Twin Covilhã International Conferences
5th Int'l Conference on The Concrete Future
26-29 May 2013, Covilhã, Portugal

# ASSESSMENT OF MEASURES TO MITIGATE CONCRETE SHRINKAGE

**Júlio Nunes* and Aires Camões†**

*University of Minho, Department of Civil Engineering
4800-058 Guimarães, Portugal
e-mail: <julio_nunes@hotmail.com>

**Keywords:** shrinkage, autogeneous shrinkage, drying shrinkage, concrete.

**Abstract**. *Concrete can have high tendency to shrink over time and this can cause its cracking and thus jeopardize its durability and increase significantly maintenance, repair or rehabilitation costs. In this context, this study intends to evaluate measures to mitigate concrete shrinkage through the incorporation of different percentages of fly ash (FA), shrinkage reducing admixtures (SRA) or superabsorbent polymers (SAP). For this, one has developed an experimental campaign on mortar specimens that consisted in the manufacture and subsequent shrinkage measurement of free specimens and sealed ones made with the different selected mix-designs. Shrinkage was recorded along time up to 304 days of age and not only the total shrinkage was evaluated so as the autogeneous and drying shrinkage also. For the case of FA addition, one has studied different percentages of cement replacement by weight: 20, 40 and 60 %. The SRA type and content was selected based on previous study which permits to obtain the best shrinkage performance. As for the mortar containing SAP one has adopted a dosage currently used. As a complement to the shrinkage measurements, one has evaluated also the mass loss of the samples and the compressive strength of the compositions over time. All specimens were placed in a controlled environment with an average temperature of 23.5 ºC and 89.0 % of moisture content. Based on the obtained results one can conclude that: the inclusion of FA considerably decreased the total shrinkage and also reduced, in an even more significantly way, the autogeneous shrinkage. These effects were more pronounced as the FA dosage had increased. However, it hasn't had a great effect reducing drying shrinkage; the addition of SRA was responsible for an important reduction of all the types of shrinkage measured, being more efficient on the drying shrinkage; the inclusion of SAP was beneficial in the mitigation of all types of shrinkage, being more effective in autogeneous shrinkage. The composition with 60 % of FA was the most efficient in the decreasing of autogeneous shrinkage and the one with SRA was the most effective in the reduction of drying shrinkage.*

## 1 INTRODUCTION

Concrete is a material subjected to deformation over its service life being this phenomenon

† University of Minho, Department of Civil Engineering, 4800-058 Guimarães, Portugal, aires@civil.uminho.pt

caused, among other actions, by shrinkage (volumetric variation). One can say that in the free state, that is with any degree of freedom restricted and without any type of external action, concrete can deform without suffering tensional stresses of such a magnitude that can cause it cracks or any other type of damage. However, one already knows that even in these conditions the aggregate volume will offer a certain degree of restriction to deformations of binder paste which will generate internal stresses. Nevertheless, the most critical situation happens when displacements of concrete elements are partial or totally restricted as currently happens in beams, slabs or columns. In this case, deformations by shrinkage can cause internal tensional stresses that can cause cracks when the resulting stress due to the restriction to contraction exceed the concrete tensile strength and, consequently, can create durability problems[1].

The cracks on concrete caused by shrinkage let the concrete more vulnerable to penetration of aggressive substances from the surrounding environment. This harmful substances can be gaseous (nitrogen, oxygen, $CO_2$, etc.) or liquid (water, dissolved ions, etc.) ones and can contribute for an increase of concrete degradation and, consequently, diminishing its service life. Then, a significant increase of the maintenance, repair/rehabilitation costs will be necessary. These cracks, besides to affect the performance pd concrete, namely its durability, also can cause aesthetic problems.

On the following figure (Figure 1), one can see very evident cracks on concrete surface elements due to shrinkage.

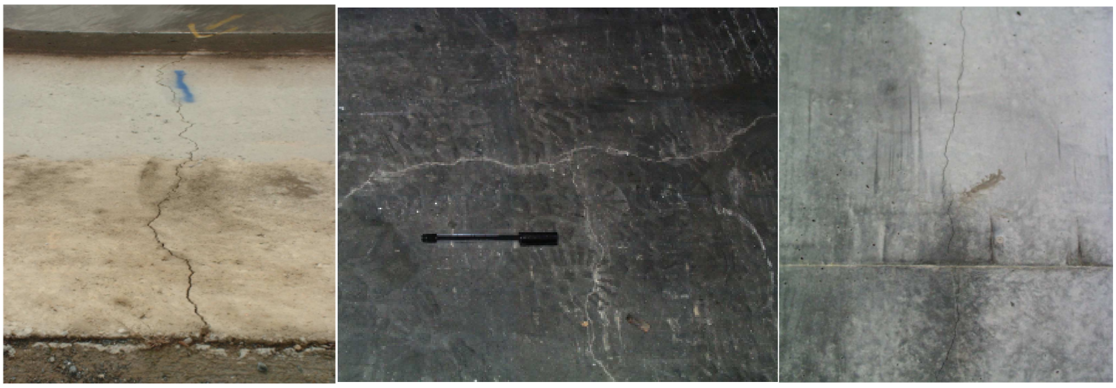


Figure 1: Shrinkage cracks in concrete elements[2].

In this context, taking into account shrinkage can be a key factor in the conception, in the design, in the overall constructive process of concrete structures and also during its behaviour in service[3].

The influence of shrinkage in concrete durability has instigated interest of many researchers in studying concrete shrinkage to better understand this phenomenon and, thus, trying to find solutions to minimize its effect. The present study also has this main objective, aiming to assess measures to mitigate concrete shrinkage. One intends to evaluate the shrinkage reducing effect due to the presence of different materials added in the concrete mixture: fly ash (FA); shrinkage reducing admixture (SRA) or a superabsorbent polymer (SAP).

