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Experimental determination of the influence of additives on shrinkage in self-compacting concrete

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Abstract. The paper deals with the influence of additives on the progress of shrinkage and mass losses in self-compacting concrete. Limestone and fly ash at varying amounts were used as an additive in the production of four types of self-compacting concrete. Volume changes were observed from an early stage of setting (the measurement was commenced within 1 hour of mixing) using shrinkage drains with a moveable wall, followed by a long-term manual measurement using an external strain gauge. For the first 48 hours the volume-change measurement was continuous, and for the next few months it was performed manually. Mass losses were determined simultaneously with shrinkage – during the first 48 hours by weighing on a special weighing table capable of continuous recording, and manually afterwards.

1. Introduction

The fresh-state properties of self-compacting concrete (SCC) make it a very popular building material which is finding very broad use. It is generally agreed that the first SCC was developed at the University of Tokyo in Japan in the late 1980s [1]. Given the typical aspects of SCC mixtures, especially the higher content of small particles and a lower water-cement ratio, these concretes are more vulnerable to shrinkage than ordinary ones [2,3]. Shrinkage is usually defined as a reduction in volume in unloaded concrete as it ages [4]. This is mainly due to changes in the water content of the concrete structure. Shrinkage is generally divided into these categories: plastic shrinkage, chemical shrinkage, autogenous shrinkage, carbonation shrinkage, and desiccation shrinkage [4]. More pronounced shrinkage can produce stress inside the concrete which may exceed its tensile strength in some places and cause microcracks and even cracks to form. These microstructure defects can lead to an overall drop in the material's load-bearing capacity and, more importantly, reduce its durability [5].

Concrete shrinkage as such cannot be eliminated, but it is possible to minimise its negative effects. Curing the concrete as it sets and hardens is one of the effective means of containing its shrinkage. Another option is to adjust the formula – for instance it is possible to reduce the generation of hydration heat or to use a shrinkage-reducing agent (SRA). SRA generally operate by reducing surface tension in the pore structure and thus containing shrinkage and minimising the risk of cracking. However, the way SRA affect pore structure delays hydration and is thus detrimental to durability [6]. Because they are easily water-soluble, they can be washed away from the material during rain or by other running water [7,8]. Using SRA can also increase the total costs of the concrete, which is why they need to be used with caution [9].

Additives, such as fly ash or limestone replace Portland cement in order to improve the concrete's fresh-state and hardened-state properties. These fine particles can improve the compaction of the cement matrix, which reduces the concrete's permeability and improves its durability [10]. Fly ash, commonly added as a substitute of 25 – 30 % of cement volume, holds several advantages for concrete durability, which can emerge during setting and hardening. These are mainly better workability, smaller water requirement, smaller degree of segregation, less hydration heat, higher long-term strength, substantial reduction in permeability (and thus better resistance to chlorides), less expansion due to the reaction of alkaline silicon dioxide, or increased sulphate resistance [11, 12].

In concretes where the replacement is 40–60 %, fly ash is usually combined with finely-milled limestone with an average particle size of 1 micrometre (5–15 % of total cement volume). The combination of limestone and fly ash produces a mixture with better workability and improves the material's durability as well [13, 14, 15].

2. Experiment

The main goal of the experiment was to observe shrinkage in self-compacting concretes and determine the influence of additives on its measured value. Over the first 48 hours the specimens were kept in moulds with the top surface exposed at a laboratory temperature of (21±2) °C and relative humidity of (55±10) %. Once demoulded, the specimens remained on racks under the same conditions and were left to dry freely through all surfaces.

2.1. Material

The experiment was performed with four mixtures of self-compacting concrete. For better orientation during result evaluation they were identified as SCC1 through SCC4. All four concretes were made with the same coarse aggregate with the fraction of 4/8 mm and 8/16 mm and the same sand of 0/4 mm. The plasticiser was likewise the same and all concretes contained it at an amount of 1.5 % of cement mass. Seeing as commercial products were used, their names and composition will not be revealed in this paper. Table 1 therefore shows only the percentages of all the components (cement and additives); the figures represent ratios of the mass of each component to the total mass of all components per 1 m^3 of fresh concrete.

Table 1. Average content of cement and additives in each concrete (mass %).

