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Internal Curing of Concrete Using Biodegradable Water-Absorptive Polymer Gels

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ABSTRACT

Appropriate wet curing of concrete at early ages can reduce autogenous shrinkage and increase strength development. This study examined biodegradable water-absorptive polymer gel as an internal curing agent applicable to mortar and concrete. It was shown that, when an appropriate water-absorption capability of polymer gel was selected, the compressive strength of concrete increased slightly and autogenous shrinkage strain reduced, confirming the applicability of the polymer gel as an internal curing agent.

INTRODUCTION

Recent trend in high-rise and longer span building structures requires higher strength for concrete material. However, high-strength concrete with a design strength more than 100N/mm^2 undergoes considerable autogenous shrinkage leading to cracking problems in the existing structures. Cracking further leads to performance degradation of concrete structures including water leakage, steel corrosion and appearance. As possible countermeasures capable of controlling autogenous shrinkage, shrinkage reducing agent, expansive agent and dispersion of water-retaining particles in concrete have been studied. As an internal curing agent, the water-retaining materials providing water to reduce self-desiccation of concrete includes lightweight aggregate (Kato et al. 2004), recycled aggregate (Takushoku & Yamada 2001), waste roof tile (Suzuki et al. 2007) and water absorptive polymer (Yokota & Igarashi 2012) (Tsuji et al. 1999).

Wet curing of concrete after placement is an important process ensuring the concrete quality because it prevents drying during hydration reactions. Hence, the wet curing more than 5 days for ordinary Portland cement concrete has been regulated in JSCE Standard Recommendations and AIJ JASS Reinforced Concrete Construction. The wet curing methods include immersion, impounding, sprinkling, wet compress, wet sand and wet membrane curing, while not all the method result in success depending on the size, shape and environmental conditions of the targeted structure (Takenaka et al. 2008) (Ogawa et al. 2008). The authors have shown that the use of biodegradable water-absorptive polymer gel (hereafter denoted as biodegradable gel) as a wet curing agent contributed to reduction in cracking near-surface region and development of compressive strength (Kasai et al. 2012).

In this study, reduction of autogenous shrinkage and development of compressive strength were attempted by reducing the drying of mixing water and capillary water and ensuring wet curing period at early stages. To this end, effects of the biodegradable gel admixed with concrete on internal curing were discussed. The materials of the biodegradable gel comprises water and carboxyl methylcellulose originated from pulp, and after mixing, electron or gamma beam was applied to establish a cross-linked structure. Because changes in irradiation duration can produce different water-absorptive capability, two types of biodegradable gels with different water-absorptive capability were introduced to concrete and mortar specimens and its effectiveness as an internal curing agent were evaluated through strength development, autogenous shrinkage and drying shrinkage experiments.

Experimental Plan

Materials Used

Two types of cement were used according to water-cement ratio. The ordinary Portland cement was used for mortar and concrete with a water cement ratio of 0.4, while silica Fume premixed cement was used for Those with a water cement Ratio of 0.25. Materials used for the experiments are listed in Table 1.Water absorption factors of the biodegradable gel were 1500 and 6000 percent by dry mass of the biodegradable gel.

Table 1. Materials Used

	Notation	Type	Properties
Mixing water	W_1	Tape water	
Absorbed water	W_2	Tape water	
Cement	C	Ordinary Portland cement	Bulk Density:3.16g/cm^3
		Silica fume premixed cement	Bulk Density:3.09g/cm^3
Fine aggregate	S	Pit Sand from Kikugawa river	Sutured surface-dry density:2.59g/cm^3, Water absorption :2.18%
Coarse aggregate	G	Crushed hard sandstone from Oomi	sutured surface-dry density:2.70g/cm^3, Water absorption :0.62% max aggr.size: 20mm
Superplasticizer	SP	High range AE water reducing agent	Polycarboxylic acid ether
Biodegradable Gel	BG_1	Carboxyl methylcellulose	Water factor: 1500%, (water content: 71.3%)
	BG_2		Water factor: 6000%, (water content: 15.3%)

