Drying Shrinkage of "Norwegian" Self-Compacting Concrete

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ABSTRACT

Drying shrinkage has been tested on typical Self-Compacting Concretes (SCC) used in Norway (w/b of 0.6). The application for Norwegian practice with respect on SCC has focused at maintaining the paste content and composition as close to equivalent traditional concretes as possible. Consequently, the risk of cracking of the SCC is not significantly different either as demonstrated by the results presented in this paper. However, reduced w/b and/or increased paste volume is occasionally required and contributes to increased shrinkage.

Key words: self-compacting concrete, type of co-polymer, grain size distribution and drying shrinkage.

1. INTRODUCTION

SCC recipes are often associated with high contents of binder, fillers and plasticizing admixtures, which all may contribute to increased drying shrinkage. Thus, questions have been raised about cracking of SCC due to drying shrinkage. The application for Norwegian practice with respect on SCC focused at maintaining the paste content and composition as close to equivalent traditional concretes as possible, mainly from a cost point of view. Thus, the main agents to make a SCC are fillers, especially in concretes with higher w/b than 0.45, which increases the need of plasticizers, and use of co-polymer plasticizing admixtures with a stabiliser included (thickening agent) [1]. Also, the focus on cost entails not to use lower w/b than required for e.g. environmental reasons. In Norway the major volume of concrete is in the “Moderately Aggressive Environment” class, requiring a w/b lower than 0.60 (according to Norwegian Standard 3420). Therefore, the research and development work includes development of SCC with w/b = 0.60.

It is important to consider that the risk of cracking is not solely linked to the shrinkage. Cracks develop when the shrinkage leads to stress equal to the tensile strength of the concrete. The stress is dependent on the product of **shrinkage**, **modulus of elasticity** and **creep /**

relaxation (provided that the structure is 100% restrained). Nevertheless, shrinkage is the most important indication as to ranking of concrete in view of risk of cracking.

2. TESTS AND CONCRETES

2.1 Tests

The drying shrinkage was tested as the length change of 100/100/500 mm beams. The beams were cured in water for six days from the time of de-moulding (24 hours after casting) and then exposed to drying at 50 % RH and 22°C.

The measurements were done with an extensiometer and with measuring points of steel studs cast in the ends of the beams. The scale corresponds to 0.005 mm (i.e. 0.01 ‰).

2.2 Concretes without silica fume

The concretes, all with w/c = 0.60, were designed for a parameter study on fresh concrete properties. The parameters tested were:

- Co-polymer type (three types available in Norway)
- Paste-aggregate volume-ratio (27/73 and 30/70)
- Grain size distribution

A total of ten mixes were tested. All concretes fulfilled the Norwegian definition of SCC; a slumpflow at least 650 mm without separation. The nominal recipes are given in Table 1. The aggregate was composed of Norwegian glacifuvial gneiss/granite aggregate with dry density 2650 kg/m^3 plus limestone filler with dry density 2700. Three different grain size distributions between 0.125 and 8 mm were used, composed by combining of fine sand, 0-2 mm, and a coarse sand 0-8 mm, see also Figure 1, where Modulus of Fineness (MF) is defined in [2].

