Study on Shrinkage of Ordinary Concrete Under Different Temperatures and Humidity

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Abstract. All cement concrete undergoes drying shrinkage or volume change as the concrete ages. The volume change in concrete is very important to the engineer in the design of a structure. Shrinkage cracks can impact the durability and safety of the structures. The degree of dry shrinkage is affected by many factors. This paper investigated three different cement grades (C30, C40, C50) and three different humidity (30, 60, 95%) at two temperature conditions (10, 25 °C). The dry shrinkage of three cement grades was tested and the results were measured at 7, 14, 28, and 60 days. Through the analysis of the test results, it was found that the humidity has the most profound impact on dry shrinkage. When concrete was subjected to a dry atmosphere, it would lead to a greater drying shrinkage. Lower temperatures generally produce a decrease in drying shrinkage because of higher humidity and slower evaporation.

1 Introduction

Dry shrinkage is an inherent characteristic of cement-based concrete which is the shrinkage of concrete in an unsaturated environment during cement hydration. Drying shrinkage happens mostly because of the reduction of capillary water by evaporation and the water in the cement paste. Concrete is in flowing state during placement and in solid state after hardening. Hardening is a chemical process that produces solid materials such as calcium silicate. It is also a physical process that is accompanied by evaporation of water. When the water evaporation rate is greater than the rate of bleeding, the surface begins to shrink, but it can adapt to the volume change without cracking because of the plastic state of concrete at this time. After that, the concrete becomes thicker because cement hydration and the possibility of plastic cracking increases with the evaporation. After the concrete is set, the drying shrinkage of the hardened concrete may lead to cracking when the amount of shrinkage is large. The water loss rate of concrete is related to many factors, such as water glue ratio, total amount of gelation material, dosage of mineral admixture, temperature and humidity, etc. Ruimin Xiao, Xiong Zhang and Jialin Le have studied that water glue ratio is less affected in the early stage of concrete drying shrinkage and there is a critical value in the later stage. When water glue ratio exceeds concrete critical value, the relationship between the drying shrinkage and the water gel ratio was not obvious. When water glue ratio is below concrete critical value, the concrete drying shrinkage increased with the water glue ratio increase in the later stage. The total amount of gelled material has little

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effect on the early drying shrinkage of concrete, and the shrinkage value increases with the total amount of gelled material increase [1]. Now concrete is generally mixed with mineral admixtures. For high performance concrete, mineral admixtures are necessary. Different mineral admixture is studied by Kang Bai, Hongfa Yu, etc. the influence of different dosage on drying shrinkage of concrete, the drying shrinkage development within 7 day is rapid, 7–60 day drying shrinkage speed slow, stabilized after 60 day, and they put forward the measure of using expansive agent to reduce drying shrinkage [2]. The effect of temperature and humidity on the shrinkage of concrete is studied in this paper.

2 Determination of Concrete Shrinkage Test Method

There are many concrete shrinkage tests in the world. In China alone, there are China national standard GB/T50082-2009, China Ministry of Communications Standard JTJ270-98 and the China power industry standard DL/T5120-2001. Many international institutions have provided concrete shrinkage deformation test standards, such as ASTM, the European EN, the British BS, Japan JIS. There are differences among the test methods. For example, GB/T50082-2009 included both contact and non-contact methods. The contact method included a concrete shrinkage measuring device and the non-contact method comprised a non-contact concrete shrinkage deformation tester. ASTM C157 and British EN utilized gauge for measuring shrinkage. European EN uses contact sensors to measure shrinkage [3].

The non-contact method of GB/T50082-2009 (China national standard) is mainly testing the shrinkage rate of concrete for the first 3 days [4, 5]. In contrast, the contact method is mainly measuring the dry shrinkage of concrete after 3 days. Thus, the contact method was selected and employed in the study.

3 Preparation of Concrete Specimens

Concrete strength and workability (typically reflected in slump) are the two main controlling parameters in China. The cement grades included in the study are C30, C40 and C50. The slump was controlled at 200 ± 20 mm.

The selected materials were tested to comply with the China national and industry standards.

The specimens were prepared according to the mixing design given in Table 1.