Table 2. Mix Proportion of Mortar

W/C	Composition	S/C	SP dosage (% by cement mass)	Gel content (% by cement mass)
40	40-0	2.4	0.675	0
	40-G-1			0.05 (BG_1)
	40-G-2			0.05 (BG_2)
25	25-0	1.9	1.2	0
	25-G-1		1.3	0.5 (BG_1)

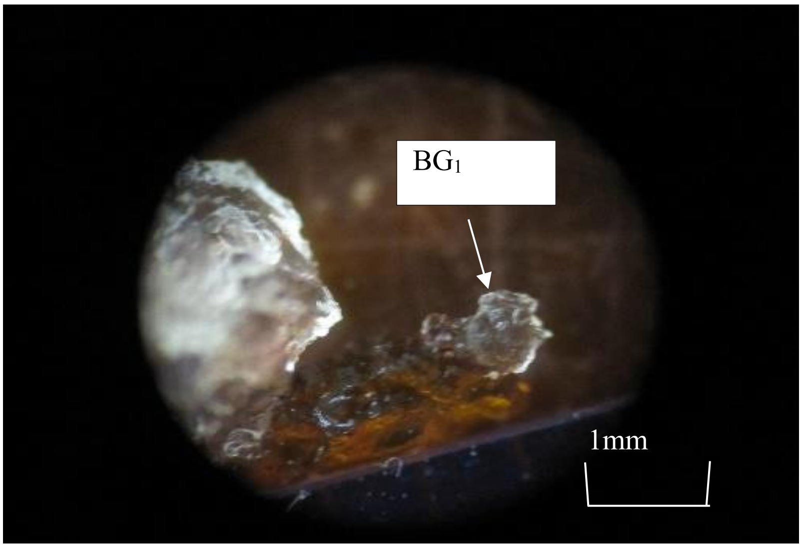

Figure 1. Gel (BG1) with water absorption of 1500% by dry mass

Mix proportion of mortar and concrete

Mix proportions of mortar and concrete are listed in Tables 2 and 3. For specimens with a water-cement ratio of 0.4, biodegradable gel BG_1 and BG_2 were used while only BG_1 was used for those with a water-cement ratio of 0.25 and their effectiveness were compared. Prior to mixing, biodegradable gels of BG_1 and BG_2 were subjected to water absorption to have a water absorption factor of 300 and 600 percent respectively. BG_1 at a water-absorption factor of 1500 percent is shown in Fig 1.

Mixing and preparation of specimen

Mixing of mortar was performed with a Hobart mixer and introduction of biodegradable gel was controlled according to the sequence shown in Figure 2. Mixing of concrete was performed with a Pan Type forced mixer as shown in Figure 3. Introduction of biodegradable gel was made three different manners depending on inclusion of absorbed water mass as listed in Table 4. For mixes with a water-cement ratio of 0.4, water absorbed by biodegradable gel was inclusive.

Table 3. Mix Proportion of Concrete

Notation	G_{max}	W/C (%)	s/a (%)	Unit content (kg/m^3)						SP (% by cement mass)	BG_1 (% by cement mass)
				C	W_1	W_2	S	G			
								5-10 mm	10-15 mm		
25-0	15	25	48.2	644	154	0	797	357	535	1	0
25-O-W					153	4.092				1.1	0.05
25-I-W					149						

	Low speed	High speed				High speed	
$C+W_1+SP$	→	→	+S	→	+ (BG_1 or BG_2+W_2)	→	Discharge
	30s	60s		90s			

Note: BG1, BG2-Biodegradable polymer gel

Figure 2. Mixing method of mortar

C+S+G	→	$+(W_1+W_2)$	→	$+(BG_1)$	→	Discharge
	15s		90s		90s	

Note: BG_1-biodegradable polymer gel, G-Coarse aggregate

Figure 3. Mixing method of concrete

Table 4. Conditions Of Gel

Notation	Conditions of BG_1 gel before mixing
25-0	N/A
25-O-W	Exclusively mixed after water absorption for 1500%
25-O-D	Exclusively mixed with water to be absorbed by gel for 1500% separately.
25-I-W	Inclusively mixed after water absorption for 1500%

