



# An experimental study on the shrinkage response of industrial pavements cast with ENVISIA® and normal concrete

2019

**Presented at Concrete 2019 Conference, Sydney**

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# An experimental study on the shrinkage response of industrial pavements cast with Envisia<sup>®</sup> and normal concrete

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**Abstract:** Industrial pavements are widely used throughout the world in warehouses and industrial facilities. This paper focuses on their service behaviour and, in particular, on the influence of shrinkage effects on their structural response. The particularity of this form of construction is to be cast on ground. Under these conditions, the ability of the concrete to dry from its underside is limited or prevented due to the presence of the subgrade or waterproof membranes. Under these conditions, shrinkage gradients develop over time through the slab thickness and these are usually the main cause of curling and of the possible consequent cracking. This paper presents an experimental comparative study carried out to investigate the shrinkage response of samples cast with two concrete mixes, i.e. one low-shrinkage concrete mix (Envisia<sup>®</sup>) and one normal-shrinkage concrete (typical burnished mix). A total of nine samples have been prepared and consist of six small concrete specimens used to characterise the shrinkage profile that develop over time and three slab specimens cast on ground that aim at reflecting the behaviour of a real industrial pavement. Plain concrete as well as different dose rates of steel fibres have been used in the samples. All specimens have been instrumented to monitor their total deformations induced by shrinkage over time and, for the slabs cast on ground, uplift displacements at the slabs' ends. Preliminary results of this experimental study are presented and highlight the main differences observed for the two concrete mixes considered.

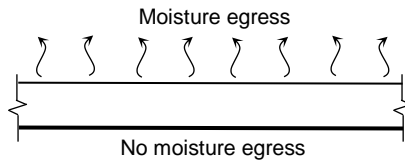
**Keywords:** concrete, industrial pavement, shrinkage, time effects.

## 1. Introduction

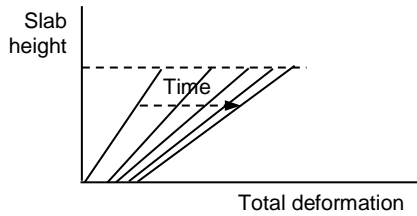
Industrial pavements are widely used throughout the world in warehouses and industrial facilities. This paper deals with the influence of shrinkage effects on their service response. This form of construction is cast on ground and, under these conditions, moisture egress is limited or prevented from the underside of the pavement due to the presence of the subgrade or waterproof membranes. Under these non-symmetric drying conditions, shrinkage gradients develop over time through the slab thickness and these are usually the main cause of curling and of the possible consequent cracking, e.g. (1-4).

This paper presents the preliminary results of an experimental comparative study that is underway to investigate the qualitative shrinkage response of concrete samples that account for the non-symmetric drying conditions exhibited by concrete floors in industrial pavement applications. A total of nine samples have been prepared with two concrete mixes with nominal 40 MPa strength, i.e. with a low-shrinkage mix (Envisia<sup>®</sup>) and a normal-shrinkage one (typical burnished mix), and these have been monitored over time. In particular, six concrete specimens have been prepared to characterise the time-dependent shrinkage profile that develops over time following a long-term test setup developed and adopted in recent years for the identification of shrinkage distributions in composite steel-concrete floor systems, e.g. (5-8). Considering the drying conditions of a slab sealed on one side and exposed for drying on the other (Fig. 1a), the consequent qualitative total deformations that develop through the cross-section are depicted in Figure 1b. These are produced by the non-uniform shrinkage profile shown in Figure 1c. For typical design applications, such as for composite floor systems, it is acceptable to approximate this shrinkage distribution by means of a linear profile as illustrated Figure 1c (9). The remaining three samples consist of slabs cast on ground and aim at representing the response of a slice of an industrial pavement to gain insight into its curling behaviour that occurs in one direction. All specimens prepared in this study have been monitored over time.

