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Evaluation of the shrinkage and creep of medium strength self compacting concrete

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Abstract. The difference between self compacting concrete (SCC) and conventional concrete (CC) is in fresh state, is the high fluidity at first and the need for vibration at second, but in hardened state, both concretes must comply with the resistance specified, in addition to securing the safety and functionality for which it was designed. This article describes the tests and results for shrinkage and creep at some medium strength Self Compacting Concrete with added sand (SCC-MSs) and two types of cement. The research was conducted at the Laboratorio de Tecnología de Estructuras (LTE) of the Universitat Politécnica de Catalunya (UPC), in dosages of 200 liters; with the idea of evaluating the effectiveness of implementation of these new concretes at elements designed with conventional concrete (CCs).

1. Introduction

Self Compacting Concrete (SCC) is characterized by its high workability and resistance to segregation. In its basic composition it has the same materials as conventional concrete (CC), but their characteristics are different fresh. The SCC containing a larger amount of fine and maximum aggregate size is less than a CC; also for mixing water-reducing high range they are used.

It is important to note that concrete with high volumes of pasta and low volumes aggregate exhibit higher shrinkage strains (Neville, 1996), (R. Loser et al, 2009). Under the same environmental conditions, the retraction curve - Time of a SCC is very similar to that of a CC (Xiao-jie Liu et al, 2008), (De La Cruz, 2006); when resistance also remains constant, the properties (when hardened) of SCC are similar to a CC (De La Cruz, 2006), (Persson, 2001), (Bravo, 2004).

For the performance of medium strength self-compacting concrete (SCC-MS) in the cured state, it was initially decided to make the shrinkage and creep tests up to 180 days (DEMEC and gauges embedded points) (De La Cruz, 2006). Finally results were obtained up to 629 days to start the test; with the idea of meeting the deferred behavior for this type of concrete. With the completion of these trials (shrinkage and creep), they wanted to know the degree of dimensional stability over time, two (2) types of SCC-MS specifically SCC-MS with cements CEM II 32.5 R and CEM I 42.5R; for water / cement (W / C) 0.45 and 0.42; since both SCC-MS had the best features of self-compactability and compression resistance than expected, at lower cost, as De La Cruz (2006). All tests were performed at the *Laboratorio de Tecnología de Estructuras* (LTE) of the *Universitat Politécnica de Catalunya* (UPC).

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2. Experimental details

Two (2) batches were done for each type of SCC-MS (with CEM II 32.5 R CEM I 42.5 R and 120 liters each), in the forced action mixer LTE capacity of 250 liters.

Each SCC-MS were performed two (2) of characterization tests in fresh, as are trials Slump and Extension Bars with ring (De La Cruz, 2006), (Bravo, 2004), to verify self- compactability of concrete; because they are the two (2) that define processes quickly and reliably the behavior in fresh SCC. Three (3) specimens of each type of control SCC-MS were also developed for evaluating the compressive strength after curing in a humid chamber to specification UNE 83-301 (Gettu et al, 2000), at a temperature of 23 ° C and humidity on 90%, tested at 28 days according to the UNE 83-304 (Gettu et al, 2000). Dosages and results of characterization tests are shown in Table 1. In the same batches 14 cylindrical samples, 150 x 300 mm were prepared; corresponding three (3) of each type of concrete for testing shrinkage and four (4) of each type of concrete for fluence.

Table 1. Dosages (Kg/m^3) and fresh characterization and compression resistance in specimens SCC-MS [MPa]

Concrete		SCC-MS	SCC-MS
Type of Cement		II 32.5 R	I 42.5 R
W/C		0,45	0,42
Cement		392	340
Water		196	163
Additives		4,11	8,84
Sand 0-2		651	680
Sand 0-5		434	453
Gravel 5-12		723	756
Characterization Tests			
Slump	T50 [s] D_f	2	2
	[mm]	680	690
J. Ring	D_f	650	640
	C.B	0.8	0.8
Real U.W	[Kg/m^3]	2420	2420
Strength and C.V	[MPa] y [%]	30 2.9	42 2.2

These concretes were compared with a conventional concrete (CC) of the same strength. To evaluate deformations, the molds were provided with strain gauges (120 Q) of length 10 cm, arranged in the center of the vertical axis as shown in Figure 1. This is to capture the axial strain in the central third of the specimen.