The selection of FA as a way to prevent shrinkage may be justified considering that such addition can be responsible for, on one hand, a decrease on mixing water and, on the other hand, for a finer porosity matrix, hindering water outlet[4]. One also already knows that having a decrease on cement content there will be an autogeneous shrinkage reduction[4]. Therefore, replacing cement by FA will result in a binder with less susceptibility to react and shrink, and it is expectable that it will be advantageous for autogeneous shrinkage reduction. Nowadays, SRA admixtures are one of the most common ways used to control concrete shrinkage. SRA has the property to reduce the water surface tension present in the pores by decreasing the capillary pressure. This way one can reduce drying shrinkage and consequently concrete cracking[5, 6]. The use of polymers in concrete in order to decrease shrinkage was recently tested and studied[7]. Among the polymers used one can stand out the superabsorbent ones (SAP) which have the ability to absorb water up to 5000 times its own weight[8]. The size of its particles is about 100 to 150 μm and when mixed saturated on cement pastes or mortars increases about three times its size due to water absorption[9]. In some studies the utilization of SAP in cement pastes or mortars varies between 0.3 % and 0.6 % of cement mass[10, 11]. In spite of the scarce quantity of studies related to concrete shrinkage containing SAP its inclusion in this study is justified once it is expected that one of their benefits in cementitious mixtures will be both the reduction of self-desiccation and the portion of shrinkage associated to it (autogeneous shrinkage). Such is verified once SAP makes available additional water to cement hydration over time providing internal curing and by the fact of its ability to absorb large quantities of water and fill in open pores causing a drying shrinkage decrease[10, 11, 12].

In this context, one has prepared an experimental program to evaluate the efficiency of these three different measures for the mitigation of total, autogeneous and drying shrinkage of concrete. The effect of percentage of cement replaced by FA was also evaluated aiming to evaluate FA potential to reduce the different types of shrinkage.

In addition to the shrinkage determination over time some complementary tests were also realized. One has determined the specimens mass loss over time once drying shrinkage is intimately related to water loss to the external surrounding environment. The compressive strength of the tested compositions was also determined in order to evaluate the effect of FA, SRA and SAP inclusion on concrete mechanical strengths.

Despite of using mortar specimens this experimental program was carried out in order to qualitatively extrapolate the conclusions for concrete since the concrete part which suffers shrinkage is the binder paste. Despite the obvious drawback of the non possibility to correlate results obtained in mortars with the ones of equivalent concretes it is possible to make a comparative analysis between the various solutions tested. The use of mortar specimens was motivated by the inherent advantages of their use: ease in manufacturing mortar compositions in spite of concrete ones; better handling of specimens and less space taken up on packaging and storage; possibility of using a method for measuring the shrinkage simpler, effective, economical and occupying less space.

## 2 EXPERIMENTAL PROGRAM

### 2.1 Materials and test procedures

The mortar mixtures studied are presented on table 1. The cement used on all the mortar compositions was a CEM I 42,5R type with a density of 3159 kg/m$^3$. The FA used was from the Portuguese thermoelectric power plant of Pego, presenting a density of 2200 kg/m$^3$ and a high loss on ignition with a medium value experimentally determined of 7.3 %. This value of loss on ignition permits to frame these FA in category C of EN 450-1[13]. The selected SRA was a commercial one: Sika Control 40. The SAP used was a common one used in diapers. In all the mixture one has used rolled river sand with a density of 2650 kg/m$^3$.

| Mortar | Cement [g] | FA [g] | Sand [g] | Water [g] | SRA [ml] | SAP [g] |
|---|---|---|---|---|---|---|
| Ref. | 450 | - | 1350 | 225 | - | - |
| FA20% | 360 | 90 | | | - | - |
| FA40% | 270 | 180 | | | - | - |
| FA60% | 180 | 270 | | | - | - |
| SRA | 450 | - | | | 9.0 | - |
| SAP | | - | | | - | 2.7 |

Table 1: Mortars composition

The reference mortar, designated “Ref.”, contains only cement, fine aggregate and water and is a chemical admixtures or mineral additions free mortar. Not only this reference mortar but also the remaining mortars were manufactured with a W/B of 0.5 (in which “W” represents water and “B” the total binder material used, i.e. cement plus FA). Mortars containing FA are called “FA20%”, “FA40%” and “FA60%”, and were produced replacing cement by the following FA dosages by mass: 20 %, 40 % and 60 %. The mortar containing shrinkage reducing admixture is denominated “SRA” and was produced with a SRA dosage of 2 % by cement mass. The selection of this SRA dosage of 2 % was based in previously work[6] which had permitted to quantify the dosage that takes more effect on shrinkage reduction. The “SAP” mortar was manufactured with a SAP dosage of 0.6 % of cement mass.

The mortars mixture was based on the process described on EN 196-1[14]. The SRA was added to the mixture 30 seconds after the time zero (when water was mixed with cement) while the SAP was included dry and in conjunction with cement.

### 2.2 Test procedures

The present study was developed considering the realization of three different types of tests: compressive strength, shrinkage and mass loss.

To determinate the compressive strength of mortars over time cubic specimens of 50 mm edge were used. For each type of mortar 3 specimens were manufactured for testing at each selected age. Compressive strength tests were realized at 7, 28, 56 and 90 days of age.