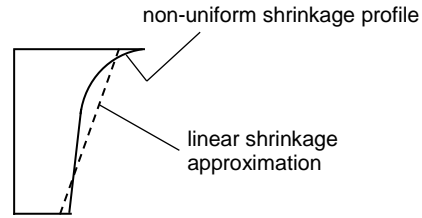
In the first part of the paper, the samples and their preparation are presented, followed by the instrumentation arrangement and the discussion of the experimental measurements.



(a) typical non-symmetric drying conditions (limit condition adopted in the experimental setup in which drying is prevented from the underside of the slab)



(b) qualitative long-term variation of the total deformations (plotted strains represent shortening)



(c) qualitative representation of the shrinkage profile and its linear approximation

**Figure 1. Schematic of the non-uniform shrinkage occurring through the depth of the slab**

## 2. Description of samples

This experimental program has included the preparation and long-term monitoring of nine plain and fibre-reinforced concrete specimens summarised in Table 1. These can be subdivided into two sets of samples based on their geometry. The first set consists of samples S1-S6 that have plane dimensions of 900 mm × 900 mm and thickness of 160 mm (Figure 2a), while the remaining three samples, denoted as S7, S8 and S9, are 3600 mm long fibre-reinforced concrete slabs cast on ground with width of 600 mm and thickness of 160 mm (Figure 2b).

To reflect the condition in which the slab cannot dry from its underside, the underside surfaces and the side edges of the specimens have been covered with plastic. In this study, the plastic has been carefully placed in the formwork before casting (see Figures 3a and 3b for samples S1-S6 and S7-S9, respectively). Plastic inserts attached by means of common sticky tape to the plastic have improved the ability of the plastic to remain firmly attached to the concrete after the removal of the formwork and during the long-term testing. The sealing condition can certainly be provided also by means of other techniques but the adopted one has been preferred for its ease of execution and for its robustness (the adopted approach has been tested in previous experimental work carried out by the authors).

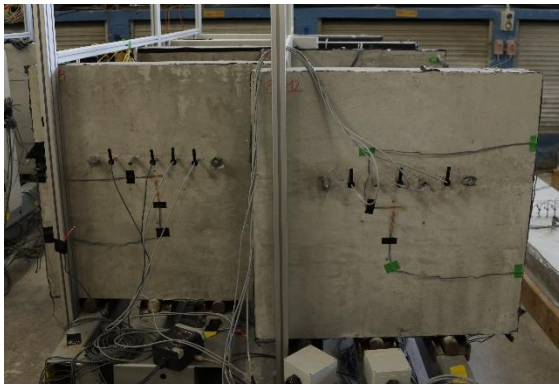
**Table 1. Summary of samples.**

Sample ID <sup>(3)</sup>	Width (mm)	Length (mm)	Thickness (mm)	Nominal concrete strength (MPa)	Inclusion of fibre N=no Y <sub>1</sub> =yes with 35 kg/m <sup>3</sup> Y <sub>2</sub> =yes with 28 kg/m <sup>3</sup>
S1	900	900	160	40 <sup>(1)</sup>	N
S2					Y <sub>1</sub>
S3					Y <sub>2</sub>
S4				40 <sup>(2)</sup>	N
S5					Y <sub>1</sub>
S6					Y <sub>2</sub>
S7	3600	600	160	40 <sup>(1)</sup>	Y <sub>1</sub>
S8				40 <sup>(2)</sup>	Y <sub>1</sub>
S9				40 <sup>(2)</sup>	Y <sub>2</sub>

Notes: <sup>(1)</sup> normal-shrinkage concrete (typical burnished mix)

<sup>(2)</sup> low-shrinkage concrete (Envisia<sup>®</sup>)

<sup>(3)</sup> all samples were exposed to dry on one surface and sealed on opposite surface as well as on all four edges

