XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Study on the Practical Use of Urea to Reduce Drying Shrinkage of Concrete by Spraying Urea Solution under Cold Environment

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Abstract. *Concrete cracking caused by drying shrinkage adversely affects the durability of a structure. The results of past research has shown that drying shrinkage can be reduced by adding urea as an admixture to the concrete. However, mixing various admixtures at the factory increases the costs for equipment and labor. To reduce drying shrinkage more easily and inexpensively, the urea solution can be applied to the concrete surface by soaking or brushing. However, urea solutions are not suitable for use in cold weather because urea in solution crystallizes at low temperatures. This study attempted to solve this problem by mixing antifreeze, which resists freezing, with a urea solution. It was found that the crystallization temperature of urea can be lowered by mixing the urea solution the antifreeze. Furthermore, it was confirmed that the antifreeze/urea solution reduced drying shrinkage for both mortar and concrete.*

Keywords: *Urea Solution, Drying Shrinkage, Soaking, Antifreeze, Cold Weather.*

1 Introduction

Concrete cracking caused by drying shrinkage adversely affects the durability of a structure. Adding urea to concrete is an effective method for reducing drying shrinkage[1)]. However, in ready-mixed concrete factories in Japan, adding various admixture materials to concrete will increase equipment and labor costs. Moreover, drying shrinkage occurs mainly on the surface of concrete, so applying an agent to the surface is more efficient and economical. This paper describes a method of applying urea solution to the surface of concrete after demolding that efficiently and economically reduces drying shrinkage.

2 Past Achievements

In previous studies, specimens soaked in a urea solution had less drying shrinkage than untreated specimens (Figure 1). Moreover, the amount of drying shrinkage continue to fall as the soaking time increased[2)]. However, soaking concrete in a urea solution of site is not practical, so an experiment was conducted in which urea solution was brushed onto the surface of the concrete. It was found that the brushing method provide an equal or greater effect on drying shrinkage as soaking[3)].

On the other hand, the specimens had higher compressive strength after soaking in a urea solution, as shown in Figure 2. Moreover, the strength increased as the soaking time increased. These results were likely due to the urea solution entering the concrete and the urea recrystallizing in the voids. The expansion pressure from the urea crystals helped to reduce the drying shrinkage and increase the compressive strength. The water retention effect of the urea crystals may also prevent the dissipation of moisture inside the concrete, which also helped to suppressing drying.

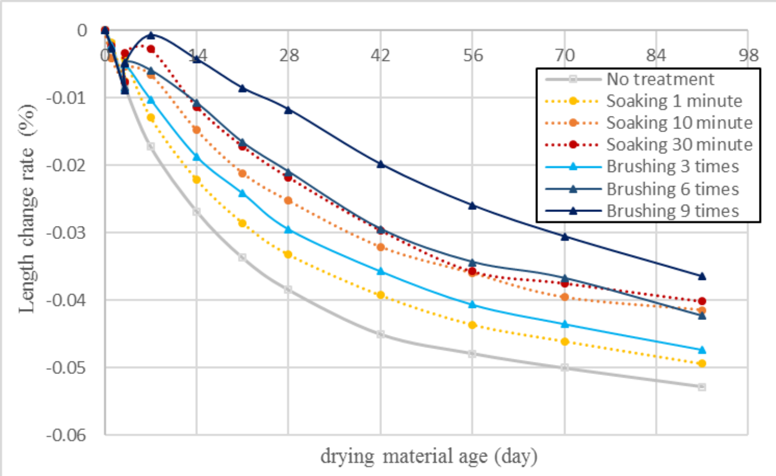

Figure 1. Drying shrinkage reduction.

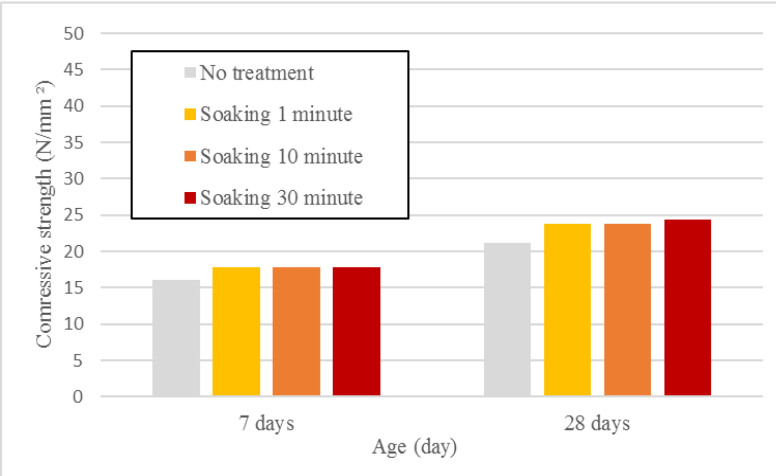

Figure 2. Result of compressive strength test.