The selected method to evaluate the different mortars shrinkage was based in the American standard ASTM C 151[15]. One has used 25x25x250 $mm^3$ mortar specimens with inserted stainless steel studs partially embedded on each top. Different specimens were produced, some for the measurement of total shrinkage (free specimens), and others, completely sealed, for the measurement of autogeneous shrinkage. These procedures also have allowed estimating drying shrinkage by subtracting the autogeneous shrinkage to the total shrinkage. The sealed specimens were involved on various layers of polyethylene film. After that, each one was placed and conserved in a plastic bag with hermetic closing. For each mortar type three free specimens and three sealed ones have been produced.

This method also requires a measuring device composed by a steel frame containing a dial gauge. The specimen's length will be measured along time adjusting its end studs to the measuring device allowing registering the mortars shrinkage over time. The specimens after the demoulding, labelling and, in the case of sealed specimens, the sealing, were immediately measured with one of the faces positioned to the operator, annotating the value provided by the comparator. Afterwards, effectuating rotations on specimens the values for all the other faces were registered. After, the stud position of the specimens was reversed and the measurements for each face were once more recorded. This process was repeated over time, more specifically at 3, 7, 13, 20, 28, 42, 56, 90, 124, 169, 214, 259 and 304 days of age. Before putting each specimen on the steel frame a reference bar of stainless steel was also tested always in the same position. The continuously measurement of this reference bar permits to take into account possible maladjustment of the inserted studs into steel support and even of the measure equipment (entering directly to the shrinkage calculation). Furthermore, using the reference bar will annul the effect associated to the variation of length due to eventual thermal variations in specimens once that the coefficients of thermal expansion of standard bar and mortar specimens are similar. Observing Figure 2 one can see the overall setup of this measurement method.

In parallel to the mortars shrinkage tests and for its complement one has determined the mass loss over time for each mortar specimen used in the shrinkage tests. Before each reading of length, the free and sealed specimens were weighted on a high precision balance, placed in the same room where the shrinkage measurement was performed.

All the measured specimens were maintained in an environment under controlled temperature and moisture. Along the all the tests duration the temperature was recorded and attained an average value of 23.5 ºC, oscillating among the minimum value of 22.5 ºC and the maximum value of 25.5 ºC. The moisture content was also recorded and achieved an average value of 89 %, resulting from a minimum of 80 % and a maximum of 94 %. Along the total time of this experimental campaign all the equipments used for measuring mortars shrinkage and its mass loss were also maintained at the same room under the same conditions of temperature and moisture.

Figure 2: Measurement device method for testing mortar shrinkage.

## 3 PRESENTATION AND ANALYSIS OF RESULTS

### 3.1 Compressive strength

Figure 3 presents the average results of compressive strength obtained over time (from 7 to 90 days) on all the tested mortar specimens. The compressive strength loss over time of mortars containing FA, SRA and SAP relatively to the reference mortar is shown in Figure 4.

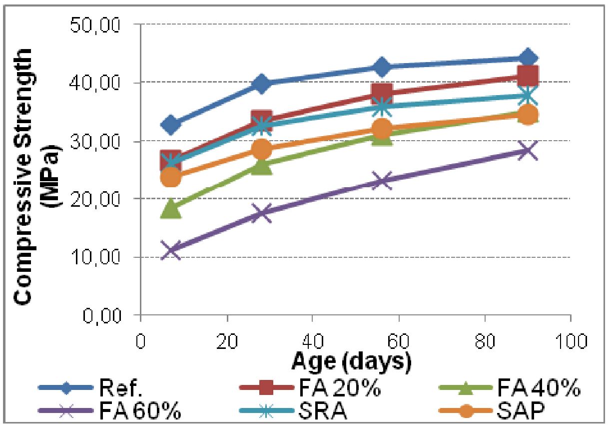



Figure 3: Compressive strength test results over time.

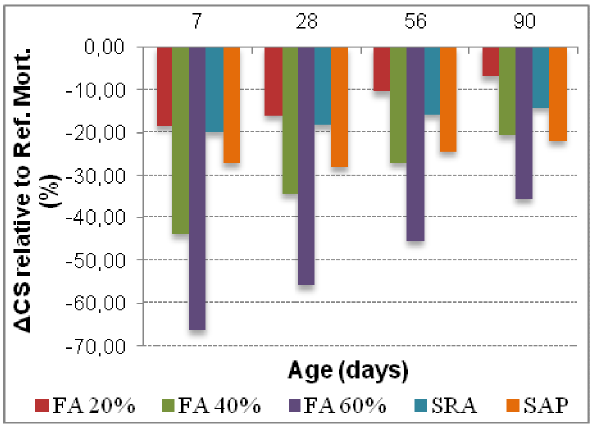



Figure 4: Compressive strength variation related to the reference mixture (Ref.).

Observing Figures 3 and 4 one can clearly see that all the tested measures to mitigate shrinkage negatively affects the compressive strength. These same figures show that for all the ages the higher the FA content, the higher is the compressive strength loss. However, as expected, compressive strength decrease on FA mixtures is softened over time. This recovery of compressive strength is more pronounced with the increase of FA content. At 90 days of age the compressive strength decrease of FA40% mixture is similar than SAP one. For 20 % of cement replacement by FA (FA20%) the strength loss is similar than SRA mixture at 7 days of age but at 90 days of age the FA20% is much better. FA20% compressive strength decrease is only about 7 % instead of SRA that, at the same time, presented a compressive strength loss of about 15 %. Comparing to reference mixture the SRA and the SAP compositions had demonstrated a slightly tendency to recover compressive strength over time.

It should be noted that the addition of SRA caused a decrease on compressive strength of about 20 % at 7 days of age and 15 % at 90 days therefore significant. More significant is the negative effect of the incorporation of SAP whose reduction of strength surpassed 20 % at 90 days of age.