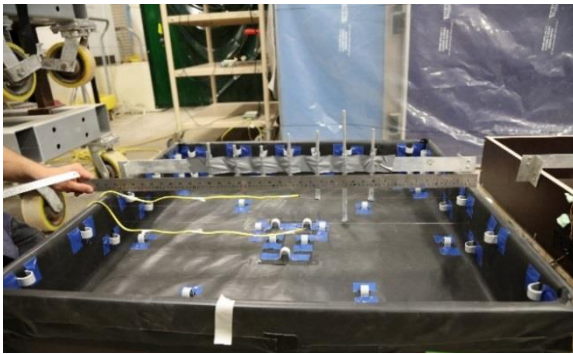


(a) samples S1-S6

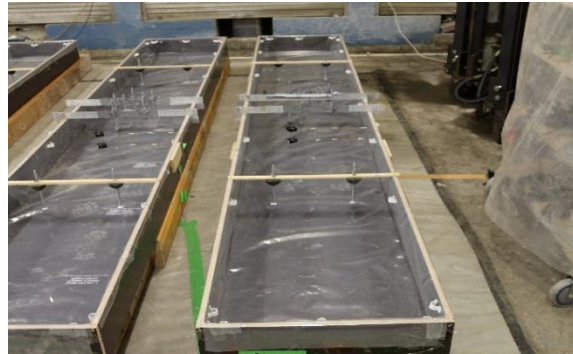


(b) samples S7-S9

**Figure 2. Overview of samples during long-term monitoring**



(a) typical plastic arrangement of samples S1-S6



(b) typical preparation of samples S7-S9

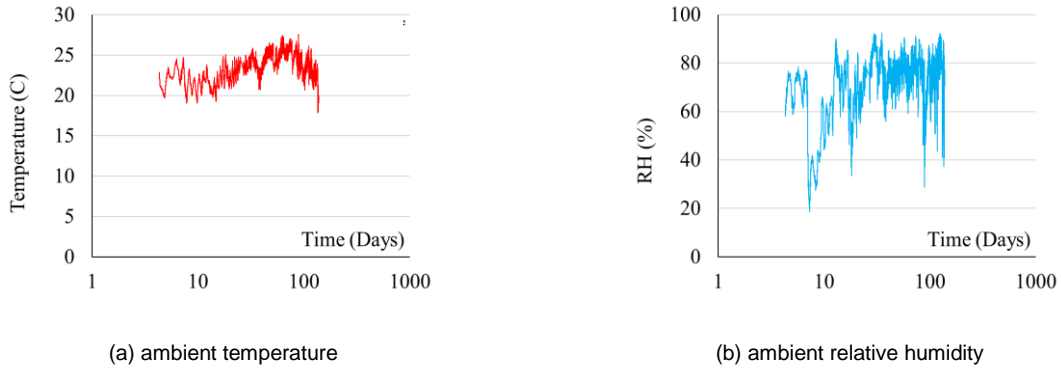


(c) plastic insert

**Figure 3. Placement of plastic before casting (plastic to prevent moisture egress during drying)**

Two concrete mixes have been used in this study with nominal concrete strength of 40 MPa, i.e. a normal-shrinkage burnished finish type concrete and a low-shrinkage concrete (Envisia®). For each concrete mix, plain concrete, as well as two levels of fibres, have been considered and consisted of the addition of no fibres and the inclusion of dosages of 28 kg/m<sup>3</sup> and 35 kg/m<sup>3</sup>. In particular, concrete with no fibres have been used for the preparation of samples S1 and S4, while 28 kg/m<sup>3</sup> and 35 kg/m<sup>3</sup> concentration of fibres have been used for the other samples as specified in Table 1.