Test Items And Methods

Test items for mortar and concrete are listed in Table 5. Sealing of specimens subjected to autogenous shrinkage test was made according to the method specified in JCI's Method of Autogenous Shrinkage/Expansion Test for Mortar and Concrete: Rev. 2002 (JCI 2002). Both mortar and concrete specimens were made with a steel mold of 100 x 100 x 400mm and a mold type strain gauge with a length of 50mm was embedded for continuous measurement till the material age of 28 days. Each test started at the initial setting time of each mix. Drying shrinkage test was performed with the same specimen converted from autogenous shrinkage test and, after stripping aluminum sealing tape at age of 29 days, then specimens were subjected to drying in a thermostatic chamber under relative humidity of 60% and to measurement of changes in length. Two specimens were tested simultaneously and the averaged value was recorded as shrinkage strain.

Table 5. Test Items and Methods

Test items	Testing methods
Compressive strength	JIS A 1108 "Test Method for Compressive strength of Concrete" Testing age 28-day: Standard curing, 1-day sealed & 27-day air curing, 3-day sealed & 25-day air curing, 7-day sealed & 21-day air curing, 28-day sealed curing. Testing age 7-day: 3-day sealed & 4-day air curing
Autogenous shrinkage	JCI-1996 "Testing method for autogenous volume changes for cement paste and concrete" Measured with a molded strain gauge with a length of 50mm till 28 days.
Drying shrinkage	Diversion of specimen for autogenous shrinkage test after stripping aluminum tape at the age of 29-day.
Slump	JIS A 1101 "Test Method for Slump of Concrete"
Air content	Mortar: Weighing method
	Concrete: JIS A 1128 "Test Method for Air Content of Fresh Concrete by Pressure Method"
Setting time	JIS A 1147 "Test Method for Setting Time of Concrete"

Results and Discussion

Comparison of Mortars with BG_1 and BG_2 with W/C Of 0.4

Fresh properties of mortars with BG_1 and BG_2 are listed in Table 6. It is shown that effects of biodegradable gel on setting time was small, while flow value of mortar decreased particularly in BG_2 rather than in BG_1. This may be attributed the shape of water-absorbed gel particle. Water-absorbed BG_1
Showed particle shape (Figure 4), while that of BG_2

Incomplete and acting like a thickening agent to decrease flow value. This also resulted in a larger volume of air involvement than that of the other mixes. Changes in mass of cylinder specimens, ϕ100-200mm and unmolded at the age of 24 hours, during drying at a temperature of 20±2°C and relative humidity of 60%±5% are shown in Figure 5, Where changes in mass of BG_2 was similar to that of plain mortar (40-0) without showing water retaining effects of the biodegradable gel.

Table 6. Test Results of Fresh Mortar (W/C=0.4)

Notation	Flow value	Air content	Setting time (h:m)	
	(mm)	(%)	Initial	Final
40-0	222 x 221	6.7	3:50	6:10
40-BG_1	167 x 168	6.5	4:00	6:35
40-BG_2	162 x 162	8.5	3:50	6:25

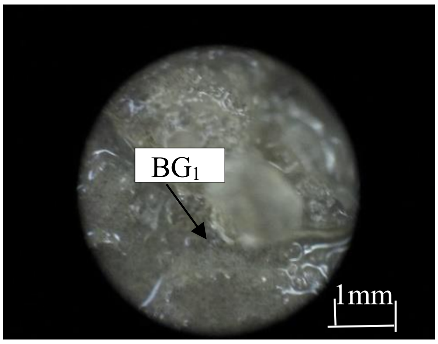

Figure 4. 25-O-W
Water absorption of mortar BG_1

On the other hand, changes in mass of BG_1 was smaller than that of the others at early ages showing water retaining effect, i.e. keeping water in the gel and reducing drying, of the biodegradable gel. This could be used as an internal curing agent. Figure 6 shows autogenous shrinkage up to material age of 28 days and subsequent drying shrinkage. Autogenous shrinkage of 40-0 and BG_2 are almost equal while that of 40-BG_1 is slightly smaller showing autogenous shrinkage reducing effects. Because water retaining effect and autogenous shrinkage reducing effect were confirmed for BG_1, applicability of biodegradable gels to internal curing was studied solely with BG_1.

