Experimental Study on the Dry Shrinkage Properties of Nano Concrete Materials

Wei Li¹,², Xiao-chu Wang¹,², LongXiong¹, Zhen Huang¹
¹Shenyang University, Liaoning, Shenyang, 110044, China
²The Key Laboratory of Geoenvironmental Engineering, Liaoning, Shenyang, 110044, China
wangxiaochu@126.com

Abstract. This paper focuses on the effect of adding nano-CaCO₃ and nano-SiO₂ to concrete with different dosages on its shrinkage performance. Studies have shown that: nano materials on the drying shrinkage of concrete will produce certain negative effect, make the drying shrinkage of concrete increases, so need through the selection of the aggregate, the optimization of mixture ratio and effective maintenance means to reduce the drying shrinkage of concrete, such as the nano materials minimizes the negative effect on the drying shrinkage of concrete; In this paper, the effects of two kinds of nano materials on concrete properties are comprehensively compared. The results show that the improvement of mechanical properties and durability of concrete by NS is slightly better than that of NC under the appropriate dosage, but the selling price of NC is much lower than that of NS. Besides, the fluidity of concrete after adding NC is better than that of concrete mixed with NS, and the drying shrinkage rate of concrete at each age is lower.

1. Introduction

Compared with the developed countries in Europe and the United States, the research on nano concrete in China started late and has few applications. Due to its small size effect and high activity, the hydration rate of concrete is accelerated to shorten the setting time after adding nano materials. The influence of nano materials on the working performance of concrete is quite different and varies with the materials [1]. Due to its small area and large water absorption, nano-SiO₂ will reduce the fluidity of concrete mixture after admixture, and this effect becomes more obvious with the increase of admixture. Nano-CaCO₃ has little effect on the fluidity of concrete and can improve the water retention and cohesion of concrete under certain dosage.

The dry shrinkage of concrete is the most common deformation of concrete materials, and the dry shrinkage of concrete is an inevitable deformation, which is also the main cause of concrete cracking [2-3]. There are many factors affecting the dry shrinkage performance of concrete, including concrete mix ratio, admixture, external environment, aggregate content and types, specimen geometry and so on.

2. Analysis on the influence of concrete fit ratio on the dry shrinkage of concrete

The mix ratio of concrete is one of the most direct factors affecting the shrinkage of concrete. By calculating the water-cement ratio, aggregate content and sand ratio, the design of concrete with good compactness is beneficial to reduce the shrinkage deformation of concrete. When the concrete has high
compactness, the internal porosity is low, the capillary water is less, the shrinkage deformation of concrete caused by the loss of capillary water is smaller. In addition, the density of concrete is better, and the loss of internal capillary water is more difficult, so as to reduce the shrinkage deformation of concrete.

3. Analysis of the influence of admixture on the dry shrinkage of concrete
Add water reducing agent while ensuring the strength of concrete, reduce the dosage of cement concrete, especially for small water cement ratio, cement dosage of high strength concrete, by reducing the dosage of cement is beneficial to reduce drying shrinkage of concrete, M.shonaka research shows that [4], poly carboxylic acid water reducing agent on the surface of cement particles has a strong adsorption ability, prevents \( \text{SO}_4^{2-} \) to \( \text{C}_3\text{A} \) gathered together to reduce the hydration rate of aluminate early. The expansion agent can be used to compensate for the maximum shrinkage of the concrete and reduce the cracks caused by shrinkage. The shrinkage reducing agent can reduce the surface tension of water in the capillary tube of cement stone, so as to reduce the negative pressure in the capillary tube. On the other hand, the shrinkage reducing agent can reduce the diffusion rate of alkali ions in the hydration process of cement [5], cause the reduction of the hydration reaction rate of cement, and thus effectively reduce the drying shrinkage of concrete.

4. Analysis of the influence of external environment on the shrinkage performance of concrete
Concrete external environment temperature and humidity is one of the important factors that affect the drying shrinkage of concrete, in terms of the doctrine of interlayer water is lost, when the external environment temperature or humidity is reduced, or work together, the two adjacent two layers of hydrated calcium silicate gel of interlayer water, interlayer water loss makes the lattice contraction, concrete will produce greater contraction deformation. Research [6] shows that the curing time and curing temperature of concrete before drying also have an effect on drying shrinkage.