	Relative content of components in the concrete formula			
Component per 1 m^3	**SCC1**	**SCC2**	**SCC3**	**SCC4**
Cement (%)	18.5	17.5	18.5	18.5
Fly ash (%)	4.5	0	0	3
Ground limestone (%)	0	3	4.5	1.7
w/c ratio (-)	0.38	0.33	0.31	0.32

2.2. Testing

For the first 48 hours shrinkage was measured using shrinkage drains with a moveable wall produced by Schleinbinger Geräte [16], which made it possible to commence measurement of relative length changes very soon after the concrete had been cast. The shift of the walls was recorded using induction transducers and a Quantum data logger. A similar test is described in [17]. The inside of the drains was lined with a Teflon sheet to minimise friction between the mould and the specimen, allowing the concrete to shrink freely (see figure 1). The spaces between the drain and the moveable wall were sealed with Vaseline to stop the concrete from leaking underneath and thus preventing the wall from moving.

Measuring dollies were embedded in the top surface of the specimens (reaching approx. 25 mm deep) to be used for shrinkage measurements after demoulding. While the specimens were being cast, the dollies were held in place by an auxiliary frame to prevent them from moving out of place. There were three dollies positioned along the length axis, making two measuring bases of 200 mm (see figure 1). These bases were used for measuring relative length changes using an external Hollan-type strain gauge with a digital dial; see figure 2. There was no need to vibrate the specimens, since they were made from SCC. During the experiment the specimens were not cured in any way.

During the first 48 hours, mass losses were measured using a special weighing table [17] and the readings were being recorded using the same data logger as deformation. Once the specimens were demoulded, the measurements were performed manually at planned intervals using a set of digital scales with an accuracy of 0.1 g.

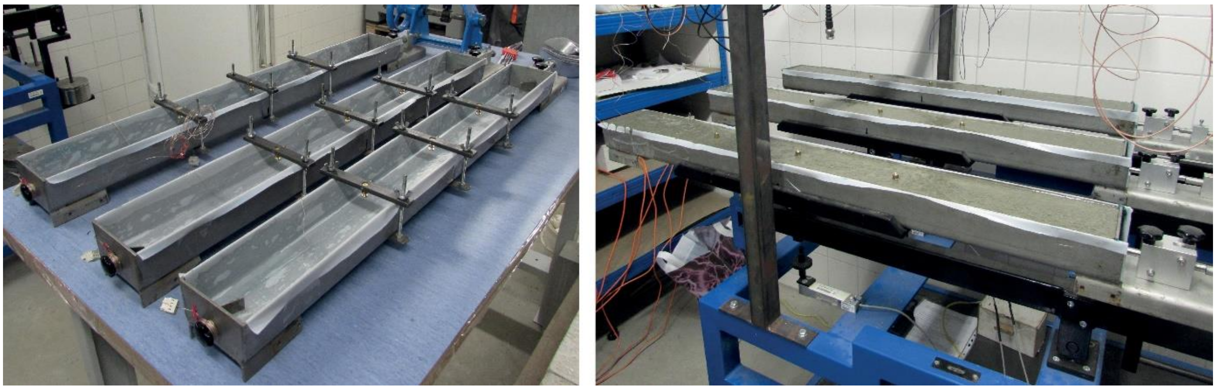

Figure 1. Shrinkage drains prior to casting with measurement dollies in position (left) and after casting mounted on a weighing table (right).

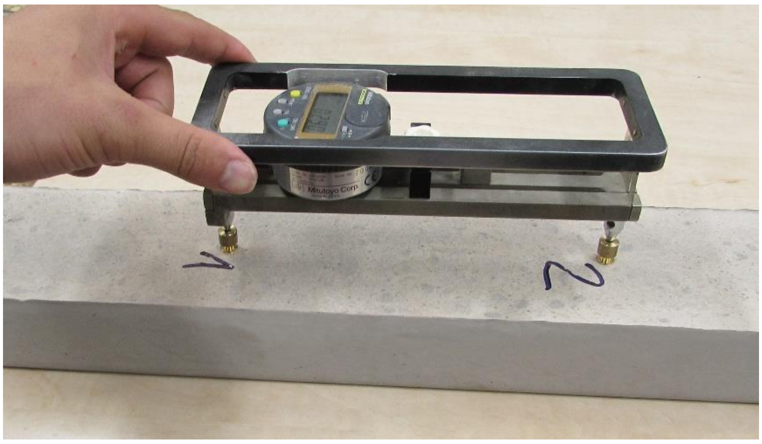

Figure 2. Manual shrinkage measurement using an external strain gauge and measuring dollies.

3. Results

The values of mass loss and shrinkage were measured for approximately 200 days. Figure 3 shows the final shrinkage values and mass losses over the first 48 hours of ageing, figure 4 shows average values of shrinkage and mass losses over the entire testing period (i.e. until the age of 200 days), and figure 5 plots the temperature developing inside the specimens during the first 48 hours.

