Experimental Study on Mechanical Properties of Nano Concrete Materials

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Abstract. This paper focuses on the influence of nano-CaCO₃ and nano-SiO₂ materials on the mechanical properties of concrete mixed with different dosages. Through the compressive strength and flexural strength tests of nano concrete, the flexural and compression ratio of each sample are calculated, and the influence of nano materials on the flexural and compression ratio of concrete is analyzed. It is proved that nanometer materials with very small particle size and large surface area have excellent properties that ordinary materials do not possess. It can be used as admixture of concrete to improve the mechanical properties and durability of concrete.

1. Introduction
As "the most promising materials in the 21st century", the research of nano materials has been widely concerned by all walks of life [1]. Concrete, as the traditional building material with the largest dosage, has been applied for more than one hundred years. The durability of concrete has always been the primary problem in the research of concrete. By adding nano material composite to concrete, a new way is opened up for the research of modified concrete.

2. Test method
The compressive strength and flexural strength tests of nano concrete were conducted in accordance with 《Standard test method for mechanical properties of ordinary concrete GB/T50081-2016》 [2], according to the concrete mixed with the varieties and dosage of nano materials are divided into nine groups, each group of testing three specimens and take the average value as the compressive strength test, in the same group, if one specimen has a difference of more than 15%, taking the mean strength value of the other two specimens as the strength value. If two specimens have a difference of more than 15%, the test results of this group will be invalid and retested.

3. Test results
For the compressive strength test of nano concrete, standard cube specimens of 150×150×150mm were used. During the test, the loading rate of the press was 0.8MPa /s. In the flexural strength test, 150×150×550mm prismatic specimens were used, and the three-point loading method was adopted (as shown in Fig.1 and Fig.2). The loading rate was 0.08Mpa /s. The test results were as follows:
The nano materials can fill the tiny void in concrete, improve the compactness of concrete and improve the mechanical properties of concrete. Nano-SiO₂ has the pozzolanic activity of nano-CaCO₃. The mechanical properties of concrete increased greatly after adding nano-SiO₂ when the content of nano-SiO₂ is 1.5%, the growth rates of compressive strength and flexural strength of concrete are 7.84% and 13.00%, when the content of nano-CaCO₃ is 1.0%, the growth rates of compressive strength and flexural strength of concrete are 6.33% and 8.99%. From the point of view of mechanical performance, 1.5% of the SiO₂ and 1.0% for two kinds of optimization of CaCO₃ test the best dosage of nano materials.
It can be seen from the figure that the compressive and flexural strength of concrete increased after the addition of nano materials, and the compressive and flexural strength of concrete decreased after the addition of a certain amount of nano materials. The compressive strength of nano concrete is lower than that of benchmark concrete when the amount of nano-CaCO$_3$ is 2% by mass of cement, so nano material has a limitation on the mechanical behavior of concrete, not blindly adding, need to study the best dosage range.

By observing the load-displacement curve of concrete, The addition of nano materials reduces the deformation performance of concrete under load and reduces the elastic modulus of concrete. Under the condition of concrete compression, The deformation performance of concrete specimens with nano-SiO$_2$ is lower than that with nano-CaCO$_3$. Under the same stress condition, The strain of concrete specimens with nano-SiO$_2$ was small. When PC is damaged under pressure, the maximum effective displacement is 4.467mm, while the displacement of NS15C is 4.066mm and that of NC10C is 4.518mm. When the concrete is under compression, The slope of concrete compression curve with nano-CaCO$_3$ is close to that of PC. The slope of the curve increases in the early stage of compression, and decreases before the peak load, and tends to be flat. However, the deformation capacity of concrete was reduced after adding nano-SiO$_2$. In the early stage of compression, with the increase of load, the slope of the load-deformation curve of NS15C gradually increases. Before the load reaches the peak load, the load-deformation graph of NS15C tends to be linear until the concrete is destroyed.

The addition of nano materials has little influence on the flexural and tensile deformation performance of concrete. Through the observation of translation, the addition of nano materials only
increases the peak load of concrete under flexural and tensile loads, and the three groups of curves are nearly parallel.