3 Applying Antifreeze in Cold Weather

3.1 Outline

Previous studies have shown that applying a urea solution to concrete helps to reduce drying shrinkage. However, the solubility of urea decreases at lower temperatures, causing the urea in the water to crystallize and separate out. In cold weather, the urea crystallizes before the solution can be applied to the concrete, thereby reducing the solution's effect on drying shrinkage. To prevent the crystallization of the urea in the solution at low temperatures, antifreeze with freezing resistance was added to the solution. This lowered the crystallization temperature, allowing the urea solution to be used in cold weather.

3.2 Crystallization Temperature of Urea When Antifreeze is Mixed at Different Rates

The freezing resistance property of the antifreeze can be varied by adjusting its concentration in the urea solution. Therefore, this study investigated the effect of different concentrations of antifreeze on the crystallization temperature of urea in a solution.

3.2.1 Antifreeze mix solution

In this test, a commercially available antifreeze used for air conditioner or refrigeration facility was used. The main component of this antifreeze is ethylene glycol. In order to produce different freezing temperatures, the ratio of antifreeze to water were set to 3:7, 4:6 and 5:5 (Figure 3). Moreover, in order to make comparisons with a urea solution containing the maximum amount of urea that can dissolve in water at 20 (°C), the maximum amount of urea that can dissolve at 20 (°C) was added to the antifreeze solution.

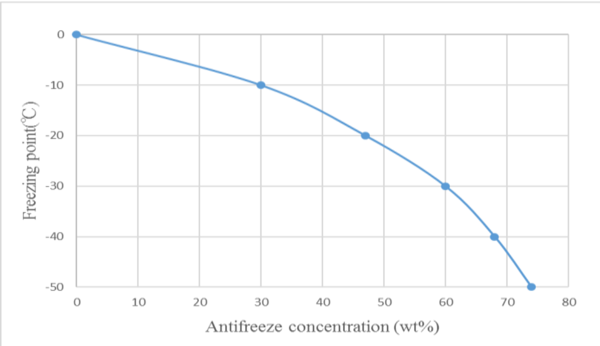

Figure 3. Freezing point of antifreeze.

Photo 1. Antifreeze concentrations in a solution.

3.2.2 Test method

Photograph 1 shows the different antifreeze concentrations in a urea solution. First, solutions with different antifreeze concentrations were placed in transparent containers. Next, the temperature of the solutions was lowered by immersing the containers in ice water. Using a thermometer, the crystallization temperature (the temperature at which urea crystals formed) was measured.

3.2.3 Test result

As shown in Table 1, the crystallization temperature decreased as the concentration of antifreeze increased. Therefore, it was considered that antifreeze solutions can be applied to concrete in cold weather to reduce drying shrinkage.

Table 1. Crystallization temperature of urea.

Name	Component (mass ratio)	Crystallization temperature (°C)
	Antifreeze : Water : Urea	
Antifreeze 30%	3 : 7 : 8	5
Antifreeze 40%	4 : 6 : 7	4
Antifreeze 50%	5 : 5 : 6.5	1
Urea solution	0 : 1 : 1	8

3.3 Effect of a 30 % Antifreeze Solution on Shrinkage Reduction in Mortar

3.3.1 Materials

Table 2 shows the materials used in this test.

3.3.2 Mix condition

Table 3 shows the mixing conditions and the properties of the fresh mortar. The target values were 200 ± 20 mm for 15 strokes flow, 2.0 ± 1.5 % for the air volume.

3.3.3 Mixing method

For mixing, an omni type mixer with a nominal capacity of 10 liters was used. First, cement and sand were mixed for 15 seconds. Next, water was added and mixed for 60 seconds. Finally, the mortar was discharged.

Table 2. Materials.

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.: 2.61,Warer absorption rate : 1.94)	S	2.61
Gravel	Crushed stone (F.M.: 2.62,Water absorption rate : 0.75)	G	2.62
Admixture	Poly-carboxylic acid-based high-performance air-entraining and water reducing admixture	SP	1.00
Chemical materials	Industrial urea	U	1.32
	Antifreeze	AF	1.03

Table 3. Mixing condition and properties of fresh mortar.

