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Development of a New Method to Reduce Drying Shrinkage of Concrete by Applying Urea

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ABSTRACT

Cracking of concrete caused by drying shrinkage adversely affects the durability of the structure. In the past research results, it is effective to add urea to concrete as a way to reduce drying shrinkage. However, in ready mixed concrete factory in Japan, adding various admixture materials to concrete will increase equipment costs and labor costs because of the increase in the number of input items, the management problem and putting problem when mixing. In this research, in consideration of the above problems, we attempted to develop a cheaper and simpler method to apply or infiltrate the urea solution on the surface of concrete after demoulding as a method to reduce drying shrinkage. As a result, it was possible to reduce drying shrinkage by spraying urea solution on the concrete surface. It was also found that when the amount of urea solution in the concrete is higher, the drying shrinkage is lesser. This is considered that the urea solution entering into the concrete crystallizes in the gaps in the process of drying, and the expansion pressure of the crystallizing resists the drying shrinkage. It can also be considered that the water holding ability of urea prevents excessive drying of concrete. Furthermore, in order to prevent elution of urea inside the concrete due to rainwater, Na_2SO_4 reacting with remaining unreacted chemical components of concrete was mixed to the solution. And it was confirmed that effect of using the mix solution of urea and Na_2SO_4 was not lost if exposed in the rain.

Keywords: drying shrinkage, urea solution, Na_2SO_4, spraying

1.0 INTRODUCTION

It is difficult to completely prevent the occurrence of cracks in concrete structures. Cracks in concrete structures adversely affect physical properties such as durability. Among them, cracks due to drying shrinkage have been considered as a problem for many years and so much of research has been carried out so far. Part of the techniques of research have already been put into practical use, and among them, one kind of effective method is using various admixtures such as chemical products to reduce drying shrinkage. The following have been found to be the effective methods of reducing drying shrinkage of concrete:

a) Mixing the expansion material
b) Mixing drying shrinkage reducing agent
c) Using limestone aggregate
d) Mixing urea

However, the method of mixing the admixture in the ready-mixed concrete factory causes an increase in costs and labor due to the increase in the number of materials, management problems, labor for adding materials at the time of mixing. What is more, there is no existing equipment in factory to add the admixtures and use the aggregates. So, temporary manpower is required each time when adding the admixtures, which has been cramping the popularity of using admixtures to reduce drying shrinkage.

In the past research results, it was reported that when urea is used 50 kg/m^3 as admixture in concrete, drying shrinkage decreases about 60% (Kawai, and Sakata, 2007). However, the drying of the concrete occurs mainly in the exposed surface portion, and drying inside the concrete does not proceed so much. Therefore, in order to suppress drying shrinkage, it is not efficient to use admixture material for the whole concrete. So, it is reasonable to use material that has a shrinkage reducing effect only on the surface portion where the drying shrinkage mainly occurred.

In consideration of the above situations, this research develop a method for reducing drying shrinkage inexpensively and easily that immersing the surface of the demolded mortar or concrete in the solution containing urea as main component. As a result of measurement of drying shrinkage up to 91 days after demolding as 0 day, it was confirmed that immersion in urea solution has shrinkage reducing effect (Liu *et al.*, 2017). After that, the mortar after 91 days was soaked in water to investigate the change in shrinkage reducing effect of the infiltrated urea solution. Further, every time when it was dipped in water, the shrinkage reduction effect was reduce and elution of the infiltrated urea solution was considered.

Next, the mirabilite solution was used to reduce drying shrinkage because mirabilite can react with unreacted cement mineral and do not elute when soaking in the water. However, shrinkage reducing effect was not observed in mortar immersed in mirabilite solution. Therefore, the mixed solution of urea and mirabilite at a certain ratio was used as drying shrinkage reducing agent to immerse mortar. As the result, as the same in the case of immersing the urea solution, the effect of the mixed solution to reduce drying shrinkage was also confirmed. Likewise, even if the concrete after 91 days had been soaked in water, the shrinkage reducing effect did not decrease but continue.

This paper presents the study of the effect on shrinkage reduction of concrete by brushing or soaking aqueous solution of urea or the mixed solution of urea with mirabilite at a certain ratio.

2.0 OUTLINE OF EXPERIMENT

2.1 Materials

Table 1 shows the used materials in this study. Urea was the kind of commercially available urea using in industry.

2.2 Mix conditions

Table 2 shows the mixture conditions of concrete. The target values of the fresh properties were 8.0 ± 2 (cm) for slump, 4.5 ± 1.5 % for air volume.

2.3 Mixing method

For mixing, a biaxial mixer with a nominal capacity of 60 (L) was used. The mixing procedures are as below. Firstly, putting cement, sand and gravel and mixing for 15 seconds. Thereafter, adding the water previously mixed with SP and mixing for 60 seconds and then the concrete was discharged.

2.4 Test items

Fresh properties tests

The concrete slump test was carried out in accordance with JIS A 1101, Air volume measurement was carried out in accordance with JIS A 1128.

Compressive strength test

This test was carried out in accordance with JIS A 1108. After demolding at the age of 1 day, the specimens were cured in the constant temperature room at 20 ± 3 (°C) with 60 ± 5 % relative humidity. Then the compressive strength tests were conducted at age of 7 and 28 days.

Drying shrinkage test

This test was carried out in accordance with JIS A 1129-3. Demolding was on the day following the preparation of the specimen, and this day was taken as 0 day of age from the start of drying. In the measurement period, the concrete was kept in a constant temperature room at 20 ± 3 (°C) with 60 ± 5 % relative humidity, and the change of length was measured.

