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Mitigation of shrinkage of ultra high strength concrete by internal curing

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ABSTRACT

Ultra high strength concrete (>100MPa) is widely used in construction field and has been actively researched, but, it has a high potential of early-age crack due to low water-binder ratio. Many researches have been conducted to mitigate the early-age shrinkage by using shrinkage reducing agent and expansive admixture.
In this study, internal curing with saturated lightweight aggregate(SLWA), which provides additional water to the hydrating cement particles, is applied to reduce the shrinkage. This paper presents the test results(compressive strength, autogenous and restrained shrinkage and so on) with different volumes of SLWA. In addition, the moisture transfer due to internal curing is verified by using embedded RH sensors. Thus, the LWA substitution improved both early and ultimate strength, and reduced cracking tendency. The results indicate the influence of SLWA volume and type on the internal humidity, autogenous shrinkage, and restrained shrinkage cracking behavior.

1. INTRODUCTION

Ultra-High-Strength Concrete (UHSC) has remarkable durability due to its dense micro-structure. Therefore, it is very proper for use in poor environment and condition. However, this UHSC has the early-age cracking resulting primary from high shrinkage, which may significantly decrease resistance to the corrosion. So, shrinkage must be mitigated in order to increase the durability of UHSC.

In a low-binder ratio, normal methods in the curing of concrete cannot support consistently to reduce shrinkage although wetting condition is applied. Because microstructure of UHSC is very dense in early age, they do not allow the enough curing water inside into concrete.

Recently, it has been proposed to use internal curing by addition materials with high water absorption ratio in mixture(Bentz, 2007). Several researchers have investigated the effect of internal curing using the water-saturated lightweight aggregates and super

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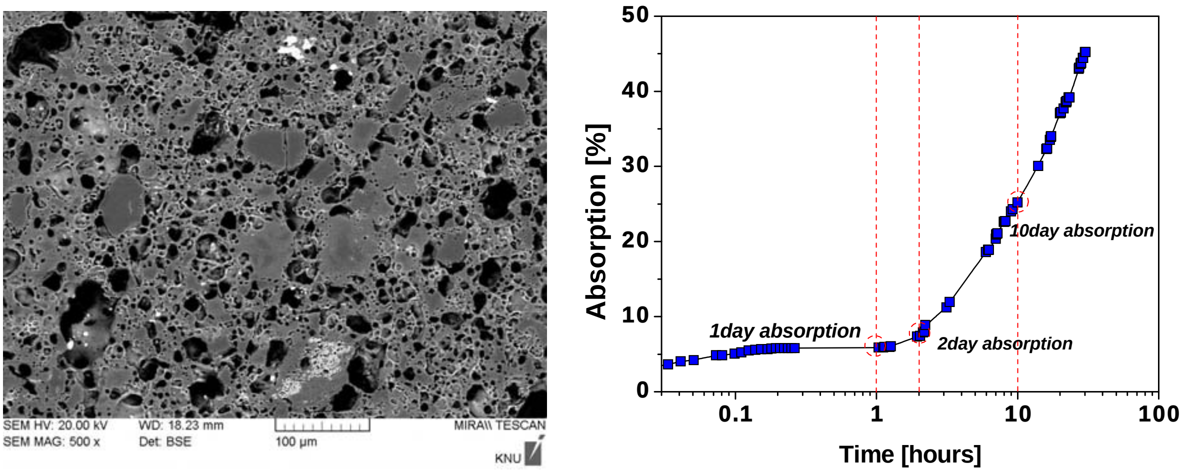
absorbent polymers in concrete(Kovler, K. and Jensen, 2007).

This paper presents the application of internal curing in UHSC using artificial lightweight fine aggregate(LWA). It focused on the results of the internal curing on shrinkage and the restrained shrinkage deformation of UHSC. In addition, the effects of the internal curing on the total shrinkage and mechanical properties are reported.

2. MIXTURE PROPORTIONS OF CONCRETE AND TEST METHOD

2.1 Materials

The cement used in experiment is ordinary Portland cement. The specific gravity was 3.15 g/m^3 and Blane's specific surface was 3,450 cm^2/g. The specific gravity of silica fume was 2.2 g/m^3 and BET specific surface was 16,584 cm^2/g. The coarse and fine aggregate was respectively 2.7 and 2.6 g/m^3. The LWA for internal curing is the shale line. The specific gravity of LWA is 1.67 g/m^3 and absorption of it is as follow Fig 1. According to experiment results, LWA immersed in water during 3 days for mixing(using 10%).