The values show that SCCs shrink rapidly during the first 12 hours, after which the shrinkage slows down and increases only gradually. Relative strain at the age of 48-hours in SCC1 reached approx. 400 μm/m, in SCC2 through SCC4 it was around 900 μm/m and never exceeded 1100 μm/m. After 200 days of measurement the value of relative strain in SCC1 was approx. 1200 μm/m, while in SCC2 through SCC4 it ranged within 1400 – 1700 μm/m. SCC1 was rather different from the others in terms

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of its w/c ratio – in SCC1 the w/c value was 0.38, while in the other three it was 0.31 to 0.33. After the SCC1 specimens had been cast, the concrete bled a little, which most likely affected its shrinkage as well.

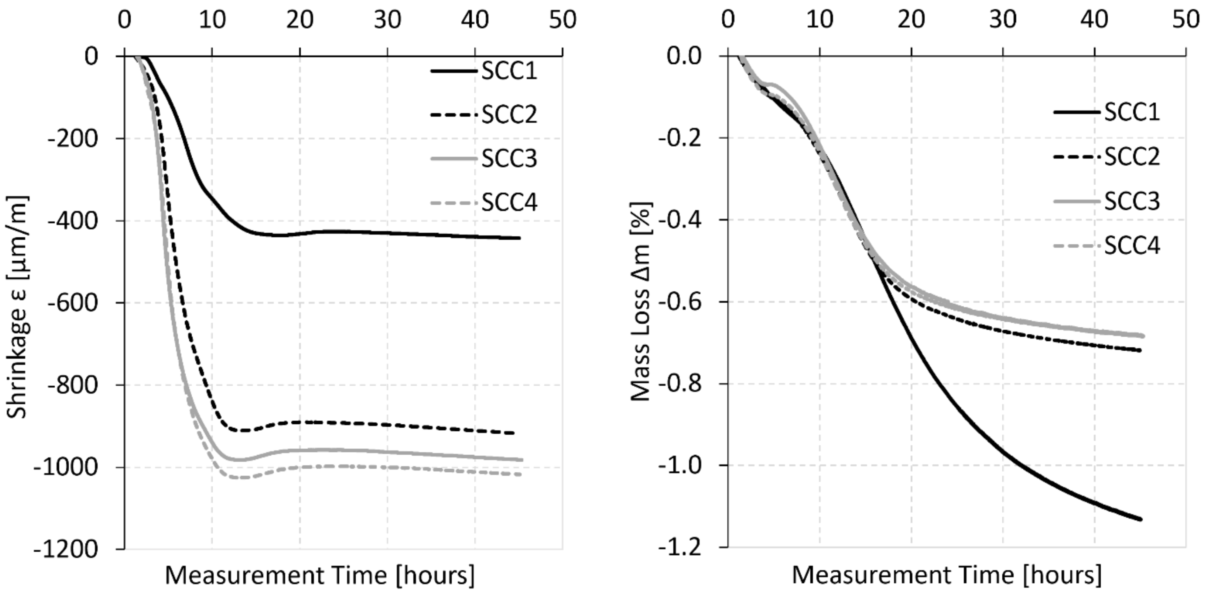

Figure 3. Development of shrinkage and mass losses during the first 48 hours.