Table 1. The materials used in this study

Type	Name	Symbol	Density (g/cm^3)
Water	Tap water	W	1.00
Binder	Ordinary Portland cement	C	3.16
Sand	River sand (F.M. 2.65, Water absorption rate:1.94)	S	2.56
Gravel	Crushed stone (F.M. 6.23, Water absorption rate:0.75)	G	2.64
Admixture	Poly-carboxylic acid-based high-performance air entraining and water reducing admixture	SP	1.00
Chemical materials	Industrial urea	U	1.32
	Mirabilite	Na	2.68

Table 2. The mixture conditions of concrete

W/C (%)	Unit quantity (kg/m³)				Addition rate (%)	Fresh properties	
	W	C	S	G	SP	Air volume (%)	Slump (cm)
40	160	400	736	1010	0.10	4.4	7.5
50	170	340	798	969	0.10	3.7	8.5
60	174	290	865	932	0.10	5.1	8.0

Freezing and thawing test

This test was carried out in accordance with JIS A 1148.

Accelerated carbonation test

This test was carried out in accordance with JIS A 1153. The accelerated carbonation conditions were temperature: 20 ˚C, relative humidity: 60 % and carbon dioxide concentration: 5 %.

Test hammer strength test

This test was carried out in accordance with JSCE-G 504. After demolding at the age of 1 day, the specimens were cured in the same room as the compressive strength test, and the test was carried out at age of 28 days.

Table 3. The test conditions in this study

W/C (%)	Immersion liquid	Immersion method	Immersion condition	Compressive strength test	Drying shrinkage test	Dry and wet repeat test	Freezing and thaw ing test	Accelerated carbonation test	Test hammer strength test
40	No treatment	—	1 minutes	○	○	—	—	○	—
	Water	Soaking		—	○	—	—	—	—
	Urea			○	○	○	—	○	—
	Mix			○	○	○	○	○	—
50	No treatment	—	1 minutes	○	○	—	○	○	○
	Water	Soaking		—	○	—	—	—	○
	Urea			○	○	○	—	○	—
	Mix			○	○	○	○	○	○
	No treatment	—	10 minutes	—	—	—	—	—	—
	Water	Soaking		—	—	—	—	—	—
	Urea			○	○	○	—	—	—
	Mix			○	○	○	—	—	—
	No treatment	—	30 minutes	—	—	—	—	—	—
	Water	Soaking		—	—	—	—	—	—
	Urea			○	○	○	—	—	—
	Mix			○	○	○	—	—	—
	Mix	Applying	3 times	—	○	—	—	—	—
			6 times	—	○	—	—	—	—
			9 times	—	○	—	—	—	—
60	No treatment	—	1 minutes	○	○	—	—	○	—
	Water	Soaking		—	○	—	—	—	—
	Urea			○	○	○	—	○	—
	Mix			○	○	○	○	○	—

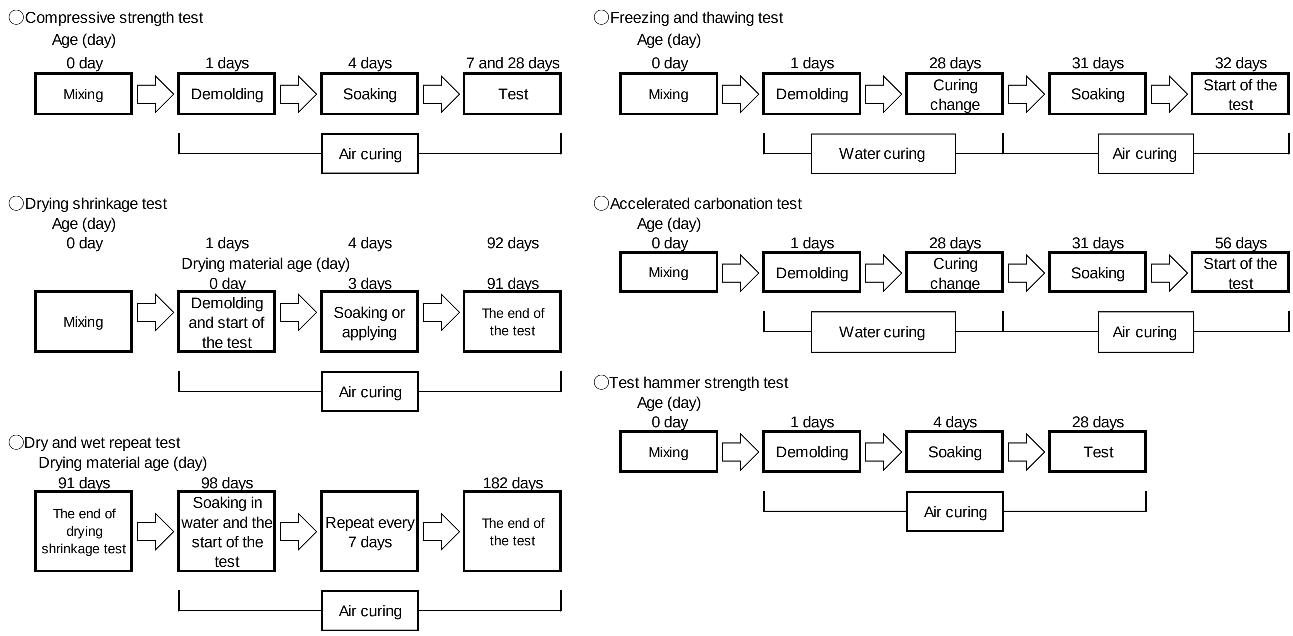

Fig. 1. The procedure of each test

2.5 Test condition

The test conditions in this study are summarized in Table 3 and the procedure of each experiment is shown in Fig. 1

2.6 Soaking and brushing method of drying shrinkage reducing agent

The soaking and brushing method of urea solution and mixed solution of urea and mirabilite (hereinafter referred to as “Mix aqueous solution”) in this study will be described below.

