Optimization of Mechanical Properties of Recycled Aggregate Concrete Based on Queuing Scoring Method

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Abstract. In order to study the optimal combination of mechanical properties of recycled aggregate concrete under the condition of multiple indexes, the orthogonal test results of recycled concrete were analyzed by queuing score method, taking the replacement rate of recycled aggregate, replacement rate of fly ash and incorporation rate of steel fiber as factors, and the compressive strength, splitting tensile strength, flexural strength, tension-compression ratio and flexural-compression ratio as indicators. The results show that the incorporation rate of steel fiber has the greatest influence on the mechanical properties of recycled aggregate concrete, followed by the replacement rate of fly ash, and finally the replacement rate of recycled aggregate. The optimum combination of recycled aggregate concrete is A4B2C4, that is, the replacement rate of recycled aggregate is 100%, the replacement rate of fly ash is 10%, and the incorporation rate of steel fiber is 1.8%. Queuing score method can accurately determine the influence of factors on recycled aggregate concrete and optimal combination in orthogonal tests.

1. Introduction
In recent years, some scholars have carried out orthogonal experimental research on recycled aggregate concrete (RAC). Jin Baohong et al. [1] take the replacement rate of recycled aggregate (RA), the replacement rate of fly ash (FA) and the incorporation rate of steel fiber (SF) as factors, take the slump, compressive strength and splitting tensile strength as indexes, and carry out orthogonal test research through range analysis and point diagram analysis. Sun Chengkai [2] et al. studied the effect of RA substitution rate, FA substitution rate, water binder ratio and PVA fiber incorporation rate on the compressive strength and splitting tensile strength of RAC by means of AHP, ANOVA and factor index analysis. Kuang Chenggang [3] designed the orthogonal test scheme of 3 factors, 4 levels and 3 indexes, and studied the relationship between the best strength combination and factors and indexes of RAC by using visual analysis, range analysis, analytic hierarchy process, factor index analysis and variance analysis. It can be seen that the analysis method in the current orthogonal test scheme is more complex, and the queuing analysis method only needs range analysis on the total score, which greatly reduces the workload and improves the analysis efficiency [4]. Queuing scoring method is a common concrete multi index optimization method. It scores the test results according to the order of the test results in a single index, and then sums up the scores under each index, which is the final score of the test group [5].
Therefore, based on the research of Kuang Chenggang [3] in Xiangtan University, this paper studies the best combination scheme of RAC under the condition of multi index by using queuing scoring method, taking RA substitution rate, FA substitution rate and SF incorporation rate as factors, compressive strength, splitting tensile strength, flexural strength, tension compression ratio and fracture compression ratio as indexes, so as to provide a reference for the theoretical research of RAC.

2. Test overview
The L16(43) orthogonal test scheme with 3 factors, 4 levels and 5 indexes was designed. The specific factor levels of the test are shown in Table 1. Factors A, B and C correspond to RA substitution rate, FA substitution rate and SF incorporation rate. The raw materials, mix proportion, specimen preparation and specific test methods are shown in reference [3]. The test results of RAC indexes (28d compressive strength $f_{\text{cuk}}$, splitting tensile strength $f_s$, flexural strength $f_f$, tension compression ratio $f_s-f_{\text{cuk}}$ and folding compression ratio $f_f-f_{\text{cuk}}$) are shown in Table 2.