(a) (b)

Fig. 1 The BSI Image and absorption of artificial lightweight aggregate

2.2 Mixture proportions

The mixtures were composed on the basic of the reference data. In this study, two mix compositions were experimentally evaluated: one reference concrete mix with no internal curing and one mix with internal curing (10 % replacement of fine aggregate). The mix proportion of test is as follow in Table 1. The maximum size of coarse aggregate was 13mm. A certain scatter of slump-flow values between 600 mm and 650 mm occurred in the experiments on fresh concrete

Table 1 The proportion of mixing

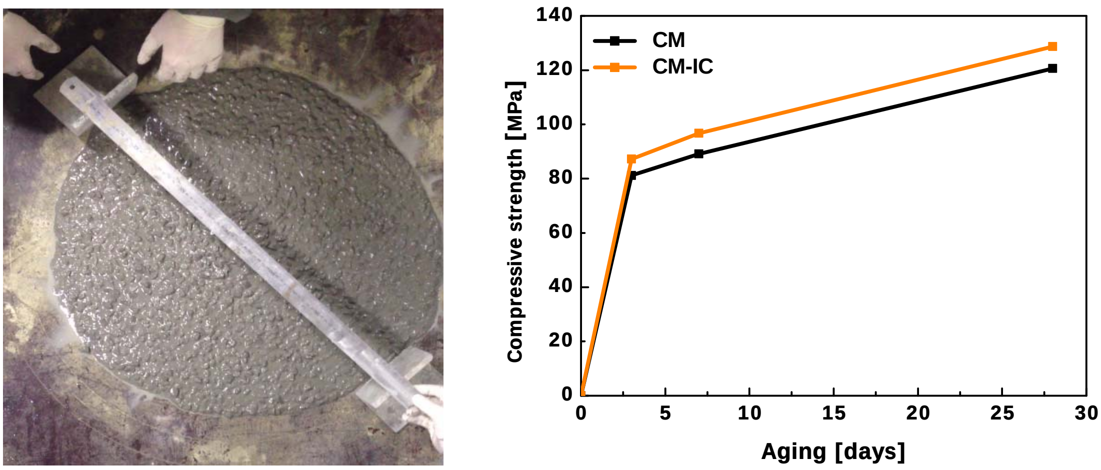
Variables		Water	Cement	Silica fume	Coarse aggregate	Fine aggregate	Lightweight aggregate
CM	Mass(kg)	144	662	74	976	651	-

	Volume(m^3)	0.14	0.21	0.03	0.36	0.26	-
CM-IC	Mass(kg)	144	662	74	976	586	42
	Volume(m^3)	0.14	0.21	0.03	0.36	0.23	0.03

2.3 Test method

After demolding, all specimens were cured at room temperature until testing. The mould size for compressive strength used Φ100X200mm.

To evaluate the effects of internal curing on shrinkage(autogenous and drying shrinkage), the electronic embedded strain gauge was used for the measurements on prisms 75X75X300mm. Deformation before de-moulding could not be measured in this case. In case of measurement of autogenous shrinkage, while stored in moulds the specimens were additionally protected against desiccation by wrapping in a few layers of thick polymer foil tape. To measure of restrained shrinkage, the concrete was cast around a steel ring of dimensions according to ASTM C 1581. The strains were measured by surface strain gauges to the inside of the steel ring for the deformation of steel ring. The specimens were exposed to environment of 23°C and 60% RH.



(a) Slump-flow (b) Compressive strength

Fig 3 The results of slump-flow test and compressive strength

3. TEST RESULTS AND DISSCUSSIONS

3.1 Compressive strength

The compressive strength of specimens were measured at 3, 7, 28 days. The values of compressive strength are shown in Fig. 3. It can be seen that the specimens using IC had a tendency of increasing strength from early ages. The internal stresses resulting from the interruption of shrinkage deformations by general aggregate must be considerably lower in the case of specimens with lightweight aggregates due to the reduction of the shrinkage of the cement paste. This is positive from the position of concrete strength. Finally, it must be said that the entire pore system of the cement paste has an effect on the strength of concrete. And in result of mercury intrusion porosimetry at 28 days(Fig 4), the porosity of CM and CM-IC was 9.32 and 8.69%, respective. In addition, the specimen using IC(CM-IC) had the smaller pore size distribution than the specimen(CM). Therefore, these results are produced the increasing strength according to dense microstructures by internal curing.

