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Shrinkage of self-compacting concrete. A comparative analysis

Miguel José Oliveira[a,*], António Bettencourt Ribeiro[b], Fernando Garrido Branco[c]

[a] CEPAC, Universidade do Algarve, Faro, Portugal
[b] Laboratório Nacional de Engenharia Civil, Lisboa, Portugal
[c] INESC Coimbra, Universidade de Coimbra, Departamento de Engenharia Civil, Portugal

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ABSTRACT

Self-compacting concrete (SCC) is a concrete type that does not require vibration for placing and compacting. SCC possesses special technical features and properties that recommend its application in many jobs. Nevertheless, in some situations, it has been observed an inadequate behaviour of the material at early ages due to shrinkage. The existing shrinkage prediction models were developed for standard concrete. In this paper three SCC mixtures, with different compressive strength, are studied in terms of autogenous and total shrinkage. The results are compared with the Eurocode 2 model. For the studied mixtures it was found that this model underestimates the autogenous shrinkage, while the total shrinkage is generally overestimated.

1. Introduction

The estimation of time-dependent behaviour is still one of the most difficult aspects in designing a concrete structure. Over the last few years, the use of self-compacting concrete (SCC) has increased [1–3]. SCC is a technically advanced material, which has shown to have a high potential in the areas of productivity, working conditions and even in matters arising from their inherent characteristics. This material possesses special properties which makes it more suitable for repair jobs. Nevertheless, in some real cases, unsuitable behaviour of the repair material was observed in the early stages of hydration, due to shrinkage [4–6]. The structural concrete codes which deal with time-dependent behaviour provide general rules for standard concrete, but the validation of some established stress-strain-relations have to be confirmed via laboratory testing when special mixtures are used [7,8].

The most important changes in mix design between conventionally vibrated concrete (VC) and SCC are the higher paste volume, the large use of mineral additions, and the high dosage of superplasticiser, as well as the optional resource to a viscosity-modifying agent. The variations in paste volume and binder composition lead to a significant influence on the viscoelastic properties of this type of concrete [9–13].

According to the ACI Terminology [14], shrinkage is the decrease in either length or volume of a material subsequent from changes in moisture content or chemical changes. This decrease occurs in the absence of stress attributable to actions external to the concrete [15–17]. When no moisture transference with the surrounding environment is allowed, and temperature is kept constant, this volume change is called autogenous shrinkage and is attributed to self-desiccation due to binder hydration [16,18–32]. It is accepted that autogenous shrinkage is a consequence of RH changes in the pores [33–35]. The volume of internal liquid water decreases due to hydration. Depending on the pore structure and water available, different mechanisms are triggered. Changes in the surface tension of the solid gel particles, disjoining pressure and tension in capillary water are parameters that have been discussed [16,23,36,37]. In addition to these main mechanisms, other phenomena may be involved in the early volume changes: swelling phase related to sulfate-to-alkali ratio of the clinker and the amount of free lime [19], influence of the type of hydration products [21,24,27,32,34,38], creep in the C-S-H phases [30].

Autogenous shrinkage does not usually appear significantly in normal VC, but in high-performance concrete types such as high-strength and SCC with a low water-cement ratio (w/c), autogenous shrinkage it is not an unimportant role [6,22,26,28,29,39–41]. In those cases, the low water/powder ratio leads to refined pores, and the SCC is more sensible to cracking at early shrinkage than VC, even when good practical curing is applied.

As the use of SCC becomes more widespread, some innovative techniques to combat this singularity have been developed. The means and procedures for mitigating shrinkage include cement modification, chemical admixtures, mineral additives, control of curing conditions, fibers and advanced methods of internal curing [42–44]. Lately, innovative shrinkage control methods using the combined effect of expansive and shrinkage reducing admixtures have been presented [45–48].

In order to optimize the shrinkage reducing effect, an appropriate curing is usually suggested, since curing conditions affect both shrink-

* Corresponding author.
E-mail address: mjolivei@ualg.pt (M.J. Oliveira).

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age and cracking processes [49,50].

In this study, autogenous and total shrinkage in three different SCC mixtures with different compressive strength are studied. The curing effect on the total shrinkage is also assessed. The objective of the experimental work carried out is to compare the results with the Eurocode 2 model (EC 2) [7]. A better understanding of early and long-term shrinkage will promote good performance of the concrete structure during its service-life.

2. Materials and methods

In this study, three different concrete mixtures were studied. The preparation of specimens (40×40×160 mm) was carried out according to EN 196-1, in a room with a temperature of 20 ± 2 °C and relative humidity of 55 ± 5%. Nevertheless, the aggregates and mixture proportions used in the study are different from those established in EN 196-1 (see Tables 4, 7). Furthermore, due to the low viscosity of the mixture (SCC), the test specimens were not compacted mechanically, and the SCC was just poured into molds.

The removal of molds took place about 8, 18 and 26 h after mixing, according to the strength class. This length of time was defined as the minimum necessary to ensure concrete strength between 2 and 5 MPa, to avoid specimen's damage due to molds removal. Subsequently, the specimens were weighed, their length was registered and, in the case of the samples used for measurement of autogenous shrinkage, they were sealed with a plastic film.

