SHRINKAGE AND CREEP OF MEDIUM-LOW STRENGTH SELF-COMPACTING CONCRETE

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ABSTRACT

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compacting. SCC, developed in Japan in the 1980s, provides a present-day and attractive challenge for many researchers, as the long list of papers on the topic corroborates. Nevertheless, the durability of SCC, especially medium-low strength SCC, provides the researcher with opportunities for study in depth.

This paper deals with the shrinkage and creep of SCC: three SCC mixtures, with 30 MPa compressive strength, are studied. The main differences among the SCCs involve the type of the cement: one SCC with type I cement and two SCCs with blended cements.

The shrinkage and creep of the three SCCs are studied and compared. Fresh properties and mechanical properties are also evaluated.

The shrinkage strains and creep are calculated by means of ACI 209 and Eurocode 2 models. These models overestimate the shrinkage strains and undervalue the creep for the studied concretes.

Keywords: Shrinkage, Creep, Self-compacting concrete, Medium strength.

INTRODUCTION

Self-compacting concrete (SCC) was originally developed in Japan in the mid-1980s, under the leadership of Prof. Okamura[1]. SCC has been increasingly used in ready-mix concrete and in the precast industry to improve several aspects of construction. In comparison with vibrated concrete (VC), SCC contains larger quantities of mineral fillers such as finely crushed limestone or fly ash, higher quantities of high-range water-reducing admixtures. In addition to this, the maximum size of the coarse aggregate is smaller. These modifications in the composition of the mixture affect the behavior of the concrete, including the shrinkage deformation and creep[2,3].

Various investigations on shrinkage of SCC have been published in the past few years and the conclusions are varied. According to some authors[3-7], the shrinkage strains of SCC and VC are equivalent for concretes with similar compressive strength. Other researchers conclude[8-11] that the shrinkage strains of SCC are higher in comparison with VC.

Similar results have been reached for creep. Some authors[7,12] conclude that the creep of SCC and VC are equivalent for concretes with similar compressive strength. Others [4,6,10,13] point out that the creep of SCC is higher in comparison with VC.

This paper presents the experimental results of shrinkage strains and creep of medium-low strength SCC (characteristic compressive strength of 25-30 MPa). Three SCCs, with the same mix design, but different types of cement were cast and tested. Limestone powder was used to make the concrete. Properties of fresh mix concrete and mechanical properties of hardened concrete were also measured.

Whereas the following section introduces the materials used, the subsequent section examines the experimental programme. Results are then presented, with discussion and conclusions being provided at the end.

MATERIALS

Three mixes of SCC were studied. These mixes were cast using different cements: CEM I 42.5 R (without additions), CEM II/A-S 42.5 N (blast furnace slag addition) and BL II/A-L 42.5 R (white cement with limestone powder addition). Siliceous rolled with grade 0/4 sand and 4/16 gravel were adopted. Limestone powder was adopted as addition, with an upper limit of 250kg/m^3. Policarboxylate superplasticizer (SIKA Viscocrete 3425) was used as admixture. No viscosity modifying agent was needed.

Table 1 shows the mix proportions for SCCs. The mix design was made to perform SCC with a 25MPa characteristic strength. Table 1 shows several differences as regards the quantity of cement, water/cement (*w/c*) ratio and admixture dose.

The concrete was mixed using a vertical-axis planetary mixer with a capacity of 100 l. Concrete samples were cast in various cylindrical moulds of two sizes (15ϕ x 40cm height and 15ϕ x 30cm of height), corresponding to the programmed tests:

Table 1. Mix proportions (kg/m^3).

Concrete	1	2	3
Cement type	CEM I 42.5 R	CEM II/A-S 42.5 N	BL II/A-L 42.5 R
Addition type	Limestone powder		
Cement (kg)	350	350	375
Addition (kg)	200	200	156
Water (kg)	193	193	206
Sand (kg)	960	960	960
Gravel (kg)	695	695	695
Admixture (kg)	7.4 (2.1%)	2.8 (0.8%)	4.3 (1.15%)
w/c	0.55	0.55	0.55

EXPERIMENTAL PROGRAMME

TESTS FOR FRESH SCC

Three tests were performed: slump flow test (in accordance with the UNE 83361 standard), L box (the UNE 83363 standard) and V-funnel (the UNE 83364 standard). Fig. 1 shows the "slump-flow spread". Fig. 2 shows the fresh concrete in the L box after testing.