Tap water, urea solution at a mass ratio of 50 % dissolved in water, and the mixed solution of urea 45 % and mirabilite 5 % at mass ratio dissolved in water are used as soaking liquids in this study. However, soaking in tap water was carried out only in the drying shrinkage test to compare the effect with other soaking liquids.

Assuming the brushing to the structure at the site, after curing in the constant temperature room at 20 ± 3 (°C) with 60 ± 5 % relative humidity for three days, the concrete was soaking in different solutions. The soaking time had three levels, 1 minute, 10 minutes and 30 minutes. As for brushing after curing in the constant temperature room, a commercially available brush with a width of 70 (mm) was used to brush 36 (g) solution to the entire surface of the specimen once every 30 minutes. The number of brushing was 3, 6 and 9 times equivalent to the immersion amount of soaking for 1 minute, 10 minutes and 30 minutes. However, for the freeze-thaw test and the accelerated neutralization test, the specimens were cured in the constant temperature room for other 3 days after water curing for 28 days and then soaked in the solution for 1 minute.

In the dry and wet repeat test, the specimen whose drying shrinkage was measured up to 91 days was soaked in water for 1 hour and dried repeatedly every 7 days from the 98 days. From this test we simulated the influence of shrinkage reducing effect when rainwater cause the dissipation of urea.

3.0 TEST RESULTS AND DISCUSSION

3.1 Fresh properties tests

The test results are shown in Table 2. All results of different water cement ratios satisfied the target value of 8.0 ± 2 (cm) for slump and 4.5 ± 1.5 % for air volume.

3.2 Compressive strength test

As for the specimens immersed in an aqueous solution. The corresponding compressive strength test results with water cement ratio of 40 %, 50 %, 60 % are shown in Figs. 2, 3, and 4 respectively.

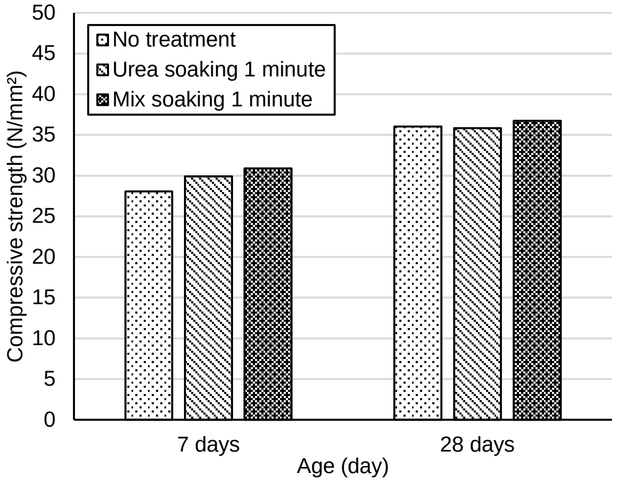

Fig. 2. Compressive strength test results when immersed in an aqueous solution (W/C=40 %)

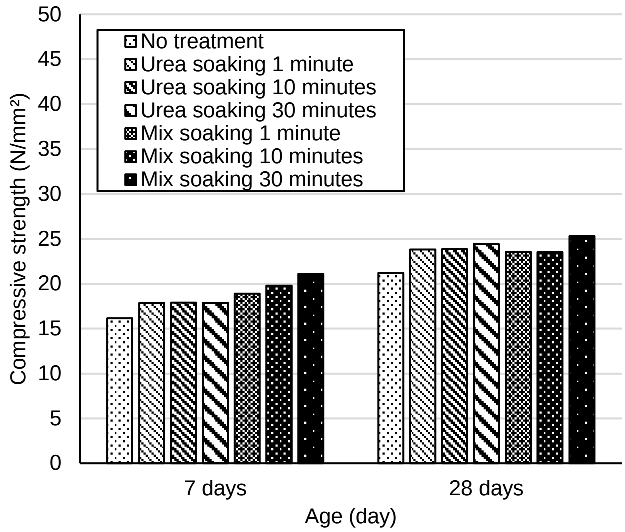

Fig. 3. Compressive strength test results when immersed in an aqueous solution (W/C=50 %)

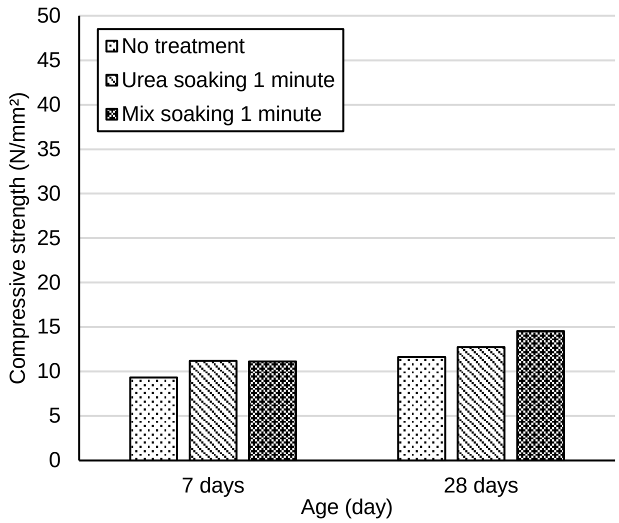

Fig. 4. Compressive strength test results when immersed in an aqueous solution (W/C=60 %)