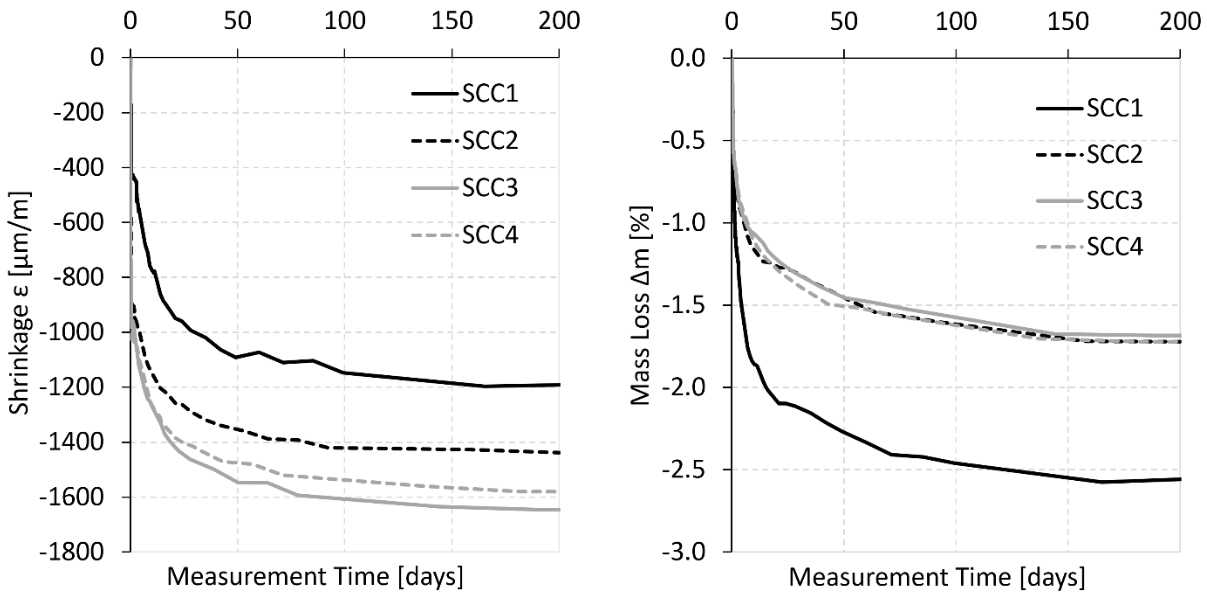

Figure 4. Development of shrinkage and mass losses during the first 200 days.

Mass losses show a similar tendency as shrinkage. In the first 48 hours the mass loss in all the concretes was almost 50 % of the total steady value measured at the age of 200 days. The 48-hour mass losses in SCC1 were approx. 1.1 % while in concretes SCC2 through SCC4 the loss was about 0.7 %. Such a marked difference was likely caused by desiccation of the top surface of SCC1 specimens. At the age of 200 days the mass loss in the first concrete was approx. 2.5 %, in the others it was 1.7 %.

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The shrinkage and mass loss data measured on all three specimens of each concrete at the age 48 hours and 200 days were verified for normality on a level of significance of 0.05. Next, a two-sample t-test was performed to compare the average values of shrinkage and mass losses at the above-stated stages of maturation on a significance level of 0.05. The statistical analysis showed that SCC2 and SCC3 did not differ with statistical significance neither in shrinkage, nor in mass loss value regardless of age. However, SCC1 does bear a statistically significant difference from the others at the age of 48 hours and both in shrinkage values and in mass losses. At the age of 200 days it differs with a statistical significance from SCC3 and SCC4, and in mass losses it differs from all the other concretes.

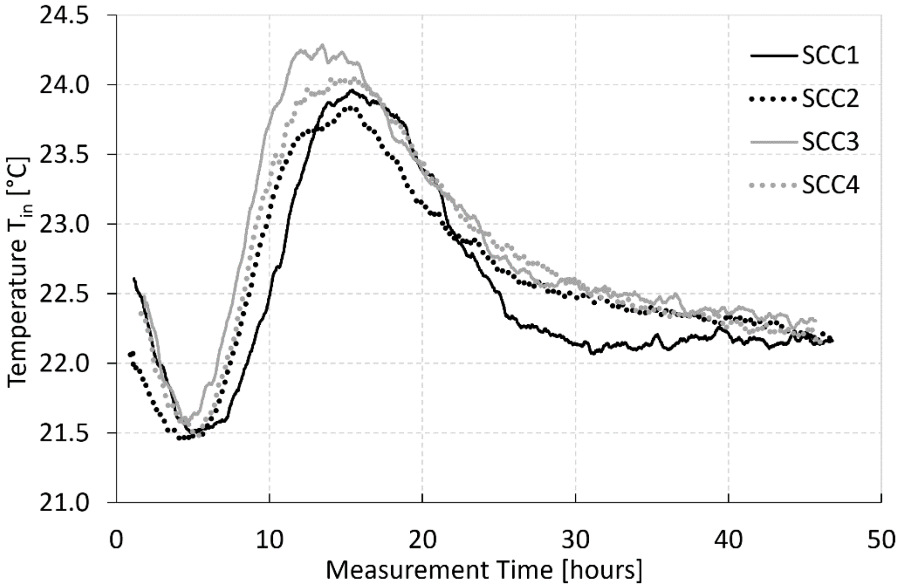

Figure 5. Development of internal temperature during the first 48 hours.

4. Conclusion

In conclusion, an influence of the additives on the short-term and long-term values of shrinkage cannot be clearly proved because the shrinkage did not exhibit any significant variation. Only the first set of specimens (SCC1) differed from the others, which may likely have been caused by the higher w/c ratio. SCC1 also manifested bleeding after it was cast in the shrinkage drains. The water, which thus gathered on the surface of the specimens, temporarily acted as curing water, which probably reduced the initial shrinkage value and thus it swayed the overall long-term progress of shrinkage. The bleeding in SCC1 also had a clear effect on the progress and final value of mass losses.

