Effects of unit cement content and aggregate maximum particle size on compressive strength of cemented sand and gravel materials

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Abstract. Cement Sand and Gravel (CSG) is a new type of construction material between RCC and ordinary concrete. At present, there are few research theories on cemented sand and gravel in China. Therefore, this paper analyses the influence of unit cement content and aggregate maximum particle size on the compressive strength of cemented sand and gravel through experimental research. The test results show that the compressive strength has increased with the increase of unit cement content; the compressive strength of the material has a decreasing trend as the maximum particle size of the aggregate increases from 20mm to 80mm. The analysis of the test results shows that when the maximum particle size of the aggregate is 40mm and the unit cement content is above 80kg / m³, the compressive strength of the material can be guaranteed and the material can be used reasonably.

1. Introduction
In recent years, cemented gravel materials have received great attention worldwide. Permanent cemented gravel dam structures have appeared abroad, such as the Tyubetsu dam cofferdam and Kubusugawa dam built in 1994 and 1999 in Japan. Cofferdam works and Nagashima dam sand retaining dams, and countries such as Turkey, Greece, and France have successively appeared cemented sand and gravel dams. The first permanent CSG dam in China, the Shoukoubao Dam, started construction in Shanxi in 2014. The actual application of CSG cemented gravel dams in China is still very small. The main reason is that CSG materials do not have uniform standards at home and abroad. The theoretical basis cannot meet the practical application of the project and limit the development of cemented gravel. In this experiment, by analyzing the unit cement content of CSG material and the maximum particle size of aggregate, the compressive tensile strength and impermeability of CSG material were analyzed, and the strength of CSG material in unit cement content, the maximum particle size of aggregate and the test Change when the maintenance age of the piece changes.

2. Test materials and methods
2.1. Test materials
The cementing material of CSG cementing material is cement, and cement is very important in the material. The cement used in this experimental study is ordinary Portland cement of type 42.5 with a density of 3.08g / cm³. The chemical mineral composition is shown in table 1 below, and its physical properties are shown in table 2 below.
Table 1. Chemical mineral composition of cement materials

| Composition | SiO₂ | Al₂O₃ | CaO | Fe₂O₃ | MgO | SO₃ |
|-------------|------|-------|-----|-------|-----|-----|
| Proportion  | 21~22.5 | 4.0~6.05 | 63~66.0 | 2.5~3.5 | 0.9~3.3 | 1.0~2.0 |

Table 2. Physical properties of cement materials

|                      | Density g / cm³ | Setting time | Stability | Tensile strength (Mpa) | Compressive strength (Mpa) |
|----------------------|-----------------|--------------|-----------|------------------------|----------------------------|
|                      | Initial setting | Final setting |           |                        |                            |
|                      | 3.08            | 2.2          | 4.5       | qualified              | 8.8                        |
|                      | 28day           | 28day        |           |                        |                            |
|                      |                 |              |           |                        |                            |

The aggregate of CSG cement material is mainly taken from the riverbed pebbles near the site and the abandoned gravel at the site. The maximum particle size of this experiment is 80mm. It is used as coarse aggregate of CSG material. The fine aggregate used in the test is also made of natural sand and gravel in the river basin near the site. Similarly, the maximum particle size is less than 80mm. The coarse and fine aggregates are mixed with the cement material to form a CSG material. The physical properties of the coarse and fine aggregates near the river bed are shown in table 3 below.

Table 3. Physical properties of coarse and fine aggregates

| Riverbed aggregate particle size | Uneven coefficient (Cu) | Curvature coefficient (Cc) | U.S.C.S | Mud content (%) | Sand content (%) |
|---------------------------------|-------------------------|---------------------------|---------|-----------------|-----------------|
| d≤20mm                          | 22.1                    | 0.42                      | GW      | 1.5             | 34.1            |
| d≤80mm                          | 22.4                    | 0.49                      | GP      | 1.3             | 30.7            |

The mix ratio of cemented sand and gravel in this test is designed according to the design experience of the RCC test mix ratio. Under the condition of ensuring the test sand rate is equal, the unit cement content of the test, the maximum aggregate particle size and the curing age are changed. Perform an orthogonal test. The maintenance age is divided into three times differences of 7d, 28d and 91d, and then compared. The test sieves the material with a maximum particle size of 80mm, and then uses the similar gradation method to calculate the 40mm and 20mm gradation curves, and finally the similar gradation forms three categories. In this experiment, the indoor compaction test was carried out according to the "Code for Geotechnical Engineering Investigation" (GB50021-2001) to obtain the maximum dry density and maximum moisture content of the material, thereby determining the amount of material and moisture used in the test. The screening results of this experiment are shown in Table 4; the test maximum dry density and the optimal water content are shown in table 5.

