Study on Preparation of Ultra-high Strength and High Performance Concrete From Diatomite and Its Mechanical Properties

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Abstract. High performance concrete plays an important role in national construction. It is found that diatomite as admixture after calcination and grinding can significantly improve the strength, fluidity, pumpability and durability of concrete. In this paper, the preparation and mechanical properties of high performance concrete (HPC) using calcined and ultrafine crushed diatomite as mineral admixture instead of partial cement (single admixture) and silica fume and fly ash as admixture instead of partial cement (double admixture) were studied.

1. Introduction

With the characteristics of high-rise, large-span and underground buildings, the development of conventional concrete to high-performance concrete is a major trend in the 21st century. High-performance concrete plays an important role in national construction and has become one of the important directions of the development of cement-based composite materials. High performance concrete (HPC) refers to concrete that meets the comprehensive requirements of economical and reasonable raw materials and mix ratio, smooth and efficient construction process, compact and complete structure appearance, excellent mechanical properties and durability in specific application occasions. Its emphasis is to ensure durability, workability, various mechanical properties, applicability, volume stability and economic rationality.

In recent years, with a large number of C50 and C60 used in high-rise buildings and long-span bridges, C50-C70 concrete has been widely used in practical construction projects. Using mineral fine admixtures scientifically and extensively can not only improve the performance of concrete, but also reduce the demand for cement clinker. It is conducive to reducing the discharge of CO₂ from burning clinker, improving and protecting the environment, and achieving good economic and social benefits. It is also conducive to the development of green high performance concrete.

Diatomite is a kind of siliceous rock. Its chemical composition is mainly SiO₂. It can be expressed by SiO₂·nH₂O. Its mineral composition is Opal and its variety. It is found that the strength, fluidity, pumpability and durability of concrete can be significantly improved by calcining and grinding diatomite as admixture. Active SiO₂ content and specific surface area of diatomite play a key role in improving cement strength. The addition of diatomite can significantly increase the amount of C-S-H in the later stage of cement hydration (28 days). The problem of strength reduction can be solved by calcining diatomite.
At present, diatomite is seldom used in the preparation of high performance concrete in practical engineering, but in the long run, the preparation of high performance concrete has good prospects for development.

This paper mainly studies the preparation of high performance concrete using calcined and ultra-fine crushed diatomite as mineral admixture instead of part cement (single admixture) and silica fume and fly ash as admixture instead of part cement (double admixture), and its mechanical properties (compressive strength) of 3, 7, 28, 56 and 90 days. Strength, flexural strength, static modulus of elasticity, etc. The test results and rules of time-varying are analyzed. The influence of calcined and ultra-fine crushed diatomite on the mechanical properties of high performance concrete was obtained by observing the micro-characteristics of diatomite under electron microscope, and the law of the above-mentioned properties changing with the composition of materials at different ages was also obtained. The micro-structure of concrete was studied by means of electron microscopy analysis.

Table 1. Chemical composition and physical properties of materials

| Material          | Chemical composition (%) | Specific surface area | Density (g/m³) |
|-------------------|--------------------------|-----------------------|----------------|
|                   | CaO         | SiO₂       | Al₂O₃       | MgO       | Fe₂O₃   | TiO₂   | SO₃   | LOI   |             |             |
| Cement            | 60.84      | 20.47      | 5.01       | 2.7       | 3.67    | 0.44   | 2.24  | 1.37   | 335       | 3.1          |
| Silica fume       | 0.67       | 92.81      | 0.67       | 1.11      | 0.91    | 0.02   | 1.33  | 2.25   | 20000      |              |
| Fly ash           | 4.93       | 63.7       | 18.2       | 1.04      | 2.22    | 0.8    | 5     | 420    |            |              |
| Calcined diatomite| 0.5        | 92.85      | 1.89       | 0.9       | 0.75    | 0.9    | 1.87  | 53800  | 0.45       |              |

2. Mechanical properties analysis

2.1. Testing of basic mechanical properties

In this experiment, according to the relevant requirements of "Specification for Design of Mix Ratio of Ordinary Concrete", "Standard for Testing Method of Mechanical Properties of Ordinary Concrete" and "Technical Specification for Application of High Strength Concrete", the water-binder ratio is 0.2 and the sand ratio is 40%. Cement, stone, sand, water, mineral admixtures, extrusion and other materials are added to the mixer. Each performance test of the mixer is made of five groups of test blocks and three blocks in each group. The amount of material used is measured by mass, and the vibration of the shaking table is adopted.

The concrete mixture is loaded into the test mould once. When loading, the spatula is used to ram along the wall of the test mould and make the concrete mixture higher than the test mould mouth. The test mould is fixed on the shaking table that meets the requirements, and the vibration lasts until the surface slurry is discharged. Immediately after the specimen is formed, the surface is covered with an impermeable film.

Under natural conditions, the specimen is placed for two days and nights, then numbered and demoulded. After demoulding, the specimen is naturally maintained on the ground of the laboratory. Water is sprayed on the surface of the specimen every 8 hours to keep the specimen wet[1].