Fig. 1 "Slump-flow spread" after slump flow test.

Fig. 2 Concrete in L box after testing.

TESTS FOR HARDENED SCC

In mechanical terms, three properties were measured: compressive strength (EN 12390-3 standard), elasticity modulus (UNE 83316 standard) and tensile strength (EN 12390-6 standard). The tests were performed at seven, 28 and 91 days of the age of the samples.

TESTS FOR SHRINKAGE STRAIN AND CREEP

The shrinkage strain and creep tests were performed in accordance with the ASTM C512 standard, with minor modifications. The creep tests were performed on cylindrical 15ϕ x 40cm height samples, loaded in compression to 35-40% of its strength at the age of 28 days. The specimens were loaded two at a time. The shrinkage strain tests were performed on cylindrical 15ϕ x 30cm height samples.

Before testing, four DEMEC points were glued to the specimens, placed on two opposite generatrixes (180º turned) and spaced 200mm vertically. On the creep specimens, two ground steel plates, perpendicular to cylinder axis, were glued on the bottom and upper faces to guarantee the alignment and perpendicular of loading. The uniaxial compressive load was applied by means of a hydraulic system which consisted of a pump, and accumulator, a pressure cell and a loading frame. The test set-up was placed in an air-conditioned room at 21± 1ºC and 50 ± 5% relative humidity. Fig. 3 shows a specimen under creep testing.

Strain readings were taken on two opposite generatrixes of the specimen, using a portable mechanical deformeter. Fig. 4 shows the measurement of the strain.

Fig. 3 Two specimens under creep testing.

Fig. 4 Measurement of the strains in a specimen during creep testing.

Table 2. Details of the creep tests.

Concrete	1	2	3
Duration of the test (days)	333	200	200
Stress (% of 28 days strength)	35	40	40
Oil pressure (bars)	135	175	160
Age of the concrete when the test began (days)	70	104	76

Table 2 shows the duration of the creep tests, the oil pressure and the age of the concrete when the test began.

RESULTS

RESULTS OF FRESH TESTS

Table 3 shows the results of the characterization of fresh tests.

Table 3. Fresh concrete tests results.

Concrete		1	2	3
Slump flow	T_{500} (s)	3	1.2	2
	$Ø_{500}$ (cm)	65	70	65.5
V funnel	T_V (s)	14	5.5	8.5
L box	H_2 / H_1	0.63	0.80	0.60

MECHANICAL RESULTS OF THE HARDENED CONCRETE

Fig. 5, 6 and 7 show the compressive strength, elasticity modulus and tensile strength (Brazilian test) of concrete at seven, 28 and 91 days. Figures show the average values of three valid tests.

Compressive strength is quite similar in all concretes, with it being a little lower on the concrete 3, made with white cement. Modulus of elasticity and tensile strength show similar behavior. There is almost no evolution on the modulus of elasticity from 28 days to 91 days.

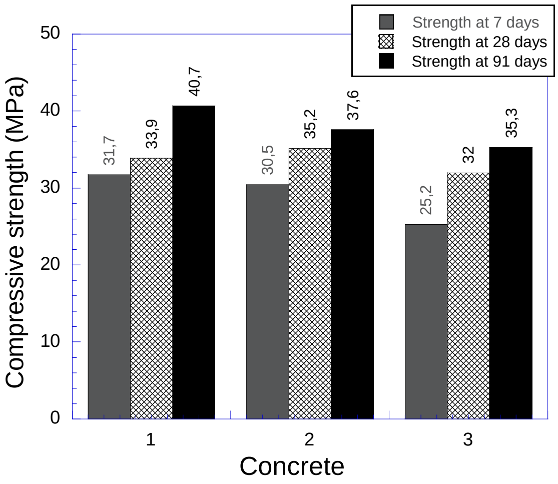

Fig. 5 Compressive strength.

