



Durability performance of self-compacting concrete

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HIGHLIGHTS

- ▶ Increased fines content in SCCs refine the pore network of the material.
- ▶ Mineral additives refine the microstructure of SCCs and improve durability.
- ▶ Linear correlations are shown to exist between durability indicators in SCC.
- ▶ Simple durability tests can be used to provide safe predictions for SCC durability.

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ABSTRACT

Although self compacting concrete (SCC) is currently used in many countries, there is a fundamental lack of the intrinsic durability of the material itself. This article presents the outcomes from a research program on principal indicators that define the durability of SCC (sorptivity, porosity and chloride ion permeability) and compares these indicators with the corresponding parameters of conventional concrete. The results show, for the first time, that there is a correlation between the various durability indicators for the specific filler additives used in the mix designs incorporated in this paper. Such a correlation may be used to assess the durability of SCC without the need to rely on time consuming artificial weathering experimental procedures.

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1. Introduction

It is essential for concrete structures to perform well not only within their specified mechanical requirements but also within their durability expectations. Very often the issue of durability is being overlooked since engineers make the assumption that strong concrete is also durable. In this article we will show how certain experimental results can lead to solid conclusions on the issues of durability and structural integrity. It is worth noting that concrete structures are vulnerable to attack both from physical and chemical deterioration mechanisms, many of which still require a lot of research in order to be fully explained and understood. All deterioration mechanisms involve complex processes that take place in the pore skeleton of concrete and the vast majority of durability problems are due to synergistic actions between two or more different processes. Therefore, it is sometimes difficult to isolate and study these actions because the dominant mechanism is indistinguishable.

Concrete is a composite material which consists primarily of three components: cement, water and aggregates. Once cement hydration has been initiated the resulting hardened concrete is a two phase material consisting of aggregates dispersed in a cement matrix. Water is still present either chemically bound to the solid structure or as free liquid. In its fresh state, concrete has to be a well balanced dispersion which will ensure good levels of homogeneity, workability and compactability, thus minimising the risk of segregation. The usual requirement for concrete in its hardened state is to comply with a characteristic 28 days compressive strength value. According to building codes and standards, concrete is expected to sustain sufficiently the loads for which it has been designed. In addition to its ability to sustain loads, concrete is also required to maintain its strength and serviceability throughout its designed service life, hence being durable. This implies that concrete has to endure all processes of deterioration (mechanical, physical or chemical) that may occur either as a result of interaction with the surrounding environment or due to reactions between constituent materials.

Surprisingly, the issue of durability has been considerably overlooked both in concrete technology research and in building codes. Although an impressive amount of data has been published in the

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last 30 years concerning the improvement of mechanical properties and mechanical response of concrete and concrete structures or indeed, in the case of self compacting concrete (SCC), on mix design and rheological issues, a disproportional improvement is observed in understanding the mechanisms and mechanics of deterioration processes in concrete. Rather impressively, building codes such as Eurocode-2 treat durability very superficially assuming good response of concrete to deterioration based on the hypothesis that the material has good quality and that the designer has followed some generic and vague rules concerning the cover of reinforcement. As mentioned above, the deterioration processes can be triggered either by external or internal factors. These processes can be physical and/or chemical, although there are some cases where durability can also be affected by mechanical actions (impact, abrasion and erosion).

2. Theory

In the field of building physics and more specifically in the area of concrete technology, it is widely acceptable that all deterioration mechanisms are triggered by movement of fluids through pores existing within the microstructure of concrete. It is therefore very important to know the nature and characteristics of the pore system within the bulk of the hardened cement paste. Pores relevant to permeation are those which are continuous and have diameters between 120 and 160 nm [1,2]. Discontinuous pores, pores containing adsorbed water and pores with very narrow openings (regardless of their diameter) do not affect the liquid transport properties of cementitious materials [3,4].

The pore structure of cement-based composites is dynamic and changes continuously. As cement hydration progresses, it transforms previously unhydrated particles to a hydrated solid material [5]. During this process, a new pore structure is developed and at the same time the free available water is consumed to allow further progress of hydration [6]. This physicochemical procedure results in the reduction of capillary (and overall) porosity since hydration products are being deposited in the capillary pore space. Capillary pores can decrease roughly to 10 nm of Calcium Silicate Hydrate gel pore size [3]. Once the solid phase has been developed what is of primary importance is the understanding and analysis of the connectivity of pores. Percolation concepts are of primary interest since they show how properties are affected by the connections existing between voids and cavities [7–9].

