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Mechanical and durability behaviour of self-compacting concretes for application in the manufacture of hazardous waste containers

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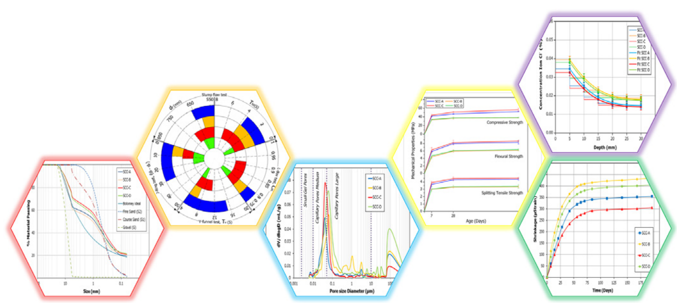
HIGHLIGHTS

- The mixes comply with the self-compacting requirements marked by the EHE-08.
- Mixes with fillers and low coarse aggregate content had finer porous structures.
- All mixes are impermeable based on the penetration of water under pressure test.
- The mixes have good performances against chloride and sulphate ion penetration.
- The presence of fillers in the dosages greatly influences concrete shrinkage.

GRAPHICAL ABSTRACT



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ABSTRACT

In self-compacting concrete (SCC), the amount of coarse aggregates, use of fillers, and type of additives play important roles in its self-compaction, including mechanical and durability properties. The use of SCC is widespread in the precast concrete industry and it can also be employed in the manufacture of containers for the storage of hazardous waste. In addition to the requirements for self-compaction, strict mechanical and durability requirements must be considered. In this work, a study on the effect of variation in the amounts of coarse and fine aggregates, and fillers on the properties of the fresh state (self-compactability) and hardened state (microstructural, mechanical, and durability behaviours) of different dosages is carried out. The factors that have more significant influences on the density of the mixes are the presence of fillers and water-cement ratio. This is because mixes with fillers and low water-cement ratios have higher densities, which agree with the lower porosity and finer porous structure observed in mixes that incorporate fillers. Mixes incorporating siliceous fillers presented better performances in the absorption of water by immersion and capillarity than mixes without them. Measuring the depth of penetration of water under pressure in various mixes makes it possible to identify those that have high compactness and impermeability. Mixes with fillers and higher microstructural densities have lower water penetration depths. After exposure to aggressive environments, none of the mixes, with and without fillers, showed signs of wearing out or deterioration. The presence of fillers in SCCs had a more significant

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influence on its shrinkage than the amount of coarse aggregates. Thus, it is possible to obtain high performance SCC in relation to its mechanical and durability properties by reducing the coarse aggregate content and incorporating siliceous fillers in the dosage. Moreover, for applications where high mechanical requirements are not necessary, it is possible to produce an SCC with high performance against the attack of aggressive agents such Cl^- and SO_3 without using siliceous fillers.

1. Introduction

Self-compacting concrete (SCC) was developed in Japan in the mid-1980 s under the direction of Professor Okamura of the University of Tokyo [1]. Previously, it was named High Performance Concrete, but was later renamed Self-Compacting Concrete. The objective was to create a type of concrete whose performance did not depend on manpower during the implementation process. In 1988, the first prototype of self-compacting concrete that worked satisfactorily in terms of shrinkage, heat of hydration, density, and other properties was successfully completed [2].

The SCC can be defined as a type of concrete whose main characteristic is its ability to flow and correctly fill the volume to be concreted by the action of its own weight, i.e., without any method of compaction [3]. The main characteristics of SCC compared to conventional concrete (OC) are its fresh state, superior fluidity, cohesiveness, homogeneity, resistance to segregation, and good finishes. These characteristics allow the concreting of more complex and/or tall reinforced concrete buildings, including the design of more complex architectural and structural elements [4,5]. In SCCs, the amount of coarse aggregates, use of fillers, and type of additive play important roles both in its mechanical and durability properties [6].