Figure 1. Molds for specimens duly provided with strain gauges (De La Cruz, 2006)

Processed specimens for the tests were demolded at 24 hours of being emptied, they are polished and immersed in water in a tank located in the climate chamber with relative humidity (RH) of 50% at a temperature of 19 ° C, for 28 days.

3. Shrinkage tests

Drying shrinkage is determined for three (3) specimens of each type of SCC-MS. Once the samples were immersed in water they were connected to data acquisition equipment. This, with the idea of tracking the processes of deformation of the SCC-MS during curing. In Figure 2, the process sequence once the specimens manufactured for trials presented. After 28 days of curing in water, each specimen was adhered external measurement points (DEMEC) located each on its side surface 120° as shown in Figure 3.

Figure 2. Procedure shrinkage and creep test on specimens of SCC-MS (De La Cruz, 2006)

Figure 3. Test tubes with strain measurement points on the surface and attached comparator DEMEC N°8865 lengths. (De La Cruz, 2006)

Other readings were completed 24 hours and continued to cure at 48 and 72 hours to 42 days. To have a better understanding and control of volumetric changes that could have the SCC-MS; in Figures 4 and 5, the behavior of specimens (e values) occurs from the time the curing has ended and be kept in a climatic chamber for 42 days (RH 50% and temperature 19°C). Deformation monitoring with electronic readings during the curing time, for both concrete showed an expansion (deformation negative values), which was expected given the curing conditions to which the specimens were undergoing.

So, given the performance of the test conditions (curing in water), endogenous contribution is negligible and, therefore, the measured strains are mainly to drying shrinkage. As shown in the graphs below, the securities electronic gauges in the early hours of drying, have a rapid growth of the strain, which tends to increase more gradually to 24 hours after the two SCC-MSs. Hence, the behavior is very similar during retraction measured for both SCCs-MS.

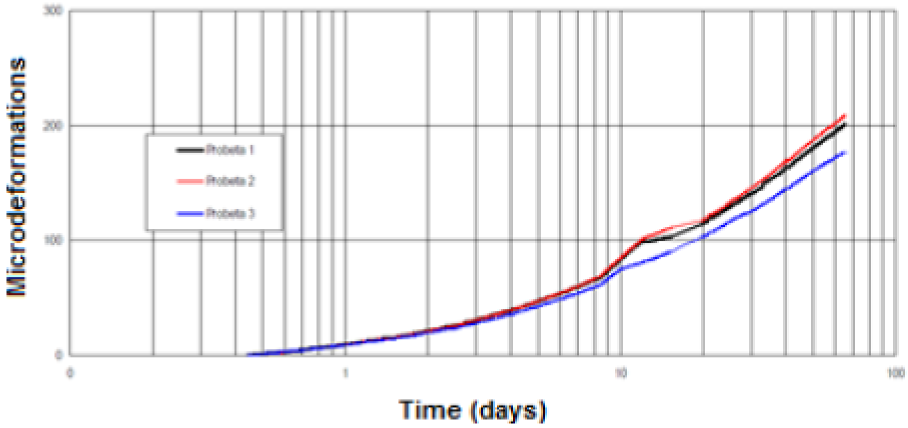

Figure 4. Evolution of the retraction SCC-MS with CEM II 32.5 R during drying (De La Cruz, 2006)

