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Early Age Properties of HPC Columns under Construction-Site Conditions

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Abstract: High performance concrete (HPC) is widely used in civil engineering due to its high durability and low permeability etc. Compared with ordinary concrete, HPC may develop much higher AS (autogenous shrinkage) at early age due to the relative low water cement (w/c) ratio and adding of mineral admixtures, which is one of the main reasons for early age micro-cracking of HPC structures. This paper studies the early age property of HPC columns under similar construction-site surroundings by embedded strain transducers. Results show that for HPC structure, early-age autogenous shrinkage especially within the first day after concrete pouring is pretty large. AS within the first day are 60% larger than those for 14 days in this research for all specimens. Therefore it should be taken into account for structure durability. By comparison of PHPC (plain HPC column) and RHPC (reinforced HPC column) specimens, the effects of reinforced bars on AS and temperature distribution have been analyzed. Also the influence of w/c ratio on AS is demonstrated.

Keywords: HPC, autogenous shrinkage, embedded strain gauge, temperature distribution.

1. Introduction

HPC is one of the vital materials for our infrastructure and is more and more widely used in construction all over the world. Although HPC can offer superior strength and low permeability, the main factors responsible for the development of tensile stresses in HPC structures are thermal and autogenous deformations under restrained conditions. If these stresses reach the tensile strength of the concrete, cracking will initiate which possibly results in premature corrosion of the steel reinforcement, and spalling of the concrete. Therefore, it has been a matter of great concern on AS to get durable structures.

Shrinkage at early age occurs when no moisture transfer is permitted with the environment. This volume change is called AS and is attributed to self-desiccation due to the hydration of cement. Typical values of the AS of ordinary concrete are about 40×10^{-6} at the age of 1 month and 100×10^{-6} after 5 years,[1] which are relatively low compared with those of drying shrinkage. Because of this, AS has been ignored for practical purposes for ordinary concrete. However, for concrete with a low w/c ratio, AS may be of significance. According to Aitcin et al.,[2] the AS will not be high if the w/c ratio is greater than about 0.42, but will develop rapidly if the w/c ratio is lower than 0.42. At a very low w/c ratio of 0.17, an AS of 700×10^{-6} for concrete was reported.[3] To acquire high durability and high strength, low w/c & w/b ratio is adopted; meanwhile mineral admixtures (such as silica fume, fly ash, superplasticizer and metakaolin etc.) are added during making HPC. Accordingly AS of HPC is an important part constituting total deformation of HPC at early age.

Some researchers have studied the AS of HPC. M. H. Zhang and C. T. Tam, M. P. Leow executed the research of w/c ratio and silica fume content influence on AS of HPC.[4] Drago Saje and Franc Saje studied the influences of different w/c ratio, superplasticizer, coarse aggregate, cement etc. on AS.[5] In Toyoharu Nawa and Tomoaki Horita's paper,[6] the relationship of concrete AS with the internal relative humidity of cement system has been investigated. Other authors executed the similar explorations.[7,8] According to these researches, the importance of AS and the influence of concrete components are known. However, these researches adopt the small size and plain specimen with prism or cylinder shape, and the specimens are put in the curing room. The specimen size or curing condition is much different from the real structure members and the ambient environment in construction site. On the other hand, autogeous shrinkages referred to in most literatures have been measured starting from the time of demoulding according to technical standards or based on a certain age for starting the shrinkage measurement. This will lose sight of the very-early age AS of HPC (before concrete hardening) due to the restriction of monitoring sensor and technique. Recently, Fiber optical sensor (FOS) has been used in civil engineering, due to its paramount advantages, outstanding work on early age property.[7,9-11] However, the results from FOS are not perfect as its high elastic modulus does not agree with that of early-age concrete (fresh concrete).

