Raw materials selection method based on the durability of the concrete for bridge

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Abstract. To enhance the durability of the cement concrete of the bridge, C40 and C50 concretes with different raw materials have been made. A method of optimal selection method for raw materials has been put forward. For different raw materials from different plant, based on the orthogonal experimental design, certain raw materials groups are gained. By the same C40 and C50 concrete mix proportion but different raw materials groups, the specimens have been made for testing the performance of the compressive strength, carbonization and anti-chloride penetration. By range analysis, the best raw material group of the concrete with higher compressive strength, lower chloride penetration coefficient and lower carbonization depth has been selected.

1. Introduction

During the construction, the construction organization often compare the same kind of raw materials among different plants and then select the raw materials with the best performance. Generally speaking, the price of the materials with the higher performance is higher than the normal ones. So selecting all of the best raw material may be not a method with high performance cost ratio[1].

Some papers have studied how to improve the durability of the concretes. Benjamin mixed the saturation light aggregate to reduce the shrinkage [2]. Lei.Y mixed nano-silicon slurry into concrete for enhancing the anti-permeability durability of the concrete [3]. She put forward a method of mix proportion concrete for bridge deck by the means of fiber optimization, paste optimization, sand coarse aggregate ratio adjusting[4]. Chengjing X. developed a kind of concrete coating with good anti-permeability performance and ageing-resistant performance to enhance the life of the concrete structure[5]. Yan Z. invent a kind of silicone emulsion with main raw materials of fluorocarbon resin, AMP silicane and deionized water[6].

By the former research, the scholars pay more attention on mixing good performance additional materials into concrete, developing new anti-corrosion coating materials, or adjusting proper mix proportion to enhance the durability of the concrete. There is few paper study on the relationship between the compound mode of the raw materials and the durability. This paper show you a kind of method for optimizing raw materials for durability of the concrete.
2. Experiments

2.1. Raw materials

Two kinds of cement, two kinds of Grade I fly ash, two kinds of Grade II fly ash, two kinds of sand and two kinds of coarse aggregate from different plant are used. The pastes properties are shown in table 1 and table 2. The water is tap one. The water reducer is the same. The solid content of the water reducer is 18.2% and the rate of reducing water is 30%.

| ID | Setting time (h:min) | Fineness (%) | Specific area | Compressive strength (MPa) | Bending strength (MPa) | Water requirement of normal consistency (%) | Stability |
|----|----------------------|--------------|---------------|---------------------------|------------------------|---------------------------------------------|-----------|
|    | Initial              | Final        |              | 3d                        | 28                     | 3d                                          | 28d       |
| C1 | 3:05                 | 5:00         | 2.32         | 348                       | 19.8                   | 44.5                                       | 4.4       | 7.1       | 28.4          | qualified   |
| C2 | 3:10                 | 5:15         | 1.25         | 345                       | 26.0                   | 47.7                                       | 5.1       | 8.1       | 30.1          | qualified   |

| ID  | Water needed ratio (%) | Water content (%) | Ignition loss | Stability | Fineness (%) |
|-----|------------------------|-------------------|--------------|-----------|--------------|
| FI-1| 93                     | 0.2               | 4.3          | qualified | 10.2         |
| FI-2| 92                     | 0.3               | 4.0          | qualified | 9.0          |
| FII-1|102                    | 0.3               | 6.4          | qualified | 18.5         |
| FII-2|101                    | 0.4               | 6.1          | qualified | 10.2         |

2.2. Mix proportion

The concrete compressive strength grades are different among different part of the bridge. C30, C40, C50 concrete are separately used on the pile foundation, the pier stud and the beam. The durability of the different parts are also different. The C40 and C50 concrete are studied in this paper. The fly ash of grade II is used in C40 concrete and the fly ash of grade I is used in C50 concrete. 5-31.5mm coarse aggregates are used in C40 concrete. 5-20mm coarse aggregates are used in C50 concrete. The mix proportions are shown in table 3.