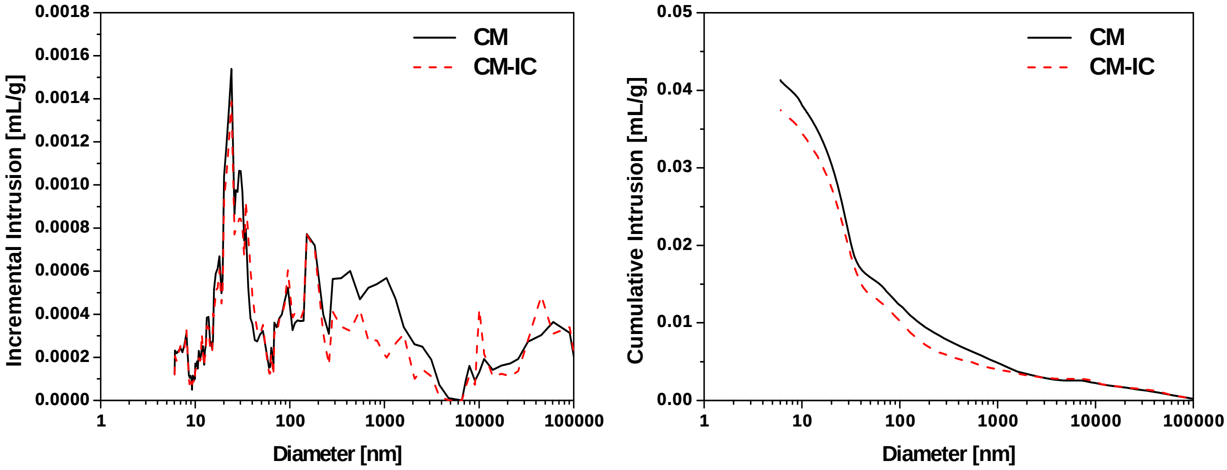


Fig 4 The results of Mercury Intrusion Porosimetry

3.2 Shrinkages

Since deformations when the concrete is still fluid have no significant influence on stress development, the evaluation of the deformations for this paper was performed starting on the final setting time. This time was determined using penetration resistance test. The results of penetration resistance test were shown in Fig. 5. Similar tendency has been shown in the results. Fig.6 shows the average curves over time for the development of autogenous and drying deformation during the first 60 days after the final set. In general, the mixtures containing LWA showed definite reductions in shrinkage deformations.

In case of internal curing, autogenous and drying deformation for 7 days and 28 days was mitigated by 35% and 21%, 26% and 18%, respectively. And these reductions were particularly dramatic at a very early age, in-deed in the first 7 days after the final setting time. Based on the measured water retardation of the lightweight aggregate it can be concluded that within this first week the desiccation of the concrete caused a high moisture difference between the capillary pores and the water saturated lightweight aggregate. The saturated lightweight aggregate provided the water towards the concrete matrix immediately after hardening. The effects of internal curing generated the reducing distance between the cement grains, a higher density and a smaller permeability.

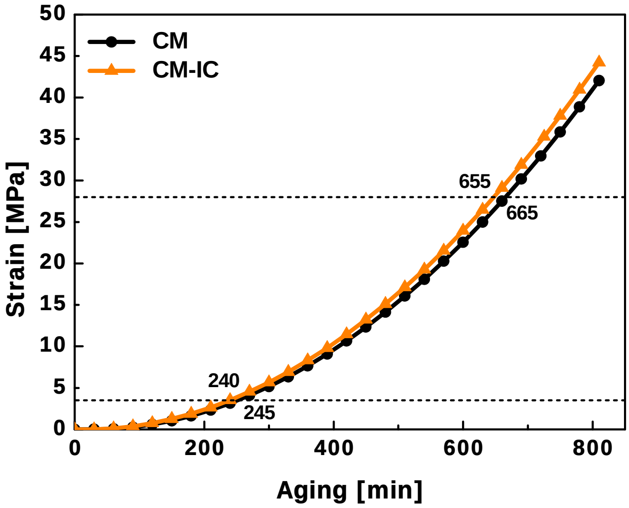
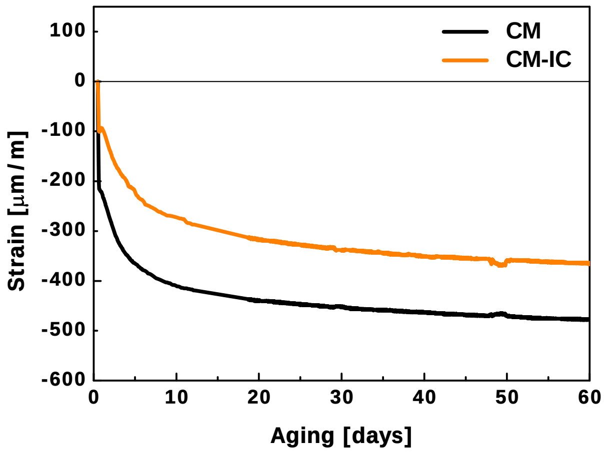
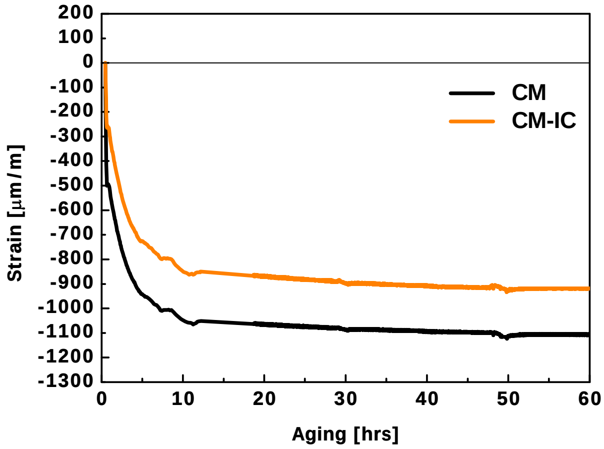


