Laboratory Assessment of Drying Shrinkage of Concretes Containing Shrinkage Reducing Agents Compared with a New Low shrinkage Concrete

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Abstract: High drying shrinkage of concrete has the potential to impact adversely on the durability, aesthetics and serviceability of concrete structures. Methods to reduce drying shrinkage of concrete have traditionally been to use special cements (e.g. SL Cement), water reducing admixtures and more recently, shrinkage reducing admixtures (SRA's). This paper assesses the shrinkage reduction potential of two common shrinkage reducing agents and compares it with a new, low shrinkage concrete (trademarked as ENVISIA™). A 32 MPa ENVISIA™ concrete was compared against a typical 32MPa concrete with addition of each agent at the dosage of up to 7 litres per cubic meter. It was noted that addition of shrinkage reducing agent had lower water demand, longer setting time, more or less bleed water (depending on the admixture type), and slightly lower 1-day compressive strength but higher later compressive strength. The free drying shrinkage can be reduced up to 30-37% when 7L per cubic meter dosage was used. The ENVISIA™ concrete required less water for the same workability, same setting time, but much less bleed, higher early strength and slightly lower later strength. The free drying shrinkage of ENVISIA™ concrete can be reduced by up to 45% compared to typical commercially available concrete. While the SRA1 concrete showed a reduction in plastic shrinkage crack width approximately 20%, neither the ENVISIA™ concrete nor the SRA2 concretes resulted in lower plastic shrinkage

Keywords: drying shrinkage, shrinkage reducing agent, admixture, concrete crack.

1. Introduction

The construction requirement for concrete to be easily placed and pumped often necessitates the use of more water than is required for the hydration process to proceed. The subsequent loss of some of this excess water from the concrete matrix as it hardens results in volume reduction in the concrete. This drying shrinkage can, with sufficient restraint in the structure and where the induced tensile stresses exceed the tensile strength in the concrete, result in cracking of the concrete member.

Many methods have been proposed to reduce the potential cracking in concrete (1), such as (i) good concreting practice includes good mix design, increase of aggregate stiffness and content, keeping lower water/cement ratio, adequate curing to reduce water evaporation. (ii) expansive cement, (iii) conventional secondary reinforcement or fibre reinforcement, . T')4--550Pn–(')4--550(')4--550(')4--550(')4--550(')4--550'(7)WW0'IPt–

with supplementary cementitious materials (usually fly ash and/or ground granulated blast furnace slag). These concretes typically exhibit lower early strength gain and higher shrinkage than standard concretes.

In 2008, Boral Cement commenced an R&D program to develop a cement with a low carbon footprint, but with strength gain similar to conventional concrete and lower shrinkage. This cement was trademarked ZEP™ and the concrete products made from it are marketed as ENVISIA™.

ENVISIA™ concrete typically has 60% lower CO_2 emissions and 40-50% lower shrinkage than conventional concrete with similar early strength performance.

2. Experimental Programs

2.1 Basic mix design

A typical 32MPa concrete mix design was used, including 330kg/m^3 cement (either SL or ZEP™), 750kg/m^3 20mm crushed river gravel, 300 kg/m^3 10mm crushed river gravel, 500kg/m^3 coarse river sand, and 300kg/m^3 river fine sand. The cement mass is air dry mass while all aggregates are SSD mass. Water was added for a slump of 80±10mm.

The ZEP™ cement was used to replace the same amount of SL. No extra SRA was added for ENVISIA™ concrete.

2.2 SRAs

Two commercially available SRA admixtures were used, SRA1 (BASF Tetraguard AS 21), and SRA2 (Sika Control Plus). Considering the compatibility of SRA and other admixtures, the water reducer or air entraining admixture from the same manufacturer of SRA was selected and used. This means there were three control concretes used.

2.3 Mixing procedures

The laboratory trials were performed as per AS 1012.2. The concrete was mixed in a pan mixer of 80 litres capacity. The low shrinkage ZEP™ cement was added in the same way as normal SL. The SRAs were added with the initial batching water within the first 1 minute to ensure the complete distribution throughout the mixing. Additional water was used if necessary to achieve slump of 80±10mm after 11 minutes.

2.4 Testing standards

The test was conducted as per the following standards:

AS 1012.2 – prepare concrete mix in a lab

AS 1012.3.1 – slump test for consistency

AS 1012.4.2 – air content of fresh concrete

AS 1012.5 – plastic density of fresh concrete

AS 1012.6 – bleeding of fresh concrete

AS 1012.18 – setting time of fresh concrete

AS 1012.8.1 & 9 – compressive strength up to 56 days

AS 1012.13 – free drying shrinkage up to 56 days

ASTM C1579 – plastic crack development at early age

All concrete work was performed at an environment of 23±2°C and 50±5% humidity except the ASTM C1579 test as detailed below.

environment. Two specimens for each mix were applied with a smooth steel trowel finish. They were exposed to an environmental chamber, about 35°C, about 30% RH and wind speed 3.7-4.0m/sec. This chamber was to provide an accelerated evaporation from fresh concrete. In this setup, the sheet metal base provides restraint, while the stress riser placed in the centre of the slab significantly reduced the slab depth and provides a preferential location for cracking. After 24 hours, image acquisition was taken by a Dino-Lite digital microscope and processed with the software provided. Approximately 32 measurements were taken for each specimen along the path over the stress riser.