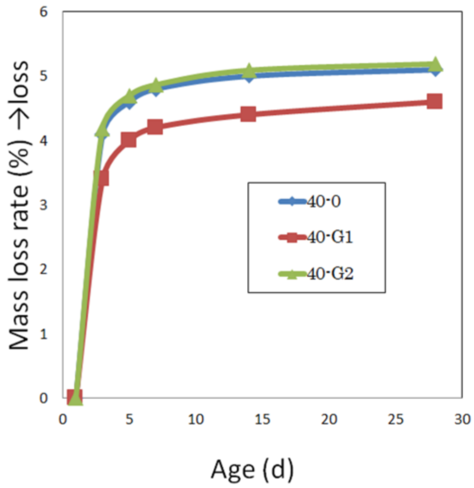

Figure 5. Mass loss rate of mortar during drying (W/C=0.4)

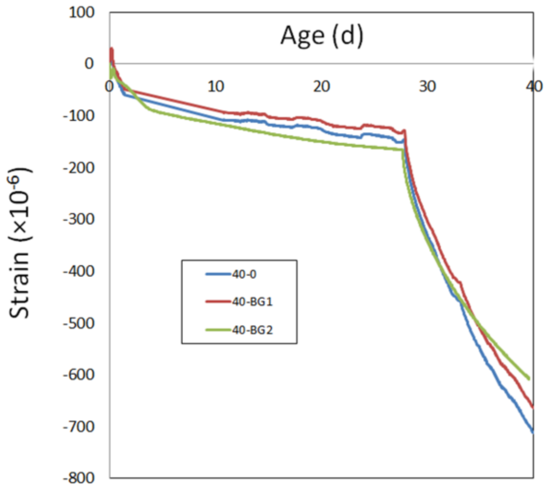

Figure 6. Autogenous shrinkage and drying shrinkage of mortar (W/C=0.4)

Internal curing with BG_1 at a W/C of 0.25

1. Mortar

Fresh properties of mortars with various types of biodegradable gel are listed in Table 7. Because addition of Biodegradable gel affects fluidity of mortar, dosage of SP was slightly increased when biodegradable gels were used, while effect of biodegradable gel on setting time was small. Mass loss of specimens was determined with the same manner as those with a W/C of 0.4 and is shown in Figure 7.

Table 7. Test Results Of Fresh Mortar (W/C=0.25)

Notation	Flow value	Air content	Setting time (h:m)	
	(mm)	(%)	Initial	Final
25-0	175 x 172	8.0	2:35	5:05
25-O-W	201 x 199	8.6	2:25	510
25-O-D	214 x 211	8.8	2:25	5:10
25-I-W	180 x 176	8.0	2:30	5:10

It is shown that in all mixes the mass loss became smaller than that with a W/C of 0.4, probably because unit water and W/C are low resulting in a dense microstructure that may inhibit drying. Mixes of 25-O-W and 25-O-D, in which water to be absorbed by gels was exclusively mixed, showed larger mass loss than that of mix 25-0, probably because the unit water was slightly larger. However, mass loss of mix 25-1-W, in which water to be absorbed by gels was inclusively mixed, was almost equal to that of 25-0 showing no distinct water retaining effect as observed in specimens with a W/C of 0.4.This may be attributed to the dense microstructure originated from low W/C that may inhibit drying as stated above.

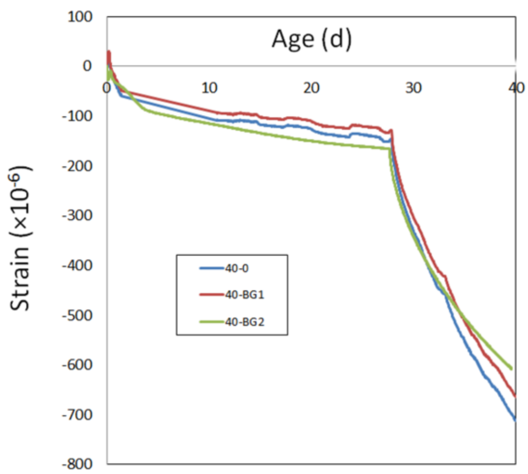

Figure 6. Autogenous shrinkage and drying shrinkage of mortar (W/C=0.4)

