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Combined effect of expansive, shrinkage reducing and hydrophobic admixtures for durable self compacting concrete

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HIGHLIGHTS

- ▶ Study of white self-compacting concretes for architectural structures.
- ▶ Rhelogical study on both cement pastes and fresh SCCs.
- ▶ Study of free and restrained drying shrinkage behaviour.
- ▶ Achievement of shrinkage-free SCC with CaO-based expansive agent and SRA.
- ▶ Effectiveness of the combined use of SRA, expansive agent and hydrophobic admixture.

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ABSTRACT

This paper presents the results of an investigation carried out to develop white self-compacting concretes (SCCs) especially devoted to durable architectural structures. In fact, shrinkage-free SCC mixtures were studied, obtained by combining CaO-based expansive agent and shrinkage reducing admixture. Also a hydrophobic admixture was added to SCC in order to preserve the white surface from the growth of micro-organisms as well as to increase concrete durability. Rheological tests were carried out on cement pastes, as well as on fresh SCCs, containing the three admixtures in order to study their influence (alone or in combination) on cement paste and concrete rheology. Also thermogravimetric analysis was carried out on cement pastes in order to evaluate the influence of various admixtures on portlandite solubility. Hardened SCCs were characterized by means of compression tests, free dying shrinkage, and restrained expansion measurements.

1. Introduction

The development of coloured self-compacting concrete opens new fields of application of SCC, since it adds attractive alternatives for challenging architectural designs in terms of shapes, textures and colours, to the advantages of fluidity and filling capacity of SCC. For example, the use of white SCC could allow to obtain a marble-like effect of the skin of the concrete, even if placed in the absence of vibration (situation very common for structures with very congested reinforcement).

As it is well known the design of SCC requires a careful combination of the various material components of the mixture. SCC must achieve high workability and flow into the formwork under its own weight without compaction and with no segregation. In rheological terms, it is accepted that SCC has a low (but positive) yield stress, while the plastic viscosity can vary significantly [1]. However, an appropriate combination of the two parameters is required to obtain a concrete with adequate fluidity and stability.

A recent example of application of architectural SCC is that of the very prestigious Museum of Modern Arts, in Rome, designed by Zaha Hadid Limited, London, UK. For this architectural structure a very special shrinkage compensating SCC was studied by Collepardi et al. [2], in order to avoid the risk of cracks in some special walls (8 m high and 55 m long), without constructions joints. In particular, in that case, CaO-based expansive agent in combination with shrinkage reducing admixture (SRA) was used.

The technology of shrinkage-compensating concrete is based on the use of special products, such as calcium sulpho-aluminates or calcium oxide, which react with water and produce a restrained

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expansion in reinforced concrete structures. In particular, the transformation of calcium oxide to calcium hydroxide by reacting with water causes its volume increase of about 90% [3].

This technology has been invented many years ago [4], but its use has been very limited in practice, due to the difficulty in adopting a continuous water curing, absolutely needed in the early ages after setting. Consequently, from a practical point of view, this technology can be adopted only in some special constructions such as concrete floors or slab foundations. However, Collepardi et al. [5] found that there is a synergistic effect in the combined use of SRA and a CaO-based expansive agent in terms of more effective expansion, even in the absence of wet curing. In fact, due to the additional effect of SRA, shrinkage-compensating concrete was used to produce crack-free concrete without wet curing for an outside industrial floor of 800 m^2 in absence of contraction joints [6]. The synergistic effect of expansive and shrinkage reducing admixtures was also more recently studied by Meddah et al. [7].

According to scientists [8–10], the main mechanism through SRAs are able to reduce plastic, autogeneous and especially drying shrinkage of concrete seems to be the lowering of surface tension of the water in capillary pores. In fact, as water-filled pore begin to loose moisture, curved menisci are formed, and the surface tension of water pulls the walls of the pores. With the reduced surface tension of water, the force pulling the walls of the pores is probably decreased, and the resultant shrinkage strain is reduced in turn. Nevertheless, this hypothesis cannot justify the slight early-age expansion due to the addition of SRA to the concrete mixture. According to other scientists [11,12], the presence of SRA in the concrete mixture could reduce the water solubility of calcium hydroxide: the lower the solubility, the less diffused is the migration of calcium ions, the lower is the distribution of calcium hydroxide, which can result in higher stresses due to crystallization, and could lead to an early-age expansion. Also Chatterji [3] found that the lower is the solubility of calcium hydroxide, the higher was the concrete expansion.

Another addition which can be useful to preserve the marble-like effect of the skin of the SCC from humidity, and then from the growth of organic micro-organisms such as fungi, lichens, etc. can be hydrophobic admixture [13]. In this work, it was used but not in the most common way of application, that is as surface treatment. In fact, it was directly introduced in the concrete mixture, with the aim of making the bulk concrete itself hydrophobic instead of the only surface, and so that improving its effectiveness and resistance to the aggressive agents in the atmosphere [14]. The use of hydrophobic admixture in reinforced concrete could be useful not only for maintaining its aesthetics but also for durability reasons. In fact, in sound concrete specimens, exposed to chloride solution, the use of hydrophobic admixture can be able to prevent the corrosion of reinforcing steel [14]. This effect is due to the very low water absorption, and then chloride ingress, through the pores of the hydrophobized cementitious matrix.