A two-sample t-test performed at a significance level of 0.05 showed that the values of shrinkage and mass losses determined from SCC1 specimens at the age of 48 hours and 200 days bear a statistical difference from those measured on the specimens of the other concretes (with the only exception being SCC2 at the age of 200 days). The measurement results show that the type and amount of additives do not affect the process of shrinkage at the selected ages of the concretes tested herein. It appears that the w/c ratio and the correct SCC mixture design play a more important role in this regard. Bleeding is considered undesirable in SCC, since it indicates that the concrete has a tendency to segregate. In terms of shrinkage measurement, it also distorts the overall progress as well as the absolute values of shrinkage and mass losses.

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References

[1] Okamura H and Ouchi M 2003 Self-Compacting Concrete *Journal of Advanced Concrete Technology* **1**(1) pp 5-15
[2] Goodier C I 2003 Development of self-compacting concrete *Proceedings of the Institution of Civil Engineers - Structures and Buildings* **156**(4) pp 405-414
[3] Dang Y, Qian J, Qu Y, Zhang L, Wang Z, Qiao D and Jia X 2013 Curing cement concrete by using shrinkage reducing admixture and curing compound *Constr. Build. Mater.* **48** pp 992-997
[4] Abdalhmid J M, Ashour A F and Sheehan T 2019 Long-term drying shrinkage of self-compacting concrete: Experimental and analytical investigations *Constr. Build. Mater.* **202** pp 825-837
[5] Dang Y, Qian J, Qu Y, Zhang L, Wang Z, Qiao D and Jia X 2013 Curing cement concrete by using shrinkage reducing admixture and curing compound *Constr. Build. Mater.* **48** pp 992-997
[6] Demir İ, Sevim Ö and Tekin E 2018 The effects of shrinkage-reducing admixtures used in self-compacting concrete on its strength and durability *Constr. Build. Mater.* **172** pp 153-165
[7] Mora-Ruacho J, Gettu R and Aguado A 2009 Influence of shrinkage-reducing admixtures on the reduction of plastic shrinkage cracking in concrete *Cem. Concr. Res.* **39** pp 141-146
[8] Maltese C, Pistolesi C, Lolli A, Bravo A, Cerulli T and Salvioni D 2005 Combined effect of expansive and shrinkage reducing admixtures to obtain stable and durable mortars *Cem. Concr. Res.* **35** pp 2244-2251
[9] Ferreira S 2014 ABC's of Crackless Bridge Decks with applications in accelerated bridge construction *Bridge Contractors / Caltrans Liaison Committee Meeting* PE California Department of Transportation March 21
[10] Altoubat S, Talha Junaid M, Leblouba M and Badran D 2017 Effectiveness of fly ash on the restrained shrinkage cracking resistance of self-compacting concrete *Cem. Concr. Comp.* **79** pp 9-20
[11] Hwang S D and Khayat K H 2008 Effect of mixture composition on restrained shrinkage cracking of self-consolidating concrete used in repair *ACI Materials journal* **105**(5) pp 499
[12] Yasumoto A, Edamatsu Y, Mizukoshi M and Nagaoka S 1998 A study on the shrinkage crack resistance of self-compacting concrete *Special Publication* **179** pp 651-670
[13] Altoubat S A and Lange D A 2002 Grip-specimen interaction in uniaxial restrained test *ACI SPECIAL PUBLICATIONS* **206** pp 189-204
[14] Paillere A, Buil M and Serrano J J 1989 Effect of fiber addition on the autogenous shrinkage of silica fume *Materials Journal* **86**(2) pp 139-144
[15] Esping O 2008 Effect of limestone filler BET(H2O)-area on the fresh and hardened properties of self-compacting concrete *Cem. Concr. Res.* **38** pp 938-944
[16] Kucharczyková B, Vymazal T, Daněk P, Misák P amd Pospíchal O 2009 SOP 01/09: Standard operating procedure for determination of shrinkage and swelling of concrete, BUT (in Czech)
[17] Vymazal T, Daněk P, Misák P and Kucharczyková B 2015 Způsob kontinuálního měření hmotnostních úbytků cementových kompozitů v raném stadiu tuhnutí a tvrdnutí a zařízení k provádění tohoto způsobu, Czech patent: 304898, CZ, BUT (in Czech)