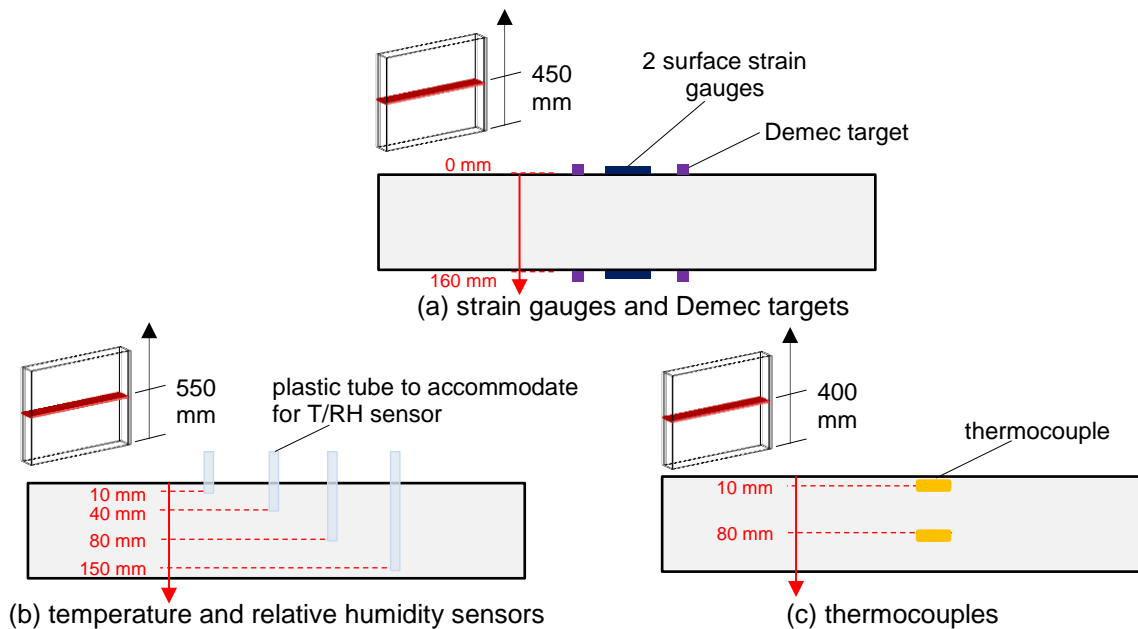
All the sample have been prepared and cast in a horizontal position. After 4 days of wet curing, specimens S1-S6 have been lifted vertically and placed on three roller supports, while samples S7-S9 have been left undisturbed on the ground. The vertical arrangement (Figure 2a) enables the specimens to deform freely during the long-term test without any external restraint. With this setup, the deformations