Table 1. Mixing design

Strength	Cement	Mineral powder	Fly ash	Sand	5–10 gravel	10–20 gravel	Water	Water-reducing agent
C30	220	80	80	735	165	937	175	8.4
C40	275	80	80	678	166	941	170	9.6
C50	330	80	80	650	166	941	160	12.3

The size of the shrinkage test specimen/prism was 100 mm × 100 mm × 515 mm. Six sets of specimens were prepared and tested under different temperatures and humidity.

4 Testing

In order to ensure the accuracy and reliability of the test results, the temperatures were controlled at between 0 and 25 °C with accuracy of ±1 °C and humidity was controlled at between 30 and 95% with accuracy ±1%. Three different concrete grades were investigated: (1) C30, (2) C40, and (3) C50. Six specimens were prepared for each concrete grade. Test variables included 2 temperatures (10 and 25 °C) and 3 humidity (30, 60, and 95%).

5 Results and Analysis

The specimens were cured for 3 days in a standard curing environment. Then, they were taken out for 4 h at a controlled temperature of 20 ± 2 °C. Measurements were made to determine their initial lengths. The position and direction of specimens on the contraction should be consistent at all times. The corresponding direction was indicated on the specimen. Test specimens/prisms were placed in the corresponding wet and dry box. When the curing was completed, the length of test specimen was measured, and the concrete shrinkage rate was calculated using Eq. 1:

$$\varepsilon_{st} = (L_0 - L_t)/L_b \tag{1}$$

where ε_{st}—the contraction rate of concrete at test age t, and t is the time when the concrete was stirred with water; L_0—initial reading of specimen length, mm; L_t—the length of the specimen at age t, mm; L_b—the length of the concrete specimen (excluding the protruding part of the side head) minus two of the head was buried in the depth [5].

The test results of shrinkage rates for different curing ages and humidity at curing temperature of 10 are shown in Tables 2, 3, 4 and Figs. 1, 2, 3.

Table 2. Shrinkage rate at 30% humidity

Grade	Age			
	7 days	14 days	28 days	60 days
C30	389	530	815	860
C40	352	552	870	904
C50	322	578	850	887

Units 10^{-6}

Table 3. Shrinkage rate at 60% humidity

Strength grade	Age			
	7 days	14 days	28 days	60 days
C30	91	167	318	382
C40	122	190	325	400
C50	145	210	340	421

Units 10^{-6}

Table 4. Shrinkage rate at 95% humidity

Strength grade	Age			
	7 days	14 days	28 days	60 days
C30	65	87	115	130
C40	109	126	150	168
C50	115	132	160	179

Units 10^{-6}

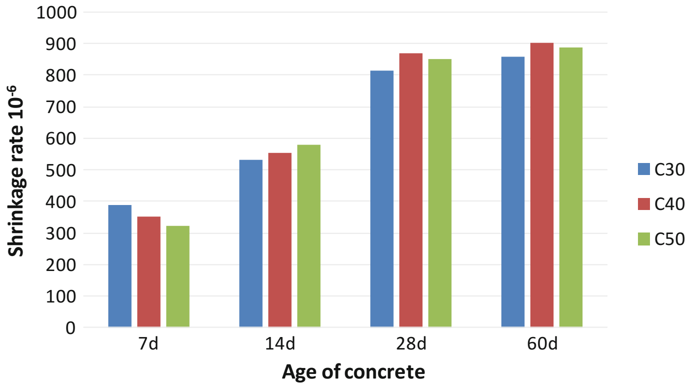

Fig. 1. Shrinkage rate of concrete for curing temperature 10 °C and humidity 30%

Through the analyses of the test results, it was found that shrinkage rate increased with decreasing humidity. It means the shrinkage rate was smaller under higher humidity. This phenomenon was more pronounce for high strength grade than the low strength grade concrete. As expected, the shrinkage rate slowed down after 28 days of curing.