### 3.2 Mass loss

Figure 5 presents the obtained mass loss results over time of all the free specimens manufactured. As it was expectable, this figure demonstrates that all the mixtures achieved a higher mass loss on early ages. After 169 days of testing one can see that there was a stabilization of mass loss in all the compositions. In this figure and comparatively to the reference mixture one can generally observe a greater mass loss for the FA compositions. One can also see that for all ages the bigger the dosage of FA the greater the mass loss was. This behaviour was possibly due to the fact that the pozzolanic reaction of FA was slow. This aspect could result in a bigger quantity of released free water that could evaporate during a period of time longer than in the reference mixture. This fact is coherent with the following that one can observe through Figure 5: the reference mixture showed a higher mass loss velocity until about 7 days and the FA compositions showed a bigger mass loss until about 13 days. Starting from this age FA mixtures showed a lesser mass loss velocity. By observing the same figure it is as well possible to verify that the SRA mixture also had a bigger mass loss than the reference one. However, the SAP mixture showed a lesser mass loss than the reference one until about 20 days of testing. Although, after 28 days this kind of mortar started to have loss mass values greater than the reference mortar.

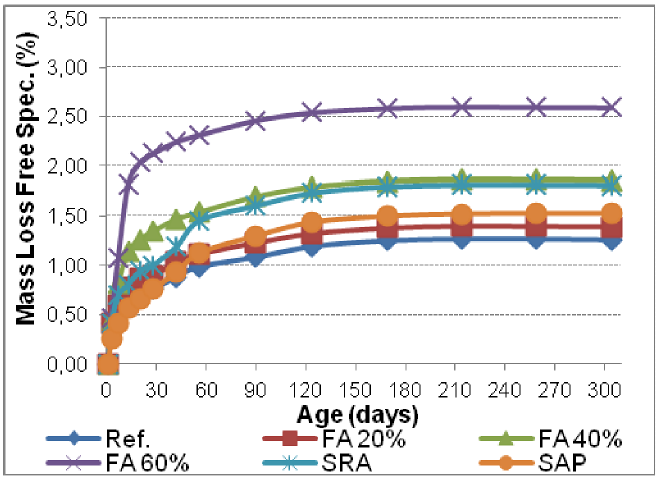



Figure 5: Mass loss of free specimens over time.

Concerning sealed specimens all of them showed an extremely similar behaviour over all the testing time. Furthermore, it was verified that the mass loss of all specimens assumed values fairly reduced over the entire experimental program. So, one has considered that the results of mass loss can be considered negligible for sealed specimens. These results also demonstrate that the procedure adopted to seal the specimens seems to be effective once that the water exchanges with the external environment were considered neglected.

## 3.3 Shrinkage

### 3.3.1 Free specimens

The shrinkage of free specimens can be assumed as the total shrinkage, i.e., the sum of all the types of shrinkage that occurred. The main results of the length change measurements of the tested specimens over time are presented in Figure 6. In Figure 7 one can observe the relative shrinkage percentage variation of free specimens over time for mixtures containing FA, SRA and SAP relatively to the reference mortar. These variations can be seen as an efficiency indicator of the incorporation of these materials on cementitious mixtures.

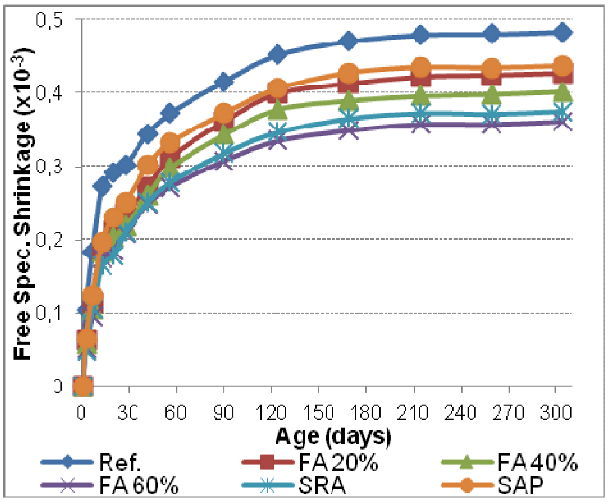



Figure 6: Free specimens shrinkage over time.

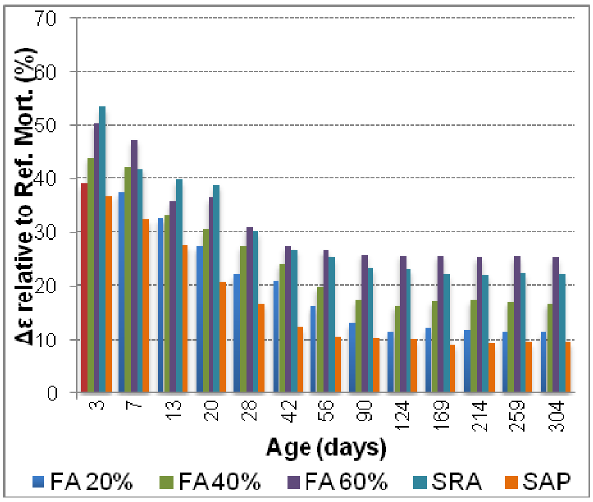



Figure 7: Free specimens total shrinkage variation related to the reference mixture (Ref.).