produced by the self-weight have no effect on the shrinkage measurements as, for the samples considered, the former ones (i.e. due to the self-weight) are negligible when compared to the latter (shrinkage) ones. The specimens have been exposed to the same environmental conditions that are reported in Figure 4.



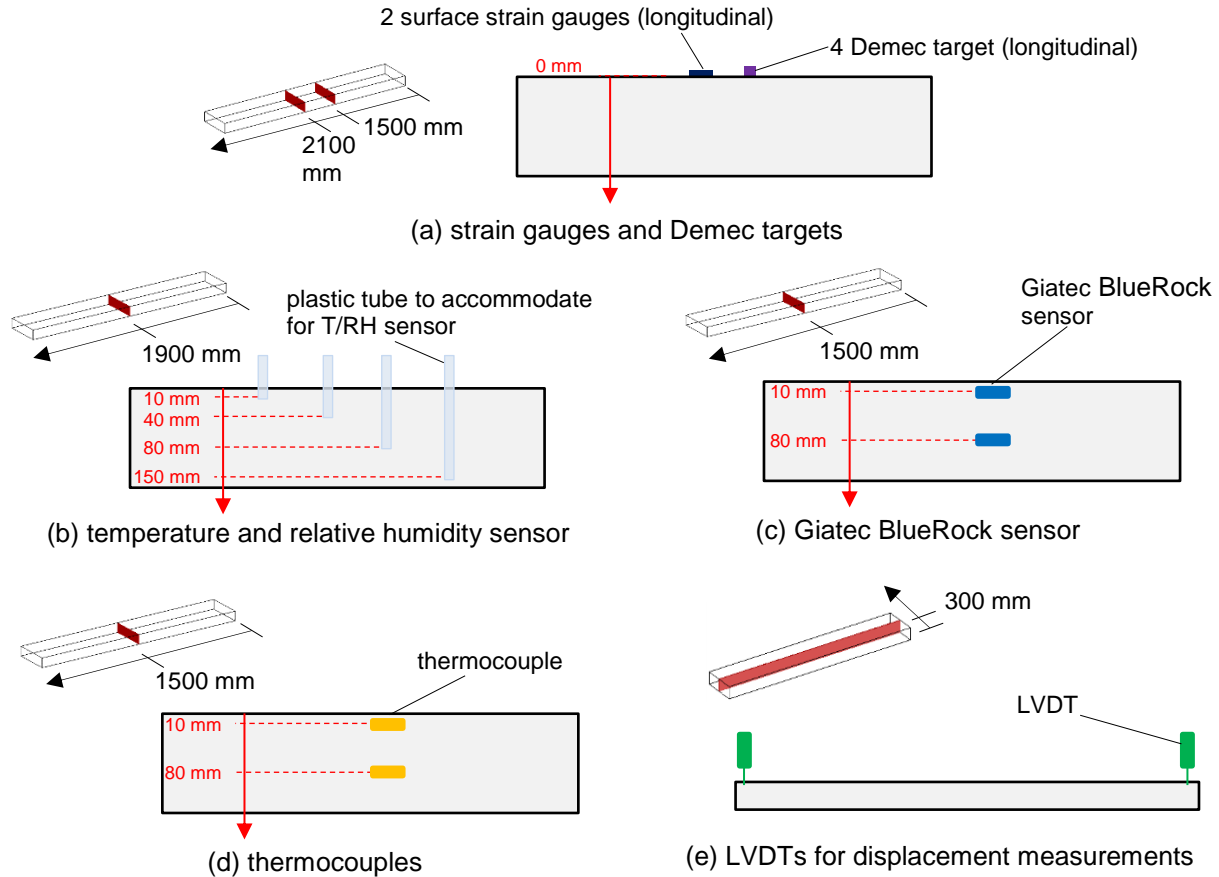
**Figure 4. Ambient temperature and relative humidity during long-term testing**