Table 2. Testing of Mechanical Properties of Foundation

| number | Water binder ratio | Dosage of cementitious materials (kg/m³) | Sand rate (%) | Active mineral content (%) | Degree of expansion | Collapse degree /mm |
|--------|-------------------|----------------------------------------|--------------|---------------------------|---------------------|-------------------|
| A0     | 0.25              | 650                                    | 40           | Silica fume               |                     |                   |
|        |                   |                                        |              | Fly ash                   |                     |                   |
|        |                   |                                        |              | Diatomite                 |                     |                   |
|        |                   |                                        |              | Cement dosage%            | 100                 |                   |
2.2. Compressive strength test

The process of concrete cube compressive strength test is as follows: after the specimen is removed from the maintenance site, the specimen surface and the upper and lower pressure plate surface are wiped clean, the specimen is placed on the lower pressure plate of the testing machine, and the center of the specimen is aligned with the center of the lower pressure plate of the testing machine, the testing machine is started, the loading speed is 0.8-1.0 MPa per second, when the specimen is connected[2]. When the damage begins to deform sharply, stop adjusting the throttle of the test machine until the damage occurs, and then recording the damage load.

| number | 3d | 7d | 28d | 56d | 90d |
|--------|----|----|-----|-----|-----|
| A0     | 420| 516| 578 | 636 | 670 |
| A1     | 647| 717| 774 | 805 | 849 |
| A2     | 650| 699| 757 | 824 | 897 |
| A3     | 561| 614| 636 | 663 | 687 |
| A4     | 427| 482| 556 | 648 | 675 |

2.3. Static Compressive Elastic Modulus Test

Three specimens were taken to measure the axial compressive strength of concrete. Three other specimens were used to measure the elastic modulus of concrete. When measuring the elastic modulus of concrete, the deformation measuring instrument is installed on the midline of both sides of the specimen and symmetrical at both ends of the specimen[3]. Adjust the position of the specimen on the pressure testing machine to align its axis with the center line of the lower pressure plate.

The results of concrete elastic modulus test are calculated and determined according to the following methods:

The elastic modulus of concrete should be calculated according to the following formula:

$$E_C = \frac{F_a - F_0}{A} \times \frac{L}{\Delta_n}$$

(1)

In style

EC - elastic modulus of concrete (MPa);
Fa - Load (N) when the stress is 1/3 of the axial compressive strength;
F0- Initial load (N) when the stress is 0.5 MPa;
A - specimen pressure area (mmA2);
L - Measuring distance (mm);
$$\Delta_n = \epsilon_n - \epsilon_0$$

(2)

In style

The average value of deformation on both sides of the specimen (mm) at the last loading from Fa to F0.

—— Mean value of deformation on both sides of specimen (mm) at Fa;
—— Mean value of deformation on both sides of specimen (mm) at F0.
The performance of high strength concrete prepared from diatomite can be obtained by analyzing the experimental data.

2.4. Splitting Tensile Strength Test

The calculation and determination of the splitting tensile strength test results of concrete are carried out according to the following methods:

The splitting tensile strength of concrete should be calculated according to the following formula:

\[ F_{ts} = \frac{2F}{\pi A} - 0.637 \frac{F}{A} \]  

(3)

Where:
- \( F_{ts} \) - splitting tensile strength of concrete (MPa);
- \( F \) - failure load (N) of specimens;
- \( A \) - Splitting surface area (mm²);

The calculation of splitting tensile strength is accurate to 0.01 MPa.

Notices should be paid attention to in this experiment:

(1) The arithmetic average value of the measured values of the three specimens is taken as the strength value of the group of specimens (accurate to 0.01 MPa).

(2) If the difference between the maximum value and the minimum value of the three measurements exceeds 15% of the median value, the maximum value and the minimum value are discarded together, and the median value is taken as the compressive strength value of the group of specimens.

(3) If the difference between the maximum value and the minimum value and the median value exceeds 15% of the median value, the test results of this group of specimens are invalid.

The splitting tensile strength measured by 100mm *100mm *100mm non-standard specimens should be multiplied by the dimension conversion coefficient of 0.85; when the strength grade of concrete is more than C60 inches, the standard specimens should be adopted; when using non-standard specimens, the dimension conversion coefficient should be determined by experiments.

In this paper, XRD, SEM and other means are used to study the changes of phase, morphology and structure of diatomite during calcination, providing theoretical guidance for the application of diatomite as active admixture in cement concrete.[4]

3. Conclusion

High performance concrete has excellent properties such as high strength, good toughness and high construction. Durability and technological performance meet the structural functional requirements and construction process requirements, they can also maximize the service life of concrete structures and reduce the cost of construction. The good workability of high performance concrete also reduces the labor intensity of constructors, reduces engineering time and labor cost, and speeds up construction progress.[5] It is feasible to use diatomite as mineral admixture to replace part of cement and silica fume and fly ash as admixture to replace part of cement to prepare high performance concrete. And its basic mechanical properties, compressive strength, compressive modulus of elasticity and tensile properties are better.[6]

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