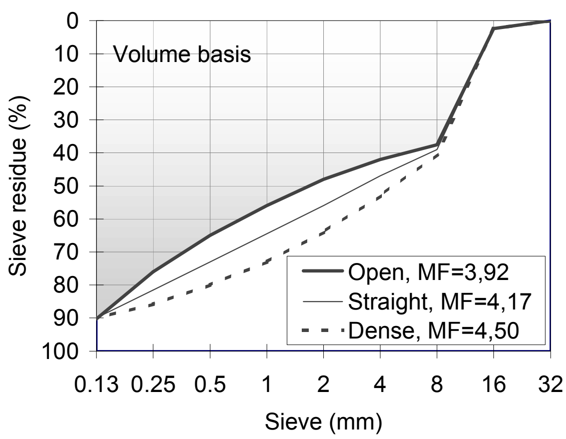

Figure 1 - Grain size distribution

1. **"Open"** distribution: Surplus of grains between 0.125 mm and 2.0 mm and with natural filler (< 0.125 mm).
2. **"Straight"** distribution: The reduced amount of filler due to less fine sand, was compensated by increased amount of limestone filler, 0-0.5 mm (49 % lime stone filler = 82 kg/m^3).
3. **"Dense"** distribution: Surplus of grains between 4 and 8 mm. The reduced amount of filler due to less fine sand, was compensated by increased amount of lime stone filler, 0-0.5 mm (96 % limestone filler = 179 kg/m^3).

Fly ash cement, type CEM II A-V 42.5 R with density 2950 kg/m^3 was used in all the mixes.

For each of the three curves (open, straight and dense) three different co-polymers, which normally are used in self-compacting concrete in Norway, were used. The three co-polymers were:

MBT Norge AS	Glenium 51	(about 35 % dry substance)
Scancem Chemicals AS	SSP 2000	(about 25 % dry substance)
	Scancem VMA	
Sika Norge AS	ViscoCrete 3	(about 28 % dry substance)

2.3 Concretes with silica fume

The silica fume content was 4, 7 and 10% by cement weight respectively. The other materials were similar to those used in the concretes without silica fume, except for the sand (included natural filler) which was another type with a nearly straight distribution.

2.4 Recipes

The recipes without silica fume are given in Tables 1, and 2. The nominal constituents are given in Table 1, and the real content of admixtures is given in Table 2:

Table 1 - Nominal recipes kg/m^3 (water-binder ratio 0.60 without silica fume):

Grain size distribution: Materials composition		Open	Straight	Dense[1)]	Dense
Paste content, l/m^3 [2)]		282	282	282	259
Matrix content, l/m^3, [3)]		350	350	350	340
Norcem Standard cement FA,		300	300	300	275
Norcem Limestone Powder, Brevik 0-0,5 mm		0	92	179	220
Årdal aggregates,	0-2 mm	726	354	0	0
dry weight	0-8 mm	392	672	941	935
	8-11 mm	372	372	373	386
	11-16 mm	372	372	373	386
Water, (water in additives included)		180	180	180	165

[1)] Only tested with copolymer SSP 2000
[2)] Paste = volume of cement + water + additives
[3)] Matrix = volume of paste and filler < 0,125 mm

Table 2 - Amount of admixtures and fresh concrete characteristics for all mixes without silica fume:

Grain size distribution: Materials and measurements		Open	Straight	Dense[1)]	Dense
Nominal paste content, l/m^3 [2)]		282	282	282	259
Nominal matrix content, l/m^3, [3)]		350	350	350	340
Co-polymer, kg/m^3:	Glenium 51	1.5	1.3		2.1
	ViscoCrete 3	2.8	2.3		3.3
	Scancem SSP 2000	3.6	3.0	2.8	4.6
Stabilizer: Scancem VMA[4)]		3.0	3.0	3.0	3.0
Slump Flow, mm:	Glenium 51	675	675		665
	Viscocrete 3	725	665		600
	Scancem SSP 2000	725	650	690	655
Density, kg/m^3:	Glenium 51	2365	2325		2389
	Viscocrete 3	2405	2375		2385
	Scancem SSP 2000	2380	2380	2385	2425
Air content, %:	Glenium 51	1.9	3.1		1.1
	Viscocrete 3	0.7	1.2		2.1
	Scancem SSP 2000	1.0	0.6	1.2	1.0

[1)] Only tested with copolymer SSP 2000
[2)] Paste = volume of cement + water + additives
[3)] Matrix = volume of paste and filler < 0,125 mm
[4)] Stabilizer was used only in combination with copolymer SSP 2000

The recipes with silica fume is given in Table 3:

Table 3 - Recipes kg/m^3 (water-binder ratio 0.60) and fresh concrete characteristics with silica fume. Nominal values except for the admixtures that are real :