2. Research significance

This paper presents the results of an investigation carried out to develop white self-compacting concretes (SCCs) by using a suitable combination of three admixtures in order to produce durable concrete for architectural structures. The combined effects of these three admixtures on cement paste and SCC rheology were studied, as well as their combined effects on mechanical performance, drying shrinkage behaviour and cracking tendency of concretes. In fact, shrinkage-free SCC mixtures were studied, obtained by combining CaO-based expansive agent and shrinkage reducing admixture. Moreover, also the influence on the concrete performance of a hydrophobic admixture was tested. Its addition to SCC could be useful in order to preserve the white surface from humidity and then from the growth of unaesthetic micro-organisms, as well as to increase concrete durability.

3. Experimental

3.1. Materials

White coloured portland-limestone blended cement type CEM II/B-LL 42.5 R according to the European Standards EN-197/1 [15] was used, its content of white clinker was in the range 65–79% by weight. The Blaine fineness of cement was 0.42 m^2/g and its relative specific gravity was 3.04.

Moreover, limestone powder (95% $CaCO_3$ and other minor constituents) was used as filler, obtained as a by-product of quarry activity. In limestone quarries, considerable amounts of limestone powders are being produced as by-products of stone crushers. High amounts of powders are being collected and utilisation of this by-product is a big problem from the aspects of disposal, environmental pollution and health hazards. Previous studies showed the feasibility of the use of limestone powders for SCC [16–18]. The Blaine fineness of limestone powder was 0.58 m^2/g and its relative specific gravity was 2.68.

As aggregate, carbonatic gravel (2–16 mm) and carbonatic sand (0–4 mm) were used. The gradation of both aggregate fractions, evaluated according to UNI EN 933-1 [19], are shown in Fig. 1, and their physical properties, evaluated according to UNI EN 1097-6 [20], are 2.66 and 2.63 relative specific gravity and 2.4% and 3.2% water absorption, respectively.

A superplasticiser was used, which consisted of carboxylic acrylic ester polymer in the form of 30% aqueous solution with a relative specific gravity of 1.09 ± 0.02.

As shrinkage-reducing admixture (SRA), polyethylene glycol was used, while as expansive agent, dead burnt lime (CaO) was employed.

Finally, hydrophobic admixture in form of 45% aqueous emulsion of butyl-ethoxy-silane was added to some mixtures. The alkyl group size influences the decrease of surface tension and thus the treatment effectiveness. As a consequence, relatively high-molecular weight groups, such as butyl (in this case), significantly reduce the substrate water absorption [14].

The same low value of water to cement ratio (0.45) was adopted for durability reasons, in order to prepare all cement pastes and SCCs.

3.2. Rheological characterization of cement pastes

The study of the rheological behaviour of cement pasts is certainly an essential step towards the optimization of SCC production [21].

Concerning the influence of the fine aggregate particles on the rheology of the 'carrying phase' (i.e. cement paste) within SCC, in this case it should not be considered, because no material is passing the sieve of 0.150 mm, as it can be seen from the grain size distribution curves of sand and gravel used (see Fig. 1).

For this purpose, eight cement pastes were prepared. The proportions of these paste mixtures are shown in Table 1. Firstly, a reference paste was prepared (REF) with a water to cement ratio of 0.45, in which water, cement, limestone powder and superplasticizing admixture were added at dosages corresponding to those of the related SCC.

Then, the effect of either calcium oxide or SRA or hydrophobic admixture on the rheology of cement paste was studied by suitably preparing further three cement pastes, in which every addition was made on the basis of its dosage on the final SCC mixture.

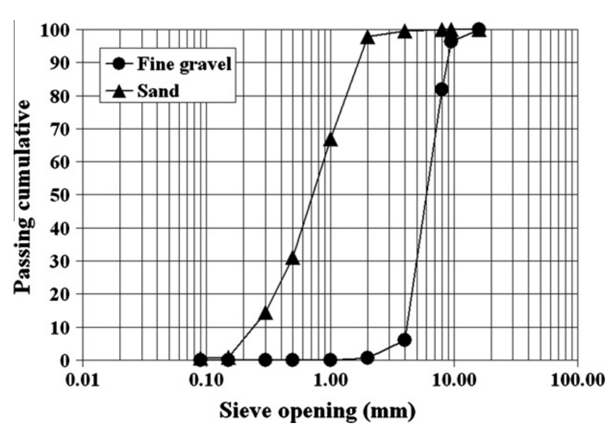

Fig. 1. Cumulative grain size distribution curves of the aggregates.