With the same water cement ratio, specimens immersed in urea and mixed aqueous solution showed tendencies of increasing compressive strength compared with untreated specimens. There are two possible reasons for this result. Firstly, it is thought that the aqueous solution entered from the voids on the surface of the specimen into the fine voids of the surface layer of the specimen, and the urea concentration increased with the dissipation of moisture in the voids, then the crystal of urea filled up the voids of the hardened structure. Secondly, the entry of the aqueous solution possibly caused some water retention effect to prevent dissipation of remaining moisture inside the specimen. Therefore, it seems that much moisture was kept in the concrete which contributes to an increase in compressive strength.

At the water cement ratio of 50 %, the compressive strength increased with the extension of the soaking time. This is because the longer the soaking time is, the more the amount of the aqueous solution entering into the concrete from the voids of the concrete surface becomes. Then, more urea is recrystallizes and remains in the hardened structure after drying.

3.3 Drying shrinkage test

Drying shrinkage test results when soaked in aqueous solutions of the water cement ratio of 40 %, 50 %, and 60 % are shown in Figs. 5, 6, and 7, respectively.

In all the drying shrinkage tests, the effect of soaking in each solution on reducing drying shrinkage was recognized. From Fig. 6, it was found that when the soaking time of the aqueous solution was set to 1 minute, 10 minutes and 30 minutes, the shrinkage reducing effect became larger as the soaking time was longer of each aqueous solution. As with the compressive strength, the longer the soaking time is, the larger the immersion amount of the aqueous solution becomes. As a result, much urea remains and crystallizes after drying. Therefore, it is considered that contraction action is suppressed.

Here, to compare the magnitude of shrinkage reduction effect of different water cement ratios, setting the length change rate of the untreated and specimen at 91 days to be 100

$$\%.\left\{100-\frac{\left(\begin{matrix}Soaked\ in\ solution\\ length\ change\ rate\end{matrix}\right)}{\left(\begin{matrix}No\ treatment\\ length\ change\ rate\end{matrix}\right)}\times 100\right\}+100 \qquad (1)$$

Figure 8 shows the comparison of the length change rates at 91 days after soaking in each aqueous solution for 1 minute at 3 days of drying material age. For comparison, the data was calculated using the following equation (1).

From Fig. 8, in each water cement ratio, there was almost no difference in shrinkage reduction effect between untreated and soaking in each aqueous solution. In the past research results, when mortar was soaked in aqueous solution for 1 minute, the higher the water cement ratio was, the greater the shrinkage reducing effect appeared. However, when compared with the mortar specimen used in this study, for concrete specimen the ratio of the surface area to the volume is small and the strength is high. For that reason, the reducing effect appeared to be small when the soaking time was only 1 minute, and the difference of the water cement ratio was not clarified.

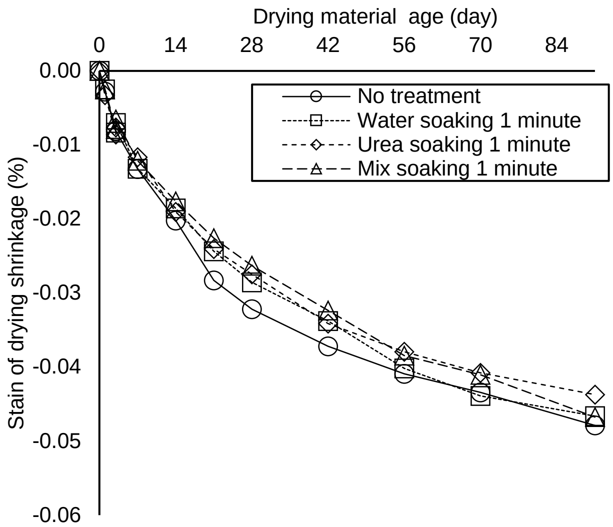

Fig. 5. Drying shrinkage test results when soaked in aqueous solutions (W/C=40 %)

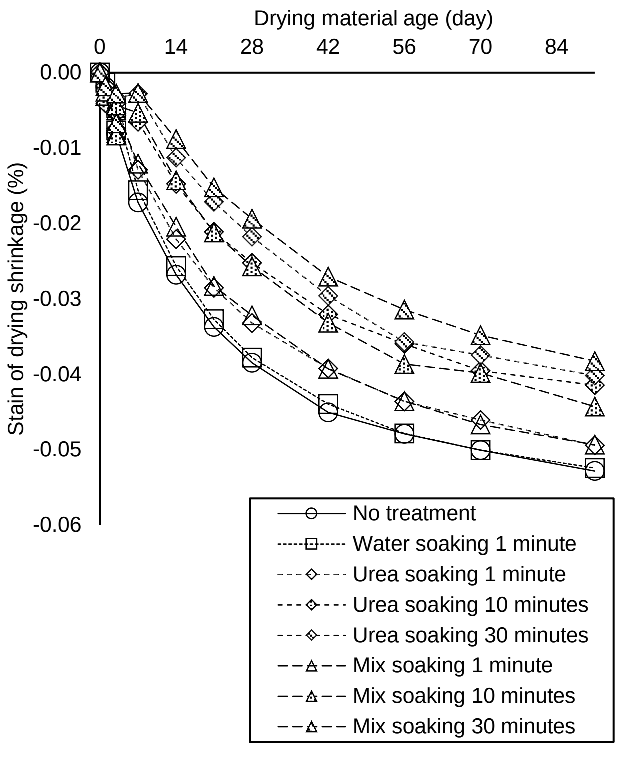

Fig. 6. Drying shrinkage test results when soaked in aqueous solutions (W/C=50 %)

