Experimental study on the electrical conductivity of SSG composite concrete

Fengyuan Yan, LinJie Li, Zhiwei Jiang, Yuhang Ji, Lei Feng, Peiling He

School of Civil Engineering, Nanjing Institute of Technology, Nanjing, 211167, China
*Corresponding author: 1622786043@qq.com

Abstract: to study the influence of steel slag, slag and graphite content and age on the electrical conductivity of concrete, the electrical resistivity of concrete specimens with specifications of A(100mm×100mm×100mm) and B(100mm×100mm×400mm) was tested. The results show that: With the increase of curing age and the increase of cement substitution by steel slag: slag, the concrete resistivity continues to increase, and the electrical conductivity continues to decrease; and the optimal blending ratio of steel slag: slag is 1:2, the influence of graphite content on concrete conductivity Larger; as the size of the test piece increases, the electrical resistivity of the concrete decreases.

1. Introduction
Concrete materials are currently the most used building materials in the world, and with the development of modern technology, there are more and more types of functional concrete. Due to the particular needs of the project, the new special materials and related technologies of conductive concrete have emerged, which are mainly used in actual projects such as snow melting, electromagnetic shielding, building heating, and self-detection of building structures in cold regions and airports [1]. To reduce the cost of the project, people have been looking for more economical materials and structural forms, and steel slag and slag are industrial wastes. The use of this material to prepare concrete, low prices, protection of the ecological environment, has a good development trend.

SSG (steel slag-slag-graphite) multiphase conductive concrete refers to a new type of special concrete prepared by adding steel slag, slag and graphite to the foundation of plain concrete. The main component of steel slag is an iron oxide, which has good wear resistance, durability, high activity and metal conductivity [2]; the chemical composition of slag is similar to ordinary Portland cement, with potential water. Hard, physical properties similar to natural sand, is a high-quality concrete admixture; graphite conductivity is one hundred times higher than general non-metallic minerals, thermal conductivity exceeds steel, iron, lead and other metal materials, so graphite is incorporated into concrete It can greatly improve the electrical conductivity of concrete, but the concrete prepared by single-doped graphite is inferior in strength, and the combination of the other two kinds of admixtures is required to give full play to the respective performance advantages of the three materials.

2. Raw materials and test methods

2.1. Raw materials
The experiment uses P-O42.5 grade cement; the fine aggregate is natural river sand with fineness modulus of 2.6; the coarse aggregate is continuous gravel with particle size of 5~10mm; the water
reducing agent is 21% concentration of polycarboxylate Acid water reducing agent; mixing and curing water is tap water; steel slag particle size is 200 mesh, Table 1 shows its chemical composition; slag is S9 granulated blast furnace slag powder produced by Lingshou County mineral processing plant, Table 2 shows its physics performance; the graphite particle size is 200 mesh, and Table 3 shows its chemical composition.

Table 1. Steel slag composition table

| Ingredients | SiO2  | Al2O3 | CaO  | MgO  | Fe2O3  |
|-------------|------|-------|------|------|--------|
| content    | 15.32% | 3.8%  | 30.12% | 16%  | 33.24% |

Table 2. Slag performance test

| Test items | density (g/cm³) | Specific surface area (m²/kg) | Seven-day activity index (%) | Loss on ignition (%) | Chloride (%) | Liquidity ratio (%) | Water content (%) |
|------------|----------------|-------------------------------|-------------------------------|----------------------|--------------|---------------------|-------------------|
| Test results | 2.89 | 425 | 78 | 0.60 | 0.036 | 102 | 0.28 |

Table 3. Graphite composition table

| Ingredients | carbon | Ash | Volatile | sulfur | Moisture |
|-------------|--------|-----|----------|--------|----------|
| content    | 98.5%  | 0.9% | 0.6      | 0.05   | 2        |

2.2. Concrete mix ratio

The concrete mix ratio is designed according to JGJ 55-2011 "General Concrete Mixing Ratio Design Regulations". Based on plain concrete, SSG composite conductive concrete was prepared by incorporating steel slag, slag and graphite. The steel slag and slag were used instead of cementitious material, and the conductive property of graphite reinforced concrete was incorporated. Table 4 is the reference concrete mix ratio.

Table 4. Reference concrete mix ratio

| cement water | Fine aggregate | Coarse aggregate | Water cement ratio | Sand rate | Water reducing agent |
|-------------|----------------|-----------------|-------------------|-----------|----------------------|
| 380 190     | 747            | 1100            | 0.5               | 0.4       | 1.2                 |

2.3. Experiment method

The conductivity of the concrete is measured by the four-pole method [3], and the resistivity of the test pieces 7d, 14d, 21d and 28d is measured separately. In the test piece, the metal mesh with a size of 40 mm×40 mm is embedded in parallel, and the wire is connected to the metal mesh. The concrete test piece voltage and current were tested using two digital multimeters of the VC86E. The test uses an adjustable steady flow transformer and a rectifier to convert the laboratory 220V AC into a low-voltage DC power and applies a voltage to the concrete test piece to make the voltage and current reach the measurable range of the instrument. The concrete resistivity is calculated by the following formula:

\[ p = \frac{UL}{IA} \]

Among them:

- \( p \) — Resistivity, Ω·m
- \( U \) — Voltage, V
- \( I \) — Current, A
- \( A \) — Cross-sectional area of the test piece, m²
- \( L \) — Distance between electrodes, m
3. Test results and analysis

3.1. Effect of curing age on the electrical conductivity of concrete

The experimental data were analyzed by measuring the resistivity of the SSG composite conductive concrete specimens of the two sizes in the curing process at 7d, 14d, 21d and 28d, and the variation law was obtained.