3. Experimental Results

3.1 Water demand, density and air content

After yield correction, the water demand, plastic density and air content are presented in Table 1.

It was noted in Table 1 that the ENVISIA™ concrete required about 16 litres/m^3 less water for the same amount of cement, 330kg/m^3, and for a similar 75-80mm slump. While the air content is higher than the control concrete, the lower water/cement ratio made it possible for the ENVISIA™ concrete to develop similar strength.

It can be seen from Table 1 that a lesser amount of water was required for a given workability, about 80mmm slump, when SRAs were used. It is interesting to note the air content was influenced when SRA1 was used. Because of the higher air content for SRA1 at 3 L/m^3 and 5 L/m^3, the water demand and density were reduced.

Table 1. Water demand, density and air content of fresh concretes

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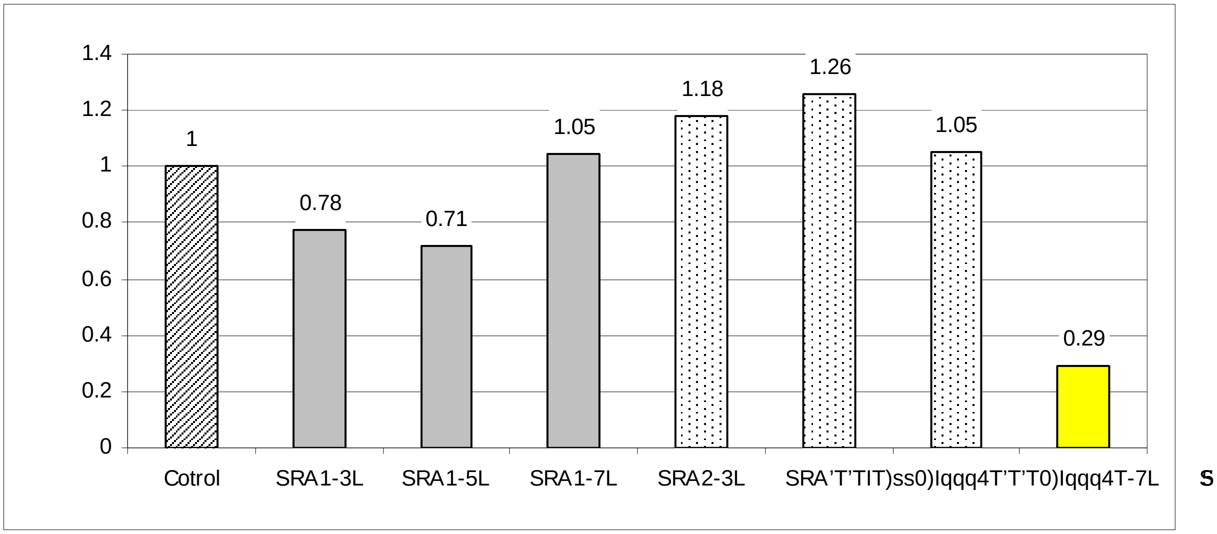
3.2 Bleed water

It is clear from Figure 1 that ENVISIA™ concrete had much less bleed water. Figure 1 also demonstrates that concrete with SRA1 has less bleed water while concrete with SRA2 has more bleed water than the control. This is probably due to the nature of the different types of SRAs.

3.3 Setting time

ENVISIA™ concrete has an equivalent setting time as compared with the control concrete. However, the results shown in Figure 2 indicate that concrete with SRAs have a longer setting time compared to the control concrete. This would indicate that SRAs retard the hydration of cement under normal conditions. This observation is in agreement with exhibited lower 1-day compressive strength (i.e. Figure 3) in concretes containing SRAs.