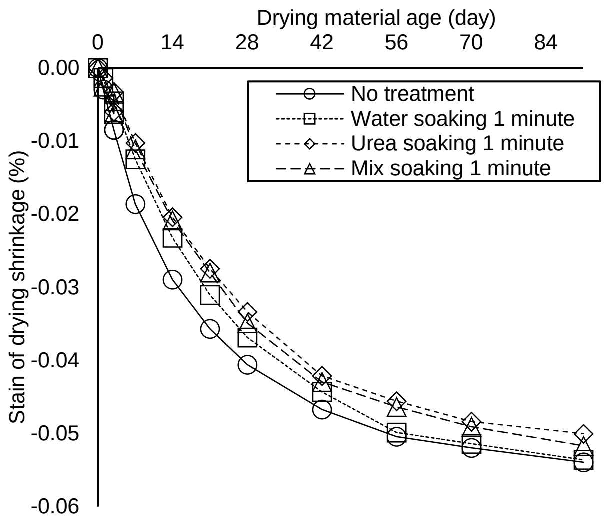

Fig. 7. Drying shrinkage test results when soaked in aqueous solutions (W/C=60 %)

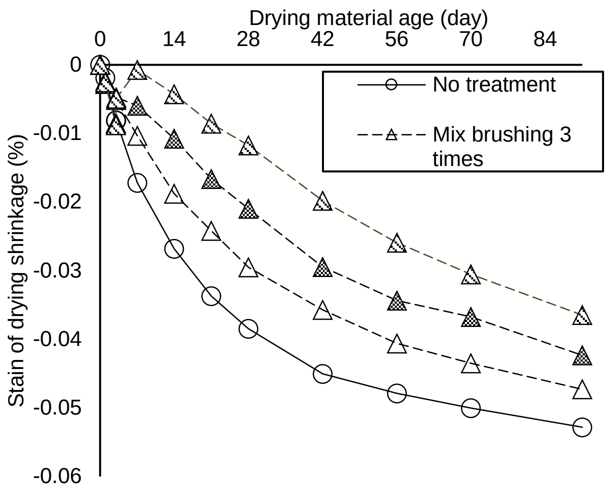

Fig. 9. The results of the drying shrinkage test when brushing to concrete (W/C=50 %)

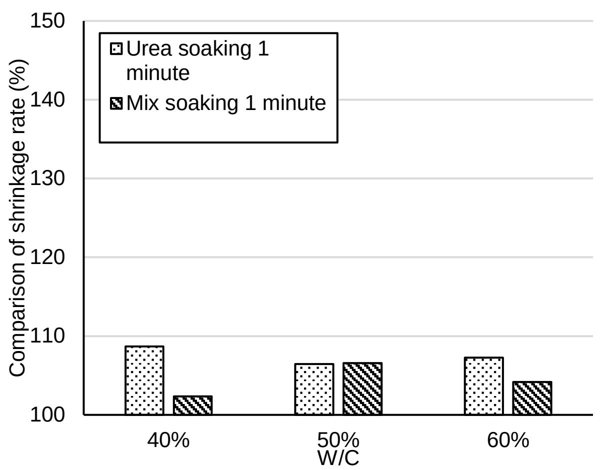

Fig. 8. The comparison of the length change rates at 91 days after soaking in each aqueous solution for 1 minute at 3 days of dried material age

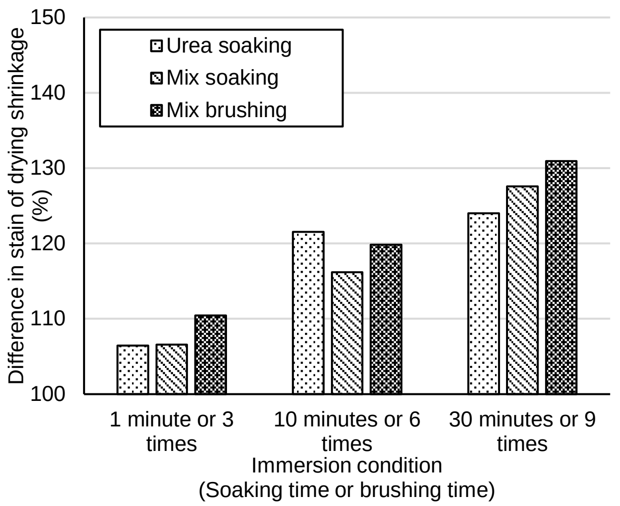

Fig. 10. The comparison of length change dates when soaking for 1 minute, 10 minutes, 30 minutes and brushing for 3, 6, 9 times (W/C=50 %)

Figure 9 shows the results of the drying shrinkage test when brushing mix aqueous solution to concrete at water cement ratio of 50 %. Also, setting the length change rate of the untreated specimen at 91 days to be 100 %. Fig. 10 shows the comparison of length change rates when soaking for 1 minute, 10 minutes and 30 minutes and brushing for 3, 6 and 9 times. This comparison was also calculated using equation (1) as in Fig. 8.

