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Experimental study of the mechanical properties and durability of self-compacting mortars with nano materials (SiO_2 and TiO_2)

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HIGHLIGHTS

- Updated research on the application of nano materials (SiO_2 and TiO_2) in the production of self-compacting mortars.
- Feasibility analysis of nano materials in self-compacting mortars mixes.
- Analysis of the properties of self-compacting mortars with nano materials in fresh and hardened states.
- Compressive and flexural strength, porosity, water absorption and carbonation penetration are discussed.

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ABSTRACT

Cement, as well as the remaining constituents of self-compacting mortars, must be carefully selected, in order to obtain an adequate composition with a granular mix as compact as possible and a good performance in the fresh state (self-compacting effect) and the hardened state (mechanical and durability-related behavior). Therefore in this work the possibility of incorporating nano particles in self-compacting mortars was studied. Nano materials are very reactive due mostly to their high specific surface and show a great potential to improve the properties of these mortars, both in mechanical and durability terms.

In this work two nano materials were used, nano silica (nano SiO_2) in colloidal state and nano titanium (nano TiO_2) in amorphous state, in two types of self-compacting mortars (ratio binder:sand of 1:1 and 1:2). The self-compacting mortar mixes have the same water/cement ratio and 30% of replacement of cement with fly ashes. The influence of nano materials nano-SiO_2 and nano-TiO_2 on the fresh and hardened state properties of these self-compacting mortars was studied. The results show that the use of nano materials in repair and rehabilitation mortars has significant potential but still needs to be optimized.

1. Introduction

Fly ash (FA) is one of the most used industrial wastes in the cement and concrete industry as an addition and they have many advantages, such as a reduction of cement consumption, an increase of concrete's workability, and a potential increase of concrete's durability and mechanical strength at later ages. However, the retarding effect on the evolution of mechanical strength in the first ages may, in some cases, represent a significant drawback. Even though this effect may be favorable for some applications, such as casting of large volume elements [1], in most cases the effect is uncalled for. In order to compensate it many methods have been experimented to accelerate the hydration process in the early ages in binary mixes of cement and fly ash including grinding processes of the components [2], chemical activation of the fly ash [3], hydrothermal treatments [4,5], among others.

Recently nano silica (nano-SiO_2) was introduced in the study of mortars and/or concrete and various studies have demonstrated that, even at small contents, it can improve the mechanical properties of these cementitious mixes [6]. According to Nazari and Riahi [1], it was possible to increase the compressive strength by 70% with the addition of 4% of nano-SiO_2 (in cement mass). Similarly Shih et al. [6] demonstrated that an addition of 0.6% of colloidal nano-SiO_2 can increase the compressive strength of cement pastes by 43.8%. Li et al. [7] refer that, with the addition of 3% and 5% of SiO_2 in cement-based mortars, the 28-day compressive strength increases by 13.8% and 17.5% respectively. Zhang et al. [2] e Li

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et al. [7] refer significant improvements of the mechanical properties of cementitious mixes with large replacement of cement with pozzolanic additions such as fly ash and/or blast furnace slag, together with nano-SiO_2.

However there are two important problems to be considered related to the use of nano-SiO_2 in powder. The first refers to the particles dispersion at the mixing stage of the mortars or concrete and the second to the loss of workability due essentially to the high specific surface of the particles. It is stressed that in the works referred to in the previous paragraphs mechanical dispersion techniques or ultra-sounds were used and in some cases the authors refer the application of systems of treatment of the particles surface. An inadequate dispersion may cause a least favorable of the compressive strength [8], among other effects.

When considering the use of binary mixes of fly ash and nano-SiO_2, the individual benefits of each of them can certainly contribute to offset the problems of the other: reactive nano-SiO_2 can improve the mechanical properties in the early ages (unlike fly ash) while fly ash can improve the workability (contrarily to nano-SiO_2). As for the dispersion problem of the nano-SiO_2 powder particles, it is possible to replace them by water-based mixtures of colloidal nano-SiO_2.

With the evolution of the study of nano materials applied on construction materials, nano titanium (nano-TiO_2) has been widely studied in various fields including the elimination of residual waters and exhaustion gases and the improvement of the mechanical and durability properties of concrete [4]. Nazari and Riahi [1] studied the influence of various nano materials on the mechanical performance and microstructure of concrete. These authors refer an increase of density of concrete with a significant improvement both at the mechanical and durability level as the content of nano-TiO_2 in the mix increases. They justify these trends with an acceleration of the formation of calcium-silicate-hydrate gel (C–S–H) due to greater volume of calcium hydroxide ($Ca(OH)_2$) crystals especially in the first ages. Li et al. [2] and Zhang et al. [9] demonstrate that the use of nano-SiO_2 and nano-TiO_2 causes a significant improvement of the refinement if concrete's porous structure, increasing its resistance to chlorides penetration. Fujishima et al. [8] also studied the influence of the use of nano particles on the mechanical strength of concrete and obtained similar results to those of Li et al. [2] and Zhang et al. [9]. The excellent photo-catalytic properties of nano-TiO_2 must also be highlighted: when incorporated in concrete production, they can contribute to the decomposition process of pollutant gases in the atmosphere, simultaneously improving the performance of concrete.