W/C (%)	S/C	Unit quantity(kg/m^3)			Air volume(%)	Flow (mm)
		W	C	S		
50	2.3	293	550	1247	2.4	220

3.3.4 Test items

(1) 15 strokes flow test
The 15 stroke flow test was carried out in accordance with ISO 679 2009.
(2) Air volume test
The air volume test was carried out in accordance with ISO 1920-2 2016.
(3) Drying shrinkage test
The drying shrinkage test was carried out in accordance with ISO 1920-8. Figure 4 shows the method used for this test. Prismatic specimens (40 × 40 × 160 mm) were made for this test. The specimens were demolded one day after mixing, and this day was taken as day 0 for the start of air curing. The specimens were cured in a room at a constant temperature of 20 ± 3 (°C) and 60

± 5 % relative humidity and changes in length and mass were measured. Next, some specimens were soaked in a 30% antifreeze solution for 1 minute, 10 minutes, and 30 minutes (Table 1). Other specimens were not soaked. Changes in the length and mass of all of the specimens were measured for 91 days.

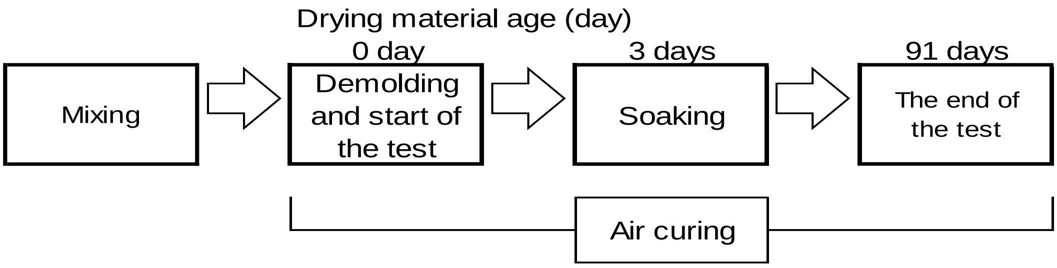

Figure 4. Method used for drying shrinkage test.

3.3.5 Test results

The results of the drying shrinkage test of mortar show that the specimens soaked in a 30% antifreeze solution exhibited a greater drying shrinkage effect than the specimens that were not soaked (Fig. 5). Moreover, the effect became larger as the soaking time increased.

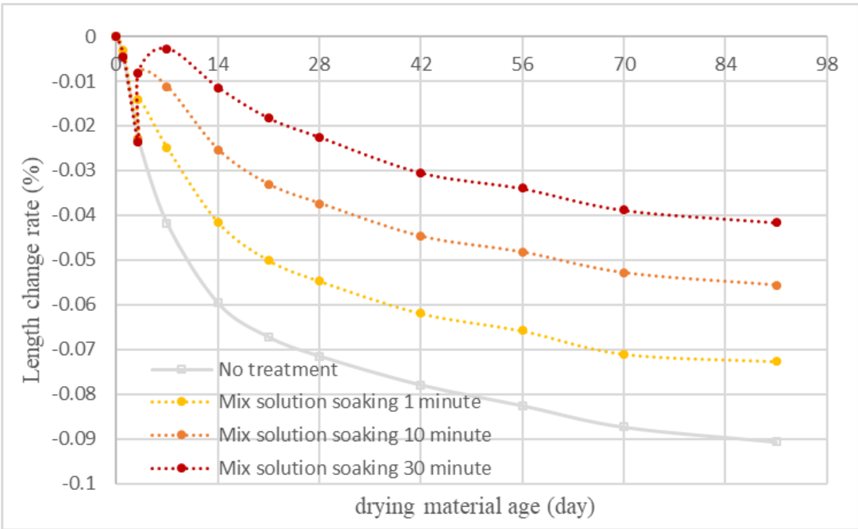

Figure 5. Drying shrinkage test of mortar.

3.4 Concrete Soaked in 30 % Antifreeze Solution

Since the 30% antifreeze solution clearly reduced drying shrinkage in mortar, the same experiment was conducted using concrete.

3.4.1 Materials

The materials used were the same as those described in section 3.3.1 above.

3.4.2 Mixing conditions

Table 4 shows the mixing conditions and properties of fresh concrete. The target values of the freshness properties were 8.0 ± 1.5 cm for slump, 4.5 ± 1.5% for air volume.

Table 4. Mixing conditions and properties of fresh concrete.

W/C (%)	Unit quantity (kg/m³)				Addition rate (C×%)	Air volume (%)	Slump (cm)
	W	C	S	G	SP		
50	170	340	798	969	0.10	4.0	8.5

3.4.3 Mixing method

A pan type mixer with a nominal capacity of 55 (L) was used for mixing. First, cement, sand, and gravel were mixed for 15 seconds. Next, water mixed with SP was added and mixed for 60 seconds. Finally, the concrete was discharged.