1.4
1.2
1
0.8
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1
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0.71
1.05
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Cotrol
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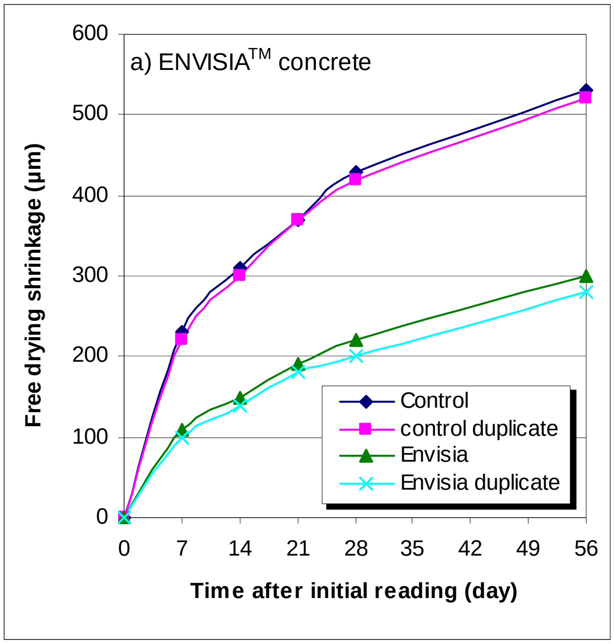
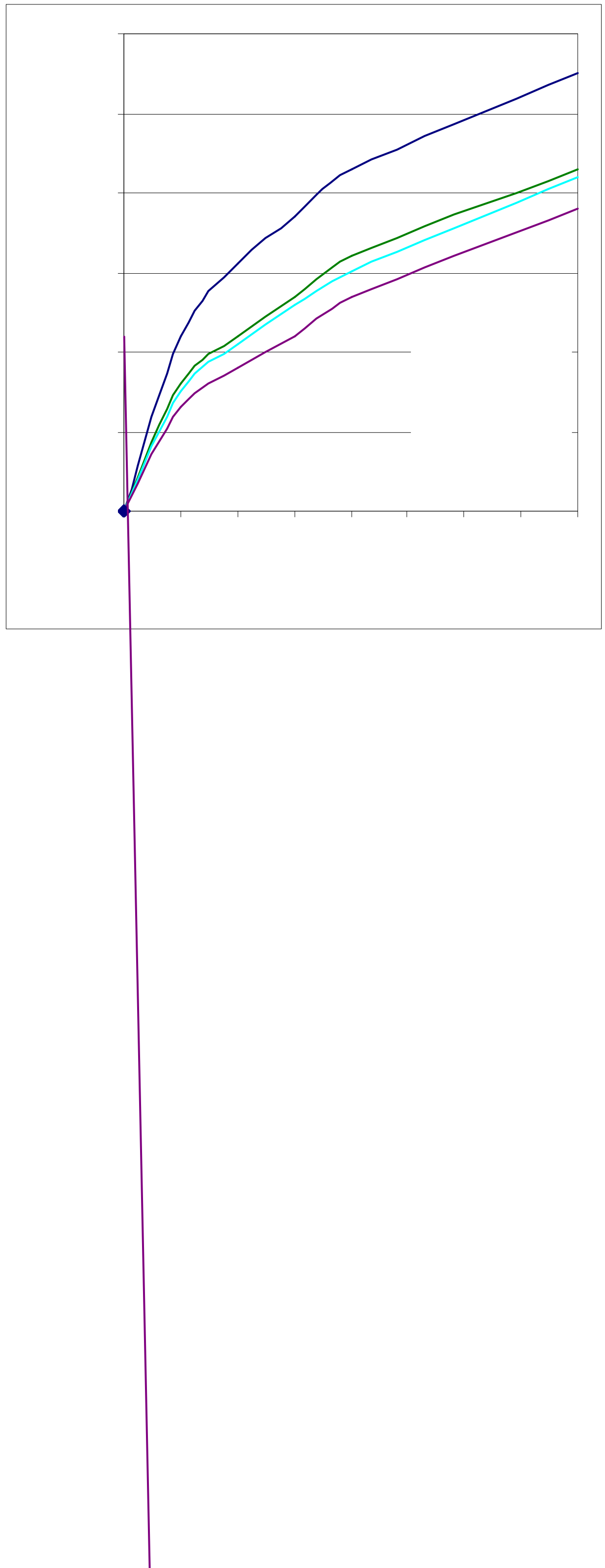
3.5 Free drying shrinkage development

The fresh drying shrinkage measurements were performed as per AS 1012.13 and the shrinkage data up to 56 days is presented in Figure 4.

It is clearly demonstrated in Figure 4 that ENVISIA™ concrete had developed dramatically lower free drying shrinkage, about 50% at 28 days and 55% at 56 days.

This test confirms that the addition of SRAs decreases the free shrinkage of concrete (1, 2, 3). Less free shrinkage occurs with a greater amount of SRAs. These maximum shrinkage reductions for 7L/m^3 dose were approximately 30-37% at 56 days. There is no significant difference between SRA1 and SRA2.





3.6 Plastic cracking development at early age

Since the concrete was exposed to a dry condition approximately 20 minutes after casting, any early age volume change (i.e. autogenous shrinkage and drying shrinakge) resulted in cracks due to the rapid loss of water and the internal restraints. The resultant plastic shrinkage crack width is presented in Table 2.

Table 2. Plastic shrinkage crack width

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4.5 ENVISIA^{TM} concrete achieved lower 56 days drying shrinkage t