| ID  | C | W  | S  | A  | F  | WR |
|-----|---|----|----|----|----|----|
| C40 | 352 | 150 | 705 | 1100 | 88 | 3.8 |
| C50 | 408 | 160 | 642 | 1191 | 72 | 3.85 |

2.3. Method of test

2.3.1 Orthogonal experimental design. Serial number of the cement, fly ash, sand, coarse aggregate are separately A, B, C and D. Every factor has two level 1 and 2. The factors and levels are listed in table 4.

| Factor       | Serial number | Level  |
|--------------|---------------|--------|
| Cement       | A             | A1, A2 |
| Fly ash      | B             | B1, B2 |
| Sand         | C             | C1, C2 |
| Coarse aggregate | D           | D1, D2 |
Table 5. The raw material groups.

| GROUP ID | A    | B    | C    | D    |
|----------|------|------|------|------|
| 1        | A1   | B1   | C2   | D2   |
| 2        | A2   | B1   | C2   | D2   |
| 3        | A1   | B2   | C1   | D1   |
| 4        | A2   | B2   | C1   | D1   |
| 5        | A1   | B1   | C1   | D2   |
| 6        | A2   | B2   | C2   | D2   |
| 7        | A1   | B2   | C2   | D1   |
| 8        | A2   | B1   | C1   | D1   |

2.3.2 Test method. The chloride penetration performance is test according to NT Build 492 “Chloride Migration Coefficient from Non-steady-state Migration Experiments”. The carbonization performance is test by the China standard GB/T 50082-2009 “Standard for test methods of long-term performance and durability of ordinary concrete”. The compressive strength is test by the standard of ASTM C39/C39M “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”.

3. Test result analysis

3.1. Raw materials optimization for C40 concrete

Based on the compound mode of raw materials in Table 5 and the mix proportion of C40 concrete, the C40 concrete specimens for testing the 28d compressive strength, diffusion coefficient of chloride ion and the carbonation depth have been made. The test result shows in Table 6.

Table 6 C40 concrete testing results

| GROUP ID | 28 d Compressive strength / MPa | 28d diffusion coefficient of chloride ion / (×10^{-12}m^2/s) | 28d carbonation depth / mm |
|----------|--------------------------------|-----------------------------------------------------------|----------------------------|
| 1        | 50.3                           | 4.52                                                      | 4.3                        |
| 2        | 52.3                           | 4.4                                                       | 4.4                        |
| 3        | 51.1                           | 4.33                                                      | 4.4                        |
| 4        | 55.1                           | 4.12                                                      | 3.7                        |
| 5        | 52.3                           | 4.44                                                      | 4.3                        |
| 6        | 52.1                           | 4.22                                                      | 4.1                        |
| 7        | 54.2                           | 4.3                                                       | 3.9                        |
| 8        | 53.3                           | 4.5                                                       | 3.8                        |

From Table 6, for the same mix proportion of the concrete and different raw materials combination, the compressive strength, diffusion coefficient of chloride ion and the carbonation depth are all different. This phenomenon indicate that the raw materials combination will aspect the durability of the concrete. Range analysis have been done to the data in the table 6. The results shows in the Table 7.

Table 7 Range analysis of the C40 concrete test result

| K1    | 207.9 | 208.2 | 211.8 | 213.7 |
|-------|-------|-------|-------|-------|
| K2    | 212.8 | 212.5 | 208.9 | 207   |
| K1'   | 51.975| 52.05 | 52.95 | 53.425|
| K2'   | 53.2  | 53.125| 52.225| 51.75 |
| Optimal level | A2 | B2 | C1 | D1 |
| R_j   | 1.225 | 1.075 | 0.725 | 1.675 |
| Order | D>A>B>C |
| K1  | 17.59 | 17.86 | 17.39 | 17.25 |
|-----|-------|-------|-------|-------|
| K2  | 17.24 | 16.97 | 17.44 | 17.58 |
| K1' | 4.3975| 4.465 | 4.3475| 4.3125|
| K2' | 4.31  | 4.2425| 4.36  | 4.395 |

