Experimental Study on Volume Deformation of Iron Tailing-steel Slag Aggregate Concrete

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Abstract: Utilization in building materials is one of the main technical ideas for realizing large-scale, high added value recycling of industrial solid wastes such as iron tailings and steel slags. It is common to use only iron tailings or steel slags instead of ordinary sands or stones as concrete aggregates, but using them at the same time and combining their performance advantages to improve the mechanical properties and durability of concrete has not yet appeared. Therefore, sands were replaced by iron tailings as fine aggregates and stones were replaced by steel slags as coarse aggregates to prepare iron tailing-steel slag concrete in this research. And the strength, early crack resistance and long-term volume deformation of iron tailing-steel slag concrete were tested. The results show that iron tailings have negative effect on concrete strength when used as fine aggregates and steel slags are beneficial to concrete strength with a small adding amount. In addition, iron tailings with proper adding amount can inhibit the deformation of concrete caused by steel slags, in consequence of which early crack resistance and volume stability of concrete are improved.

1. Introduction
With the rapid development of Chinese mining industry, the scale of mining plants is getting larger and larger, and the amount of iron tailings discharged is increasing, resulting in numerous iron tailings accumulation, serious pollution and difficult to dispose. At present, the total accumulated steel slags in China are up to 1 billion tons. A large amount of accumulated steel slags lead to cultivated land occupation, environmental pollution and ecological destruction. The application of iron tailings in concrete can not only solve the problems of resources and environment, but also benefit to construction of circular economy. The large-scale, high-value and resource utilization of steel slags has become the key to solve the problem of environmental pollution caused by the accumulation of steel slags.

In recent years, there have been related studies on the cement concrete with iron tailings as fine aggregates, including the preparation of high strength concrete [1] and self-compacting concrete [2] with them. Some researchers have come to the conclusion that the incorporation of iron tailings can improve the mechanical properties [3] and durability of concrete to a certain extent [4]. In addition, waste tailings can also be used to fill expressway subgrade [5], which can solve the problem of iron tailings accumulation and promote its application in the highway roadbed.

Compared with iron tailings, the research on steel slags was more extensive at home and abroad, using steel slags to replace part of ordinary sands and gravel [6] as concrete coarse and fine aggregates.
to prepare steel slag aggregate concrete and using waste tire particles to improve its volume stability. Moreover, some researchers have prepared foamed concrete, pervious concrete, recycled concrete, high strength and good wear resistance concrete with steel slags.

The poor workability of iron tailing concrete and the lacking of volume stability of steel slag concrete have become the main reasons for restricting the utilization of iron tailings and steel slags. Therefore, we developed experimental study on mechanical properties, early crack resistance and mid-long term volume deformation of iron tailing-steel slag aggregate concrete in this paper, which in order to make full use of the performance advantages of such two industrial solid wastes and open up a new way for the utilization of large quantities of steel slags and iron tailings in building materials.

2. Experiment

2.1 Raw materials

Chinese PO.42.5 type ordinary Portland cement conforming to GB175 was used and its chemical composition is described in table 1:

| Chemical composition | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | others |
|----------------------|------|-------|-------|-----|-----|-----|--------|
| Content%             | 20.52| 5.95  | 2.75  | 59.65| 2.58| 2.47| 6.11   |

River sands and iron tailings used as fine aggregates in the test were provided by local supplier. The sieve analysis results of iron tailings according to GB/T14684 were shown in Table 2:

| Size of square sieve pore/mm | Sieve residue /g | Divided residue /% | Accumulated residue /% |
|------------------------------|------------------|--------------------|------------------------|
|                              | A                | B                  | A                  | B              | A          | B          |
| 4.75                         | 3.2              | 3.8                | 0.64               | 0.76           | 0.64       | 0.76       |
| 2.36                         | 60.5             | 71.8               | 12.1               | 14.36          | 12.74      | 15.12      |
| 1.18                         | 73.0             | 78.9               | 14.6               | 15.78          | 27.34      | 30.9       |
| 0.6                          | 104.2            | 104.5              | 20.84              | 20.9           | 48.18      | 51.8       |
| 0.3                          | 120              | 115.0              | 24.0               | 23.0           | 72.18      | 74.8       |
| 0.15                         | 95.6             | 91.6               | 19.12              | 18.32          | 91.3       | 93.12      |
| <0.15                        | 44.2             | 33.7               | -                  | -              | -          | -          |
| Total                        | 498.7            | 499.3              | -                  | -              | -          | -          |