The decrease of the humidity of the concrete itself was the result of the chemical reaction. After the concrete was harden, the volume shrinkage caused by the hydration of the cementitious material was expressed in macroscopic volume shrinkage. In the early stage, there was sufficient internal moisture, so the internal humidity was close to 100%. With time, the rate of hydration decreases and the humidity of concrete decreases as well. When the internal humidity of concrete began to fall, it would cause

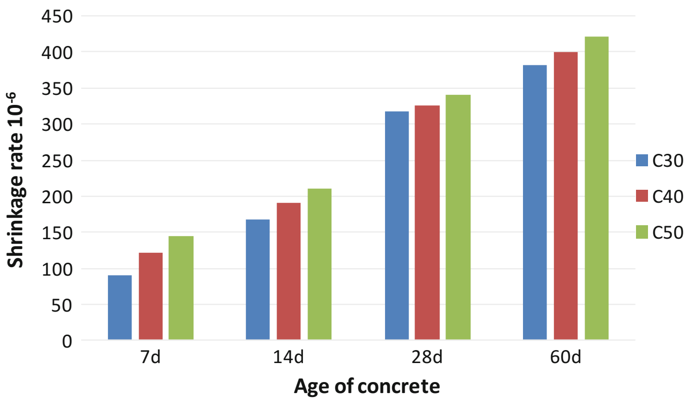

Fig. 2. Shrinkage rate of concrete for curing temperature 10 °C and humidity 60%

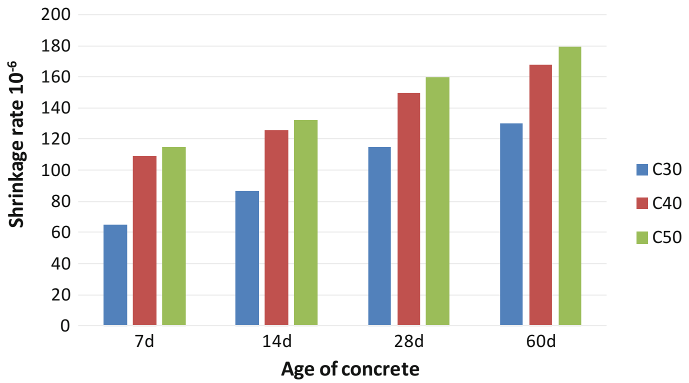

Fig. 3. Shrinkage rate of concrete for curing temperature 10 °C and humidity 95%

the macroscopic shrinkage of concrete, which was controlled by the chemical shrinkage before the internal humidity drops. Therefore, the early shrinkage of concrete was closely related to the change of internal humidity. The internal humidity was reduced because the hydration reaction consumes water. When decrease of humidity in concrete was due to the dissipation of water diffusion, it is called drying shrinkage. Therefore, the change of the internal humidity of concrete was the main driving force of early shrinkage [6].

The test results of shrinkage rate for different cement grade and humidity at curing temperature of 25 °C are shown in Tables 5, 6, 7 and Figs. 4, 5, 6.

In view of the aforementioned test results, it was found that the shrinkage rate of concrete increases with increasing ambient temperature. When the temperature was high, the first 7 days chemical reaction rate was faster, and it lead to higher shrinkage rates. The early shrinkage would be expected under high temperature and low humidity environment. Chemical reactions and hydration rates reduced with age and so as

Table 5. Shrinkage rate at 30% humidity

Grade	Age			
	7 days	14 days	28 days	60 days
C30	430	610	1040	1130
C40	406	545	970	1052
C50	378	523	916	976

Units 10^{-6}

Table 6. Shrinkage rate at 60% humidity

Grade	Age			
	7 days	14 days	28 days	60 days
C30	127	240	512	564
C40	162	276	524	603
C50	180	302	550	638

Units 10^{-6}

Table 7. Shrinkage rate at 95% humidity

Grade	Age			
	7 days	14 days	28 days	60 days
C30	78	94	120	133
C40	124	138	160	175
C50	138	155	178	193