### 3. Instrumentation layout

The instrumentation adopted in this study aims at gaining insight into the shrinkage-induced deformations and the time-dependent hydro-thermal behaviour that takes place over time. Deformations have been recorded by means of strain gauges and Demec targets. In particular, four strain gauges have been used to monitor deformations on the faces of samples S1-S6 (Figure 5a). Particular care has been placed to cut a small opening in the plastic to install the sensors and the Demec targets on the sealed face. The opening has then been closed with wax and extra plastic. Two strain gauges have been installed on the top surface of the slab samples S7-S9 (Figure 6a). The strain readings have started at 8 days from casting and, as such, do not consider the deformations due to shrinkage effects occurred before this point in time. Thermocouples cast in the concrete have allowed the measurement of the thermal variations during the first few days from casting (Figures 5c and 6d), while temperature and relative humidity sensors installed at 4 days from casting have enabled the monitoring of temperature and relative humidity profiles over the slab thickness (Figures 5b and 6b-c). The uplift displacements that have occurred at the slab ends of specimens S7-S9 due to shrinkage effects have been recorded by means of two LVDTs as depicted in Figure 6e.



**Figure 5. Layout of instrumentation for samples S1-S6**



**Figure 6. Layout of instrumentation for samples S7-S9**

#### 4. Long-term measurements

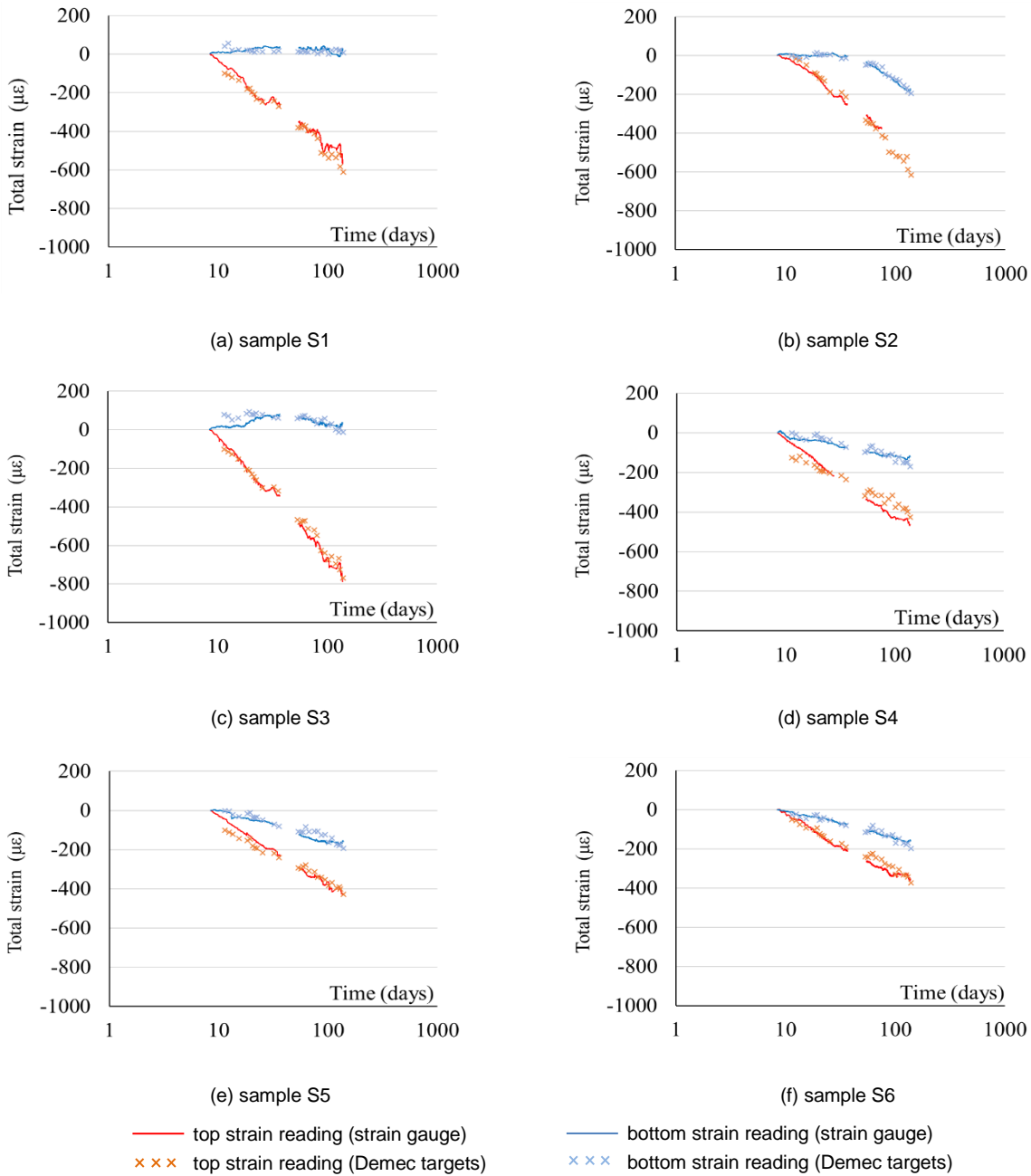
Selected measurements recorded over time have been presented in Figures 7-10.

The total deformations measured from day 8 from casting on the two sides of specimens S1-S6 are depicted in Figure 7 and highlight the presence of a gradient produced by shrinkage effects. Under the simplifying assumption commonly used in design (9) of considering a linearly varying shrinkage profile, the total deformations of Figure 7 can be considered to represent the shrinkage profile exhibited by the concrete. There are two main observations that can be drawn from the strain measurements and these consist of: (i) the curvature exhibited by the low-shrinkage concrete (Envisia<sup>®</sup>) is smaller than the one measured for the normal-shrinkage burnished concrete mix for all fibre contents (Figure 7) – this is important as the curvature has a direct impact on the development of curling, e.g. (4-10); and (ii) the strain measured at the top face of the slab samples is much larger for the normal-shrinkage concrete specimens (Figures 7a-c) than those cast with the low-shrinkage concrete (Envisia<sup>®</sup>) (Figures 7d-f). The deformation measurements of Figure 7 include data collected from both strain gauges and Demec targets to confirm the accuracy of the strain readings. The strain measurements represent the long-term deformations from the time the strains have been recorded, therefore give no insight into deformations exhibited in the first few days from casting (before the start of the strain recording at day 8 from casting).