The fineness modulus of iron tailing sands belonged to medium sand and met the requirement of concrete sand. The results of chemical analysis of iron tailings were shown in Table 3:

| Component | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ |
|-----------|------|-------|-------|-----|-----|-----|
| Content (%)| 58.87| 6.23  | 13.45 | 5.89| 2.47| 1.31|

The coarse aggregates used in this project were gravel and steel slags produced by Ma’anshan Iron and Steel Co. Ltd, and the storage time of steel slags was three years. XRD results of steel slag powder were presented in figure 1. Its chemical composition and water absorption were shown in tables 4 and 5:
In order to make concrete mixtures meet the requirement of working performance, a certain amount of naphthalene series water reducer produced by Jiangsu Subote New Materials Co., Ltd. was added into iron tailing-steel slag aggregate concrete.

2.2 Concrete Mix Proportion
In this experiment, steel slags were used to replace coarse aggregates and iron tailings were used to replace fine aggregates to prepare iron tailing-steel slag aggregate concrete with different percentage. Group OC was ordinary concrete without steel slags and iron tailings replacement of aggregates, which was used as reference group. The mix ratios of each group of concrete were shown in Table 6.

Table 6 Mix proportion of concrete

| Group   | Quantity of concrete material per m³/kg |
|---------|----------------------------------------|
|         | Water | Cement | Ordinary abrasive | Iron tailings | Stone | Steel slag |
| 1. OC   | 190   | 422    | 536              | -            | 1250  | -          |
| 2. I0% S20% C | 190 | 422    | 536              | -            | 1000  | 250        |
| 3. I0% S40% C | 190 | 422    | 536              | -            | 750   | 500        |
| 4. I0% S60% C | 190 | 422    | 536              | -            | 500   | 750        |
| 5. I20% SC   | 190   | 422    | 428.8            | 107.2        | 1250  | -          |
6. I_{20\%}S_{20\%}C  190  422  428.8  107.2  1000  250
7. I_{20\%}S_{40\%}C  190  422  428.8  107.2  750  500
8. I_{20\%}S_{60\%}C  190  422  428.8  107.2  500  750
9. I_{40\%}SC  190  422  321.6  214.4  1250  -
10. I_{40\%}S_{20\%}C  190  422  321.6  214.4  1000  250
11. I_{40\%}S_{40\%}C  190  422  321.6  214.4  750  500
12. I_{40\%}S_{60\%}C  190  422  321.6  214.4  500  750
13. I_{60\%}SC  190  422  214.4  321.6  1250  -
14. I_{60\%}S_{20\%}C  190  422  214.4  321.6  1000  250
15. I_{60\%}S_{40\%}C  190  422  214.4  321.6  750  500
16. I_{60\%}S_{60\%}C  190  422  214.4  321.6  500  750

2.3 Test method

2.3.1 Concrete Strength
According to the Standard for Test Method of Mechanical Properties of Ordinary Concrete (GB/T50081—2002), mixing, forming, curing and testing of concrete were carried out, and the strength was evaluated according to the Standard for Test and Evaluating the Strength of Concrete (GB/T50107—2010).

2.3.2 Cracking resistance at early ages
The plate method introduced in Guidelines for Durability Design and Construction of Concrete Structures (CCES01-2004) was used to carry out the early crack resistance test of concrete. The test device was shown in Figure 2. In this test, six groups with relatively good strength were selected. In order to make the concrete crack earlier, an iodine tungsten lamp was used to irradiate the device and the electric fan was used to simulate the natural service environment of concrete. During the test, the wind speed and temperature on the concrete surface were recorded by an anemometer and a thermometer. The test environment was shown in Figure 3.

Figure 2. Device for early crack resistance test
Figure 3. Experiment environment
The experiment lasted 24 hours. The total number of cracks and fracture initiation time were recorded during the experiment. The maximum width of cracks was measured by a crack width gauge, and the total length of cracks was measured by a ruler.

2.3.3 Medium and Long Term Volume Deformation Properties

The six groups concrete with mid-long term deformation monitoring of iron tailing-steel slag aggregate concrete and good strength test results was carried out by the contact method described in "Standard test method for mid-long term performance and durability of ordinary concrete". The test method was as follows, and the shrinkage specimens were shown in Figure 3:

(1) Preparing iron tailing-steel slag concrete and ordinary concrete which is regarded as control group, and putting the mixed concrete into the mold respectively.

(2) After the mixture was loaded into the die, the copper head was arranged in the specimen, 250mm apart, and the distance between each end and the edge was equal. The schematic diagram of the specimen was shown in Figure 4.