Table 4. Screening test results of aggregate

| Aggregate particle size (mm) | <2.5 | 2.5~10 | 10~20 | 20~40 | 40~60 | 60~80 |
|------------------------------|------|--------|-------|-------|-------|-------|
| Accumulated sieve residue (%)| 41.7 | 22.3   | 10.3  | 14.10 | 6.50  | 5.10  |

Table 5 Maximum dry density and optimal moisture content of materials

| Maximum particle size of aggregate (mm) | Unit cement content (kg / m³) | Maximum dry density (g / cm³) | The best moisture content (%) |
|-----------------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 20                                      | 40                            | 2.11                          | 6.15                          |
| 60                                      | 2.12                          | 7.65                          |
| 80                                      | 2.12                          | 7.05                          |
| 100                                     | 2.12                          | 7.10                          |
| 40                                      | 40                            | 2.10                          | 7.95                          |
| 60                                      | 2.10                          | 7.15                          |
| 80                                      | 2.11                          | 7.80                          |
| 100                                     | 2.10                          | 7.90                          |
2.2. Experiment method
This study refers to the "Code for Hydraulic Concrete Experiment" (SL352-2006) and "Code for Highway Geotechnical Experiment" (JTG E40-2007). The maximum dry density and optimal moisture content of the test piece are measured by the compaction test, and then the saturation and porosity of the CSG material test piece are calculated, thereby determining the amount of material required for the test piece during the test. The mix ratio design of CSG material specimens is shown in Table 1-5 above. Each mix ratio design is divided into 4 compression and 4 tensile. In the experiment, after the raw materials were stirred and mixed by a mixer, the materials were loaded into carbon steel molds three times, and each layer was compacted according to the specifications. After one day of compaction, the molds were demolded. (20 ± 2) °C, humidity is (95 ± 1) %, sprinkle water for maintenance every day. The maintenance age is divided into 7d, 28d and 91d. The uniaxial compressive and split-pull test uses a computer control system electronic universal testing machine with a maximum axial pressure of 30 kN for testing.

3. Test results

3.1. Relationship between compressive strength of CSG material and maximum aggregate particle size
The test uses a similar gradation method to set the maximum particle size of the material to 20mm, 40mm and 80mm three groups of categories for testing. The test data is organized as shown in figure 1.

![Figure 1](image)

Figure 1. The relationship between maximum particle size of aggregate and compressive strength

It can be seen from the data analysis in the above figure 1 that under certain conditions of unit cement content and curing age, the compressive strength of the material shows a downward trend as the maximum particle size of the material increases, and the downward trend is more obvious. When the curing age is 7d and the unit cement content is 40 kg/m³, 60 kg/m³, 80 kg/m³ and kg/m³, the maximum particle size of aggregate is 40mm. The compressive strength of the material is the maximum particle size of aggregate 72%, 115%, 119% and 73% of the compressive strength of the 20mm material; the compressive strength of the material with a maximum aggregate size of 80mm is 113%, 150%, 150%, 108% and 51%; when the curing age is 28d, and the unit cement content is 40 kg/m³, 60 kg/m³, 80 kg/m³, the maximum particle size of the aggregate is 40mm. The compressive strength of the material is the
The largest aggregate 104%, 95%, 104% and 70% of the compressive strength of the material with a diameter of 20mm; the compressive strength of the material with a maximum aggregate size of 80mm is 95%, 73% of the compressive strength of the material with a maximum aggregate size of 20mm %, 107% and 53%; under the condition of curing age of 91d, when the unit cement content is 40 kg/m³, 60 kg/m³, 80 kg/m³, the maximum particle size of the aggregate is 40mm. The compressive strength of the material is aggregate The maximum particle size is 88%, 89%, 75% and 90% of the compressive strength of the 20mm material; the compressive strength of the material with the maximum aggregate size of 80mm is the material with the maximum aggregate size of 20mm 113%, 93%, 88% and 90% of the compressive strength.