Through observing Figure 6 one can verify that all the mortar free specimens have suffered the most part of shrinkage on the first ages. One can also conclude that as from about 214 days the shrinkage has stabilised. This stabilisation was expected as the specimens shape and dimensions favours water outlet to the external environment. Through the analysis of Figures 6 and 7 one can see that comparatively to reference mixture all the mortars containing FA have showed a significant reduction of total shrinkage for all the tested ages. In these figures one can also observe that for all ages the bigger the FA dosage the lesser the mortar shrinkage. Figure 7 demonstrates that the efficiency on the reduction of total shrinkage of all the mortars with FA, in relation to the reference mortar, has tendency to decrease until about 56 days. After that age the efficiency tends to remain stable until the end of the experimental work. In this figure one can also observe that the mixtures FA20%, FA40% and FA60% have shown greater efficiency at 3 days reaching about 40 %, 45 % and 50 %, respectively. At the end of the experimental campaign, at 304 days of age, the efficiency was approximately 12 %, 17 % and 25 %, respectively. An important mitigation in all ages on total shrinkage was detected in SRA mixture being it quite explicit in both Figures 6 and 7. Figure 7 shows that the SRA mortar efficiency decreases over time until 90 days losing this tendency after this age. The same figure highlights that SRA mortar have showed a greater efficiency of about 54 % at 3 days and at the end of the test, at 304 days, an efficiency of about 22 %. Through both figures one can verify also that the use of SAP have reduced total shrinkage in all ages. Figure 7 shows that the mitigation of total shrinkage due to SAP usage has had a tendency to decrease over time until 56 days of test. After this age the shrinkage reduction capacity remains unchanged. The SAP has caused a major efficiency of 36 % on reducing shrinkage at 3 days and at 304 days a lesser efficiency of about 10 %. Among the tested measures to reduce shrinkage SAP was the worst in reducing free shrinkage.

### 3.3.2 Sealed specimens

The shrinkage of the sealed specimens can be considered as the autogeneous shrinkage. In Figure 8 one can see the recorded shrinkage over time of the sealed specimens and in Figure 9 the percentage decrease variation over time of the sealed specimens' shrinkage containing FA, SRA and SAP relatively to the sealed specimens' shrinkage achieved in reference mortar.

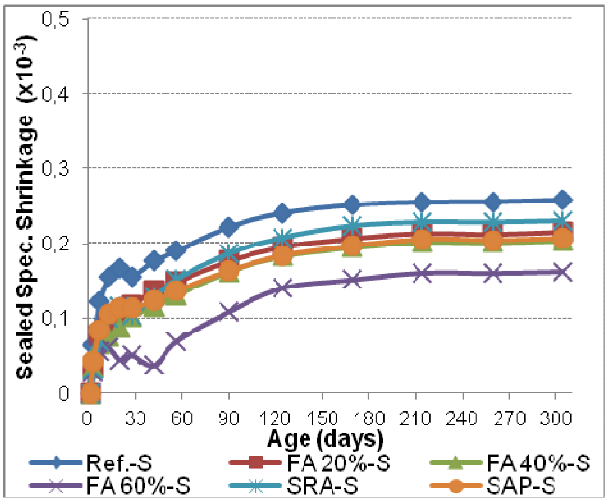



Figure 8: Sealed specimens shrinkage over time.

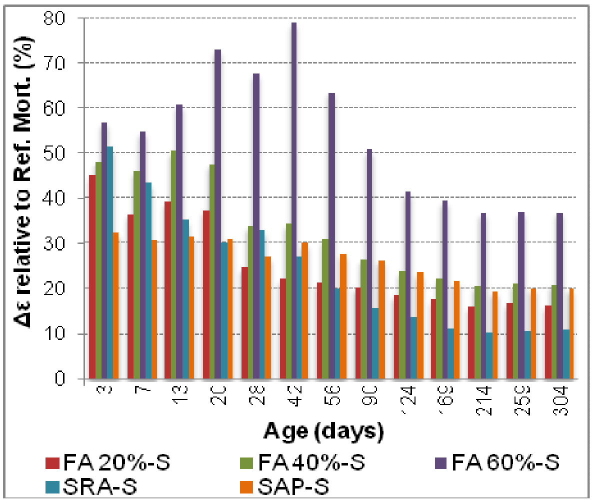



Figure 9: Sealed specimens shrinkage variation related to the reference mixture (Ref.).

Analysing these two figures and comparing results with the reference mixture one can conclude that in all ages the autogeneous shrinkage decreased significantly on mortars containing FA and that the bigger the FA content the lesser the shrinkage. Figure 9 permits to verify that the autogenous shrinkage reduction efficiency of the compositions FA20% and FA40% decreases until about 124 days and after this age the efficiency stabilizes. The efficacy of the reduction of autogeneous shrinkage of FA60% composition have increased over time until about 40 days and after that the efficiency had reduced until about 169 days remaining stable until the final of the study. In this same figure one can observe that the mortars FA20%, FA40% and FA60% have obtained a bigger efficacy at 3, 13 and 42 days, respectively, attaining autogeneous shrinkage reductions of about 45 %, 50 % and 80 %, respectively. At the end of the tests, after 304 days, the reduction attained was about 15 %, 20 % and 35 %, respectively, comparatively to the autogeneous shrinkage obtained in specimens made with the reference mixture. Concerning SRA one can verify in both figures that its addition have caused a reduction of autogeneous shrinkage. This reduction is visible in all ages being evident on Figure 9 that has the largest efficiency of about 50 % at 3 days and at the end of the test, at 304 days, an efficiency of about 10 %. Relatively to the SAP mixture one can see in both figures that showed an important reduction of the autogeneous shrinkage in all ages. Figure 9 shows that the autogeneous shrinkage was reduced due to SAP addition at a maximum of about 35 % at 3 days and at 304 days of about 20 %. Figure 9 also demonstrates that the efficiency of the mortar with SAP have decreased until about 124 days, remaining afterward stabilised until the end of the test, as much as verified in the mortar with SRA.