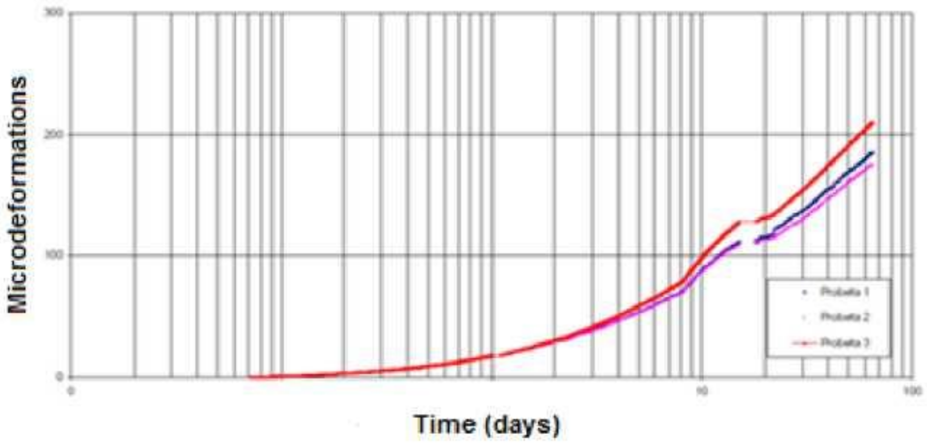

Figure 5. Evolution of the retraction SCC-MS with CEM I 42.5 R during drying (De La Cruz, 2006)

In Table 2, the results of deformation are summarized shrinkage both methods (points DEMEC and average of electronic values embedded gauge), which shows that the specific values (old) are approximately equal from 19 days.

The trend and behavior of each individual specimen and their average age (three (3) specimens for concrete) compared to the average electronic readings from the two (2) days of curing be removed. The differences in average readings deformation of the two (2) methods. For each type of SCC-MS at 28 and 42 days it is approximately 18% with CEM II 32.5 R and 25% with CEM I 42.5 R (De La Cruz, 2006).

It seems that at the age of 19 days of trial, the concrete specimens manage both internal and external balance. So the data obtained with both methods are becoming very similar, if not the same after this age. The differences are not comparatively high if one considers that the strain readings with DEMEC points, were performed manually with higher possibility of error (attached implement points- and strain measurements- sample), and electronic values are taken directly from the data acquisition equipment (embedded gauges). So, given the performance of the test conditions (curing in water), endogenous contribution is negligible and, therefore, the measured strains are mainly to drying shrinkage.

In Table 3, the shrinkage of SCC-MSs at ages 28 and 42 days and the results are presented as further research to conventional concrete (CCs), as is the Gettu et al. (2000) and Structural Concrete, EHE (2003).

Table 2. Values of drying shrinkage measured in single specimen. (De La Cruz, 2006)

Drying time (days)	SCC-MS CEM II 32.5 R (microdeformations)						SCC-RM CEM I 42.5 R (microdeformations)					
	DEMEC					GAUGES	DEMEC					GAUGES
	1	2	3	Average	C.V [%]	Average	1	2	3	Average	C.V [%]	Average
2	14	10	10	12	17	21	10	21	25	19	39	23
3	21	18	26	22	20	31	52	35	49	45	20	34
4	49	42	42	44	9	40	66	53	88	69	26	44
7	59	49	53	54	10	59	77	67	84	76	12	65
8	73	77	89	80	10	65	94	91	91	92	2	71
14	105	101	100	102	3	100	122	123	140	128	8	110
19	133	126	121	127	5	112	147	137	154	146	6	115
21	140	154	131	142	8	117	157	151	165	158	4	117
28	165	189	152	169	11	135	175	172	172	173	1	130
42	199	210	179	196	8	160	203	203	203	203	0	153

Table 3. Results of retraction points DEMEC and gauges in SCC-MS specimens (microdeformations) (Davies, 2006) (De La Cruz, 2006)