This paper carries out the early age AS study of HPC by moni-

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toring HPC columns with actual dimension under similar construction site surroundings with one kind of "soft" (low elastic modulus)strain transducer. Early age AS especially within 24 hours after casting is obtained, and the w/c ratio effect is discussed. Also the influence of reinforcing bars on autogenous shrinkage is analyzed.

2. Experimental program

2.1 Embedded strain transducer and concerned data logger

The embedded strain transducer used in our experiment is KM-100B belonging to KM series made by Tokyo Sokki Kenkyujo, which can measure the strain of concrete that undergoes a transition from compliant to hardened state. Its low elastic modulus (40 MPa) is close to that of fresh concrete before hardening, and its waterproof construction is suitable for internal strain measurement during the very early stages of curing. In addition, they are impervious to moisture absorption; thus, they can produce stability for long-term strain measurement as well. As shown in Fig. 1(a), the sensor is small, light and strong enough (concerned parameters given in Table. 1) to be installed easily without influencing the strain distribution of measured object. Concerned data-logger used here is TDS-602 static data collecting system (Fig. 1(b)) made by the same company, which can collect data with high resolution (for strain, 1 $\mu\varepsilon$ and for temperature, 0.1°C). This equipment can connect strain sensor and thermocouple simultaneously, and it is fit for long-term measurement with small-sized battery by sleep interval timer.

Table 1 Size and weight parameters of KM-100B.

Type	Dimensions (mm)						Weight (g)
	A	B	C	D	E	F	
KM-100B	104	20	17	100	4	M3 Depth6	75

2.2 Specimen making and transducer installing

Table 2 lists the concrete mixture proportion selected for the AS test and the 28 day compressive strength cylinder specimens. Two w/c ratios were adopted to study their effect on AS of HPC. In the mixture, KS (Korean Standard) type I portland cement was used. For good workability and consolidation of the concrete, a super plasticizer, which meets the KS requirements, was also used. Cylindrical specimens for compressive strength test were removed

Table 2 Concrete mixture proportion. (unit weight: kg/m^3)

w/c	S/a	w	c	S	Ga	Adb(%)
0.27(0.30)	0.37	171	633	591	1,000	0.2

a: Maximum coarse aggregate size is 20 mm.
b: Super plasticizer (high-range water-reducing admixture), ratio of cement weight.