### 3.3.3 Drying shrinkage

The values of drying shrinkage are presented on Figure 10 and were estimated through the subtraction of sealed specimen's shrinkage to total shrinkage, verified on free specimens, i.e., resulting of the subtraction of autogeneous shrinkage to total shrinkage.

Analyzing Figure 10 one can verify that in all the compositions the bigger part of drying shrinkage occurred on early ages, which was expectable once that drying shrinkage is intimately connected to moisture loss for the external environment[2, 16, 17] and it was on the early ages that one has verified a higher loss of water, according to the observed in 3.2. Furthermore, it was visible that in the reference compositions and in the mixtures with FA and with SAP the drying shrinkage stabilised from about 124 days, contrarily to the mortar with SRA inclusion which drying shrinkage stabilized from about 42 days. Generally the compositions with FA have obtained a lower drying shrinkage on the first ages comparatively to the reference mortar. However, starting from 90 days FA mixtures showed to have a drying shrinkage similar than the reference mortar demonstrating low efficacy on the reduction of this kind of shrinkage. Comparatively with the reference mixture the SRA composition registered a reduction on drying shrinkage quite significant in all ages. This reduction was more expressive until 20 days of test. As regards to the mixture containing SAP the results showed values of drying shrinkage similar to the ones of the reference composition.

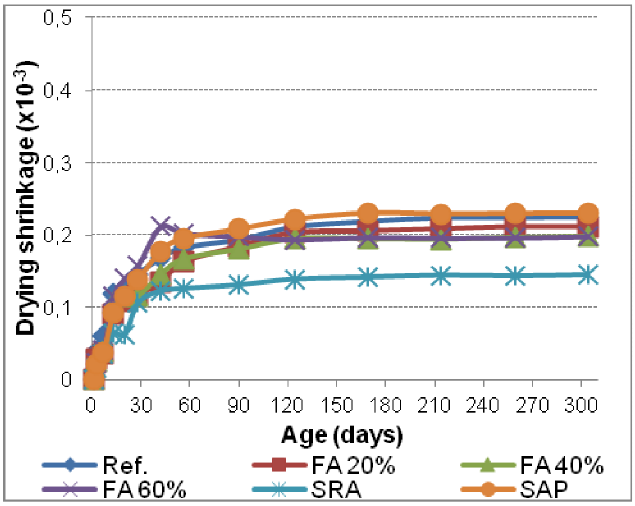



Figure 10: Drying shrinkage over time.

## 4 CONCLUSIONS

Based on the results obtained in the experimental campaign one can conclude that all the tested measures (replacing cement by FA, adding a SRA admixture or adding a SAP) could mitigate concrete shrinkage or other cement based materials. In more detail we can observe that:

- The inclusion of FA:
  - decreases considerably the total shrinkage and also reduced even in a more substantial way the autogeneous shrinkage. However, it hasn't had a great effect reducing drying shrinkage;
  - the effect described on the previous point was more pronounced as the FA dosage had increased;
  - increases the mass loss as much more as the FA content was;
  - decreases the compressive strength, being this effect more notorious as the higher its dosage. However, FA mixtures tend to recuperate the compressive strength over time.

- The SRA inclusion:
  - is responsible for a significant reduction of all the types of shrinkage measured instead of being more efficient on dry shrinkage;
  - increases the mass loss;
  - decreases significantly the compressive strength between about 15 % (at 90 days) and 20 % (at 7 days).

- The SAP inclusion:
  - is welcome for the mitigation of total and autogeneous shrinkage, being more effective in reducing autogeneous shrinkage. However, it didn’t produce a great effect on drying shrinkage;
  - reduces the mass loss only on the first ages, increasing it as from 42 days;
  - decreases even more significantly the compressive strength between about 20 % (at 90 days) and 30 % (at 7 days).

- In general, comparing all the compositions produced:
  - all the tested ways to mitigate shrinkage negatively affects the compressive strength;
  - for 20 % of cement replacement by FA the strength loss is similar than SRA mixture at 7 days of age but at 90 days of age the FA20% is quite smaller;
  - at 90 days of age the compressive strength decrease of FA40% mixture is similar than SAP one;
  - the mixture made with 60 % of cement replaced by FA and the one with SRA addition have showed the higher mitigation capacity of total shrinkage. Comparatively to the reference mixture, FA60% and SRA mixtures have caused both a reduction of total shrinkage until about 50 % (at 3 days) and 25 % as from 298 days;
  - the composition made with 60 % of FA was the most efficient in decreasing autogenous shrinkage and the one with SRA was the most effective in the reduction of drying shrinkage, giving to understand that a possible synergy between this two constituents may be quite beneficial to mitigate the total shrinkage of concrete.

## 5 REFERENCES

[1] D. W. Mokarem, *Development of concrete shrinkage performance specifications*, Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, U.S.A. (2002).

[2] A. Carrajola, *The Influence of shrinkage reducing admixtures on the cracking control of concrete*, Instituto Superior Técnico, Master Dissertation, Portugal (2006) – *in Portuguese*.

[3] T. O. Santos, *Concrete shrinkage in bridges*. *Observation and analysis*, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa & National Laboratory for Civil Engineering, PhD Thesis, Portugal (2007) – *in Portuguese*.

[4] A. S. Coutinho and A. Gonçalves, *Manufacturing and properties of concrete*, Vol. III, National Laboratory for Civil Engineering, Portugal (1994) – *in Portuguese*.

[5] A. A. M. Neto, M. A. Cincoto, and W. L. Repette, *Shrinkage reducing admixture (SRA) effect on early high-strength Portland cement*. Congress of Construction, 3rd National Congress, University of Coimbra, Portugal (2007) – *in Portuguese*.