METHODOLOGY USED								
Type of concrete	**DEMEC**		**Gauges**		**By al. (CC)**	**Gettu et (2000)**	**By article (CC)**	**EHE 39º**
Days	28	42	28	42	28	42	28	42
SCC-MS CEM I 42.5 R	173	203	130	153				
SCC-MS CEM II 32.5 R	169	196	135	160	160	180	99	112

If the results established by shrinkage compared Gettu et al. (2000) (EHE), the EHE (Article 39, Section 39.7) for a CC at 42 days, it is observed that for SCC-MS with CEM I 42.5 R is higher by 27%, and for the SCC-MS with CEM II 32.5 R is increased by 30%. These percentage differences are relative, as in studies for CC by Gettu et al. (2000) (EHE), increased shrinkage is obtained at 15% that of the SCC-MSs and 38% higher than that proposed by the Article 39 of the EHE (Gettu et al, 2000). As described, the values obtained with DEMEC points and gauges, are intermediates to research and the article being compared, on the premise that these proposals are given for CC.

Besides measurements taken manually, can have more precision errors (sticking points and readings) with the embedded gauges, the results have not large percentage differences, suggesting verify the effectiveness of the measurements with both methods, being either I them suitable for determining shrinkage SCC-MSs.

One of the conclusions of De La Cruz (2006), regarding the shrinkage behavior of the SCC-MSs with different types of cement; for the same strength, they are similar. And also it notes that trends in the evolution of the shrinkage after 28 days of curing (considering zero (0) to read just after curing) for the two SCC-MSs are very similar during the 42 days of drying. In Figure 6, the evolution of the shrinkage occurring up to 530 days, the specimens SCC-MS with CEM II 32.5 R Reaching a maximum strain of 331 microstrain.

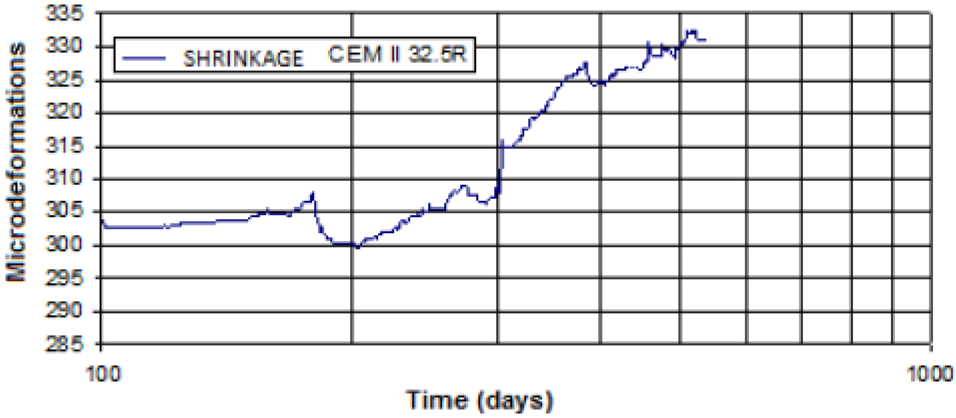

Figure 6. Evolution of drying shrinkage of SCC-MS with CEM II 32.5 R

Is fundamentally important to note that mentioned comparisons between concrete is based on mechanical and environmental properties are similar, regardless of the component materials.

4. Creep test

For the creep tests (ASTM C 512-87), they were prepared four (4) samples of each type of SCC-MS. The specimens were embedded strain gauges as shown in Figure 7, once demolded spot faced and were immersed in water for 28 days. As for the shrinkage test, once the SCC-MS (120 liters for each SCC-MS) obtained the procedure shown in Figures 1 and 2. After the curing is followed, a voltage was applied uniaxial compression equivalent to 40% of its compressive strength at the age of 28 days; that is for SCC-MS with CEM I 42.5 R of 17 MPa and with the SCC-MS CEM II 32.5 R of 12 MPa; oleopneumatic using racks of charge as shown in Figure 7.