Although concrete is a composite containing cement paste combined with aggregates, the porosity of the latter is not considered important in the permeation properties of the bulk material. The reason is that the vast majority of aggregates not only have relatively low porosity values but also do not have interconnected pore structures [10]. Therefore, it is the level of percolation of pores of the bulk cement paste as well as of the interfacial transition zone which define the fluid motion paths within cement-based composites [11–14]. Boel and Schutter [15] using mercury intrusion porosimetry observed that the pore structure of SCC is more dense compared to conventional concrete, a result that has also been confirmed by other experimental procedures [16,17].

2.1. Water absorption

Absorption is the process during which the volume of the pore space in concrete is penetrated by a liquid with the aid of capillary suction [18]. The rate of absorption of liquid under capillary forces (sorptivity) is measured on dry concrete samples which rest on small supports so that a few millimetres of the lower end of the specimen are submerged to the wetting liquid [19]. By recording the time the specimen is in contact with the aqueous solution,

Gummerson et al. [19] found that there is a relationship between the increase in the volume of liquid absorbed per unit of specimen cross sectional area (i) and the square root of time ($t^{1/2}$):

$$i = St^{1/2} \quad (1)$$

The parameter relating i with $t^{1/2}$ is the capillary absorption coefficient or sorptivity (S) of the material under test [20]. The sorptivity is a property depending on both the wetting liquid and the test specimen. The capillary absorption of cement-based composites is a topic which has been widely discussed in the literature [21–27]. In many cases in fact, the sorptivity has been used as a durability indicator [28–33]. A relatively limited number of published studies examine the sorptivity of SCC. These studies report that SCC seems to absorb less liquid in its capillary pore network compared with similar conventional concretes [34–38]. However one has to be very careful in interpreting the sorptivity results in concrete since the method requires that the material examined is homogeneous and chemically unaltered during the test. Nonetheless, water absorption tests give a very good indication for the potential durability of concrete.

2.2. Chloride ion diffusion

Chloride attack to concrete is most commonly initiated when chloride ions ingress from the surface of the material. Chloride ions exist in salts, sea water and contaminated water. It has to be noted that a structure does not need to be exactly on the sea front in order to be affected by chlorides, since the latter can be airborne and attack concrete located even a few hundred metres away from the shore [39,40]. Chlorides can access concrete's microstructure by three distinct mechanisms: transport of aqueous solution, diffusion and absorption [41]. Additionally, chloride ingress is possible with ion migration under the existence of differential voltage [42–44]. In all mechanisms chlorides use either the interconnected network of pores or any existing surface cracks. Chloride attack has long been appreciated as the most common cause of steel corrosion in reinforced concrete structures [45–47]. Chlorides, in the presence of oxygen and moisture, attack concrete's passivity, thus exposing steel and making it susceptible to corrosion development [14,48]. Corrosion products (iron oxides) occupy larger volume than the steel they come from. This difference in volume results in cracking in the interface between steel and concrete.

As corrosion progresses, cracks become larger promoting further attack both on concrete and steel. If the corrosion is very severe concrete spalling and delaminations between concrete and steel are possible. Existing literature reports that the chloride permeability in SCCs is somewhat reduced compared to corresponding normal vibrated concretes; however this reduction is more distinct when cement replacement materials are incorporated into the mixtures [38,49].

3. Experimental procedure

The concrete mixtures presented in this study were prepared with standard CEM-II 42.5R grade cement. In total eight mixtures, with varying water-to-binder ratios (w/b) are examined. Six of them are self compacting concretes, whereas the remaining two are typical normal vibrated concrete mixtures (NVC), representing two different slump categories.

3.1. Materials

Graded crushed calcareous coarse aggregates in two different particle size gradings (8–20 mm and 4–10 mm) and two different gradings of calcareous sand (0–4 mm and 0–2 mm) were used for the production of both SCC and NVC mixtures. In the production of all SCC mixtures, fine limestone powder (72% CaCO₃) with specific gravity (sg) 2.80 was also used besides the cement. Silica fume (97% SiO₂ – sg = 2.20) was used as a cement replacement in three different percentages

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