Amount of silica fume in % cement weight		4	7	10
Paste content, l/m^3		280	278	276
Matrix content, l/m^3		350	350	350
Norcem Standard FA		279	265	250
Condensed silica fume, CSF		11.2	18.6	25.2
Årdal	0-2 mm	132	133	152
aggregate [1)]	0-8 mm	827	815	796
	8-11 mm	376	379	379
	11-16 mm	376	379	379
Grefsrud filler 0-0.5 mm		169	190	190
Co-polymer SSP 2000		3.03	3.58	4.03
Stabilizer, Scancem VMA		1.39	1.33	1.26
Free water [2)]		180.8	182.2	182.4
v/(c+2csf) – ratio		0.601	0.602	0.604
Slump Flow, SU in mm		647	650	680
Density, kg/m^3		2365	2375	2370
Air content, %		1.8	1.6	1.1

[1)] Oven dry weight of aggregate
[2)] Water in additives included, but absorbed water in aggregate excluded

3. RESULTS AND DISCUSSION

3.1 Influence of co-polymers, paste content and grain size distribution

Drying shrinkage was measured until 49 days of drying. This is a relatively short period of time, but still, it gives a strong indication about the influence of the parameters on the drying shrinkage. The results at 56 days (49 days drying) are given in Table 4.

Table 4 - Measured drying shrinkage, mm/m (49 days). Each number represents the average of two prisms.

Aggregate / Copolymer		Glenium 51	ViscoCrete 3	SSP 2000
Open (300)	Shrinkage 56 days	0.55	0.53	0.48
Straight (300)	Shrinkage 56 days	0.54	0.50	0.48
Dense (300)	Shrinkage 56 days	-	-	0.40
Dense (275)	Shrinkage 56 days	0.31	0.31	0.34

In general, the results for open and straight grain size distribution showed values quite similar to normal concretes with the same cement type and w/b, [3]. The results showed that the type of co-polymer did not have any significant influence on the drying shrinkage, see Table 4. The grain size distribution, however, showed apparently a large influence, i.e. the dense distribution had significantly lower shrinkage, see Figure 2. This is supported by the weight measurements of the specimens, Figure 3) showing that the evaporation decreases in the order: “Open” > “Straight” > “Dense”. This is quite unexpected since the paste composition is unchanged and the amount of admixture is fairly equal. According to Neville "The size and grading of aggregate per se do not influence the magnitude of shrinkage" /4/. Another difference is the composition of the filler, i.e. the ratio between natural and lime stone filler. The concrete with the highest content of limestone filler (“Dense”) had the lowest shrinkage and evaporation, see Figure 3. We have not found other results showing this effect of limestone filler. New tests will be performed in order to verify the results.

The concrete with less cement content (corresponding to less paste volume of 25 litres/m^3 or 8 % by volume) showed less shrinkage, as expected. The reduction, at 49 days of drying, corresponds to approximately 15 %.

