Construction and Building Materials 165 (2018) 93–103

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Influence of nano- and micro-silica additions on the durability of a high-performance self-compacting concrete

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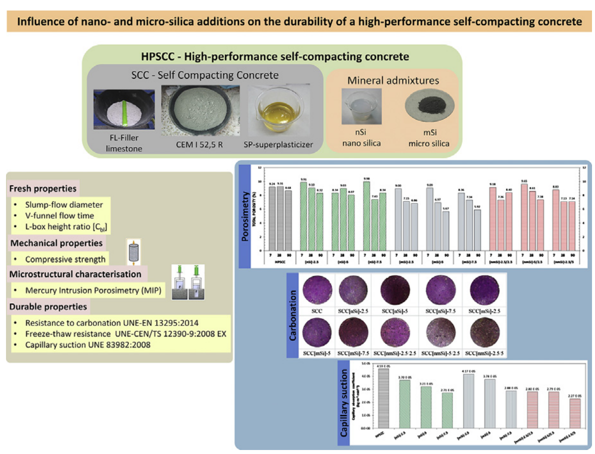
HIGHLIGHTS

- The effects of a binary and ternary mixture with nSi and mSi on HPSCC were examined.
- The use SP produced bubbles directly proportional to the nSi quantity incorporated.
- The ternary mixture 2.5%/2.5% of nSi and mS was the highest compressive strength.
- Generally ternary mixtures show the greater resistance to the carbonation.
- Usually ternary mixtures show the greater resistance to freeze-thaw cycles.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 July 2017
Received in revised form 5 November 2017
Accepted 11 December 2017

Keywords:
High-performance self-compacting concrete
Microsilica
Nanosilica
Durability
Accelerated carbonation
Freeze-thaw cycles

ABSTRACT

The main purpose of the research is to examine the effects of binary and ternary mixtures of nSi and mSi on the durability of a high-performance self-compacting concrete (HPSCC). Compressive strength at 28 days, accelerated carbonation processes after 60 and 200 days of exposure to CO_2, resistance to freeze-thaw cycles and capillary suction coefficient, were analyzed. In addition, microstructural characterization was carried out by Mercury Intrusion Porosimetry (MIP). Ten blends were manufactured: one without additions as control, three with 2.5%, 5% and 7.5% of nSi, three more with 2.5%, 5% and 7.5% of mSi and three using both admixtures, with 2.5%/2.5%, 5%/2.5% and 2.5%/5%, of nSi and mSi, respectively. The highest compressive strength is achieved in the ternary admixture with 2.5%/2.5%. A wider particle size distribution creates a low porosity, improves packing density, decreases water demand in comparison with mixtures with the same amount of total addition using only nSi, provides higher compressive strength and an improved durable performance. The porous network in mixtures with nSi involved a smaller pore diameter with respect to control, proportional to the amount of nSi. In concretes with mSi, there was a lower total porosity with an average pore size similar to the reference concrete. In ternary mixtures, the porous network presented concretes with a smaller average pore size and a smaller total porosity. This produced concretes with a high compactness and improved durability properties, with a lower capillary absorption and a lower susceptibility to carbonation and freeze-thaw cycles. The low capillary

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https://doi.org/10.1016/j.conbuildmat.2017.12.100
0950-0618/

absorption deduced in this type of concrete might prevent the penetration of aggressive agents afflictively and hence, increases the life span of concrete structures in aggressive environments.

Contents

1. Introduction

In designing a concrete structure, one of the most important properties to be considered, in addition to have an adequate mechanical strength, is durability. Durable concrete must resist any chemical, physical or biological process that tends to damage it during the service life of the structure.

There are several aggressive agents and environmental conditions that can significantly affect reinforced concrete structures or precast concrete elements, and to date there are many unresolved issues regarding the physical and chemical durability of concrete, in particular when additions or by-products are used [1]. This study focuses on two of the most important and frequent actions: freeze-thaw cycles and carbonation of a high-performance self-compacting concrete with nano and micro silica additions. Damage due to the freeze-thaw action can occur when concrete pores are fully saturated or close to saturation, since during the process of freezing, water volume increases around 9%. If there is insufficient space in the concrete to control this expansion, damage can occur. Such damage can be both internal (specifically, microstructural damage generated by micro-cracking) and external (loss of material by peel) [2]. Another agent that can cause significant damage is CO_2 from the atmosphere which can penetrate the concrete pores and reacts with calcium hydroxide. This creates calcium carbonate which then progressively reduces concrete or cement paste alkalinity. This phenomenon is the known process of carbonation. If the pH value of concrete reaches 9.5 or lower, the alkalinity of the media is insufficient to keep the protective oxide coat of reinforcing steel bars in a passive manner. Therefore, under the action of both moisture and oxygen, a steel corrosion process can be initiated which leads to concrete prone to developing a generalised corrosion [3]. Hence, in order to guarantee a good durability of precast, as well as on site concrete elements regarding the two above-mentioned damaging processes it is necessary to use high-performance concrete to prolong concrete service life.

Self-compacting concrete (SCC) has been used for more than 20 years both in civil engineering and in building works. The main property of this type of concrete is its high workability [4,5]. This allows placement, under its own weight, without the usual vibrating compaction requirements, in densely reinforced and congested structures and/or with complex geometries. Additionally, it shows no segregation, coarse aggregate blocking or bleeding. These workability properties are mainly due to the high content of fine aggregates, a reduced content and size of coarse aggregates and the action of superplasticizer admixtures that provides the fluidity required for placement on site [6]. Moreover, SCC allows the final cost of the structural element to be reduced and concrete productivity to be improved. At the same time, good mechanical properties, durability and uniformity of the hardened material can be achieved. Such advantages increase the use of SCC in several projects. Moreover, the high workability of SCC reduces the production costs and maintenance of equipment, which is particularly relevant in the prefabrication industry. In order to obtain an adequate flowability in fresh state, the use of a high amount of cement, mineral admixtures and superplasticizer is often required, as the water/cement ratio is low. Special care should be taken in ensuring the required workability when additions or by-products are used in the concrete mixture [7].

According to the experts for specialised construction and concrete systems, SCCs can be classified in three classes in terms of the flowability, measured by the slump-flow test [6]. The slump-flow classes defined are the following:

SF1 (550–650 mm) is appropriate for unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. housing slabs).

SF2 (660–750 mm) is suitable for many normal applications (e.g. columns and walls).

SF3 (760–850 mm) is typically produced with a small maximum size of aggregates (fewer than 16 mm) and used for vertical applications in congested structures, structures with complex shapes, or for filling areas under formwork.

Shi et al. [8], proposed different methods to design a SCC mixture. In their published research, they suggest use different methods according to the properties required. A high-performance self-compacting concrete (HPSCC) is understood to be a self-compacting concrete with both high-compressive strength and durability properties. In general, such a HPSCC is obtained through high cement contents and a low water/cement ratio, which can be improved by the use of inactive or active additions to the mixture. Nepomuceno et al. [9] proposed a methodology to design SCC mixtures. For this purpose, they obtained correlations between parameters of the properties of the fresh-state and hardened concrete.