(3) Placing the molded blocks in a normal environment for 24 hours, then removing, and maintaining them in the curing box.

(4) Measuring the initial length. Measuring the standard length of the supporting rod before each measurement and recording the data.

(5) Measuring data every two days, totally 60 days and 30 times.

(6) Compiling data and analyzing test results.

Figure 4. Layout diagram of pre-buried probes

In this test, the YB-25 hand-held strain gauge was adopted. The base distance was 250mm. The displacement measurement range was ±5mm. The minimum scale value of the instrument was 40με. The linear expansion coefficient of the standard gauge in the instrument was almost zero, and the specific size was 1.5×10⁻⁶/℃.

3. Test results and analysis

3.1. Strength of iron tailing-steel slag aggregate cement concrete

The 7d and 28d compressive strengths of the iron tailings-steel slag cement concrete with various contents are shown in Table 7:

Table. 7 7d/28d Compressive strength of concrete

| Symbol | Maintenance time | N-1 (MPa) | N-2 (MPa) | N-3 (MPa) | Average emphasis (MPa) | Reduction Strength (MPa) |
|--------|-----------------|-----------|-----------|-----------|------------------------|-------------------------|
| 1.OC   | 7d              | 46.0      | 48.6      | 46.8      | 46.80                  | 44.46                   |
|        | 28d             | 65.8      | 64.2      | 62.8      | 62.38                  |                         |
| 2.10%S₂₀%C | 7d          | 46.8      | 52.4      | 48.5      | 49.23                  | 46.77                   |
|        | 28d             | 66.4      | 68.6      | 71.0      | 68.67                  | 65.23                   |
| 3.10%S₄₀%C | 7d          | 46.4      | 46.0      | 45.8      | 46.07                  | 43.76                   |
|        | 28d             | 62.8      | 64.2      | 61.4      | 62.80                  | 59.66                   |
What can be seen from the table is that iron tailings acting as fine aggregates are not conducive to concrete strength, especially when the iron tailings replace sands with a large amount (60%) as fine aggregates of concrete. The strength of iron tailing-steel slag aggregate concrete deteriorates more obviously than that of ordinary cement concrete with the same mix ratio. The strength of cement concrete increases first and then decreases with the increase of steel slags (acting as coarse aggregates),

| Group | 28d | 7d |
|-------|-----|----|
| 4.10%S60%C | 7d | 48.0 | 47.6 | 48.0 | 47.87 | 45.47 |
| 5.10%S | 28d | 64.6 | 65.2 | 57.2 | 62.33 | 59.22 |
| 5.10%SC | 7d | 43.6 | 45.1 | 44.6 | 44.43 | 42.21 |
| 6.10%S20%C | 28d | 58.4 | 63.2 | 62.4 | 61.33 | 58.27 |
| 7.10%S40%C | 7d | 45.1 | 50.0 | 44.0 | 44.70 | 42.47 |
| 8.10%S60%C | 28d | 58.6 | 61.0 | 57.6 | 59.07 | 56.11 |
| 9.10%SC | 7d | 46.9 | 46.2 | 46.6 | 46.57 | 44.24 |
| 10.10%S20%C | 28d | 66.2 | 61.6 | 63.8 | 63.87 | 60.67 |
| 11.10%S40%C | 7d | 44.8 | 44.3 | 45.6 | 44.90 | 42.66 |
| 12.10%S60%C | 28d | 58.2 | 61.8 | 60.0 | 60.00 | 57.00 |
| 13.10%SC | 7d | 42.6 | 44.0 | 42.6 | 43.07 | 40.91 |
| 14.10%S20%C | 28d | 60.8 | 63.6 | 61.4 | 61.93 | 58.84 |
| 15.10%S40%C | 7d | 45.0 | 44.6 | 45.4 | 45.00 | 42.75 |
| 16.10%S60%C | 28d | 62.4 | 61.2 | 60.2 | 61.27 | 58.20 |
| 17.10%SC | 7d | 56.2 | 54.0 | 53.8 | 54.67 | 51.93 |
| 18.10%S20%C | 28d | 38.8 | 39.0 | 42.6 | 40.13 | 38.13 |
| 19.10%S40%C | 7d | 57.6 | 53.0 | 55.0 | 55.20 | 52.44 |
| 20.10%SC | 28d | 46.8 | 47.8 | 45.6 | 46.73 | 44.40 |
| 21.10%S20%C | 7d | 61.2 | 60.0 | 55.2 | 58.80 | 55.86 |
| 22.10%S40%C | 28d | 48.6 | 48.4 | 47.8 | 48.27 | 45.85 |
| 23.10%SC | 7d | 60.8 | 62.4 | 61.6 | 61.60 | 58.52 |
| 24.10%S20%C | 28d | 46.4 | 44.0 | 47.0 | 45.80 | 43.51 |
| 25.10%S40%C | 7d | 55.8 | 58.0 | 61.0 | 58.27 | 55.35 |
| 26.10%SC | 28d | 45.6 | 45.4 | 47.2 | 46.07 | 43.76 |
| 27.10%S20%C | 7d | 57.0 | 51.2 | 57.8 | 55.33 | 52.57 |