5. Analysis of the influence of aggregate type and content on the shrinkage performance of concrete
The drying shrinkage of concrete is usually caused by cement slurry shrinkage, the aggregate forms the skeleton structure of concrete, the shrinkage of suitable aggregate-grade matched cement was inhibited and slowed, choose less needle flake, small stones and silt sand fineness modulus in 2.3 above can effectively reduce the pore porosity of concrete and cement dosage, so as to reduce dry shrinkage of concrete. Dan Zheng [7] pointed out in his research on the dry shrinkage deformation of full-grade concrete that appropriately increasing the volume ratio of aggregate can enhance the inhibition of aggregate on the dry shrinkage of concrete and reduce the dry shrinkage deformation of concrete.

6. Analysis on the influence of specimen geometry size on the dry shrinkage of concrete
The geometrical size of the specimen has a certain effect on the rate of concrete water loss, so it has an effect on the drying shrinkage of concrete. Literature suggests that [8], Concrete water loss rate is related to water diffusion path, especially in mass concrete, thickness of 600 mm of concrete outer take 10 years to reach the humidity balance, 225 mm thick outer balanced humidity need to 1 year, and 75 mm thick outer reach moisture balance only 1 months or so, therefore have a larger size or larger size of concrete specimen, the water exchange, loss rate is slower, the dry shrinkage deformation also develops slowly. According to Yingxing Huang [9], concrete specimens of the same volume with larger surface area lose water at a higher rate, and the drying shrinkage of concrete increases with the increase of the specimen surface area. With the increase of the concrete age, the influence of the concrete surface area on the drying shrinkage is smaller and smaller.
7. Dry shrinkage test method for nano concrete
The dry shrinkage test specimen was 100×100×515mm prismoid member. During the concrete pouring, copper nail probe was embedded at both ends of the specimen, and the mould was removed after 2 day curing under standard curing conditions to avoid loosening of the probe or damage to the specimen. After curing the specimen for 3 days in the standard curing room, the specimen was moved to the constant temperature curing room (temperature 20±2℃, humidity 60±5%). During the test, the contact method was used, and the horizontal concrete shrinkage meter and electronic micrometer (accuracy ±0.001mm) were used for the test.

8. Analysis of dry shrinkage test results of nano concrete
The concrete shrinkage rate is calculated according to formula (1), and the concrete shrinkage rate-age diagram is drawn according to the measured data:

\[ \varepsilon_t = \frac{L_t - L_0}{L_c} \]  

In the formula: \( \varepsilon_t \) — the dry shrinkage rate of the specimen t (d), t is calculated from the time when the initial length is determined; \( L_0 \) — initial reading of micrometer (mm); \( L_t \) — reading at t (d) of the micrometer (mm); \( L_c \) — the measuring distance of the specimen, the length of the specimen minus the embedding length of the two probes (mm).

| specimen type | Dry shrinkage / 10^-6 |
|---------------|------------------------|
|               | 1 d | 3 d | 7 d | 14 d | 28 d | 56 d |
| The PC        | 3.91 | 18.13 | 36.52 | 69.7 | 82.73 | 90.44 |
| NS05C         | 5.45 | 24.81 | 41.47 | 77.84 | 92.61 | 104.43 |
| NS10C         | 6.94 | 28.93 | 46.85 | 82.66 | 99.74 | 117.61 |
| NS15C         | 8.75 | 33.55 | 56.37 | 94.34 | 121.42 | 131.35 |
| NS20C         | 9.05 | 36.44 | 62.56 | 108.74 | 126.45 | 137.28 |
| NC05C         | 4.96 | 22.63 | 43.84 | 76.53 | 92.52 | 102.64 |
| NC10C         | 7.21 | 29.57 | 46.23 | 85.88 | 96.13 | 122.38 |
| NC15C         | 6.32 | 25.19 | 42.30 | 81.11 | 91.83 | 108.36 |
| NC20C         | 4.32 | 19.78 | 39.62 | 74.56 | 87.91 | 99.44 |

Table 1. The dry shrinkage of concrete at different ages.