Section 5 of EN 12390–2:2009, Testing hardened concrete - Part 2: Making and curing specimens for strength tests [51], prescribes leaving the test specimens in the mold for at least 16 h, protected against shock, vibration and dehydration. Taking into consideration that autogenous deformation of high strength concrete may start very early [19,20,34,52] with this type of concrete the first length measurement should be made at an earlier age. The RILEM recommendation TC 107-CSP [25], for measurement of time-dependent strains of concrete, does not provide indications about demolding. The three different demolding periods (about 8, 18 and 26 h) where chosen after carrying out compressive strength tests, which have shown similar values (2–5 MPa) to those specimens tested at early ages. Shrinkage deformations of each specimen were measured using a length comparator, sensitivity of 1 µm, and gage studs on the end sections of the concrete prisms (Fig. 1). Stability of the length comparator was checked by a reference invar bar.

Samples for measurement of autogenous shrinkage were placed on two thin supports and kept sealed. The results of the measurements present fluctuation which should not be taken into account. The manual method of measurement implies some error and variation on laboratory room temperature and humidity could not be avoided.

Since first length measurement was performed very early (compressive strength not higher than 5 MPa), and the autogenous shrinkage is not relevant for stress analysis before the solid percolation, it is assumed negligible the difference between the actual autogenous shrinkage and the measured shrinkage on the sealed specimens.

At the ages of 1, 2, 3, 5, 7, 14 and 28 days, and 2, 3, 4, 5, 6, 7, 8 and 9 months, the length variation of the samples was evaluated. After mold removal, 2 levels of curing were specified:

- Uncured (air curing with the temperature of 20 ± 2 °C and relative humidity of 55 ± 5%);
- Curing until the concrete reaches near 70% of the average strength at 28 days (3, 5 or 7 days), which satisfies the requirements of curing class 4 specified in the EN 13,670 standard [53] (70% of specified characteristic 28 days compressive strength).

The specimens were prepared with Portland cement, CEM I 52.5 R, CEM II/A-L 42.5 R or CEM II/B-L 32.5N (see Table 1 – Chemical properties and Table 2 – Physical properties), according to EN 197-1, siliceous fly ash from Compostilla in Spain (Tables 3, 4), siliceous sand and limestone coarse aggregate from Algarve in Portugal (Table 5), potable tap water and three superplasticizers (Table 6).

The work presented in this paper is part of a PhD study, which involved a wide range of tests. In order to limit the amount of work and materials used, it was decided to use small specimens (40×40×160 mm^3), since the ratio between smallest size of the specimen and largest aggregate size is about 4, thus the size effects were considered having minor influence on the results.

Table 7, exhibits proportions of high (Hs), intermediate (Is) and lower (Ls) strength concrete mixtures. The concrete constituents and dosages adopted were chosen in order to produce mixtures that could be used in commercial production of concrete. Three different superplasticizers were used in order to obtain similar flow characteristics with different W/C, using normal dosages of the commercial chemical admixtures.

The three compositions were designed based on the continuity of the work presented in [54]. It was considered beneficial to keep the non-inclusion of fillers in the compositions, except those coming from cement, so that this study corresponds better to possible practical

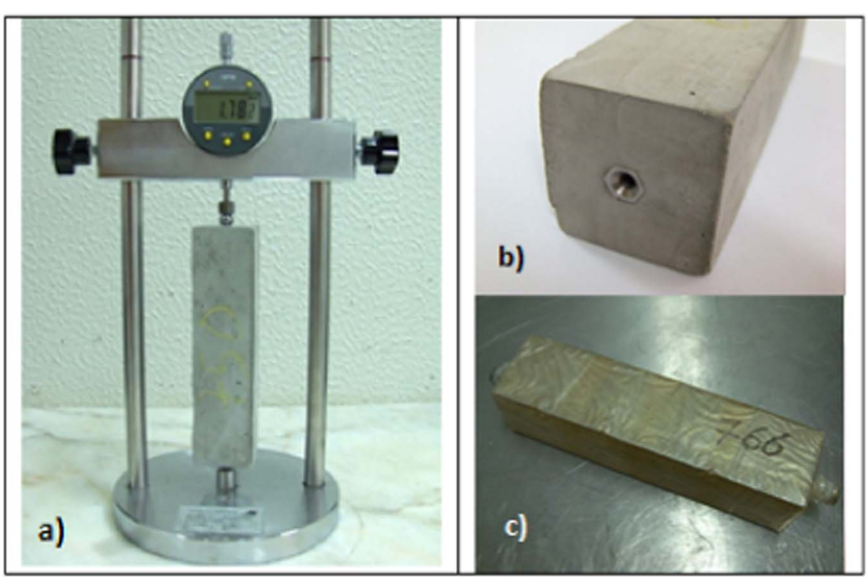

Fig. 1. Shrinkage equipment and samples; a)- length comparator; b) sample for drying shrinkage; c) sample for autogenous shrinkage.