3.4.4 Test items

(1) Concrete slump test
The concrete slump test was carried out in accordance with ISO 1920-2 2005.
(2) Air volume test
The air volume test was carried out in accordance with ISO 1920-2 2016.
(3) Drying shrinkage test
The drying shrinkage test was carried out using the same method and room conditions used for the mortar experiment, but with 100 × 100 × 400 mm prismatic specimens.
(4) Compressive strength test
The compressive strength test was carried out in accordance with ISO 1920-8. After demolding on day 1, the specimens were cured in a room at a constant temperature of 20 ± 3°C and 60 ± 5 % relative humidity. but soaked in antifreeze mix solution at 3rd day. Then the compressive strength tests were conducted at age of 7 and 28 days.

3.4.5 Test result

The test results confirmed that soaking concrete in a 30% antifreeze solution reduces drying shrinkage (Fig. 6). Previous studies have shown a drying shrinkage reduction effect when specimens are soaked in a urea solution. This study showed that antifreeze solutions also reduce drying shrinkage. Urea recrystallizes in the voids of concrete after soaking in an antifreeze solution also reduce drying shrinkage due to the recrystallization of urea in the voids of the concrete.

Figure 7 shows the results of the compressive strength test. As shown in previous studies, this study confirmed that soaking concrete in an antifreeze solution increased the compressive strength. Moreover, the strength increased as the soaking time increased. The urea crystals help improve compressive strength.

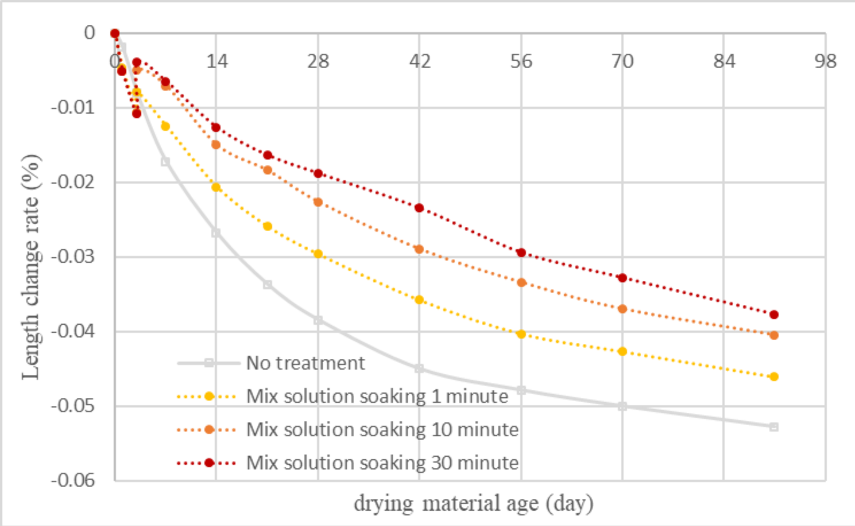

Figure 6. Drying shrinkage test of concrete.

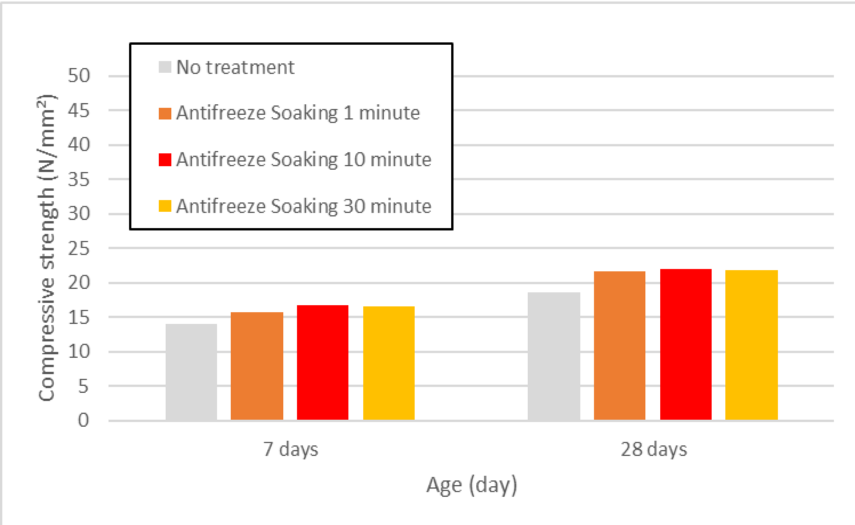

Figure 7. Compressive strength.

3.5 Conclusion

This study showed that the crystallization temperature of urea can be lowered by mixing it with antifreeze. Furthermore, soaking the concrete in an antifreeze solution reduces drying shrinkage, as indicated by the lower length change rate in the drying shrinkage test. These results confirm that an antifreeze solution can be used as a drying shrinkage reduction agent in cold weather. The practical application of this method in the field, however, requires further study.

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