Currently, there is a strong line of research related to the use of materials with fine granulometry (powder), both natural and residual, from industry and/or mining, as substitutes for cement or fine aggregates in SCC [7–13]. Another line of research on SCCs—although less frequent but very important—deals with the study on the influence of the amounts of aggregates and paste on the properties of SCC. Along this concept, Fung and Kwan [14] carried out an analysis of the blocking effect in SCCs having different aggregate contents. They found that the fluidity of the mixture was greater with the increase in fine aggregate content, which is attributed to the ball bearing and filling effects of the finer particles. These reduced the blocking action of coarse aggregates and increased the packing density of aggregates. Kwan and Ling [15] analysed the performance of SCC by varying the amounts of aggregates in the dosage. Fly ash was used in all mixtures and the water-binder ratio was kept constant. These authors concluded that the effect of reducing coarse aggregate content and increasing the amount of fine aggregates did not present negative effects on the mechanical behaviour and nor on the depth of water penetration. On the other hand, Santos et al. [16] observed that the performance of SCC is influenced by the particle size distribution of the aggregate mix because it is related to the packing density and volume of voids to be filled. Likewise, Nikbin et al. [17] carried out a study on the effects of coarse aggregate size and volume on the mechanical resistance of SCCs, where it was observed that increasing the volume of coarse aggregates from 30 to 60% caused a non-constant mechanical behaviour. This conclusion was reached because when the volume of coarse aggregates was increased to 40%, there was a decrease in compressive and splitting tensile strengths, whereas for larger volumes (50 and 60%) these strengths increased. Jawahar et al. [18] analysed the short-term mechanical behaviour of SCCs with varying mixes of coarse aggregates. These authors concluded that the compressive strength was not affected by the variation of the proportions of coarse aggregates although other mechanical properties—unit weight, modulus of elasticity, and splitting tensile strength—were affected.

Currently, there is no consensus in obtaining SCC with a specific performance to suit the particular needs of each project using available materials. Consequently, production companies will have to rely on their own knowledge derived from experience and technical skills of their staff [19]. In this regard, research on SCC is the only instrument that can be used to respond to quality requirements for every specific use. Therefore, companies must use published results as guide in implementing their own dosages to satisfy the required performance in each of their particular applications.

Today, SCCs are widely used in the construction and building sector, particularly in the precast concrete industry. One specific use of this type of concrete is the manufacture of containers for the storage of hazardous waste. For that purpose, strict mechanical and durability requirements must be satisfied in addition to self-compactability.

Several research groups are studying cement-based materials for the immobilisation and containment of hazardous waste [20–24] with the objective that companies dealing with waste management can apply the results to their activities. In this context, SCC can be used as immobilizer and waste container in place of the commonly used OC but one with better performances both in concrete placement, and mechanical strength and durability. Simply put, SCC is concrete that is easier and safer to use.

In the present study, an analysis of the self-compacting, mechanical, and durability properties of SCCs with different dosages is carried out. Moreover, the effect of variations in the amounts of coarse and fine aggregates, and fillers in the properties of the concrete material is examined. This study has been carried out in collaboration with the National Company for Radioactive Waste (ENRESA) [25], which investigates the use of SCC as substitute for OC in structures used for storing wastes of low and medium radioactive levels located at El Cabril (Córdoba). To determine the behaviour of SCCs, a fresh-state study was first conducted by measuring self-compactability properties such as flowability, blocking resistance, and segregation resistance. Subsequently, an extensive investigation of hardened SCCs was carried out by focusing on the porous structure and its mechanical behaviour. In addition, as an important part of the research, a comparative study of the durability of the different mixes was carried out. All the properties analysed were correlated with the microstructural characteristics of the dosages. Finally, the work was completed with the study of shrinkage. The analysis of all the parameters considered made it possible to define the optimum dosage with a high degree of certainty.

2. Experimental methodology

2.1. Materials

The aggregates were gravel 4/16, coarse sand 0/4, and fine sand 0/2 (henceforth referred to as G, S1, and S2, respectively) of siliceous nature. The particle size distributions of these aggregates