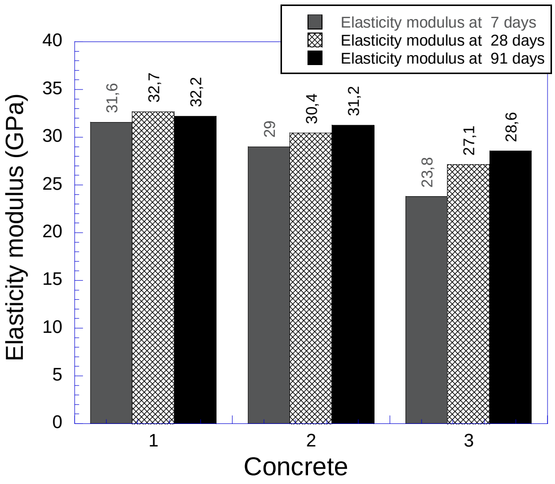

Fig. 6 Elasticity modulus.

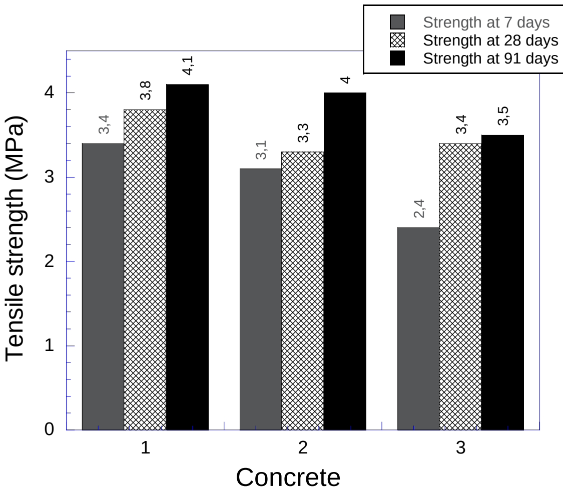

Fig. 7 Tensile strength (Brazilian test).

SHRINKAGE STRAIN AND CREEP

Figure 8 shows the shrinkage strains. Concrete 2 shows the large value of the shrinkage strain.

Fig. 9 shows the creep. Concrete 1 shows lower creep than concretes 2 and 3.

Fig. 10 shows the creep coefficient. This value is lower in concrete 1 than in concretes 2 and 3. This coefficient has been calculated as follows:

$$\varepsilon_c = \varepsilon_t - (\varepsilon_i + \varepsilon_s) \quad (1)$$

$$\varphi(t, t_0) = \frac{\varepsilon_c}{\varepsilon_i} \quad (2)$$

Where: ε_i: instantaneous strain; ε_t: total strain, ε_s: shrinkage, and $\varphi(t, t_0)$: creep coefficient.

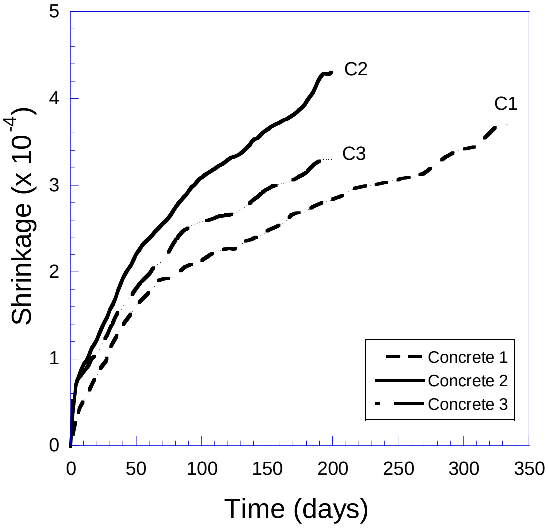

Fig. 8 Shrinkage strain.