In Table 4, results are summarized creep test deformation with both methods (DEMEC points and average values of the embedded electronic gauges).

Figure 7. Creep test in the LTE (De La Cruz, 2006)

Table 4. Values of creep measured in single specimen. (De La Cruz, 2006)

DAYS	SCC-MS CEM II 32.5 R (microdeformations)							SCC-RM CEM I 42.5 R (microdeformations)						
	1	**2**	**3**	**4**	**AV.**	**C.V [%]**	**GAUGES**	**1**	**2**	**3**	**4**	**AV.**	**C.V [%]**	**GAUGES**
2	214	175	186	196	190	2	530	305	25	228	186	186	17	650
3	249	227	301	284	260	7	590	343	409	340	238	330	9	700
4	420	325	322	399	370	6	620	466	480	357	322	400	9	730
7	406	392	403	427	410	3	690	504	550	413	381	460	9	800
8	476	462	525	539	500	5	670	595	578	574	448	550	7	830
14	637	633	642	630	640	1	830	742	648	644	606	660	6	940
19	700	805	766	756	760	5	840	886	731	749	690	760	8	950
21	721	822	781	798	780	5	840	900	742	819	728	790	7	960
28	819	910	942	896	890	5	890	1001	928	872	826	910	6	1020
42	956	1001	1117	1005	1020	6	1010	1120	1047	1001	917	1040	5	1080

If the deformations are compared with two (2) methods for each type of concrete, you can see that they are showing the same values at 28 days with cEm II 32.5 R and with a difference of 11 *%* with CEM I 42.5 R. A 42 days differences in the value of creep deformation between 4% and 6%. Electronic Observing the readings 28 and 42 days, the percentage difference between the two (2) SCC-MSs is 12%. It is older also the CEM I 42.5 R. That is consistent according to Mari's comments and Cladera (2003).

In this paper partial data and the evolution of creep deformation (under constant pressure) of the SCC-MSs occur during the 629 days of being subjected to load in the racks (I report given by the LTE (records sent to Colombia by the LTE (UPC) / 2008)). This evolution occurs both with electronic readings of gauges, as with DEMEC points.

To determine the creep deformation, it must be subtracted from the total deformation (£$_{total}$) (Eq. (1).) the initial deformation and shrinkage strain. The voltage- dependent deformation, at time t, for a constant voltage applied at t0, can be estimated according to the Article 39 of the EHE (2003) (Gettu et al, 2000), the following criteria:

$$\varepsilon_{total} = \sigma(t_0) \cdot \frac{\frac{1}{E_{0,t0}} + \varphi(0 - t0)}{E_{0,28}} \tag{1}$$

Where:

σ(to): It is the constant applied tension in to

E 0,t0 : Initial modulus of elasticity of concrete at the time of application to the load (defined in section 39.6 of the EHE (2003) (EHE)).

E0,28 : Initial modulus of elasticity of concrete at 28 days of age (defined in section 39.6 of the EHE (2003)).

φ (t-t0): Creep coefficient whose expression involves φo basic creep coefficient.

Then the evolution of creep for SCC-MSs occurs after 530 days of experiment. In Figures 8 and 9, the evolution of creep deformation occurs in SCC-MSs with cements CEM I 42.5 R and CEM II 32.5 R (Barcelona-Spain).