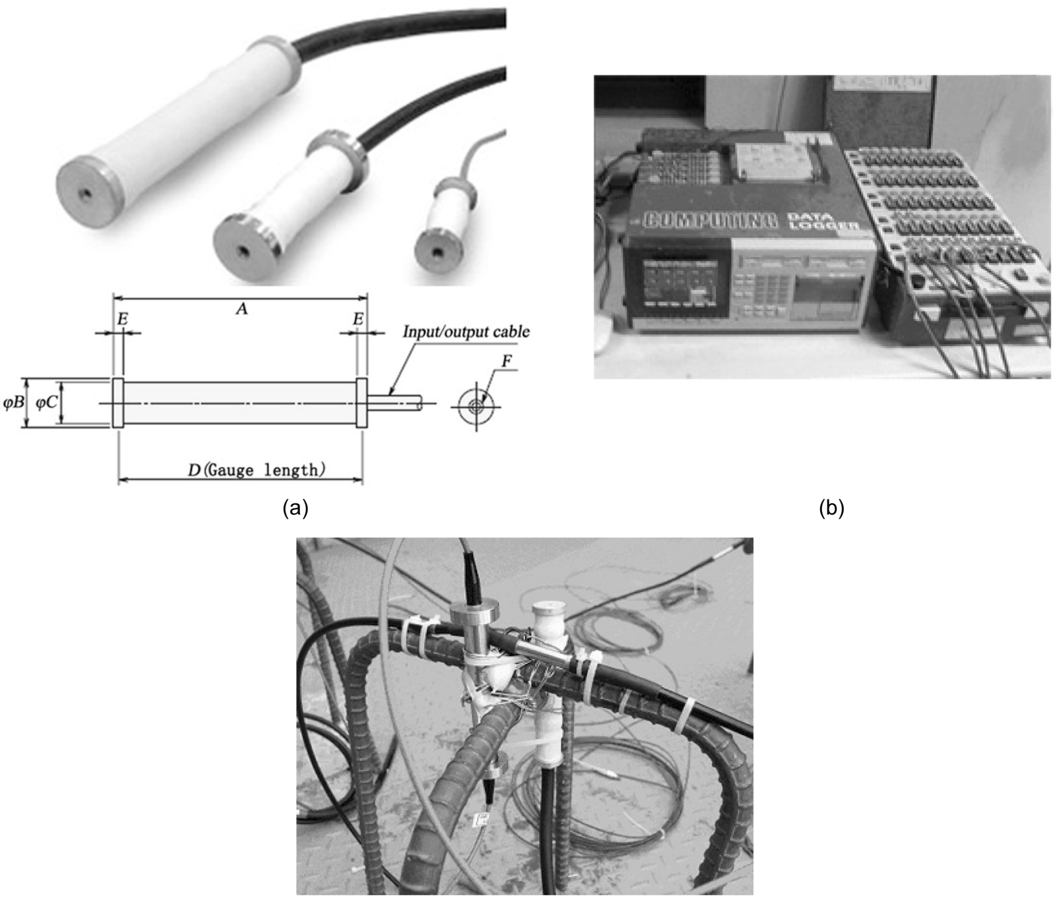


Fig. 1 (a) Used embedded strain transducer-KM-100B (b) Data logger TDS-602 and (c) Sensor installing technique.

from the mould after 24 hours and were wet-cured in a curing room with 100% relative humidity (RH) at 20°C until the testing date. The compressive strength of concrete was determined according to KS standard. In order to eliminate drying shrinkage influence in the test, AS measured specimens were covered by polyethylene plastic sheet immediately after concrete casting to prevent evaporation. The ambient temperature around specimens did not need to be controlled as that in construction-site, which was monitored by thermocouple and showed in Fig. 2. Most of time, ambient temperature was in the range of 20~23°C. Because experiment was carried out in summer, temperature changes during day and night were slight.

As there is still no specification on monitoring HPC AS in very early age, and in order to simulate the actual column member in construction site, the real size specimens were made (Table 3). Four same size specimens were used in this experiment, one was reinforced HPC specimen (RHPC3 specimen 3), and the other three were plain HPC specimens (PHPC1, 2, 4-specimen1, 2, 4), from which the influence of reinforced bars on AS can be obtained. Fig. 1(c) shows the installation technique of embedding sensor. Inside the specimen, two "U" steel bars intersected in perpendicular style, and then the strain gauge was bound at that intersection with its axial orientation along the longitudinal direction of the specimen.

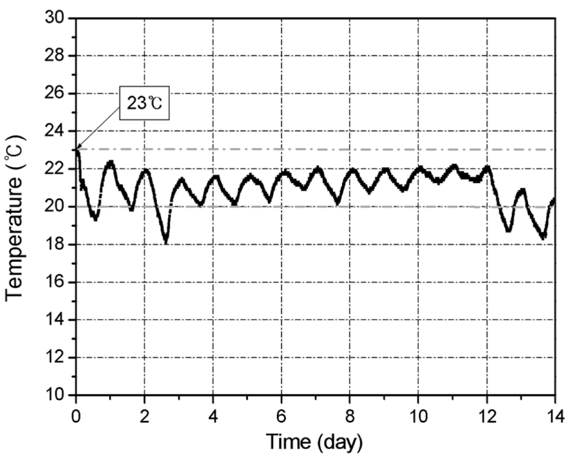


Fig. 2 Ambient temperature varying within 14 days surrounding specimens.

Tabel 3 The specification for experiment specimens.