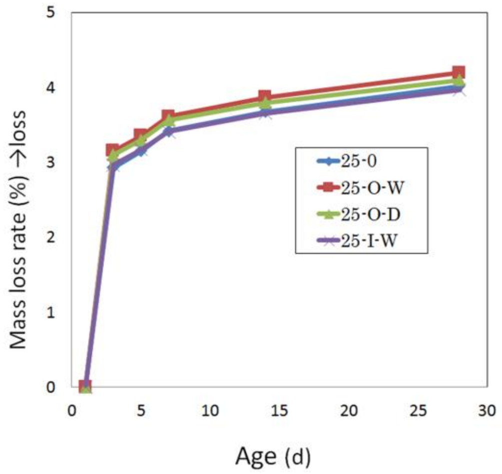

Figure 7. Mass loss rate of mortar during drying (W/C=0.25)

Compressive strength of specimens cured with various conditions is shown in Figure 8. It is shown that mixes 25-O-W and 25-O-D, in which water to be absorbed by gels was exclusively mixed, showed lower compressive strength than that of plain mortar of 25-0 at all the curing conditions. In spite of hydration reaction promotion for cement due to internal curing effects of gels, this may rather be attributed to the several factors including an increase in W/C due to exclusively mixed water, and flaws remained after setting as a result of dispersion of gel particles. On the other hand, mixes 25-I-W in which water to be absorbed by gels was inclusively mixed showed equal or slightly larger compressive strength than that of mix 20-0 at all the curing conditions. When BG_1 is added, it naturally results in compressive strength reduction due to remained flaws as stated above, while the strength was rather increased probably because hydration was promote by BG_1 acting as an internal curing agent. Autogenous shrinkage till the age of 28 days and subsequent drying shrinkage of specimens are shown in Figure 9. Autogenous shrinkage of mortar with BG_1 is remarkably smaller at all the conditions than that of 25-0. Reduction in autogenous shrinkage of 25-O-W and 25-O-D can be attributed to a larger W/C due to exclusively mixed water, while autogenous shrinkage of 25-I-W, in which water to be absorbed by gels was inclusively mixed, is also largely reduced showing effectiveness of gels as an internal curing agent.

2. Concrete

Fresh properties of concrete with gels of different conditions are listed in Table 8.

Table 8.Test Results Of Fresh Concrete (W/C=0.25)

Notation	Flow value (mm)	Air content (%)
25-0	470 x 440	3.2
25-O-W	530 x 520	3.2
25-I-W	500 x 480	3.2

Concrete was a high-fluidity concrete and its fluidity was evaluated with flow value. Results of air content showed not influences of gel addition.