The above data analysis shows that as the particle size increases, the compressive strength of the material shows a downward trend. When the unit cement content exceeds 80 kg/m³, the maximum particle size of the aggregate has a more obvious effect on the strength of the CSG material. When the unit cement content is less than 80 kg/m³, the cementitious material and aggregate can be fully contacted, and the cement and aggregate can work well together, and the material exhibits good ductility; when the unit cement content exceeds 80% At this time, the cement content increases, the temperature difference effect is large, shrinkage cracks are easy to occur, the bonding effect between the aggregate and the cementitious material cannot be optimized, brittle properties are prone to appear, and the strength is reduced. The size of the maximum particle size of the aggregate will affect the degree of bonding of the cementitious material and the aggregate, which will affect the strength of the CSG material. This property is similar to concrete.

Figure 2 is the relationship between the unit cement content measured by the test and the compressive strength of the CSG material. When the maximum particle size of the aggregate is 20mm, 40mm and 80mm respectively, when the curing age of the test piece is 7 Day, the unit cement content The compressive strength of the 60 kg/m³ test piece is increased by 24%, 102% and 65% respectively compared with the unit cement content of 40kg / m³ test piece; the unit cement content is 80 kg/m³ test piece is compared with the unit cement content of 40 kg/m³ test The compressive strength of the test piece is increased by 48%, 268% and 141% respectively; the compressive strength of the test piece with a unit cement content of 100 kg/m³ is increased by 301%, 308% and 79% compared with the test piece with a unit cement content of 40 kg/m³ ; When the maximum particle size of aggregate is 20mm, 40mm and 80mm respectively, when the curing age of the test piece is 28Day, the unit cement content is 60kg / m³ specimen than the unit cement content is 40 kg/m³ compression The strength is increased by 50%, 38% and 16% respectively; the compressive strength of the specimen with a unit cement content of 80
kg/m³ is increased by 76%, 76% and 99% compared with the specimen with a unit cement content of 40kg/m³; the unit cement content The compressive strength of the 100 kg/m³ specimen increased by 291%, 163%, and 118 compared with the unit cement content of 40 kg/m³ specimen, respectively; When the maximum particle size of aggregate is 20mm, 40mm and 80mm respectively, when the curing age of the test piece is 91 Day, the unit cement content is 60 kg/m³ test piece than the unit cement content is 40 kg/m³ test piece The compressive strength was increased by 26%, 83% and 4% respectively; the compressive strength of the specimen with a unit cement content of 80 kg/m³ was increased by 90%, 161% and 48% compared with the specimen with a unit cement content of 40 kg/m³; unit cement The compressive strength of the test piece with a content of 100 kg/m³ increased by 305%, 250% and 222% compared with the test piece with a unit cement content of 40 kg/m³.

The experimental data shows that with the increase of the unit cement content, the compressive strength of the CSG material has been significantly improved. The presence of cement increases the bonding force inside the material and increases the bonding between the aggregates, so it is regarded as unit cement within a certain range as the content increases, the compressive strength of the CSG material is greatly improved. This characteristic is the same as that of ordinary concrete.

4. Conclusions
(1) The compressive strength of the CSG cement material is affected by the amount of cement content and the size of the maximum particle size of the aggregate. The degree of influence per unit cement content is greater than that of the maximum particle size of the aggregate. At the same time, the compressive strength characteristics of cemented sand and gravel are similar to those of ordinary concrete.

(2) Insufficient unit cement content and larger aggregate maximum particle size will reduce the compressive strength of CSG cement material, in order to ensure the quality of cement material and reduce the economic cost of the project. This study recommends the use of CSG cement with an aggregate particle size of 40 mm and a minimum cement content of 80 kg/m³.

(3) The test data of this study are obtained from actual tests. The design of the mix ratio and calculation parameters of the CSG material proposed in the test can provide a reference for the CSG project. This experiment is devoted to the theoretical research of CSG materials and promotes the actual engineering progress. In the future, we will continue to study the durability and impermeability of CSG materials.

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