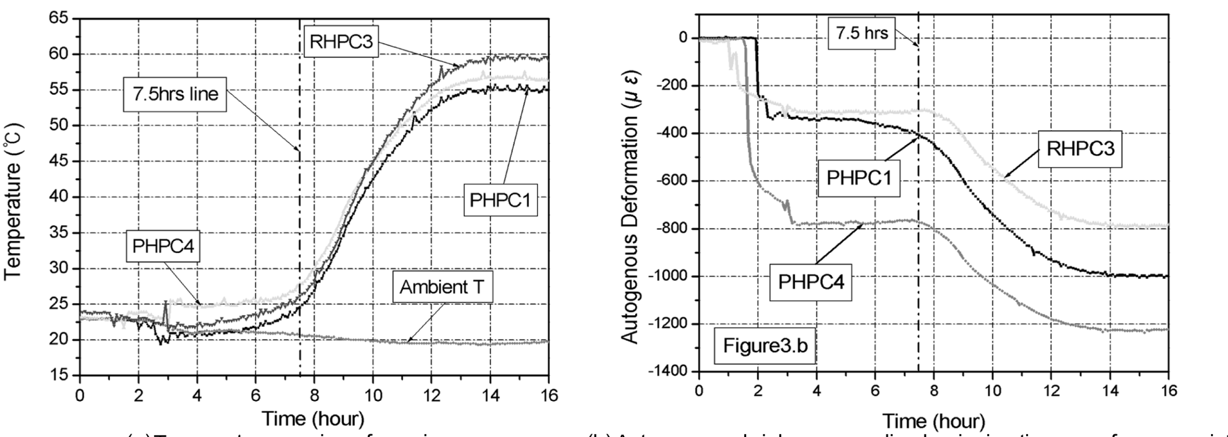
Specimen no	Size (mm)	Reinforcing or not	w/c
PHPC 1	400 × 400 × 1,000	Plain	0.27
PHPC 2*		Plain	-
RHPC 3		Reinforced	0.30
PHPC 4		Plain	0.30

* The plastic sheet covering PHPC2 was damaged during curing, drying shrinkage maybe occur. As PHPC2 and PHPC4 has the same condition such as w/c ratio, curing condition et al., only monitoring data for PHPC4 used in results and discussions has no influence on our experiment objective.

3. Results and discussion

Generally, before initial setting of concrete, the elastic modulus tends to zero. During this liquid concrete phase there is no structure to hold the body firmly in place. Any movement due to applied stresses will be immediately corrected by a shift in the position of the body. Therefore, during this stage, the deformation of concrete (also called chemical shrinkage) can be neglected for long term durability of structures. After initial setting, Young's modulus of concrete will rapidly increase to 10~100 MPa, and skeleton to resist stress will form, which implies that concrete deformation is restricted. Hence, monitoring concrete deformation from initial setting time is important for control possible micro cracks in concrete structures.

AS and thermal deformation were measured just after casting by the embedded strain transducers inside the specimens and the temperature can be measured simultaneously. The measured values or data obtained directly from the data logger included the shrinkage values before calibration and the temperature variation with time. The start of autogenous shrinkage is from initial setting time,[12] which is used as a reference value. Subsequent values obtained are subtracted from the reference values and multiplied by the calibration coefficient of the transducer to obtain the concrete shrinkage, and then thermal deformation is subtracted to obtain autogenous shrinkage. The measured CTE (coefficient of thermal expansion) for HPC after final setting time is $1.2 \times 10^{-5}/^{o}C$. The CTE for fresh concrete (during initial and final setting time) is $1.48 \times 10^{-5}/^{o}C$ according to Drago Saje and Franc Saje.[5] Fig. 3 shows the early-age AS and temperature variation of HPC speci-



(a) Temperature varying of specimens (b) Autogenous shrinkage regarding beginning time as reference point

Fig. 3 Within the first 16 hours after HPC pouring.

