to investigate the suitability of durability index (DI) tests as a screening test in evaluating the effectiveness of curing methods. The primary intention of the paper is to investigate and propose the possibility of durability index test as a screening test for curing compounds and not to investigate the chemical actions of various curing compounds. Mortar is used in this study instead of concrete because the use of concrete could complicate the analysis by the variability introduced by the use of coarse aggregates. The use of mortar facilitates more sensitivity and easier assessment of curing efficiencies of curing compounds. This is important for producing reproducible results across different laboratories and eventual standardization. This may be the reason why the ASTM C156 also suggests using mortar (instead of concrete). However, to evaluate the actual impact of a curing method on the properties of a specific concrete at site, it is imperative to conduct tests on that specific concrete and is a subject of further study.

2. Experimental procedure

2.1. Materials

Cement mortar was used in this study with a cement-to-sand ratio of 1:2.75 and a water-to-cement ratio of 0.5. A water-to-cement ratio of 0.5 was chosen to avoid self-desiccation in cement paste. It is well known that a w/c of 0.42 to 0.44 is needed for complete hydration of cement [30]. A w/c less than that can lead to self desiccation of cement paste. In such case, the use of wet curing would provide external water to the cement and help in cement hydration over and above what could be possible with the mixed water. This gives an undue advantage to wet curing when the curing efficiencies are evaluated over other methods where no such additional water is involved. To avoid such biased comparison, a rounded value of 0.5 was chosen which is above the limiting value of 0.42 to 0.44. However, in practice the use of low w/c is becoming common and is also recommended for strength as well as durability. In such cases, the use of curing compounds in isolation might not give the best possible results.

Five curing compounds, procured from three manufacturers, were used in this study. The specifications of these curing compounds and the abbreviations that are used for them in this study are presented in Table 1. Out of the five curing compounds, the curing compounds WX-1 and WX-2 were wax emulsions; RW was a resin emulsion; and RS-1 and RS-2 were resin-based compounds in organic solvents.

As per the manufacturers' data sheets, the curing compounds that were used in this study conform to ASTM C309 [3]. The curing compounds WX-1, RW, and RS-1 formed a white membrane. On the other hand, the curing compound WX-2 was white initially, but formed a translucent film upon drying. The curing compound RS-2 was aluminized and was silver-grey in colour, but left a clear film on drying. Curing compounds were applied on mortar specimens at a rate of 5–6 m^2/L (or 167–200 mL/m^2) as recommended by the manufacturers and ASTM C309 [3]. The solids content (non-volatile matter) of curing compounds was measured in the laboratory. The curing compound was spread on a glass slide as per the recommended coverage rate of 5–6 m^2/l and was left for drying in air at 25 °C and 65% RH for 24 h. The solids content is