Units 10^{-6}

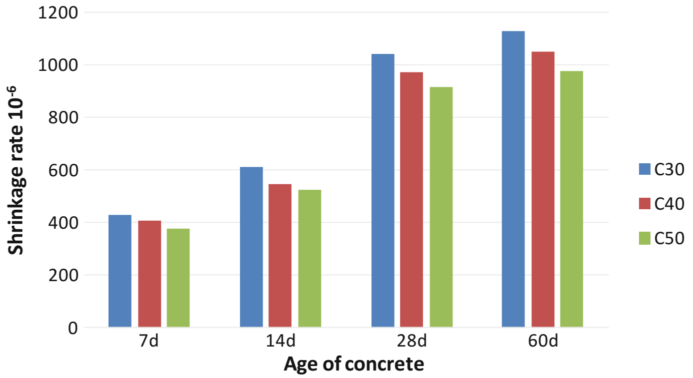

Fig. 4. Shrinkage rate for curing temperature 25 °C and humidity 30%

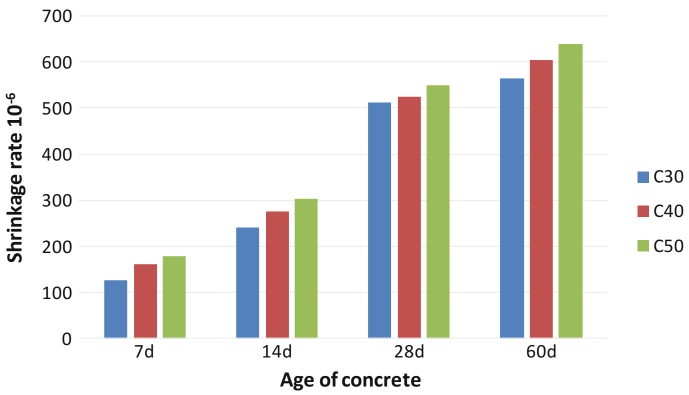

Fig. 5. Shrinkage rate for curing temperature 25 °C and humidity 60%

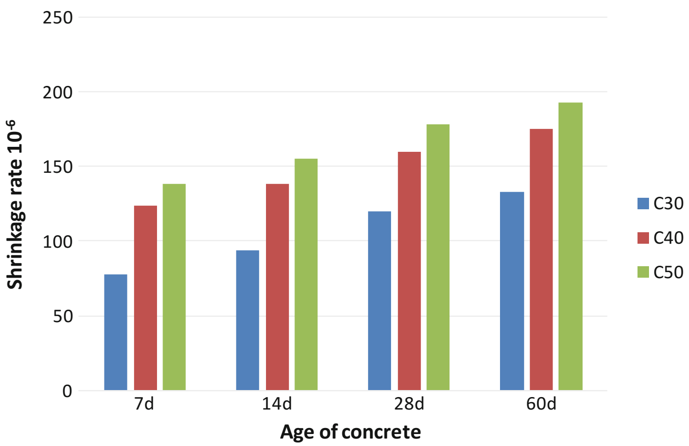

Fig. 6. Shrinkage rate for curing temperature 25 °C and humidity 95%

shrinkage rate. Shrinkage rate for the first 7 days was higher than those from 7th to 60th days. When the temperature was low, the concrete chemical reaction and the wet exchange rate would be slow. It led to lower early concrete shrinkage rate [5].

The shrinkage of concrete is affected by the relative humidity of the environment. The higher shrinkage rate was associated with lower relative humidity. For C30 concrete at 25 °C, when the relative humidity reduced from 95 to 30%, the dry shrinkage value increased from 133×10^{-6} to 1130×10^{-6}. For C50 concrete, the dry shrinkage value raised from 193×10^{-6} to 976×10^{-6}. It was confirmed in this study that the relationship between dry shrinkage and environmental relative humidity cannot be described by a simple linear relation [7].

When humidity was less than 60%, and the water dissipation rate of concrete was higher. In early life of concrete, when there was insufficient humidity, it would cause the water in the concrete to evaporate massively. It would impact hydration of cement due to loss of water. The dry shrinkage led to development of tensile stress in low strength state and caused cracks on the concrete surface. The durability index such as strength and impermeability of concrete would be adversely affected. Therefore, concrete curing immediately after placement was very important to ensure sufficient moisture during hydration as it would ultimately affect the performance of concrete [7].

6 Conclusions

Drying shrinkage happens mostly because of the reduction of capillary water by evaporation and the water in the cement paste. Effects of humidity, temperature, and cement grade on dry shrinkage were investigated in this study. It was found that humidity has the most profound effects on concrete dry shrinkage. To minimize shrinkage crack and improve concrete durability, the curing immediately after placement for the first 7 days was very important to ensure sufficient moisture during cement hydration. It is advisable to keep humidity higher than 60% such that the shrinkage of concrete can be minimized.

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