mens during the first 16 hours after casting. From Fig. 3, it can be seen that in the first 6 hours, there is no strain as the cement paste are still in plastic condition. After 6 hours mixing, deformation arises. Due to the low stiffness of cement paste, the deformation can not be transferred to sensor precisely. Accurate prediction of the initial setting time is difficult. In this experiment, the estimation of the initiation of the AS is based on the start of shrinkage observed. This usually corresponds to rapid rise in temperature of the concrete (Fig. 3(a)), simultaneously performed needle penetration tests confirmed this assumption. Then the reference point (initial setting time) is chosen as the 7.5 hours after mixing. From initial setting time, concrete temperature increases rapidly due to large hydration heat, and peak temperature value occurs at about 14 hours after concrete pouring (Fig. 4(a)) which is most likely to correspond to the final setting of the concrete.[13] Then as most hydration reaction finishes, temperature decreases slowly. According to Fig. 4(b), concrete temperature almost tends to constant after about 2 days. Namely, temperature deformation is invertible which only occurred during first 2 days, and then it reverts with decreasing temperature.

Fig. 5 shows the total deformation including temperature deformation, which is expansion during first one day or so. That is because the pretty high temperature deformation due to concrete hydration exceeds autogenous shrinkage. After temperature deformation reversion, concrete specimens display shrinkage in succession. Part reason for the highest total strain of RHPC3 is the higher temperature deformation than other two specimens. Based on Fig. 6(b), the increasing rate of AS within the first day is pretty high for whatever specimens. And the absolute values within the first day are also very large. According to Fig. 6(a), AS values for RHPC3, PHPC4 and PHPC1 are 85 $\mu\varepsilon$, 155 $\mu\varepsilon$ and 250 $\mu\varepsilon$ respectively. After about one day, the increasing rate of AS decreases remarkably. Until two weeks later as shown in Fig. 6(b), AS values for RHPC3, PHPC4 and PHPC1 are up to 130 $\mu\varepsilon$, 210 $\mu\varepsilon$ and 300 $\mu\varepsilon$, respectively. This demonstrates that first day AS values for all specimens are 60% larger than those for 14 days correspondingly. Therefore, autogenous shrinkage of HPC within the first day after concrete pouring should be surveyed and taken into account while other literatures ignore it.

The w/c ratio for PHPC1 is 0.27, others are 0.30. According to Fig. 6, the AS of PHPC1 is larger than those for other specimens, which infers that lower w/c ratio could lead to larger autogenous shrinkage. The RHPC3 is the reinforced HPC column specimen, others are plain HPC columns. Fig. 4 implies that reinforced bars has little effect on the temperature distribution of HPC; however, due to the restraint of the frame composed of reinforced bars to HPC deformation, the AS of RHPC3 is the smallest one compared with other PHPC ones as shown in Fig. 6. Further it can be predicted that the more the reinforcement ratio is, the less the AS is.