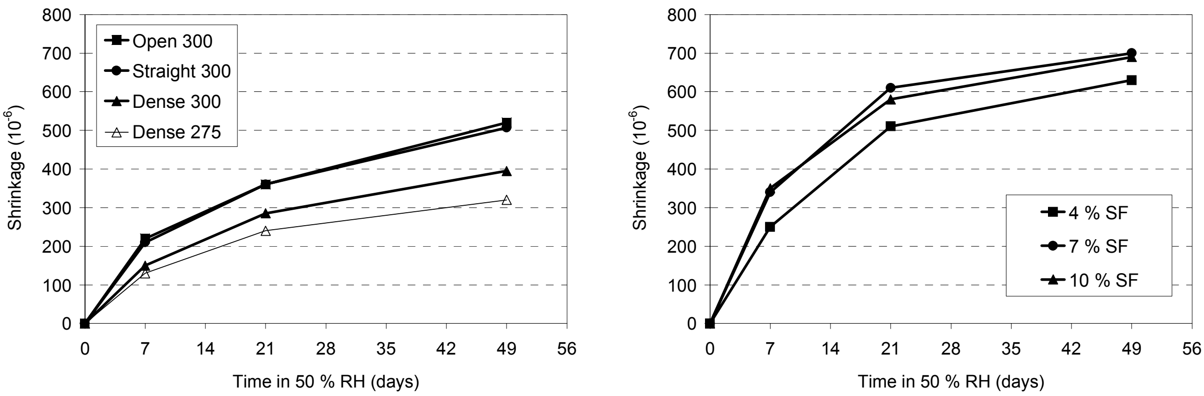

Figure 2 - Left: Drying shrinkage of SCC with “Open”, “Straight” and “Dense” grain size distribution and cement contents of 300 and 275 kg/m^3, respectively. Right: Drying shrinkage of SCC with w/b = 0.60 and different silica fume (SF) contents

The weight loss of SCC with "Open", "Straight" and "Dense" grain size distribution is shown in Figure 3. (average of three mixes with Glenium 51, Viscocrete 3 and SSP 2000, respectively). The weight increase between 1 and 7 days when the prisms are stored in water was not measured.

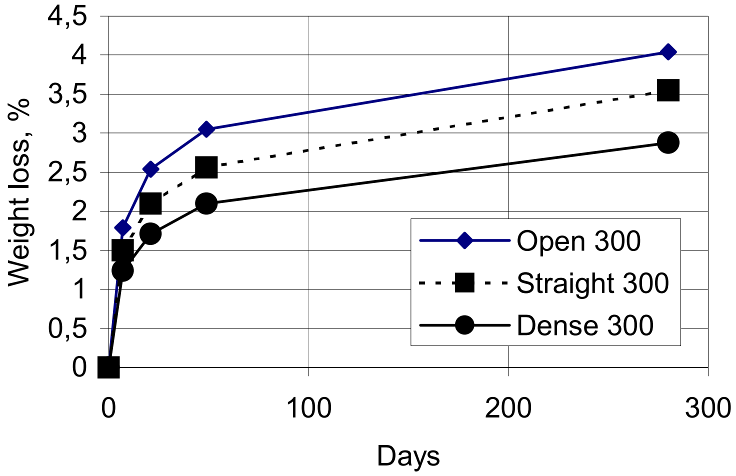

Figure 3 - Weight loss of SCC with "Open", "Straight" and "Dense" grain size distribution and cement contents of 300 kg/m^3.

3.2 Effect of silica fume

Silica fume is a very good aid in order to attain sufficient resistance against separation of SCC, especially when using relatively high w/b-ratio. The silica fume was added as replacement for cement using an efficiency factor of 2. The investigation did not include a reference without silica fume, see section 2.3. The paste volume was kept constant. The results indicate that the silica fume content between 4 and 10% does not influence significantly the drying shrinkage, see Fig 2. However, a comparison with the results from investigation of concretes without silica fume (with similar cement type, w/b and admixture, but different sand), see Figs 2 and 3, indicates that the addition of silica fume increases drying shrinkage the first 2 to 3 weeks of drying. The conclusion from a review on the influence of silica fume [5] is that there is no uniform influence of silica fume on drying shrinkage.

4. CONCLUSIONS

In general, the risk of cracking of concrete due to drying shrinkage is linked to the paste content, w/b and binder type as the main material parameters. The application for Norwegian practice on SCC has focused on maintaining these parameters as close to equivalent traditional concretes as possible, mainly from a cost point of view. Consequently, the risk of cracking of SCC as mentioned, is probably not significantly different from equivalent traditional concretes. The present results confirm that the drying shrinkage is not significantly different, and the type of copolymer admixtures did not have significant influence on the drying shrinkage. Reduced w/b and/or increased paste volume are effective, and thus, tempting tools in order to fulfil workability requirements, but one should keep in mind that the consequence may be increased cracking risk, as demonstrated in the present investigation.

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