![Graph showing 7/28d Compressive strength of concrete](image)

Figure 5 7/28d Compressive strength of concrete
so steel slags are suitable to replace concrete coarse aggregates with smaller content to improve the mechanical properties of concrete.

3.2 Early crack resistance of iron tailings-steel slag aggregate cement concrete

This experiment mainly studies the effect of iron tailings and steel slags on early crack resistance of concrete with different substitution proportions. According to the results of compressive strength test, six test groups with less strength change are selected. The test data are compiled and summarized and are shown in Table 8:

| Test group | OC | I0%S20% | I20%S40% | I20%S60% | I40%S20% | I60%S20% |
|------------|----|---------|---------|---------|---------|---------|
| Initial cracking time (h:min) | A | B | C | D | E | F |
| - | 5:45 | 5:15 | 3:50 | 9:30 | - |
| Number of cracks | - | 3 | 5 | 17 | 1 | 0 |
| Maximum crack width (mm) | - | 0.3 | 0.33 | 0.42 | 0.1 | - |
| Maximum crack length (mm) | - | 31.2 | 44.0 | 89.5 | 8.4 | - |

Note: In the test environment, the wind speed is 2.6m/s, the temperature is 45°C, and the humidity is 35%.

It can be seen from the table that the more steel slags are added, the more disadvantageous the early crack resistance of iron tailing-steel slag aggregate concrete is. On the contrary, iron tailings can improve the early crack performance of iron tailing-steel slag aggregate concrete.

3.3 Iron tailing-steel slag aggregate concrete volume deformation

The volume deformation results of six test groups at different ages are shown in Figure 6:

![Figure 6: Concrete volume shrinkage rate](image)

As can be seen from the figure above, the volume stability of iron tailing-steel slag aggregate concrete is significantly better than that of ordinary cement concrete with the same mix ratio. In addition, from the test results of B, E and F groups, it can be concluded that when iron tailings replace some fine aggregates of concrete, the shrinkage of concrete decreases gradually with the increase of replacement rate of iron tailings; from the test results of C and D groups, it can be concluded that when steel slags replaces part of coarse aggregates, the larger the proportion of steel slag is, the smaller the shrinkage value of concrete volume.
4. Conclusion
In this paper, iron tailings are used to replace river sands as concrete fine aggregates, and steel slags are used to replace gravel as concrete coarse aggregates to prepare iron tailing-steel slag aggregate concrete. The strength, early crack resistance and mid-long term volume deformation of concrete are tested and studied.
(1) The use of iron tailings as fine aggregate is not conducive to the strength of concrete, especially when iron tailings replace sands as fine aggregates with a large amount (60%) of iron tailings, the strength of concrete deteriorates more obviously than that of cement concrete with the same mix ratio.
(2) The strength of cement concrete increases first and then decreases with the increase of steel slags content. Therefore, steel slags are suitable to replace concrete coarse aggregates with smaller content in order to improve the mechanical properties of concrete.
(3) The more steel slags were added, the worse the early cracking resistance of iron tailing-steel slag aggregate concrete is. On the contrary, iron tailings can improve the early crack performance of iron tailing-steel slag aggregate concrete.
(4) Replacing part of concrete coarse aggregates with steel slags will reduce the shrinkage rate of concrete. The larger proportion of steel slags is, the smaller volume shrinkage value of concrete is. When iron tailings replace part of concrete fine aggregates, the shrinkage rate of concrete decreases gradually with the increase of replacement rate of iron tailings.
(5) Considering comprehensively the strength enhancement effect of steel slags as coarse aggregates and the strength deterioration effect of iron tailings as fine aggregates, it should be considered that iron tailing-steel slag aggregate concrete should be prepared with small amount of steel slags and small amount of iron tailings instead of coarse and fine aggregates of concrete respectively.

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