Il Young, Jang et al. used Fiber Bragg grating sensor to monitor

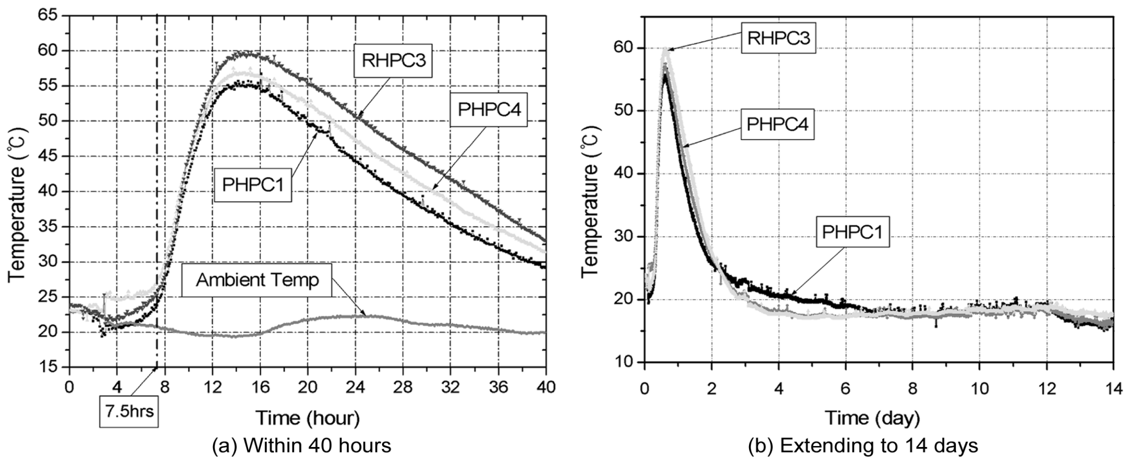


Fig. 4 Temperature distribution of specimens.

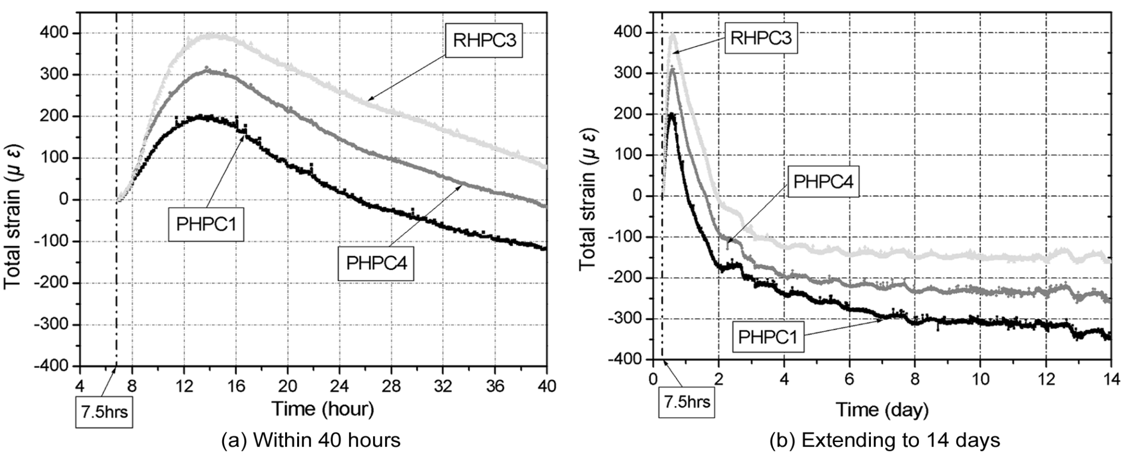
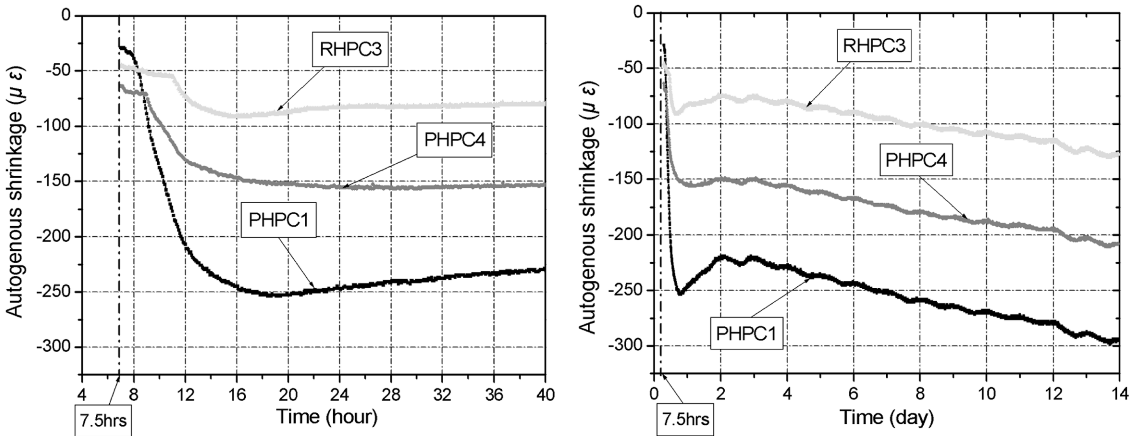


Fig. 5 The total deformation of HPC.