In the case of brushing as shown in Fig. 9, shrinkage reducing effect was similar to that of soaking. By increasing the number of brushing, shrinkage reducing effect was greatly exhibited as well as increasing the soaking time. Comparing the effect of soaking and brushing as shown in Fig. 10, in any soaking condition, the immersion method by brushing contributes to the shrinkage reducing effect more or equal to that of soaking. There are two reasons for this result. Firstly, when using a brush to brush aqueous solution, a small amount of air remaining in the voids on the surface of the specimen was extruded by the action force of brushing. Therefore, more aqueous solution entered than soaking. Another reason is that since the brushing was made once every 30 minutes, the moisture in the aqueous solution brushed to the surface evaporated before the next brushing. Therefore, the concentration of urea increased. Then the recrystallization of urea suppressed moisture escaping. However, further investigation is necessary.

3.4 Dry and wet repeat test

The dry and wet repeat test results when soaked in the aqueous solutions of the water cement ratio of 40 %, 50 %, and 60 % are shown in Figs. 11, 12, and 13, respectively. For the length change rates at each water cement ratio in dry and wet repeat test, the difference of soaking aqueous solutions is small. Figure 14 shows the mass change rates in dry and

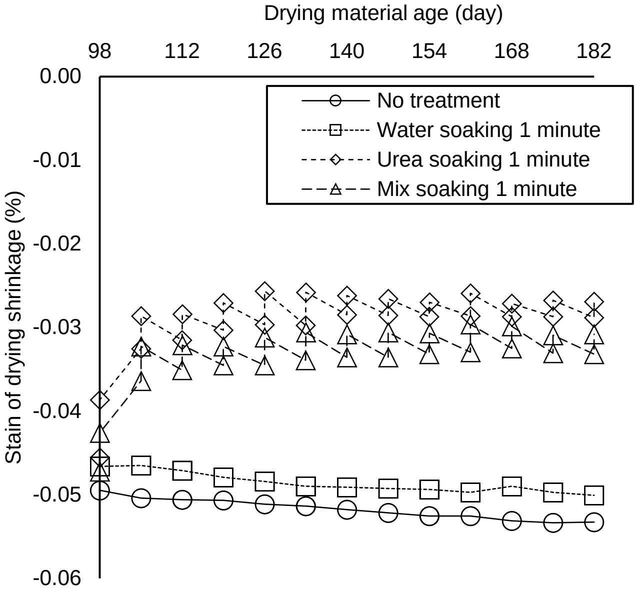

Fig. 11. Dry and wet repeat test results when soaked in the aqueous solutions (W/C=40 %)

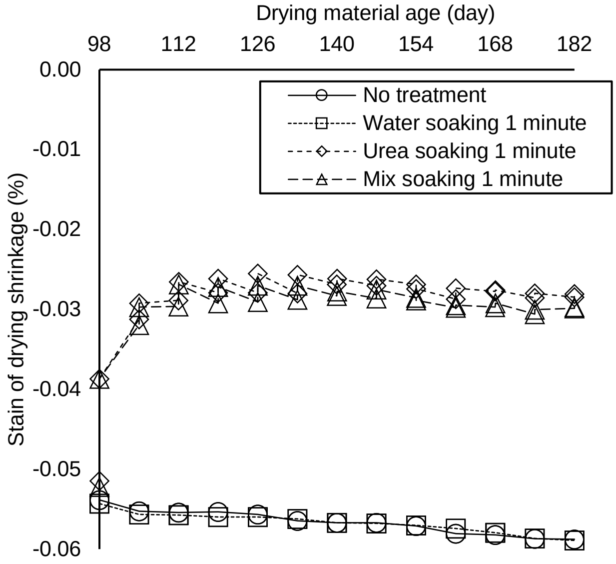

Fig. 13. Dry and wet repeat test results when soaked in the aqueous solutions (W/C=60 %)

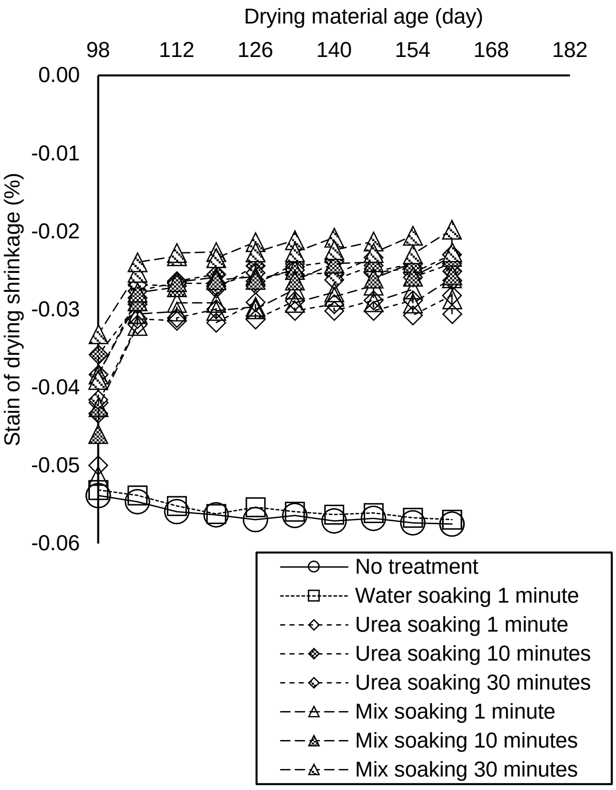

Fig. 12. Dry and wet repeat test results when soaked in the aqueous solutions (W/C=50 %)

