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Durability of self-compacting concrete made from non-conforming fly ash from coal-fired power plants

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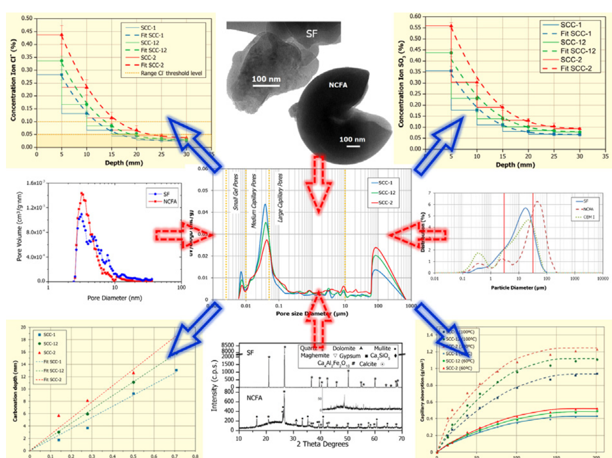
HIGHLIGHTS

- A durability-related comparative study of three SCCs was carried out.
- The porous structure of SCC-2 is less fine than that of SCC-1.
- SCCs could be used in aggressive environments in terms of water absorption.
- The mixes have good performance regarding chloride and sulphate ions penetration.
- The penetration depth of CO_2 is related to the porosity and curing mechanism.
- SCC–NCFA showed better features than SCC–SF regarding long-term shrinkage.

GRAPHICAL ABSTRACT



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ABSTRACT

The search for answers to the environmental challenges is one of the obligations of the current society. Therefore, the optimisation of natural resources and the minimisation and revaluation of waste should be present in any activity. These purposes should be included in both the construction and energy sectors owing to the large amount of resources consumed and of pollutants and waste generated by them. The present work carries out a feasibility study of the use of fly ash from coal-fired power plants as a filler for self-compacting concrete (SCC). This kind of fly ash does not meet the compliance criteria determined by the regulations, and thus, it is non-conforming fly ash (NCFA). The dual objective of this work is the optimisation of a natural non-renewable resource and the recovery of waste, which should achieve the qualification of end of waste before being used as a by-product. For this purpose, a comparative study of three mixes is performed, namely, SCC-1 with commercial siliceous filler (SF) (SCC reference), SCC-12 with a mix 1:1 by volume of SF and NCFA, and SCC-2 with NCFA. All the mixes showed good self-compactability. The analysis of the relevant parameters, i.e., apparent and dry density, open porosity,

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mercury intrusion porosimetry, absorption of water by immersion, and capillarity, has been significant to know in depth the durability of the mixes. The results show that it is possible to obtain a SCC with high performance with respect to durability, attack of aggressive agents, and shrinkage by replacing the SF of siliceous nature with NCFA.

1. Introduction

One of the construction materials that consume more natural resources is concrete. Owing to its good structural properties, simple manufacture, and low cost, concrete is the most used material, ahead of others such as wood, steel, plastic, and aluminium [1]. For this reason, since its appearance, the concrete industry has been evolving towards technologies that are more efficient. An evolution of the normally vibrated concrete was the self-compacting concrete (SCC) [2]. It was intended to find a concrete whose performance and quality did not depend on the labour force in the execution process. This special concrete allows the reduction of execution deadlines, the manufacture of complex structures, better surface finishes, reduction of labour, saving in costs, improvement in job security, and reduction in noise and vibrations [3]. The SCC incorporates a high content of fines and chemical additives in its dosage. For this reason, the SCC can be considered as unfriendly to the environment.

Nowadays, a potential alternative to the use of these conventional materials of fine granulometry is the use of residual powders of industrial and/or mining origin. This would allow an optimisation of the used resources, along with the recovery of waste and reduction of its emission to the environment. However, the use of residual materials always involves an uncertainty in their quality from the points of view of mechanical strength and durability. In order to achieve high reliability in all types of environments, the durability properties of these alternative materials must be evaluated against carbonation processes, degradation by attacks of chlorides, sulphates, etc., and the attack mechanisms that govern their processes of deterioration should be identified. To achieve a complete knowledge, it is necessary to carry out a study of the hydration processes, microstructure of the material, and transport mechanisms to the interior of the cement matrix. Therefore, an in-depth investigation of these materials will allow us to continue with innovation in the construction sector.