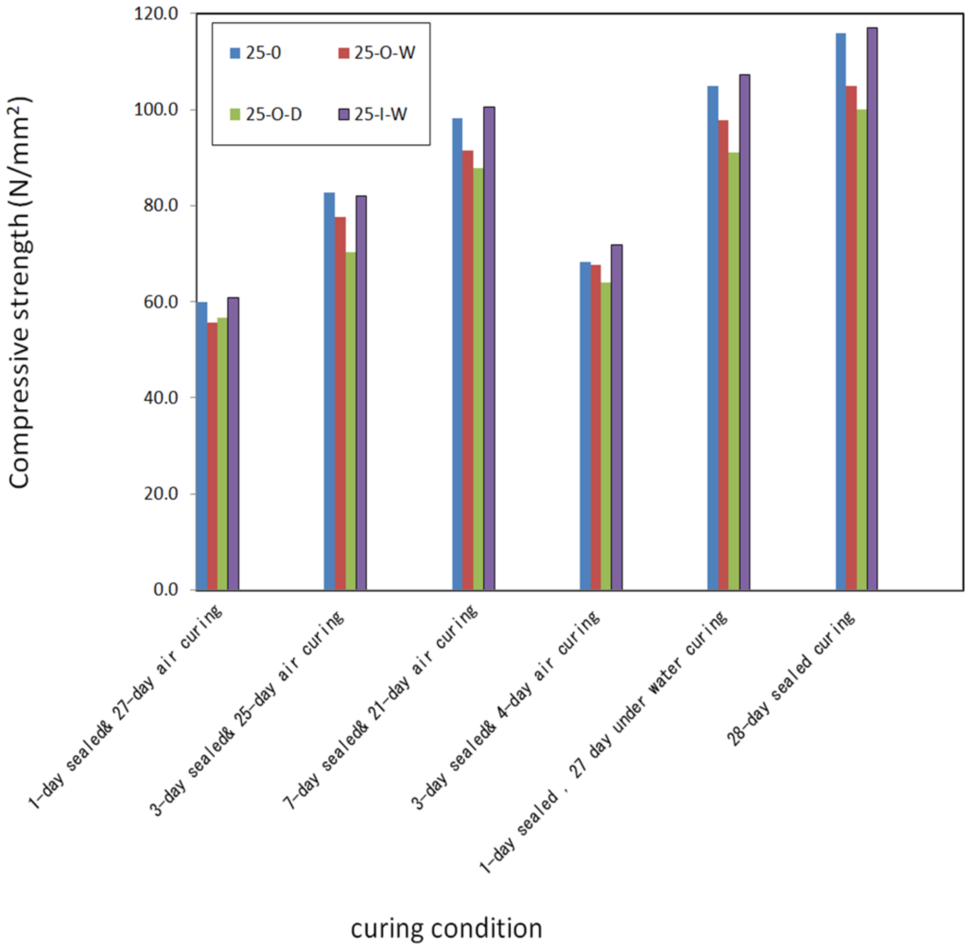

Figure 8. Compressive strength of mortar (W/C=0.25)

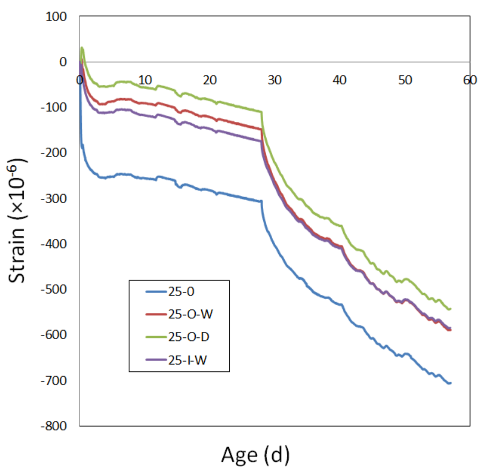

Figure 9. Autogenous and drying shrinkage of mortar (W/C=0.25)

Concrete was a high-fluidity concrete and its fluidity was evaluated with flow value. Results of air content showed not influences of gel addition. Mass loss of concrete specimens, measured with the same manner as that of mortar in Figure 5, is shown in Figure 10. It is shown that mass loss of specimens with gels became slightly small showing the water retaining effect of gels.

Compressive strength of concrete specimens with different curing conditions is shown in Figure 11. Similar to the case of mortars, compressive strength of mix 25-O-W, in which water to be absorbed by gels was exclusively mixed, was equal or slightly smaller than that of control concrete.

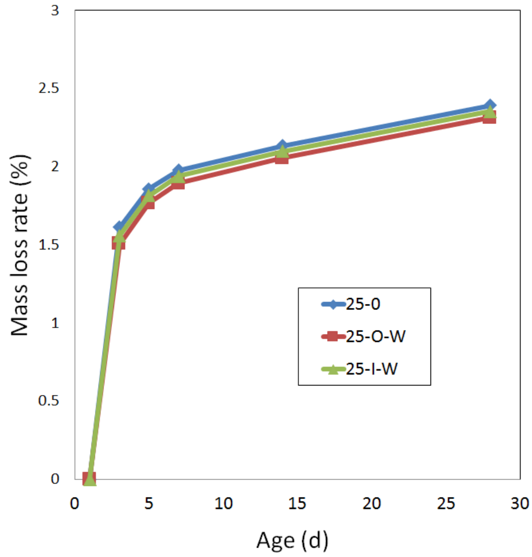

Figure 10. Mass loss rate of concrete during drying (W/C=0.25)