[6] J. Farinhoto, *Controled shrinkage concretes*, University of Minho, Individual Project, Portugal (2009) – *in Portuguese*.

[7] L. Esteves, *Internal curing in cement-based materials*, University of Aveiro, PhD Thesis, Portugal (2009).

[8] S. Mönning, *Water saturated super-absorbent polymers used in high-strength concrete*, Otto-Graf Journal, Vol. 16, Germany (2005).

[9] T. Tanabe, *Creep, shrinkage and durability mechanics of concrete and concrete structures*, Proc. of the CONCREEP 8 conference, Ise-Shima, Japan (2008).

[10] O. M. Jensen and P. F. Hansen, *Water-entrained cement – Based Materials II. Experimental Observations*, Cement and Concrete Research, Elsevier Science, pp 973-978, (2002).

[11] B. Person, D. Bentz and O. Nilson, *Self-desiccation and its importance in concrete technology*, Lund Institute of Technology, Lund University, Sweden (2002).

[12] D. P. Bentz, M. R. Geiker and O. M. Jensen, *Mitigating autogeneous shrinkage by internal curing*, National Institute of Standards and Technology, U.S.A. (2004).

[13] EN 450-1, *Fly ash for concrete. Definition, specifications and conformity criteria* (2006).

[14] EN 196-1, *Methods of testing cement. Determination of strength* (2005).

[15] ASTM C 151, *Standard Test Method for Autoclave Expansion of Hydraulic Cement* (2009).

[16] D. A. Lange, M. D. D'ambrosia and Z. C. Grasley, *Drying stress and internal relative humidity in concrete*, Material Science of Concrete, Wiley, USA (2005).

[17] A. Carrajola, A. Gonçalves and B. Ribeiro, *Effect of shrinkage reduction admixtures on the pore structure properties of mortars*. Materials and Structures, 39, pp 179-187 (2006).

# Proceedings of the

# 5th International Conference on
# The CONCRETE FUTURE
## 26–29 May 2013

*Venue*

**University of Beira Interior,**

**Engineering Faculty, 6200-001 Covilhã, Portugal**

*Editors*

**Castro Gomes, Sérgio Lopes, Luís Bernardo**

Twin Covilhã International Conferences on

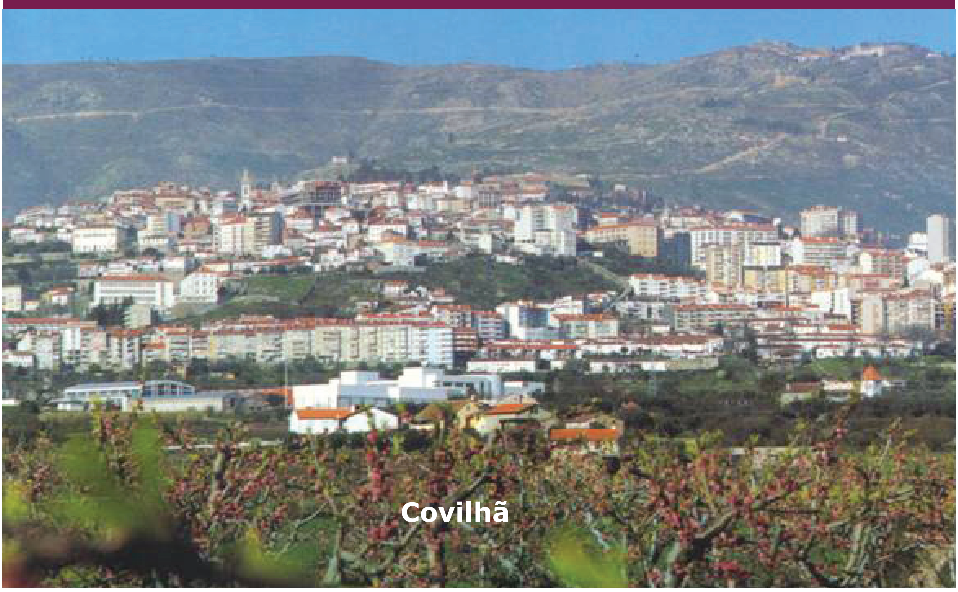
# Civil Engineering

## (Towards a Better Environment)

## and

# The Concrete Future

26–29 May 2013
Covilhã, Portugal




*Organisers:*

University of Beira Interior

University of Coimbra

CI-Premier Conference

Proceedings of the
Twin Covilhã International Conferences on

# Civil Engineering

-Towards a Better Environment

and

# The Concrete Future

**26-29 May 2013**
**Covilhã, Portugal**

*Organisers:*

- University of Beira Interior, Portugal
- University of Coimbra, Portugal
- CI-Premier Conference, Singapore

**ISBN: 978-981-07-606**7-0

*Editors*
**CE13 –** Victor Cavaleiro, Isabel Pinto, Luís M. Ferreira Gomes
**CF13 –** Castro Gomes, Sérgio Lopes, Luís Bernardo

*Published by:*
CI-PREMIER PTE LTD
150 ORCHARD Road, #07-14 Orchard Plaza
Singapore 238841. Republic of Singapore

Tel: +65 67332922 Fax: +65 62353530
E-mail: ci-p@cipremier.com
Website: www.cipremier.com



The papers have been peered reviewed, and the Organising Committee is not responsible for the statements made or for the opinions expressed in this Proceedings.

## PREFACE

The 2nd International Conference on Civil Engineering towards a Better Environment (CE13) and the 5th International Conference on the Concrete Future (CF13) are held at the University of Beira Interior, in the city of Covilhã, Portugal, from 26 to 29 of May, 2013. These events are organized by the University of Beira Interior, the University of Coimbra and CI Premier.