Sideris et al. [4] investigated the potential use of ladle furnace slag, the main by-product of the secondary steel-production process, as an alternative filler for SCC production because it showed latent pozzolanic and hydraulic properties. They concluded that this residue could be used as a filler because it had a positive effect on the self-compactability, compressive strength, and durability of the mixes. Another residue used in SCC has been copper slag. Sharma et al. [5] observed an improvement in self-compactability and good mechanical and durability performance of the SCC with a high substitution percentage (60%) of fine aggregate. Esquinas et al. [6,7] carried out an analysis of SCCs incorporating a dolomitic waste powder. The setting mechanisms and the microstructure of the mixes were analysed and correlated with their mechanical and durability behaviours, demonstrating the good performance of the SCCs. Tennich et al. [8] investigated the use of marble and tile waste as a replacement of the conventional mineral admixtures in SCC. The results showed that the use of these residues gave rise to high resistance of the SCC to attack by sulphates, higher than that of the normally vibrated concrete.

Other residues that come from the combustion processes of various industries (ashes) have appropriate physical and chemical characteristics for their use as mineral admixtures in SCCs. Prior to their use, it is necessary to know their behaviour and evaluate their applicability. Kannan [9] studied the effect of rice husk ash on the mechanical and durability properties of SCCs. This author observed a good behaviour in the fresh and hardened states of the mixes that incorporated up to 15% of this residue. The use of palm oil fuel ash in SCC has been investigated by authors such as Ranjbar et al. [10]. The effect of this residue improved the results of the mixes with respect to the attack of chemical agents (chlorides and sulphates), water absorption, and shrinkage. Sua-Iam and Makul [11] carried out an analysis of SCCs incorporating incinerated sugarcane filter cake, which is considered as the largest waste of the sugar industry. These authors concluded that it is possible to produce SCCs using this by-product with acceptable workability and hardened properties. The results obtained by Cuenca et al. [12] clearly indicated that biomass ash could be used in high-quality self-compacting concrete.

Currently, worldwide, one of the most important residues is the fly ash from coal-fired power plants [13]. This waste could be used in the construction sector as long as it complies with the conformity criteria established by the regulations (EN 450-1, EN 450-2, EN 14227-4, and ASTM C 618) [14,15], and it is called conforming fly ash. This by-product is characterised by its pozzolanic and cementitious properties. In the SCCs, this by-product has been extensively studied, being the object of numerous works [16–30].

When this residue does not comply with the required fineness, it is considered as non-conforming fly ash (NCFA) [31], which represents between 30% and 40% of the total production of fly ash and, unlike the conforming fly ash, it has had non-existent or poor applicability [32]. The world production of NCFA is estimated in 250 million ton per year [31,33]. The European Union Directive-2008/98/EC considers fly ash as a waste that must be recovered [34].

The purpose of this work is to carry out an evaluation of the use of NCFA as a filler in SCC from the point of view of durability, which has not been studied yet. A comparative analysis of three mixes has been carried out; in the first SCC, a commercial siliceous filler (SF) was used as reference; in the second one, a mix 1:1 by volume of SF and NCFA was utilised; and in the third one, only NCFA was used. The amount of filler used by volume was similar in all the cases. To determine the behaviour of the three SCCs, a fresh-state study was carried out in the first place, where the self-compactability properties were addressed. Subsequently, the microstructural and physical properties of absorption were analysed. Finally, a study of the durability of these materials was carried out, which was completed with the analysis of their long-term shrinkage.

As a result, it will be possible to reach similar reliability, if not higher, than that of conventional materials. This is an essential aspect to solve the uncertainties in relation to their stability over time. Therefore, this study will be useful for the valorisation of the industrial by-product NCFA, and consequently, the minimisation of its environmental impact, which will undoubtedly contribute to the conversion of concrete into a material friendlier to the environment.

2. Experimental methodology

2.1. Materials

The aggregates used were gravel 4/16, coarse sand 0/4, and fine sand 0/2 (hereinafter G, S1, and S2, respectively). A characterisation of the aggregates was carried out by Esquinas et al. [31] and it was determined that the aggregates are suitable according to the EHE-08 guideline [35].