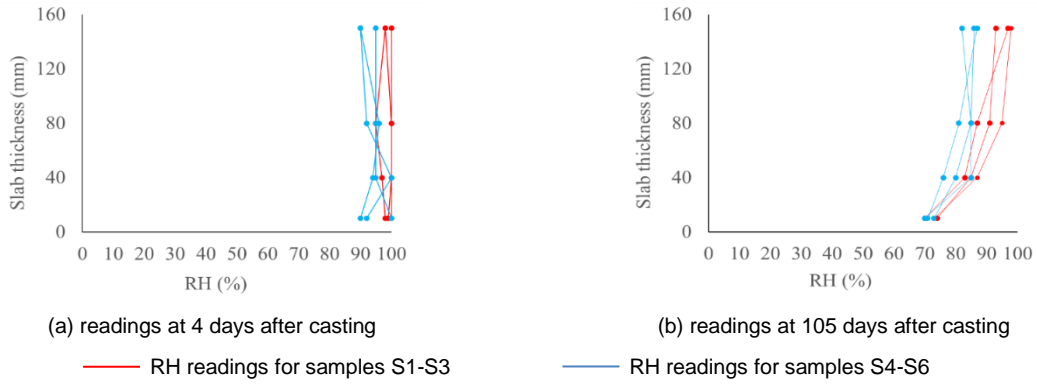
The different curvatures exhibited by the low- and normal-shrinkage concrete specimens are also observable by considering the relative humidity distributions measured through the slab as shown in Figures 8a and b for measurements recorded at 4 and 105 days, respectively, from casting. Figure 8a presents a slight difference between the two concrete profiles at 4 days from casting, therefore

highlighting how the samples prepared with the low-shrinkage concrete might have already undergone a higher reduction in moisture within the first 4 days that could be attributable to consumption and loss of water in the chemical reaction due to the acceleration of the ettringite formation. The difference in gradients observed in Figure 8b leads to the measured deformations depicted in Figure 9 in which there is a clear difference in the response of the two concrete mixes (as already pointed out for Figure 7).

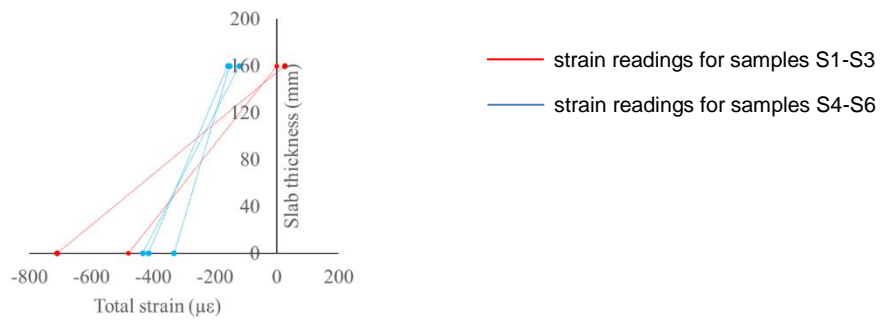
For the slab specimens cast on ground (i.e. samples S7-S9), the vertical displacements of the slab ends are depicted in Figure 10, in which negative LVDT readings represent uplift displacements. Also in this case, the samples cast with the low-shrinkage concrete (Envisia®) exhibit lower uplift movements at the member ends due to the smaller strain gradient developed through the concrete specimens (well depicted with samples S1-S6) for the period monitored in this study.