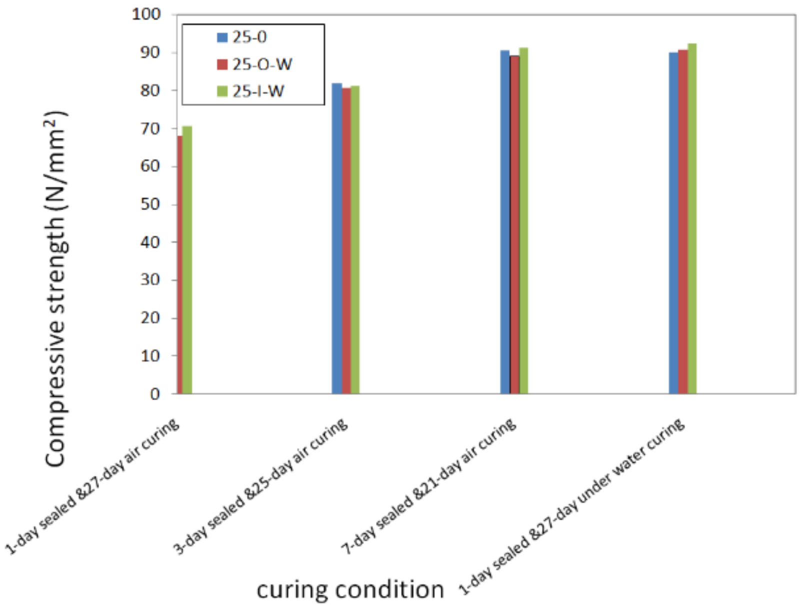

Figure 11. Compressive strength of mortar (W/C=0.25)

On the other hand, compressive strength of mix 25-I-W, in which water to be absorbed by gels was inclusively mixed, was equal or slightly larger than that of control concrete at all the curing conditions. Compressive strength tended to increase as the duration of sealed curing increased without regard to gel addition, and specimens with 7-day sealed curing and subsequent 21-day air curing showed nearly equal compressive strength as that with 27-day underwater curing.

Autogenous shrinkage till the age of 28-day and subsequent drying shrinkage of concrete specimens is shown in Figure 12. Measurement was started at the setting time that was determined using mortar specimens with the same conditions regarding gel addition. It is shown that autogenous shrinkage of concrete with BG_1 was remarkably smaller than that of control concrete. Further, autogenous shrinkage of mix 25-I-W, in which water to be absorbed by gels was inclusively mixed, was considerably small showing favorable internal curing effect of gels capable of reducing autogenous shrinkage of concrete in the same manner as that of mortar.

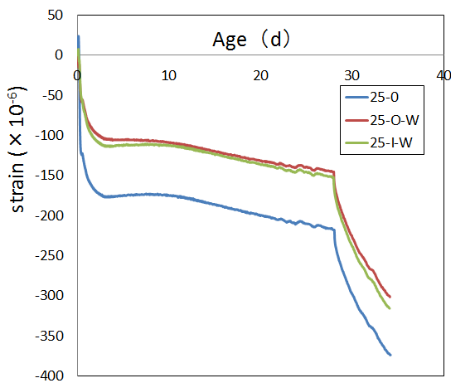

Figure. 12 Autogenous and drying shrinkage of concrete (W/C=0.25)

SUMMARY

Effectiveness of biodegradable water-absorptive polymer gels as an internal curing agent was evaluated in terms of strength development and autogenous shrinkage reduction in mortar and concrete specimens. Major findings are as follows.

(1) Internal curing effects of biodegradable gel were not shown when absorption factor of gel was as large as 6000 percent while it can be expected when absorption factor of gel was as small as 1500 percent and gel particles can be dispersed in the matrix after mixing.

(2) Compressive strength of mortar and concrete using biodegradable gels as an internal curing agent became smaller than the control of mix when water to be absorbed by gels was exclusively mixed, while became almost equal to the control mix when water to be absorbed by gels was inclusively mixed.

(3) Autogenous shrinkage of mortar and concrete using biodegradable gels as an internal curing agent became smaller than that of control mix without regard to conditions of gel addition. It became particularly small when water to cement ratio of specimen was low and water to be absorbed by gels was inclusively mixed.

With above discussions, it was concluded that autogenous shrinkage could be largely reduced keeping sufficient strength when biodegradable water-absorptive polymer gels are used as an internal curing agent.

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