![Figure 1. The dry shrinkage of concrete nano-SiO2 at different ages.](image1.png)

![Figure 2. The dry shrinkage of concrete with nano-CaCO3 at different ages.](image2.png)
As shown in Fig.1, after adding nano-SiO₂, the shrinkage rate of concrete at each age was higher than that of PC, the same age of nano the dry shrinkage of concrete increases with the increase of dosage of nano materials. When the amount of nano-SiO₂ added is 2% of the cement mass fraction, The dry shrinkage of 1 d, 3 d, 7 d, 14 d, 28 d and 56 d is higher than the base concrete respectively of 101.0, 71.3%, 56.0%, 52.8%, 51.8%. After adding nano-SiO₂, the drying shrinkage rate of nano concrete in the early stage is much higher than that of benchmark concrete. With the continuous hydration reaction, the percentage difference between the drying shrinkage rate of nano concrete and benchmark concrete in the late stage of hydration reaction gradually decreases and becomes flat.

Nano-SiO₂ has a certain hygroscopicity, which reduces the free water in the wool pores of concrete, so it needs to absorb more water from the outside to promote the hydration reaction of cement, thus causing greater shrinkage compared with ordinary concrete. Inside the concrete water content has very big effect to the hydration speed, as the growth of the concrete, non-crystalline state of water less and less make concrete hydration reaction rate is reduced. After adding nano-SiO₂ can accelerate the hydration reaction of cement, so need to consume more non-crystalline water, in the late of hydration reaction of nano inside the concrete capillary pressure is bigger, the result of the nano-SiO₂ concrete as the growth of the age and the benchmark concrete shrinkage rate difference gradually increased.

Due to the addition of nano-SiO₂ will increase the dry shrinkage of concrete, especially the dry shrinkage in the early stage of concrete, it is necessary to pay special attention to the early curing of nano concrete in the practical engineering application, to avoid the adverse effects of the dry shrinkage of concrete, and to control the amount of nano-SiO₂, to avoid over-dose.

As shown in Fig.2, the influence of nano-CaCO₃ on dry shrinkage of concrete is less than that of nano-SiO₂ materials. Taking NC10 with the largest dry shrinkage rate as a reference, The dry shrinkage of 1d, 3d, 7d, 14d, 28d and 56d is higher than the base concrete respectively of 84.4%, 63.1%, 26.6%, 23.2%, 16.2% and 35.3%. In addition, It is different from adding nano-SiO₂ material, after adding nano-CaCO₃, the dry shrinkage of concrete at the same age increases first and then decreases with the increase of nano-CaCO₃, In a certain range of nano-CaCO₃, nano-CaCO₃ compacts the concrete and reduces the pore size and porosity of the concrete, and the porosity and pore diameter reduced will make concrete internal capillary pressure after water loss increases, cause the increase of dry shrinkage. When the nano-CaCO₃ content exceeds a certain range, produce too much acicular ettringite AFt will reduce the compactness of concrete, resulting in the decrease of the negative capillary pressure and the reduction of the dry shrinkage of concrete.

Summary

The dry shrinkage rate of nano concrete of the same age increases with the increase of the content of nano materials. When the content of nano-SiO₂ is 2% of the cement mass fraction, the dry shrinkage of 1d, 3d, 7d, 14d, 28d and 56d is higher than the base concrete respectively of 131.5%, 101.0, 71.3%, 56.0%, 52.8% and 51.8%.

With the addition of nano-CaCO₃, the shrinkage rate of concrete increases first and then decreases with the increase of it. The drying shrinkage at each age of NC10C is the maximum drying shrinkage of concrete with nano-CaCO₃, The dry shrinkage of 1d, 3d, 7d, 14d, 28d and 56d is higher than the base concrete respectively of 84.4%, 63.1%, 26.6%, 23.2%, 16.2% and 35.3%.

The higher water absorption of nano-SiO₂ reduces the free water in the wool pores of concrete, so needs to be absorbed more water from the outside to promote the hydration reaction of cement, thus causing the increase of dry shrinkage; the reduction of porosity and pore size of concrete with nano-CaCO₃ increases the capillary negative pressure of concrete after water loss, resulting in the increase of dry shrinkage. When the content exceeds a certain range, produce too much acicular ettringite AFt will reduce the compactness of concrete, resulting in the decrease of negative capillary pressure and the reduction of dry shrinkage of concrete.
Acknowledgement
This research was financially supported by LiaoNing Revitalization Talents Program (Project Name: research on the Key Technology of Application of High-performance of the New-type antonym Material; The project number: XLYC1802018)

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