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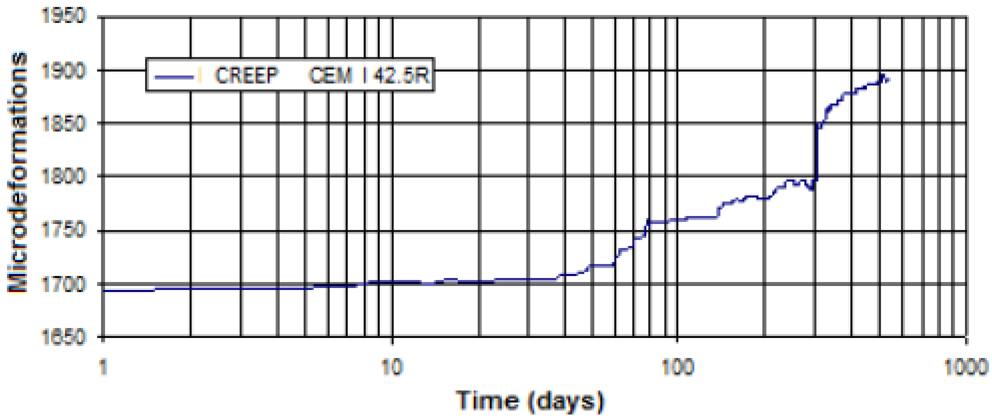

Figure 8. Evolution of the creep of SCC-MS with CEM I 42.5 R

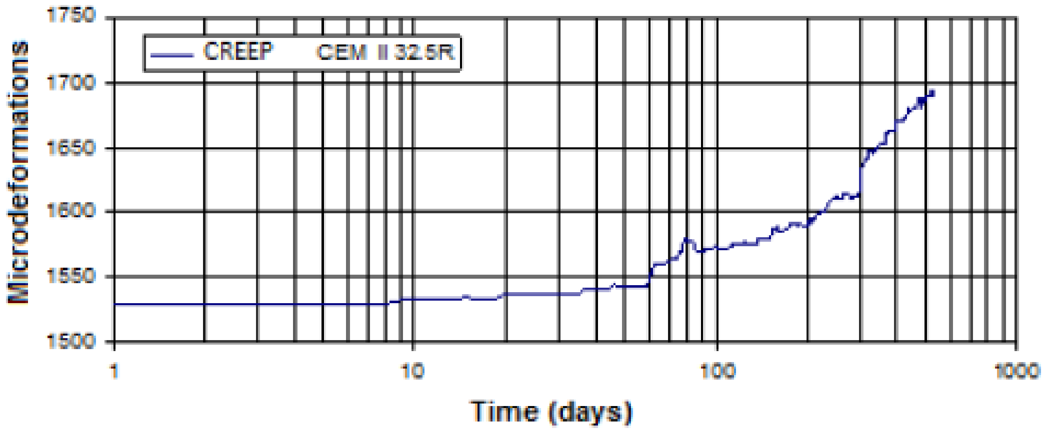

Figure 9. Evolution of the creep of SCC-MS with CEM II 32.5 R

To calculate the evolution of the flow coefficient ($) two (2) SCC-MSs with electronic reading values (gauge), the following Eq. (2) is applied according to Article 39 of EHE (2003):

$$\varphi = \frac{\varepsilon_{fluencia}}{\varepsilon\sigma} - 1 \quad (2)$$

With recent records deformation (microstrain) of the specimens prepared for determining shrinkage, creep coefficient ($) and creep of the SCC-MSs, it is shown in Figure 10. Next, the evolution of creep coefficients ($) for both concretes.

ϕvalue, for SCC-MS with CEM II 32.5 R 629 days to prepare specimens, is 1.67, as shown in Figure 11. Similarly, the $ results are presented for SCC-MSs concretes with CEM I 42.5 R, up to 629 days:

As shown in the previous figure, ϕ values are lower for concrete with CEM I 42.5 R 50% at 28 days and 61% at 42 days, compared to the other concrete CEM II 32.5 R.

According to the results of De La Cruz (2006), which are presented in Table 5, in the same specimens and 169 days, ϕ it had a value of 1.15 for SCC-MS with CEM I 42.5 R . Establishing compared to Cc and SCC (Roncero et al, 2001) ϕ has a value of 0.80 and 0.81 respectively; which according to the experimental data to 629 days, it is 1.24 (see Figure 11).