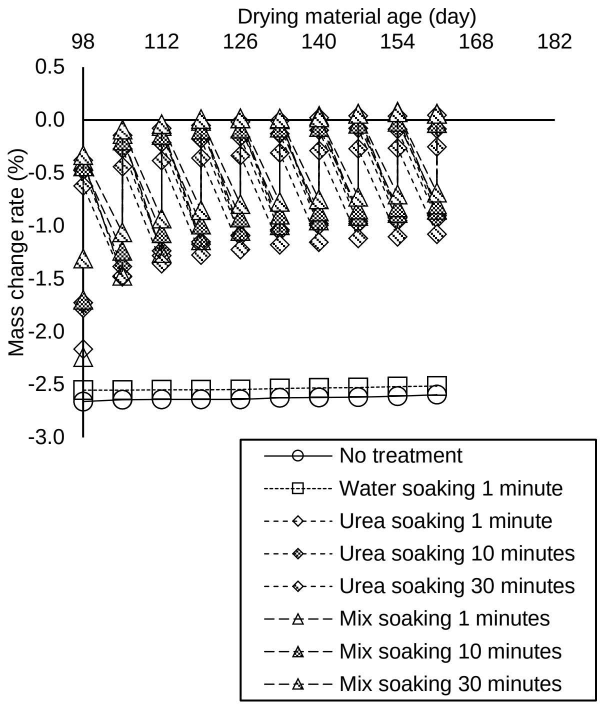

Fig. 14. The mass change rates in dry and wet repeat test (W/C=50 %)

wet repeat test water cement ratio of 50 %. Figure 15 shows the difference between the mass change rate before soaking in water and the mass change rate after soaking in water 7 days before.

As shown in Fig. 15, when compared to the specimens soaked in urea solution for 10 and 30 minutes, the difference in mass change rate of the specimen soaked in mixed solution was smaller. The reason for this is considered as follows. When soaked in mixed aqueous solution, unreacted cement mineral on the concrete surface react with mirabilite. As the urea aqueous solution remains in the voids of the product, the urea recrystallizes in dense structure compared with soaking in urea solution. From the above, it is considered that the escape of moisture is prevented. From this, it is presumed that when the drying shrinkage over a long term period is considered compared to the present measurement period, the case of soaking in mixed aqueous solution has the water retention effect and contributes to the shrinkage reduction effect.

3.5 Freezing and thawing test

Figure 16 shows the results of the freeze-thaw test when soaked in mix aqueous solution. As shown in this figure, the relative dynamic modulus of elasticity was more than 75% even when subjected to freeze-thaw action for 300 cycles at any water cement ratio. It is considered that there is no adverse effect on freezing and thawing resistance when soaking in the mix aqueous solution.

3.6 Accelerated carbonation test

Figure 17 shows the carbonation depth of the accelerated carbonation test for each water cement ratio. It was found that carbonation depth when soaked in solutions becomes smaller at any water cement ratio compared to untreated case. This is because that urea solution entering into the voids on the surface of specimen recrystallized, filled up the voids of the hardened structure and suppressed the infiltration of carbon dioxide gas. It was also found that carbonation depth when soaked in mix aqueous solution was the same or smaller compared to the carbonation depth when soaked in urea aqueous solution.

3.7 Test hammer strength test

As shown in Fig. 18, the specimens soaked in the mix aqueous solution showed a tendency for increasing the surface strength of concrete compared to untreated specimens.

Figure 18 shows the test hammer strength test results when soaking in mixed aqueous solution. As with the compressive strength test, the aqueous solution entered into the specimen from the voids on the surface, then the crystal of urea filled up the voids of the hardened structure and contributed to

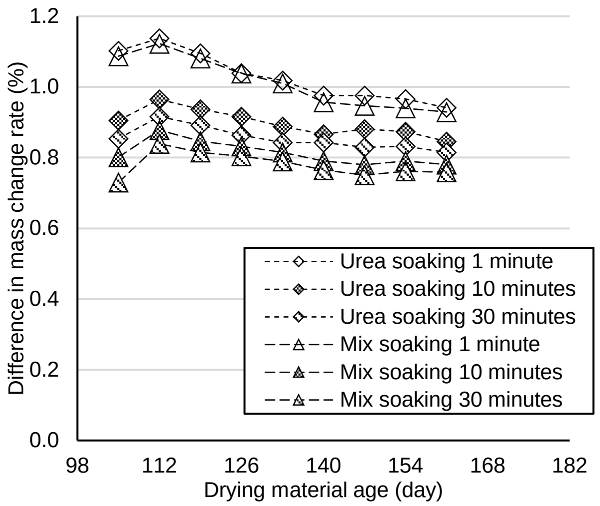

Fig. 15. The difference between the mass change rate before soaking in water and the mass change rate after soaking in water 7 days before (W/C=50 %)

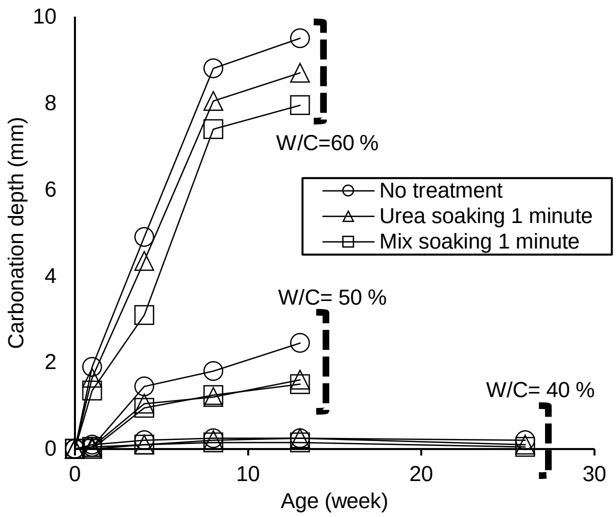

Fig. 17. The results of the carbonation depth of the accelerated carbonation test