2. Literature review

Jawahar et al. [11] investigated the use of the mini slump cone test to optimize the super plasticiser (S_P) and viscosity modifying agent (VMA) contents in SCMs. The SCMs mixes had 35% replacement of cement with class F FA and two different water/cement (W/C) ratios by weight: 0.32 and 0.36. It is observed that, for the same cementitious proportions, the optimum S_P content was the same for the mixes with 0.32 and 0.36 W/C. Mortar mixes with 0.36 W/C showed an increase in the rate of flow, i.e. lower viscosity at each level of S_P content than that of mixes with 0.32 W/C. It is also observed that a minimum VMA content was required in the mortar mixes with 0.36 W/C in order to stop bleeding, whereas no VMA was required in the mortar mixes with 0.32 W/C as no bleeding was observed at the optimum S_P content. In practical terms, it was seen that the mini slump cone test is the best choice for SCM tests to evaluate the mortar spread and its viscosity (T_{20}). Also, it was seen that the sand content in mortar does not affect the optimum S_P content (saturation point) when the cementitious proportions remain constant.

Nepomuceno and Oliveira [13] reported an experimental study on the mortar phase for SCC. A series of SCMs were produced with similar flow properties, measured by spread and mini V-funnel tests, adequate to produce SCC. The water content and the modified carboxylic S_P content were determined experimentally for each mortar. Different contents of cement replacement materials were used in binary blends, each one combining one of the two types of cement with one of the three mineral additions selected: limestone filer (LF), granite filler (GF) and FA. Each of the binary blends of powders was combined in five proportions in volume with the fine aggregate (V_P/V_s). Mortars were tested for compressive strength at 28 days and this value was related to the water/cement ratio, the percentage of cement replacement materials, and the V_P/V_s parameter. The analysis revealed the possibility of establishing adequate mortar parameters to obtain simultaneously self-compatibility and the required compressive strength of self-compacting concrete.

Porro et al. [14] mentioned that the use of Nano-SiO_2 particles increases the compression strength of cement pastes. They also stated that this phenomenon is not due to the pozzolanic reaction, because calcium hydroxide consumption was very low but, instead, to the increase of silica compounds that, in turn, contribute to a denser microstructure.

Hui et al. [15] studied the mechanical properties of nano-Fe_2O_3 and nano-SiO_2 cement mortars were experimentally studied. The experimental results showed that the compressive and flexural strengths at 7 and 28 days of the cement mortars mixed with the nano-particles were higher than those of a plain cement mortar. Therefore, it is feasible to add nano-particles to improve the mechanical properties of concrete. The SEM study of the microstructures between the cement mortar mixed with the nano-particles and the plain cement mortar showed that the nano-Fe_2O_3 and nano-SiO_2 filled up the pores and reduced the $Ca(OH)_2$ compound between the hydrates. These mechanisms explained the supreme mechanical performance of the cement mortars with nano-particles.

Arefi et al. [16] did research on the compressive, tensile and flexural strength of cement mortar containing Al_2O_3 nanoparticles at 1%, 3% and 5% by weight of cement. The results show that the mechanical properties of samples containing 1% and 3% Al_2O_3 nanoparticles are better than those of the ordinary cement mortar. But, by increasing Al_2O_3 nanoparticles to 5%, the mechanical properties decreased severely. A SEM study of the microstructure of cement mortar containing nanoparticles and ordinary cement mortar showed that Al_2O_3 nanoparticles reduced the $CaOH_2$ crystals, filled the pores and increased the density of cement mortar.

Oltulu and Sahin [17] studied the addition of both nano-SiO_2, nano-Al_2O_3 and nano-Fe_2O_3 powders and their binary and ternary combinations on the compressive strength and capillary water absorption of cement mortars containing FA. The powder content used corresponded to 0.5%, 1.25% and 2.5% of the binder for all mixes. The authors concluded that the addition of any single type of oxide powders at 1.25% increased the compressive strength of the mortars more efficiently than the other proportions. The use of NS + NA powders at 1.25% maximized the compressive strength relative to the control specimen. For all binary powder combinations, the rate of increase in strength reached generally their peak at 28 days and gradually decreased through aging. Of all the groups, the best results were obtained in the mortars added with NS + NA + NF powders at 1.25%. For this specific mortar, 7–32% increase in compressive strength and 14% decrease in capillary absorption occurred relative to the control specimen.

Meng et al. [18] studied the effect of nano-TiO_2 on the mechanical properties of cement mortar. The test results indicated that