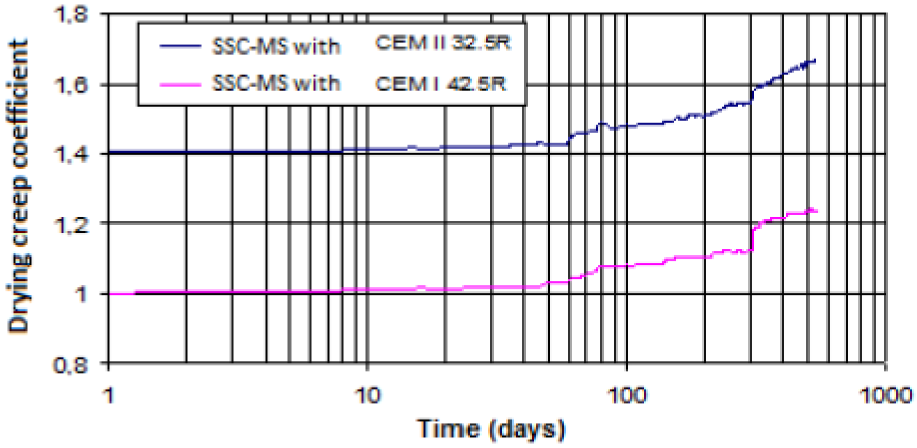

Figure 10. Evolution of creep coefficient (ϕ) for SCC-MSs with CEM II 32.5 R and CEM I 42.5 R

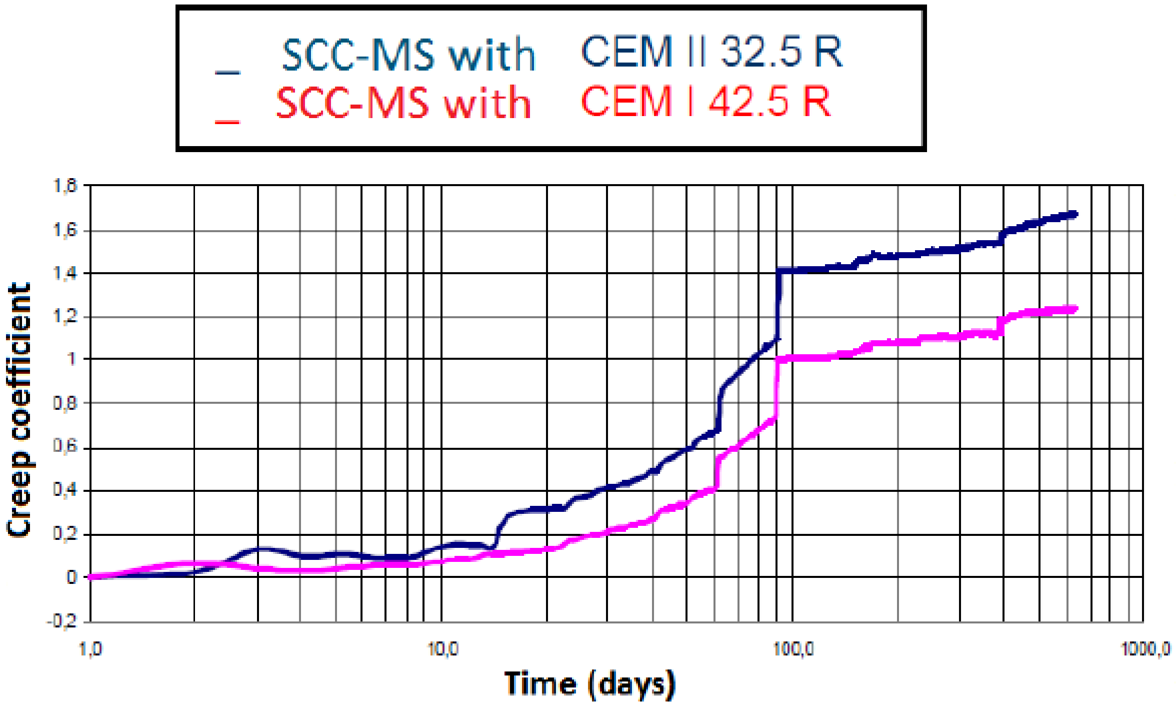

Figure 11. Evolution of creep coefficient (ϕ) for SCC-MSs with CEM II 32.5 R and CEM I 42.5 R