Fig. 5 Setting time of mortars by penetration resistance



(a) The results of autogenous shrinkage



(b) The results of drying shrinkage

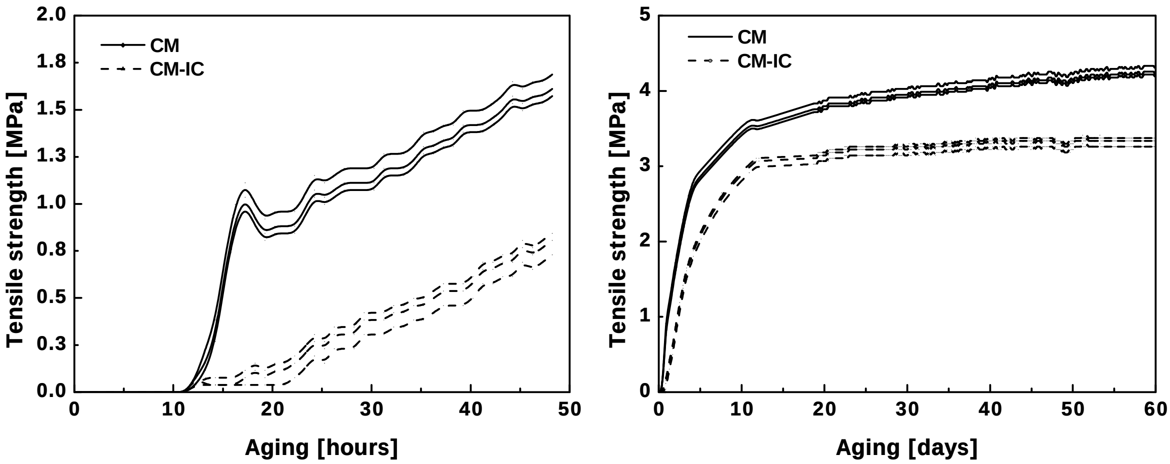
Fig. 6 The deformations of shrinkage

3.3 Restrained shrinkage measurement

Instrumented ring tests were performed to measure the restrained shrinkage deformations of specimens, both with and without lightweight aggregate addition and hence to estimate quantitatively the tendency of concretes to crack. Negative volumetric changes in the concrete induce pressure at the steel ring, resulting in its contraction. At the same time the tensile stresses in the concrete occur since the steel ring restrains the deformation of the concrete. Because the stresses due to restrained autogenous deformation should be investigated at the place of origin, an outer steel ring was used in addition to the inner ring. It served as a part of the mold when producing the concrete and subsequently as protection against desiccation for the circumference of concrete. The top of specimen was sealed with self-gluing aluminum foil. The data obtained by the strain gauge were used for calculating tensile stresses in concrete according to the equations proposed in Weiss, et al(2004) and Moon, et al(2006). The tensile results of restrained ring test are shown in Fin.7.

Fig 7(a) showed the first results obtained for 48 hours after mixing. According to results, tensile stresses of CM reached approximately 1.6 to 1.8 MPa at early ages already. While the stresses of CM-IC with internal curing rise hardly 1.5MPa. Thus, the effect of internal curing could be observed as early as the 1~2days after mixing. The decrease in the stress after roughly 15 hours follow mixing can be considered to the thermal expansion due to the hydration heat in the concrete.

Fig 7(b) showed the results of the ring tests from the continuously measurements up to age of 60 days. The mitigation of autogenous shrinkage using internal curing caused the reduction the stresses due to restraint. At the 60 days, the stresses of CM-IC were 22% smaller than the CM at the same age. This demonstrates clearly a considerable reduction of the cracking potential of CM due to internal curing.



[a] [b]

Fig. 7 The results of the restrained autogenous shrinkage

4. CONCLUSION

The following conclusions can be drawn from the results of this investigation with regard to the effect of the internal curing using LWA :

- The specimen using internal curing with lightweight aggregate increased the compressive strength due to dense microstructures by internal curing
- Internal curing using LWA reduces the autogenous and drying shrinkage. The reduction of deformations showed the shrinkage due to the internal curing is much more definite in the early age after final setting time than the subsequent increase in shrinkage.
- The stresses due to restraint of autogenous deformation were found to be considerably lower in the study when the internal curing was used.

ACKNOWLEDGEMENT

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