Optimal level: A2 B2 C1 D1

Rj: 0.0875 0.2225 0.0125 0.0825

Order: B>A>D>C

Range analysis of carbonization depth

| K1  | 16.9  | 16.4  | 16.2  | 15.8 |
|-----|-------|-------|-------|------|
| K2  | 15.6  | 16.1  | 16.3  | 16.7 |
| K1' | 4.225 | 4.1   | 4.05  | 3.95 |
| K2' | 3.9   | 4.025 | 4.075 | 4.175|

Optimal level: A2 B2 C1 D1

Rj: 0.325 0.075 0.025 0.225

Order: A>D>B>C

From the line of optimal level, based on the indexes of the compressive strength, diffusion coefficient of chloride iron and carbonization depth, the raw materials group of the C40 concrete is A2B2C1D1.

From the order line, by the important degree of the influence factor to the compressive strength, the raw materials can be line up with coarse aggregate, cement, fly ash and the sand. For the diffusion coefficient of chloride iron, the order is fly ash, cement, coarse aggregate and sand. For the carbonization depth, the order is cement, coarse aggregate, fly ash and sand.

3.2. Raw materials optimization for C50 concrete

Based on the compound mode of raw materials in Table 5 and the mix proportion of C40 concrete, the C50 concrete specimens for testing the 28d compressive strength, diffusion coefficient of chloride ion and the carbonation depth have been made. The test result shows in Table 8.

Table 8 C50 concretes testing results

| GROUP ID | 28 d Compressive strength / MPa | 28d diffusion coefficient of chloride ion / (×10⁻¹²m²/s) | 28d carbonation depth / mm |
|----------|---------------------------------|--------------------------------------------------------|----------------------------|
| 1        | 65.1                            | 3.75                                                   | 3.4                        |
| 2        | 62.3                            | 3.71                                                   | 3.7                        |
| 3        | 62.1                            | 3.82                                                   | 3.7                        |
| 4        | 60.3                            | 4.1                                                    | 4                          |
| 5        | 65.1                            | 3.84                                                   | 3.6                        |
| 6        | 62.3                            | 4.12                                                   | 3.9                        |
| 7        | 62.3                            | 4                                                      | 3.7                        |
| 8        | 60.2                            | 3.85                                                   | 3.9                        |

From Table 8, as same as the C40 concrete, for the same mix proportion of the concrete and different raw materials combination, the compressive strength, diffusion coefficient of chloride ion and the carbonation depth are all different. This phenomenon indicate that the raw materials combination will also aspect the durability of the C50 concrete.

Comparing Table 6 and Table 8, taking the raw materials group 1 for example, the diffusion coefficient of chloride iron of C40 concrete is $4.52\times10^{-12}m^2/s$ while the date is $3.75\times10^{-12}m^2/s$ for C50 concrete. The same rule happens at group 2 to group 8. While, for the same cement concrete grade but different raw material group, the durability difference is not so much clearly. So, during the field construction, improve the strength grade of the concrete is much more effective than changing the raw materials group.

Range analysis have been done to the data in the table 8. The results show in the Table 9.
Table 9 Range analysis of the C40 concrete test result

|                  | Range analysis of compressive strength data |                  |                  |                  |
|------------------|--------------------------------------------|------------------|------------------|------------------|
|                  | K1  | 254.6 | 252.7 | 247.7 | 244.9 |
|                  | K2  | 245.1 | 247   | 252   | 254.8 |
|                  | K1' | 63.65 | 63.175| 61.925| 61.225|
|                  | K2' | 61.275| 61.75 | 63    | 63.7  |
| Optimal level    | A1  | B1    | C2    | D2    |
| Rj               | 2.375| 1.425 | 1.075 | 2.475 |
| Order            | D>A>B>C |