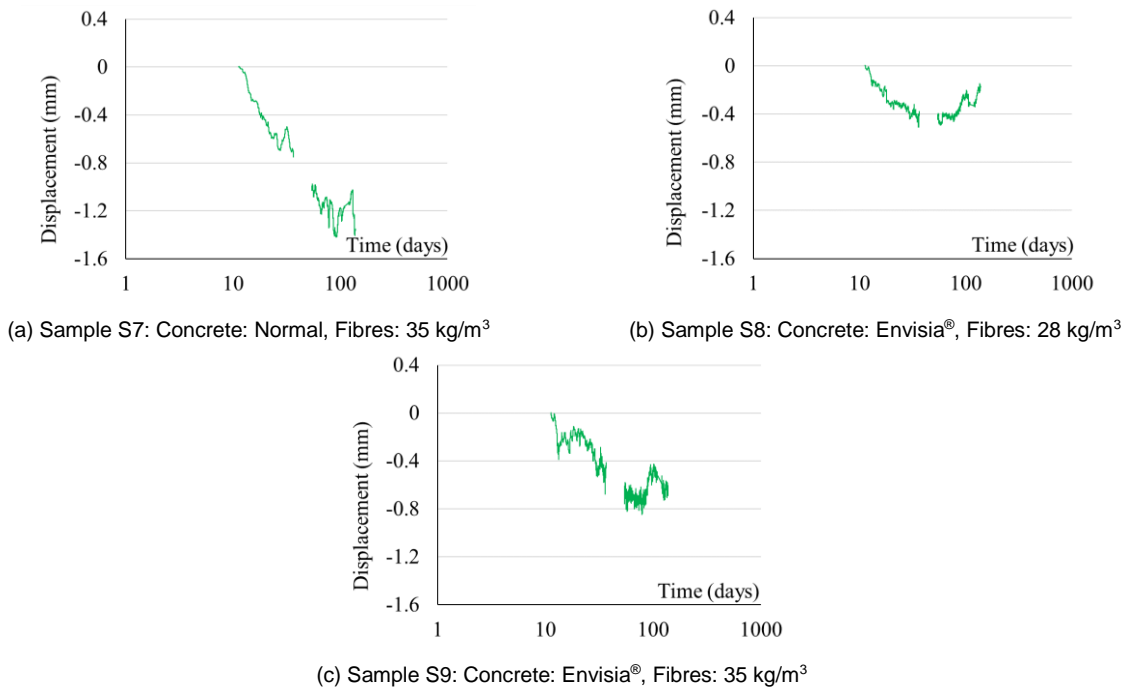
**Figure 7. Long-term total strain profiles for samples S1-S6**



**Figure 8. Relative humidity profiles of S1-S6**



**Figure 9. Strain profiles of samples S1-S6 measured at 105 days from casting**



**Figure 10. Vertical end displacements of samples S7-S9 (negative displacement depicts uplift)**



## 5. Conclusions

This paper presented the preliminary results of a long-term study carried out on concrete samples to gain insight into the shrinkage effects exhibited by concrete pavements in industrial applications. For this purpose, nine samples have been prepared and tested with two different concrete mixes with nominal 40 MPa concrete strength, i.e. a low- and a normal-shrinkage concrete mix. Six specimens have been used to characterise the shrinkage distributions that develop through the slab thickness over time, while the remaining three samples have been used to observe the possible uplift displacements that develop at the member ends of the slab specimens cast on ground. The main preliminary outcomes of this study are that, over the period during which the deformations have been monitored (from day 8 to day 105 from concrete casting), the low-shrinkage concrete (Envisia®) produced a smaller shrinkage curvature and exhibited reduced total deformations at the top surface of the unrestrained samples free to deform over time and subjected to the limit drying boundary condition of pavements, i.e. free to dry from one side and sealed on its opposite side. Within the first 4 days from casting, the relative humidity measured through the thickness of the specimens identified that the low shrinkage samples had undergone a reduction in free water and thus increased 'drying' and lower humidity, which is deemed to be attributable to accelerated ettringite formation. Future work will aim at reproducing these results and at gaining insight into the role of shrinkage effects in the first few days from casting and on the influence of the surface treatments commonly specified in industrial applications on the shrinkage effects of concrete pavements.

## 6. Acknowledgement

The work presented in this paper was supported through a research contract and the financial support of Boral Australia – Innovation Factory / Construction Materials and Cement is acknowledged.

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