Figure 2 is a graph showing the change of resistivity of specimens with specifications of A with age, and Figure 3 is a graph of resistivity of specimens with specifications of B as a function of age, as can be seen from the figure. As the age of maintenance increases, the electrical resistivity of concrete continues to rise.

Water is a good conductor, so in the initial stage of curing, the water content in the test piece is high, the concrete resistivity is small, and the electrical conductivity is good. With the occurrence of hydration, the water in the concrete gradually decreases, the electrical conductivity decreases, and the electrical resistivity gradually increases. There is another possibility that the conductive network in concrete is generated by electronic transitions, with age. Growth, the number of electronic transitions is gradually reduced [4], until the transition is no longer generated, resulting in an increase in the resistivity of the test piece and a decrease in electrical conductivity.

3.2. Effect of steel slag and slag content on the electrical conductivity of concrete

The experiment investigated the influence of steel slag and slag on the substitution of cement and the ratio between the two and explored the influence of the steel slag on the conductivity of concrete. It
can be seen from Fig. 4 and Fig. 5 that under the three conditions of steel slag: slag composite ratio of 2:1, 1:1 and 1:2, with the increase of steel slag and slag instead of cement, two sizes The electrical resistivity of the concrete increases; and when the steel slag and slag composite ratio is 1:2, the resistivity of the test piece is the smallest, and the concrete conductive performance is optimal.

When the ratio of steel slag to slag is 1:2, the average resistivity of concrete specimens of two specifications is: 3.93Ω·m and 2.51Ω·m, respectively, the conductivity of concrete is optimal, indicating that the steel slag is more likely to form a conductive network than the slag. This is mainly because the metal content of the steel slag is much higher than that of the slag, and the dense metal particles inside are more likely to conduct current with each other to form a conductive network, thereby enhancing the electrical conductivity of the concrete.

### 3.3. Effect of graphite content on the electrical conductivity of concrete

The experiment studied the effect of graphite on the conductivity of concrete by changing the amount of graphite. Figure 6 and Figure 7 show that when the graphite content is 2%, the concrete has the lowest resistivity and the best conductivity, and the dosage is 6%. The concrete resistivity has extreme points, and the concrete has better conductivity. When the graphite content exceeds 8%, the concrete resistivity changes little, and the concrete conductivity tends to be stable.

Graphite is a material with excellent electrical conductivity, and its incorporation into concrete can greatly improve the electrical conductivity of concrete. When the amount of graphite is small, fine aggregate and cement surround the graphite particles, and there is less contact between them, the conductive path cannot be formed, and the conductivity is poor. When the graphite content reaches 2% and 6%, its content can form a complete and stable conductive path, so the electrical conductivity is good; and when the graphite content exceeds 8%, the hydration exotherm causes the vibration. The transition of the electrons is gradually stabilized, and the tunnel current generated is relatively stable, so the electrical conductivity of the concrete tends to be stable.
3.4. Influence of specimen size on concrete conductivity

Through the preparation of two different sizes of SSG composite concrete specimens, the influence of size on the electrical conductivity of concrete was investigated. Figure 8 is a plot of the ratio of the resistivity of the two-dimensional concrete specimens of the specifications 100mm × 100mm × 100mm and the specifications of 100mm × 100mm × 400mm. As can be seen from the figure, the conductive concrete test with the specification of 100mm × 100mm × 100mm The electrical resistivity of the piece is higher than that of the conductive concrete specimen with the specification of B, and the ratio between the two is between 1 and 3. When the steel slag: slag is 1:1, the total replacement of cement is 30%, and the graphite content is 6%, the resistivity ratio of the two sizes of test pieces reaches the maximum.

Throughout the test process, we found that as the size of the test piece increases, the concrete resistivity decreases gradually, which can be considered as the result of the "size effect" of the concrete resistivity. The larger the size of the test piece, the higher the internal temperature during the curing process, and the uneven distribution of the component temperature can accelerate the chemical reaction \(^5\), and lead to changes in the properties of the conductive materials such as steel slag, slag and graphite, and the conductive properties of the concrete are degraded.

4. Conclusion

- The degree of correlation between the three conductive admixtures on the electrical conductivity of concrete is steel slag > graphite > slag. During the first 28 days of curing, the electrical resistivity of SSG multiphase conductive concrete continued to rise, and the concrete conductivity decreased.
- With the increase of steel slag and slag instead of cement, the resistivity of concrete of two sizes increased; and when the ratio of steel slag and slag was 1:2, the resistivity of the specimen was the smallest and the conductivity of concrete was the best.
- When the content is 6%, the concrete resistivity has extreme points, and the concrete has better conductivity. When the graphite content exceeds 8%, the concrete resistivity changes little, and the concrete conductivity tends to be stable.
- Due to the influence of the "size effect", the resistivity of the test piece decreased with the increase of the size of the SSG composite conductive concrete specimen.

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References
[1] Shen Gang and Dong Faqin, Conductive Concrete and Its Development Trends. Industrial Construction, 2004. 34(3): pp. 62-64.
[2] Qian Jue et al. Experimental study on the preparation of conductive concrete by air-quenched steel slag. Journal of Building Materials, 2005. 8(3): pp. 233-238.

[3] Chen Zhiwei, Freezing and Thawing Damage of Multiphase Conductive Concrete and Self-Induction of Bending Damage, 2013, Dalian University of Technology.

[4] Ouyang Ping, Experimental study on strength and electrical conductivity of three-phase conductive concrete. Concrete and Cement Products, 2015(9): pp. 14-19.

[5] Liu Han, CFRC strength and size effect research, 2011, East China Jiaotong University.