Table 5. Comparison of creep coefficients up to 169 days. (De La Cruz, 2006)

TYPE OF CONCRETE (y)(	169 DAYS)
SCC CEM I 42.5 R	0,81
SCC-MS CEM I 42.5 R	1,15
CC (Roncero et al. (2001))	0,80

In Table 6 below, the values of ϕ for concrete with the same mechanical properties similar environmental conditions while testing are presented, as proposed calculation Article 39 (EHE (2003) (Gettu et al, 2000)), Roncero et al. (2001) and Mari and Cladera, 2003 ("RH = 60%"); and it is observed that the value of ϕ with CEM I 42.5 R is less than for concrete with CEM II 32.5 R, by 75% and 62% respectively.

Table 6. Coefficients of creep ($) with points DEMEC and gauges in SCC-MS specimens (microdeformations) (Davies, 2006) (De La Cruz, 2006)

METHODOLOGY USED					
TYPE OF CONCRETE	**DEMEC**	**GAUGES**	**BY EHE**	**Roncero et al (2001)**	**Man y Cladera (2003)**
Days	28 42	28 42	42	42	42
SCC-MS CEM I 42.5 R SCC-MS CEM II	0,10 0,23 0,40 0,61	0,21 0,27 0,40 0,60	180	0,60	1,0

For purposes of analysis, comparing the electronic results (more data) with the calculations for CC 42 days of trial, as proposed by Article 39 the difference is 61% for SCC-MS - CEM I 42.5 R and to the other of only 14%. But if we make the same comparison with the research $ Roncero et al. (2001), the percentage difference is 55% for SCC-MS with CEM I 42.5 R and zero (0) for SCC-MS with CEM II 32.5 R. Finally, if we consider the proposal $ according to Mari and Cladera (2003), the SCC- MS with CEM I 42.5 R presents a percentage difference of 73% and 40% with the SCC-MS with CEM II 32.5 R, considering that this proposal is the most remote research (See Table 5.).

Another conclusion of De La Cruz (2006), regarding the creep coefficient ($) of the SCC-MSs with different types of cement, and according to estimates suggesting CCs Article 39 is applicable to SCC-MSs.

5. Conclusions

- As the percentage comparisons with the SCC-MS CEM II 32.5 R, it has a deformation similar to a CC yield the same mechanical properties. This situation differs in a high percentage to the other concrete CEM I 42.5 R. This does not preclude in any way that the latter has a strain similar to that of a CC creep, as it has been compared to concrete characteristic strength of 35 MPa, and its compressive strength at 28 days is 43 MPa.
- If the methodologies and approaches used only with SCC-MS with CEM II 32.5 compared, one can say that the results have not large percentage differences, suggesting verify the effectiveness of the measurements with both methods, whichever one it appropriate to determine the deformation creep of the SCC- MSs.
- It seems that the calculations suggesting the Article 39 to determine the evolution of the creep coefficient is applicable to SCC-MSs.
- The strain values obtained to 629 days, the specimens for shrinkage and creep tests show the same trend until 169 days (De La Cruz, 2006), but are increasing. Higher for SCC-MS with CEM II 32.5 R, which for SCC-MS with CEM I 42.5 R.
- As in the case of determining the retraction of this type of concrete, it is not excluded in any way, do a more thorough study of creep deformation and evolution of $ for SCC-MSs, continuing with measurements and calculations to help identify reliably, the deferred behavior of this type of SCCs.

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