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Comparison of carbonation of lightweight concrete with normal weight concrete at similar strength levels

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Abstract

This paper presents a study on accelerated carbonation testing of normal weight concrete (NWC) and lightweight concrete (LWC) mixes proportioned for three levels of strength grades. Two types of curing regimes were applied; (1) hot curing in water at 60 °C for 3 days and (2) normal curing in water at 27 °C for 28 days. Pulverized fuel ash (PFA) at 25% and silica fume (SF) at 5% and 10% replacement of ordinary Portland cement (OPC) in concrete were utilized to blend binary and ternary mixes in addition to OPC mixes. The results indicated that the effect of hot water curing on compressive strength development was more prominent in PFA/SF incorporated mixes than OPC mixes. The carbonation of LWC mixes was lower than NWC mixes at similar strength levels. The mixes with 25% PFA had marginally higher carbonation than OPC mixes under both hot and normal curing. The incorporation of SF in concrete mixes also increased the carbonation. Mixes under hot water curing had higher carbonation than mixes under normal curing.

Keywords: Lightweight concrete; Fly ash; Silica fume; Carbonation; High temperature curing

1. Introduction

Carbonation is one of the most common causes of deterioration in reinforced concrete. With the growing use of structural lightweight concrete for prefabrication of precast modules in high rise building construction, it is important to investigate the carbonation performance of lightweight concrete (LWC). Carbonation is regarded as a physiochemical reaction that takes place between carbon dioxide (CO_2) and alkalinity of concrete due to calcium hydroxide (CH) and calcium silicate hydrate (CSH). The CO_2 gas is present in the atmosphere at approximately 0.03% by volume of air; it could penetrate in concrete and react with CH and CSH in the presence of moisture forming $CaCO_3$. Generally, the relative humidity, the concentration of CO_2, the temperature, the permeability and alkalinity of concrete are the influencing factors for carbonation in concrete.

LWC, generally, has porous aggregate in contrast to aggregate in normal weight concrete (NWC). Past study also observed that the interfacial zone between porous aggregate and cement paste in LWC is denser and thinner than that of NWC [1,2]. Therefore, the propagation of carbonation in LWC may be different from NWC. A number of studies exist on the carbonation performance of NWC but only few studies have investigated the carbonation of LWC.

1.1. Carbonation of lightweight concrete

Lightweight concretes have generally performed satisfactorily for carbonation performance in varying field conditions. Some field investigations on the carbonation performance of LWC in ships and bridges at exposure age from 15 to 43 years, compressive strength from 23 to 35 MPa and density from 1650 to 1820 kg/m^3 have been reported [3–6]. Carbonation depth in these structures varied with density, strength and exposure conditions and was mostly less than 10 mm. Laboratory studies by Grimer

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[7] and Schulze and Gunzler [8] have also shown that the carbonation rates were low in high density and strength LWC.

The effect of various parameters on carbonation such as moisture content, porosity, water to cement ratio, compressive strength, sand replacement and aggregate to cement ratio has been studied. Swenson and Sereda [9] found that too high or too low moisture content of LWC was not conducive to rapid carbonation. Swamy and Jiang [10] found that carbonation was higher for concrete with higher total porosity at a given water to cement ratio. Bilodeau et al. [11] attributed the low carbonation in high strength LWC to low water to cement ratio. Roy et al. [12] and Atis [13] found that the carbonation was inversely proportional to compressive strength. Haque et al. [14] reported an improvement in carbonation performance of LWC when fine LWA 'lytag' in LWC was replaced with normal weight sand and the carbonation depth in sanded LWC was comparable to that of equal grade NWC. Gündüz and Uğur [15] investigated the carbonation of pumice aggregate LWC and found that carbonation lowered as the aggregate to cement ratio was lowered.

Carbonation depth also varied with the type of LWA used. Rodhe and X-Betong [16] compared the carbonation performance of concrete specimens made with one type of NWA to three types of LWA. They found that the carbonation in sintered clay LWC was lower than NWC even with the lower strength of LWC. This was attributed to the modified pore structure in LWC due to addition of a polymer admixture in LWC and the pozzolanic reaction between cement and sintered clay aggregates. But the specimens made with volcanic aggregates (pumice and polystyrene) showed much higher carbonation and lower strength than NWC. Although, the polymer admixture was also used in these specimens to improve the pore structure of cement matrix, however, it was not effective in these types of aggregates because of the high suction of moisture and CO_2 by pumice and polystyrene aggregates.

Bremner et al. [17] performed investigations on carbonation depths of various combinations of LWA and NWA in concrete at different strength levels. They concluded that the carbonation depths obtained from field and accelerated tests were lower with LWC compared with similar grade NWC. However, for both types of concrete, a good quality matrix (high-strength concrete with low water to cement ratio) was necessary to have better carbonation performance.

1.2. Carbonation of pozzolanic normal weight concrete

The influence of pozzolanic finer supplementary binders such as pulverized fuel ash, (PFA) and silica fume (SF) on the carbonation has been mostly studied for NWC [13,18–22]. The general agreement from these studies for the use of PFA and SF in NWC for carbonation is that the partial replacement of cement with PFA or SF increases carbonation. However, if fine aggregate is partially replaced with PFA or SF then carbonation reduces. When PFA and SF are used as partial replacement of cement, the concentration of the carbonatable constituents of cement (CH and CSH) are reduced, so it causes faster concrete carbonation. However, in the case of aggregate replacement by PFA or SF, the carbonatable constituents of cement are not reduced and also the porosity decreases, therefore, carbonation decreases [20].

Nonetheless, there is a potential for the mitigation of increase in carbonation with the use of PFA or SF at mild replacement levels and adequate initial curing. Fattuhi [23] and Balayssac et al. [24] have highlighted the importance of adequate wet or moist curing for better carbonation performance of NWC. In some cases, longer initial curing period of PFA incorporated concrete has shown better carbonation performance due to better pore refinement achieved through enhanced moist curing [13,22].

1.3. Compressive strength development of lightweight concrete

For LWC, an almost similar 28-day or over compressive strengths at moderate levels of replacement of cement with PFA and SF can be achieved. This was demonstrated by Berntsson and Chandra [25] and Swamy and Lixian [26] for sintered fly ash aggregate and by Lo et al. [27] for expanded clay aggregate. But for NWC, generally, the 28-day compressive strength at 25% PFA replacement level under normal curing with water is lower than the strength of OPC concrete [28]. The higher relative strength development of PFA and SF incorporated LWC can be attributed to the improved bond between LWA and binder paste [1].

1.4. Effect of high temperature curing on compressive strength

Thomas et al. [29] and Berhane [30] have shown that the elevated temperature curing (>35 °C) exposure reduces the 28-day compressive strength of NWC. However, for fly ash concrete, the 28-day compressive strength increases [28,31]. The reduction in the OPC concrete strength was attributed to cracking caused by thermal stresses. However, it has been suggested that medium term strength reduction in the compressive strength of OPC concrete under elevated temperature curing can be recovered with simultaneous exposure to ambient humidity [32].

1.5. Research objectives

The review above indicates that, while the comparative studies of carbonation of LWC with NWC have been performed for a few LWA types and for other parameters, there is a lack of data on the comparison of carbonation of equal grade NWC and LWC incorporating PFA and/or SF. Also, no study describing the effect of high temperature curing on the compressive strength and carbonation of LWC could be found. The main objective of this study,