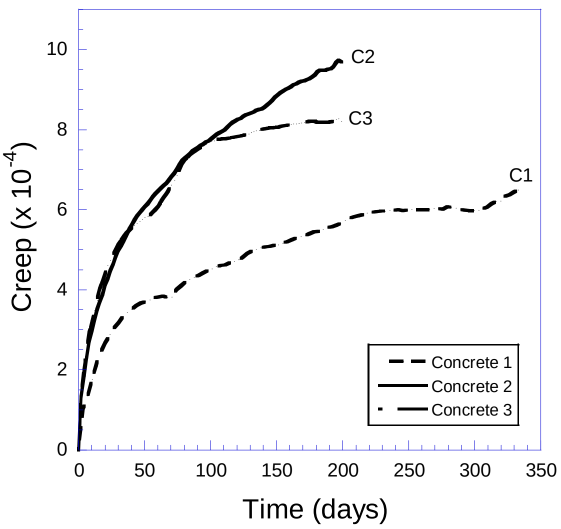

Fig. 9 Creep.

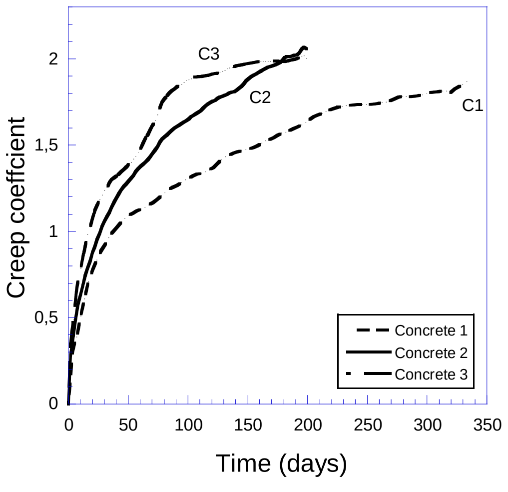

Fig. 10 Creep coefficient.

APPLICABILITY OF EXISTING MODELS

The models for shrinkage strain and creep for VC proposed by ACI[14] and Eurocode-2[15] have been used for comparison with the experimental results of the three SCCs.

Fig. 11, 12 and 13 show the experimental results and the model predictions of the shrinkage strain for the three concretes.

Fig. 14, 15 16 show the experimental results and the model predictions of the creep coefficient for the three concretes. Fig. 17, 18 and 19 show analogous results.

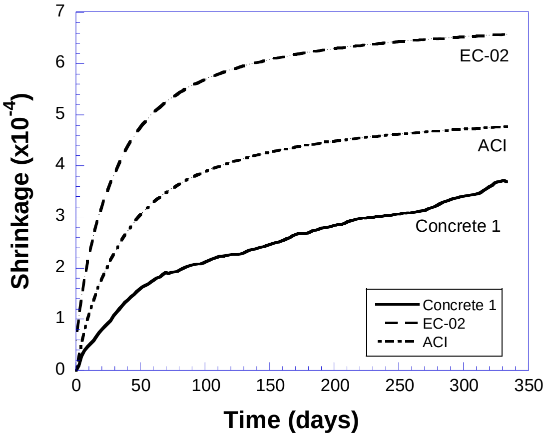

Fig.11 Shrinkage strains for concrete 1.

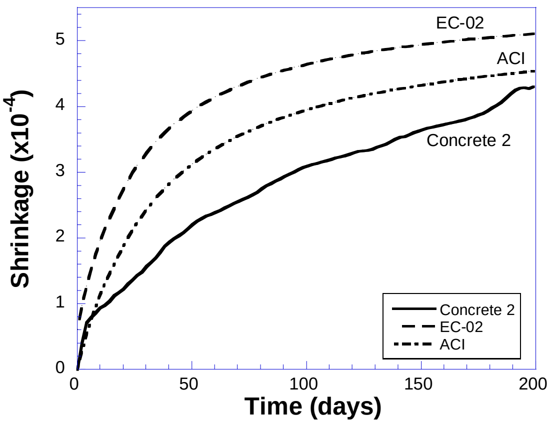

Fig.12 Shrinkage strains for concrete 2.