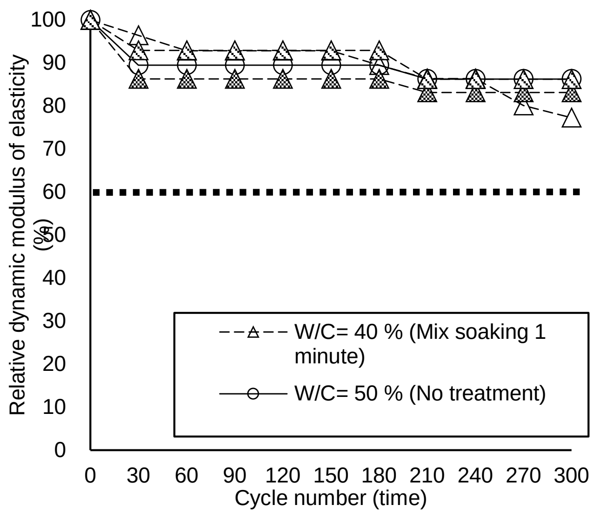

Fig. 16. The results of the freeze-thaw test

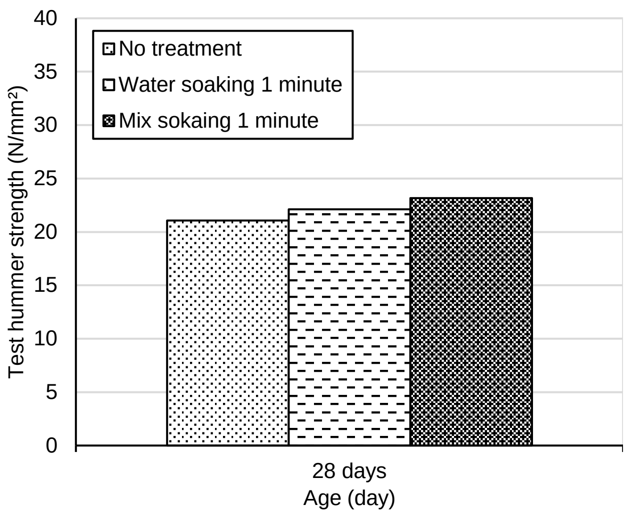

Fig. 18. The results of the test hammer strength test

the improvement of the surface strength. From the above, it is considered that there is no adverse effect on the surface strength when soaking in the mix aqueous solution.

4.0 CONCLUSIONS

The conclusions obtained from this research are summarised below:

(1) Strength test
Compressive strength of the specimen soaked in the aqueous solution was higher than that of the untreated specimen. This is probably because the aqueous solution entered into the interior and the urea recrystallized to fill up the voids of the hardened structure. It is also thought that water retention effect to prevent dissipation of moisture appeared and much moisture remained in the hardened concrete. For test hammer strength test, similar results and same reasons were confirmed.

(2) Drying shrinkage test
Drying shrinkage of specimens soaked in urea aqueous solution was smaller than that of the untreated specimen. It is considered that urea in the aqueous solution on the surface of the specimen recrystallizes and a large amount of moisture remained in the hardened concrete to prevent drying due to the water retention effect of urea crystal. Furthermore, as the soaking time becomes longer, the amount of urea aqueous solution entering the specimen increases. It is considered that the shrinkage reducing effect became higher as the soaking time was longer because the amount of urea recrystallizing from this increased.

(3) Soaking and brushing method of drying shrinkage reducing agent
Compared to soaking, brushing repeatedly had higher shrinkage reducing effect. There are two reasons for this. First, it is thought that a small amount of air remaining on the surface was extruded by using brush to brush aqueous solution, and more aqueous solution entered into concrete compared to soaking. Moreover, it was inferred that the urea concentration on the surface of the specimen became higher during drying as it was set for 30 minutes interval to the time of rebrushing.

(4) Dry and wet repeat test
Neither drying shrinkage test nor dry and wet repeat test showed a large difference in length change rate when soaking in different aqueous solutions. However, when soaked in the mix aqueous solution, the difference in mass change rate due to the drying action for 7 days became smaller. There are the following reasons for this. The unreacted cement remaining on the concrete surface reacts with mirabilite to produce new product. Then, much urea aqueous solution remains in the voids of the new product and recrystallizes. Therefore, it is thought that moisture hardly escapes compared with the case when soaking in the urea aqueous solution. From the above, it is expected that immersion in the mixed aqueous solution further contributes to shrinkage reducing when changing the drying time between brushing to a long term.

(5) Freezing and thawing test
No adverse effect on freezing and thawing resistance when soaking in the mix aqueous solution was observed. From this, it is possible to realize a shrinkage reducing method by using mix aqueous solution even in a cold district.

(6) Accelerated carbonation test
It is considered that the specimen soaked in the urea aqueous solution or the mix aqueous solution densifies the surface by recrystallization of the penetrated urea. Therefore, it is presumed that the infiltration of carbon dioxide gas is suppressed.

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