(a) Within 40 hours (b) Extending to 14 days

Fig. 6 Autogenous shrinkage of HPC specimens.

the early age property of HPC by similar size HPC columns.[10] One of their results is shown in Fig. 7. Compared with our results, it shows that trend of early-age deformation is consistent while values are different due to the different WCR, curing condition et al. Also the effectiveness of KM-100B strain transducer to measure early-age deformation of HPC is verified.

4. Summary and conclusions

Autogenous shrinkage of HPC is caused by self-desiccation in pore structure of concrete, and it has much effect on the cracking of HPC structures. Early age AS of HPC column specimens has been monitored by KM-100B embedded strain transducer under construction-site conditions in our experiment, and following conclusions can be reached:

The increasing rate of HPC autogenous shrinkage is rapidly large within the 1 day after concrete mixing; also the absolute value is large. First day AS values for all specimens in this test are 60% larger than those for 14 days correspondingly. Therefore, autogenous shrinkage of HPC within the first day after concrete pouring should be investigated and taken into account for structure durability research. Reinforced bars restrict autogenous shrinkage of HPC due to the restraint of the rigid frame composed of reinforced bars.

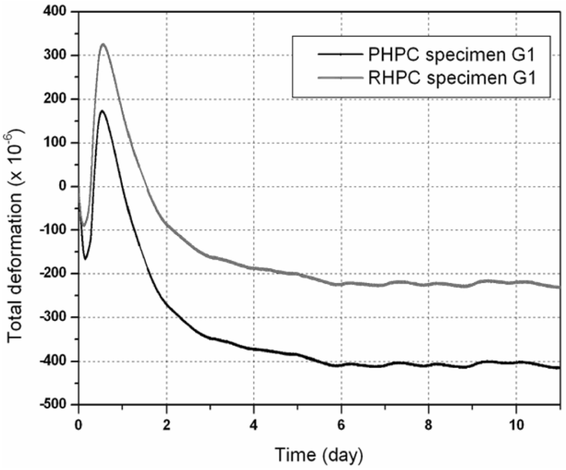


Fig. 7 Early age deformation data of HPC column by fiber bragg grating sensor[10].

Further it can be predicted that the larger reinforcement ratio will result in the less HPC AS. However, it does not influence the temperature distribution of HPC columns. The w/c ratio is most influential parameter on AS when its value is less than 0.4. For most HPC, the w/c is under 0.4, so the less of w/c ratio, the larger of the AS under the same conditions. As we use the actual size column specimen and similar surroundings to construction site, the experimental results are very useful for practical engineering.

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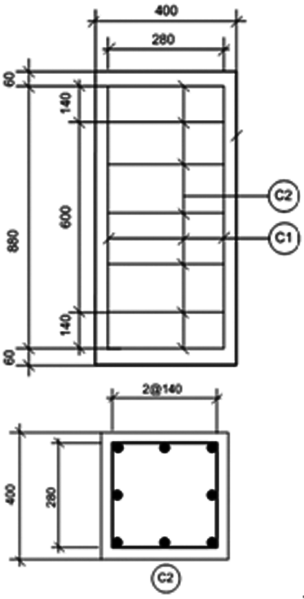
Appendices

Here shows the reinforcement drawing and table for reinforced specimen RHPC3.



Detailed items for steel material used in specimen RHPC3.

No.	Diameter	Length (mm)	Amount	Total length (m)	Unit weight (kgf/m)	Total weight (kgf)
C1	D22	880	8	7.040	3.04	21.4
C2	D16	1120	7	7.840	1.56	12.2

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