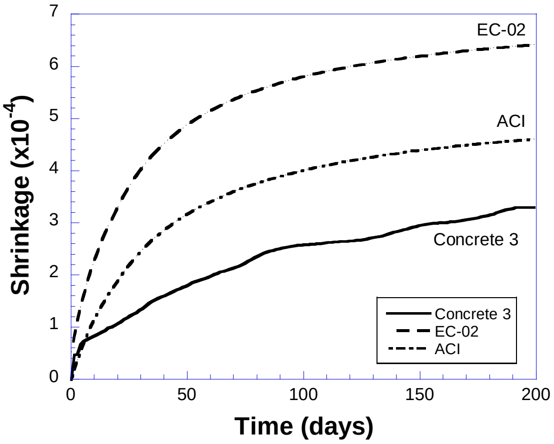

Fig.13 Shrinkage strains for concrete 3.

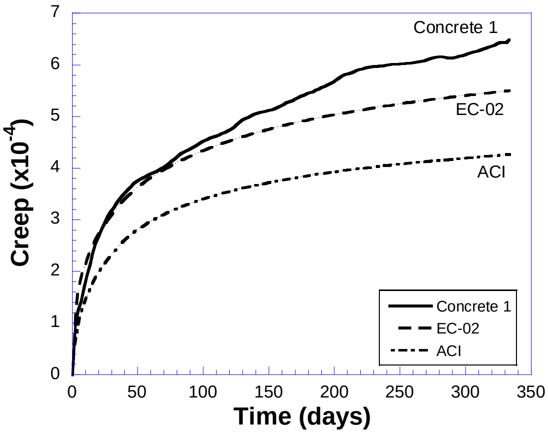

Fig.14 Creep for concrete 1.

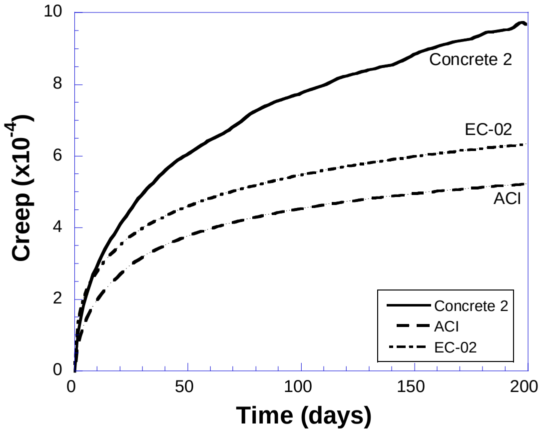

Fig.15 Creep for concrete 2.

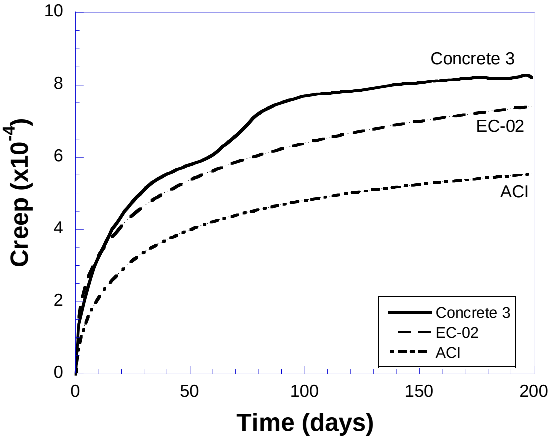

Fig.16 Creep for concrete 3.

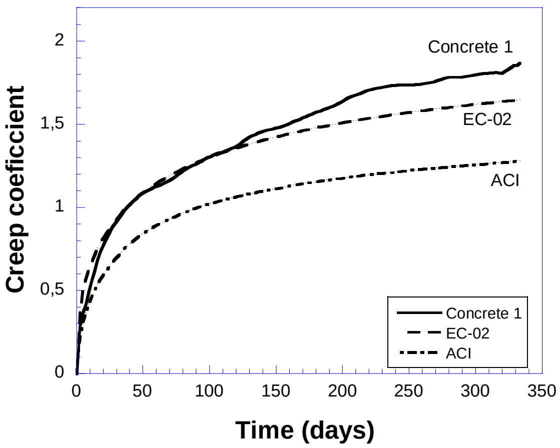

Fig.17 Creep coefficient for concrete 1.