CE13 aims at promoting a discussion on the role of Civil Engineering on the environmental aspects of the construction activities. This conference is of interest for researchers and professionals related with design and construction activities, among others. This is an excellent opportunity for people from different professional sources to meet and to share experiences and to discuss new ideas and development trends on this subject. CE 13 is the second conference of the series and is a consequence of the success of the first conference previously organized in Coimbra.

CF13 is the fifth conference of the series with the previous ones taking place in Malaysia, China and Portugal. It aims at discussing the challenges that concrete constructions are faced in the coming years. Energy efficiency and carbon emission rates are issues that are setting some requirements that are more difficult to be met. The professionals or researchers who are involved on the construction of concrete structures need to find alternative technologies to adapt the concrete to such new requirements so that the material could continue to be competitive. This conference is an excellent opportunity for researchers and professionals to discuss such aspects.

The coincidence of these two conferences is also a positive point, since there are some overlapping topics that can be discussed by a broader audience. People with different viewpoints can give their opinion on particular aspects and this will certainly enriches the discussion. To encourage a broad discussion, special few joined sessions are planned. For the rest of the sessions, the conferences will run separately.

The technical programme also includes a visit to an earth dam in River Coa, complemented with more relaxed visits to the medieval village of Sortelha and to museums in the city of Belmonte, including the Discoveries Museum and the Jewish Museum.

The technical sessions will include approximately 40 oral presentations, whose articles are included in this proceedings book. In the name of the local organising committees the chairs of the conferences would like to express their gratitude to the authors who presented their manuscripts for consideration and to the Scientific Committee for the referring work of the manuscripts. They also want to thank the presenters of the articles, the colleagues that were willing to chair the sessions, the sponsors and all the people that have collaborate in some way for the success of these conferences.

| | |
|---|---|
| Victor Cavaleiro | Castro Gomes |
| Isabel Pinto | Sergio Lopes |
| Luis M. Ferreira Gomes | Luis Bernardo |

# TWIN COVILHÃ INTERNATIONAL CONFERENCES
# 26 – 29 May 2013, Covilhã, Portugal

**2ND CIVIL ENGINEERING** – Towards a Better Environment

**CONFERENCE COMMITTEE:**

**Conference Chairs:**
Luis M Ferreira Gomes, University of Beira Interior, Portugal
Isabel Pinto, University of Coimbra, Portugal

**Conference Director:**
Er John S Y Tan, CI-Premier Pte Ltd, Singapore

**Secretary:**
Ms Peggy L P Teo, CONLOG, Singapore

**Local Organising Committee:**
Isabel Falorca, Luís Pais, Paulo de Carvalho, Pedro Almeida, José Riscado
(University of Beira Interior, Portugal)

**SCIENTIFIC AND INTERNATIONAL ADVISORY COMMITTEE:**

**Chairman:**
Victor Cavaleiro (University of Beira Interior, Portugal)

**Members:**
Ferreira Gomes (University of Beira Interior, Portugal)
Isabel Pinto (University of Coimbra, Portugal)
Andrea Segalini (Università Parma, Italy)
Amândio Teixeira Pinto (ISPT, Angola)
BaoChun Chen (Fuzhou University, China)
Claúdia Beato (Universidade Publica de Cabo Verde, Cabo Verde)
Luíz Vallejo (Complutense University of Madrid, Spain)
M Teresa Condesso de Melo (IST, Portugal)
P Seco Pinto (LNEC, Portugal and ISSMGE President, 05-09).
Ramiro Sofronie (ECOLAND, Romania)
R M Kowalczyk (Univ. of Ecology and Management, Warsaw, Poland)
Sérgio Lopes (University of Coimbra, Portugal)

# TWIN COVILHÃ INTERNATIONAL CONFERENCES
# 26 – 29 May 2013, Covilhã, Portugal

**5TH CONCRETE FUTURE**

**CONFERENCE COMMITTEE:**

**Conference Chairs:**
Luis Bernardo, University of Beira Interior, Portugal
Sérgio Lopes, University of Coimbra, Portugal

**Conference Director:**
Er John S Y Tan, CI-Premier Pte Ltd, Singapore

**Secretary:**
Ms Peggy L P Teo, CONLOG, Singapore

**Local Organising Committee:**
João Lanzinha, Miguel Nepomuceno, Paulo Carvalho, (University of Beira Interior, Portugal)
Isabel Pinto (University of Coimbra, Portugal)

**SCIENTIFIC AND INTERNATIONAL ADVISORY COMMITTEE:**

**Chairman:**
Castro Gomes (University of Beira Interior, Portugal)

**Members:**
Luis Bernardo (University of Beira Interior, Portugal)
Sérgio Lopes (University of Coimbra, Portugal)
Adelino Lopes (University of Coimbra, Portugal)
Bonet Senach (Polytechnic University of Valencia, Spain)
Frank Dehn (MFPA Leipzig GmbH, Germany, and Chairman fib Commission 8 Concrete & Convenor of fib TG 8.10)
Liaqat Ali Qureshi (University of Engineering & Technology, Pakistan)
Luiz Oliveira (University of Beira Interior, Portugal)
Marcin Gorski (Silesian University of Technology, Poland)
Marian Gizejowski (Warsaw University of Technology, Poland)
Moreira Pinto (University of Beira Interior, Portugal)
Nina Avramidou (University of Florence, Italy)
Tiejiong Lou (Zhejiang University, China)
YongBo Shao (Yantai University, China)

# TWIN COVILHÃ INTERNATIONAL CONFERENCES
## 26 – 29 May 2013, Covilhã, Portugal

## Table of Contents

## 5TH CONCRETE FUTURE

### Keynote Papers



### Technical Papers