Range analysis of diffusion coefficient of chloride iron

|                  | Range analysis of diffusion coefficient of chloride iron |                  |                  |                  |
|------------------|----------------------------------------------------------|------------------|------------------|------------------|
|                  | K1  | 15.41 | 15.15 | 15.61 | 15.77 |
|                  | K2  | 15.78 | 16.04 | 15.58 | 15.42 |
|                  | K1' | 3.8525| 3.7875| 3.9025| 3.9425|
|                  | K2' | 3.945 | 4.01 | 3.895 | 3.855 |
| Optimal level    | A1  | B1    | C2    | D2    |
| Rj               | 0.0925| 0.2225| 0.0075| 0.0875|
| Order            | B>A>D>C |

Range analysis of carbonization depth

|                  | Range analysis of carbonization depth |                  |                  |                  |
|------------------|---------------------------------------|------------------|------------------|------------------|
|                  | K1  | 14.4 | 14.6 | 15.2 | 15.3 |
|                  | K2  | 15.5 | 15.3 | 14.7 | 14.6 |
|                  | K1' | 3.6  | 3.65 | 3.8  | 3.825|
|                  | K2' | 3.875| 3.825| 3.675| 3.65 |
| Optimal level    | A1  | B1   | C2    | D2    |
| Rj               | 0.275| 0.175| 0.125 | 0.175 |
| Order            | A>D>B>C |

From the line of optimal level in Table 9, based on the indexes of the compressive strength, diffusion coefficient of chloride iron and carbonization depth, the raw materials group of the C50 concrete is A1B1C2D2.

From the order line in Table 9, by the important degree of the influence factor to the compressive strength of C50 concrete, the raw materials can be line up with coarse aggregate, cement, fly ash and the sand. For the diffusion coefficient of chloride iron, the order is fly ash, cement, coarse aggregate and sand. For the carbonization depth, the order is cement, coarse aggregate, fly ash and sand.

### 3.3. Optimization results analysis of raw materials

Put the optimization results of raw materials for C40 and C50 concrete into Table 10.

| Grade | cement | fly ash | sand | stone |
|-------|--------|---------|------|-------|
| C40   | 2      | 2       | 1    | 1     |
| C50   | 1      | 1       | 2    | 2     |

From Table 10, for different grade concrete, raw materials are different to obtain the best durability. So, in the construction field, it is not nessecary to select the best raw materials to produce concrete. Considering the ratio of performance and cost, the best durability concrete can be produced by selecting considerable raw materials but not the best ones.

### 3.4. The steps of raw materials optimizing based on durability of concrete

For convenient of field construction, the method of raw materials optimizing based on the durability of the bridge can be conclude into three steps. First of all, selecting raw materials from different plants, based on the Orthogonal Test Design, the different raw materials groups can be obtained. The second step, according to the different raw materials groups, concrete specimens are made for testing the
compressive strength, carbonization depth and chlorine ion permeability index. The third step, by the method of aberration analysis, based on the principles of high strength compressive strength, low chlorine ion permeability performance and low carbonization depth, the best raw materials group to the durability of the concrete can be obtained.

4. Conclusion

Raw materials from different plants have been selected. Orthogonal Test Design was used to obtain different raw materials groups. The compressive strength, carbonization depth and chlorine ion permeability performance were tested. By aberration analysis, the raw materials of concrete with good compressive strength and best durability have been obtained. The detail conclusion is shown as follows.

(1) A new method has been put forward for selecting raw materials to obtain the concrete with the best durability performance. The method is based on the orthogonal test design to obtain different raw materials groups. The durability parameters of the concretes mixing by former different raw materials groups are tested respectively. By aberration analysis, the best raw material group can be obtained.

(2) For the concretes with the same mix proportion but different raw materials group, the compressive strength, carbonization depth and chlorine ion permeability are all different. In order to obtain the best durability of the concrete with different compressive strength grade, adjusting the place of production of the raw materials and combination group is a good method.

(3) During construction, for different grade concrete, different raw materials such as cement, sand and stone can be sampled from different plants and then grouping them into different combination. The durability parameters of the concretes are tested and then the best raw materials group can be obtained.

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