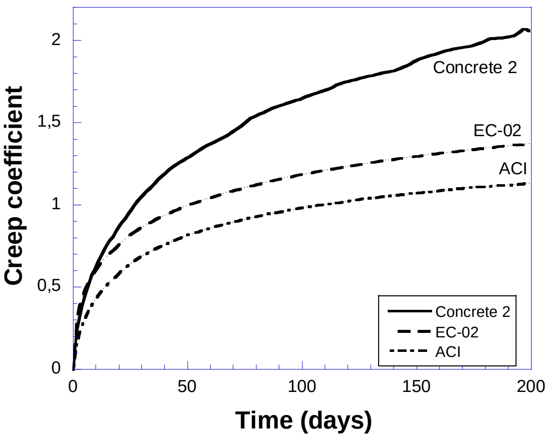

Fig.18 Creep coefficient for concrete 2.

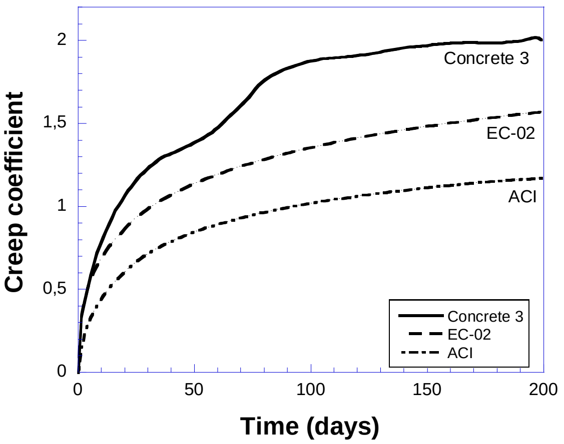

Fig.19 Creep coefficient for concrete 3.

DISCUSSION

Fig. 6 shows that shrinkage strain is larger in concrete 2 than in concretes 1 and 3. According to Chopin et al[16], whose work affirms that SCC with higher compressive strength shows lower shrinkage, the result is good for concrete 1, though it is not congruent with concrete 3, since concrete 2 shows larger compressive strength than concrete 2 and larger shrinkage strain.

The mix of concrete 3 includes the largest quantity of cement, and also the highest water/(cement + addition) ratio. These aspects should lead to the highest shrinkage strain, though it should be noted that this is not the case in the studied concretes.

The mix design of concretes 1 and 2 is rather similar and close shrinkage strains should be reached, though significant differences are found. Concrete 1 includes Portland cement, and concrete 2 cement with blast furnace slag. Neville[17] and Song et al[18] have stated that the addition and its fineness may increase the shrinkage.

Concrete 1 shows the lowest creep coefficient and concrete 2 the largest one. The main cause may be that concrete 1 was tested under stress of 35% of the strength, and concretes 2 and 3 under 40% of strength. Creep coefficient of concretes 2 and 3 is of a rather similar nature. According to the aforementioned work by Chopin et al[16], the stress level directly affects the creep of SCC.

Neville[17] states that the influence of the additions in the creep is unclear, since contradictory results may be found in the literature. Seng et al[13] found that creep coefficient increased with the increment of limestone additions; in this study, similar behavior has been shown by concrete 3. Song et al[18] affirm that the fineness of the blast furnace slag affected the creep at early ages, this effect has been observed on concrete 2, which showed higher creep at end of the test.

Eurocode-2[15] overvalues the shrinkage strains, especially for concretes 1 and 3. Improved results have been reached with ACI[14] model. Poppe et al [3] have also observed overestimation of the shrinkage when the ACI model is applied to SCC.

ACI[14] undervalues the creep and creep coefficient. A better level of results have been reached with Eurocode-2[15] model, especially at early ages.

CONCLUSIONS

- The cement type (especially the cement addition) directly affects the shrinkage strain and creep of SCC.
- ACI[14]and Eurocode-2[15] overvalues the shrinkage strains on the studied concretes (medium-low strength). Better results are reached with ACI[14] model.

- ACI[14]and Eurocode-2[15] undervalues the creep on the studied concretes (medium-low strength). Better results are reached with the Eurocode-2[15] model.

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