4. Study on the flexural and compression ratio of concrete

There are many empirical formulas for the relationship between compressive strength and flexural strength of concrete. The American Portland cement association proposed the relationship between compressive strength and flexural strength of cylindrical concrete specimens [3]:

\[ f_c = 0.0943f_f + 1.32 \]  

(1)

and the American concrete commission proposed a classic relationship [4]:

\[ f_c = 0.62\sqrt{f_f} \]  

(2)

The empirical relation proposed by the road committee of Japan cement association is [3]:

\[ f_c = 0.128f_f + 1.990 \]  

(3)

China's ministry of communications highway research institute has established the 28 day compressive strength and flexural strength of concrete [5]:

\[ f_c = 0.415f_f \]  

(4)

The formula of the expert of our country famous concrete material Zhengyong Cai [3] pointed out that flexural strength of concrete is calculated from its compressive strength, compressive strength of concrete should be used in practical engineering materials and experience data, the correlation between the two was established by experiment.

The strength of cement slurry and aggregate determines the compressive strength of concrete, while the flexural tensile strength depends on the strength of the interface transition zone [6]. Related experiments [7] show that the degree of chemical reaction between the nano meter material and Ca(OH)\(_2\) in the cement slurry body is lower than that between the nano meter material and Ca(OH)\(_2\) in the interface transition zone of concrete, so the research on the folding ratio of nano meter cement concrete is introduced.

The flexural and compression ratio of concrete refers to the ratio of flexural strength to compressive strength, which is an important index of toughness. In practical engineering, often need to reduce the water cement ratio, increase the dosage of cement and other ways to obtain high flexural strength of concrete, use reduce the water cement ratio, increase the flexural strength of cement dosage and otherwise no compressive strength increase rate is large, so will cause surplus too much concrete compressive strength. The analysis of flexural and compression ratio of nano concrete can be used as an important reference for measuring the correlation between compressive strength and flexural strength of nano concrete [8-9], and the influence of nano materials on the mechanical properties of concrete is discussed.

\[ \lambda = \frac{f_f}{f_c} \]  

(1)

In the formula: \( f_c \) — the compressive strength of concrete cube (MPa); \( f_f \) — flexural strength of concrete (MPa)

Fig. 9 shows the change of flexural and compression ratio with the addition of two kinds of nano materials to concrete. After adding nano-SiO\(_2\), the flexural and compression ratio of concrete increased with the increase of the adding amount, and the flexural and compression ratio of concrete also increased with the addition of nano-CaCO\(_3\). With the increase of the adding amount, the flexural and compression ratio of concrete increased first and then decreased. When the addition amount of nano-CaCO\(_3\) exceeded 1.0%, the flexural and compression ratio of concrete continued to be added decreased.
The reason for this difference is that nano-SiO$_2$ has a high pozzolanic activity, which can react with Ca(OH)$_2$ in the interface transition zone around the concrete aggregate, reduce the number of Ca(OH)$_2$ crystals, improve the orientation of the interface transition zone, and thus make the growth rate of concrete flexural strength greater than that of compressive strength. Nano-CaCO$_3$ has no pozzolanic activity, but nano-CaCO$_3$ can fill the gap in the transition zone and deposit Ca$^+$ ions around it. From the reversible analysis of chemical reaction, nano-CaCO$_3$ can reduce the precipitation rate of Ca(OH)$_2$, thus improving the flexure strength of concrete and increasing the flexural and compression ratio of concrete. Through the microscopic test and analysis of concrete, it is concluded that when the content of nano-CaCO$_3$ exceeds a certain amount, the hydration reaction of cement will produce too much acicular ettringite AFt. The excessive deposition of calcium carbonate hydrate and acicular ettringite AFt around the transition zone is unfavorable to the flexural strength of concrete, resulting in the reduction of the flexural and compression ratio of concrete.

5. Summary

In this paper, the effects of nanomaterials on the mechanical properties of concrete are studied by means of compressive strength and flexural strength tests. The growth rates of compressive strength and flexural strength of concrete were 7.84% and 13.00% respectively when the addition amount of nano-SiO$_2$ was 1.5%. The growth rates of compressive strength and flexural strength of concrete were 6.33% and 8.99% respectively when the addition amount of nano-CaCO$_3$ was 1.0%. In addition, the addition of nanomaterials reduces the deformation performance of concrete under load and reduces the elastic modulus of concrete. By analyzing the ratio of flexural strength of concrete to compressive strength, after adding nano-SiO$_2$, the flexural and compression ratio of concrete increases with the increase of the amount of addition, while the flexural and compression ratio of nano-CaCO$_3$ concrete increases first and then decreases with the increase of the amount of addition.

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