| No. | Factor A | Factor B | Factor C | $f_{\text{cuk}}$ /MPa | $f_s$ /MPa | $f_f$ /MPa | $f_s-f_{\text{cuk}} \times 10^{-2}$ | $f_f-f_{\text{cuk}} \times 10^{-2}$ |
|-----|----------|----------|----------|-----------------------|------------|------------|---------------------------------|---------------------------------|
| 1   | 1(0)     | 1(0)     | 1(0)     | 43.3                  | 2.73       | 4.67       | 6.30                            | 10.79                           |
| 2   | 1(0)     | 2(10)    | 1(0)     | 43.3                  | 3.05       | 5.18       | 7.04                            | 11.96                           |
| 3   | 1(0)     | 3(20)    | 1(0)     | 39.1                  | 3.06       | 4.82       | 7.83                            | 12.33                           |
| 4   | 1(0)     | 4(30)    | 1(0)     | 41.3                  | 3.76       | 5.73       | 9.10                            | 13.87                           |
| 5   | 2(30)    | 1(0)     | 1(0)     | 45.7                  | 2.68       | 5.02       | 8.65                            | 10.98                           |
| 6   | 2(30)    | 2(10)    | 1(0)     | 42.5                  | 2.77       | 4.98       | 6.52                            | 11.72                           |
| 7   | 2(30)    | 3(20)    | 1(0)     | 40.4                  | 3.91       | 6.12       | 9.68                            | 15.15                           |
| 8   | 2(30)    | 4(30)    | 1(0)     | 39.9                  | 3.06       | 5.38       | 7.67                            | 13.48                           |
| 9   | 3(50)    | 1(0)     | 1(0)     | 51.6                  | 3.80       | 6.23       | 7.36                            | 12.07                           |
| 10  | 3(50)    | 2(10)    | 1(0)     | 48.0                  | 4.57       | 6.24       | 9.52                            | 13.00                           |
| 11  | 3(50)    | 3(20)    | 1(0)     | 39.3                  | 2.47       | 4.26       | 6.28                            | 10.84                           |
| 12  | 3(50)    | 4(30)    | 1(0)     | 43.6                  | 2.74       | 4.63       | 6.28                            | 10.62                           |
| 13  | 4(100)   | 1(0)     | 1(0)     | 53.8                  | 4.64       | 7.33       | 8.62                            | 13.62                           |
| 14  | 4(100)   | 2(10)    | 1(0)     | 50.3                  | 3.62       | 6.17       | 7.20                            | 12.27                           |
| 15  | 4(100)   | 3(20)    | 1(0)     | 43.0                  | 3.06       | 4.90       | 7.12                            | 11.40                           |
| 16  | 4(100)   | 4(30)    | 1(0)     | 42.0                  | 2.62       | 4.54       | 6.24                            | 10.81                           |

3. Calculation of queuing scoring method
Using the queuing scoring method, the maximum value of each index is set as 10 points, the minimum value is 1 point, and other values are determined according to the interpolation method [6]. Considering the large amount of calculation, MATLAB software is used to calculate the interpolation method. The calculation results are shown in Table 3.

The total score was analyzed by range analysis, and the results are shown in Table 4. From the analysis of Table 3 and Table 4, it can be seen that the score of group 13 is the highest and the result is the best; the influence of various factors on the test indexes from large to small is $C > B > A$, that is, SF incorporation rate > FA substitution rate > RA substitution rate; the optimal combination of RAC is $A4B2C4$, that is, RA substitution rate is 100%, FA substitution rate is 10%, SF volume rate is 1.8%.
The analysis result of this study is slightly different from that of reference [3], because the index in reference [3] only considers the strength of RAC, and this study also considers the tensile compression ratio and flexural compression ratio of RAC.

Table 3. Calculation results based on queuing scoring method

| No. | $f_{ck}$ | $f_c$ | $f_t$ | $f_r-f_{ck}$ | $f_r-f_{ck}$ | Sum |
|-----|----------|-------|-------|--------------|--------------|-----|
| 1   | 3.57     | 2.08  | 2.20  | 2.05         | 1.33         | 11.23 |
| 2   | 3.57     | 3.41  | 3.70  | 3.79         | 3.67         | 18.13 |
| 3   | 1.00     | 3.45  | 2.64  | 5.63         | 4.39         | 17.11 |
| 4   | 2.35     | 6.35  | 5.31  | 8.64         | 7.47         | 30.11 |
| 5   | 5.04     | 1.87  | 3.23  | 1.00         | 1.72         | 12.86 |
| 6   | 3.08     | 2.24  | 3.11  | 2.55         | 3.18         | 14.17 |
| 7   | 1.80     | 6.97  | 6.45  | 10.00        | 10.00        | 35.21 |
| 8   | 1.49     | 3.45  | 4.28  | 5.26         | 6.69         | 21.17 |
| 9   | 8.65     | 6.52  | 6.78  | 4.54         | 3.89         | 30.38 |
| 10  | 6.45     | 9.71  | 6.80  | 9.62         | 5.73         | 38.32 |
| 11  | 1.12     | 1.00  | 1.00  | 2.00         | 1.44         | 6.56  |
| 12  | 3.76     | 2.12  | 2.08  | 2.00         | 1.00         | 10.96 |
| 13  | 10.00    | 10.00 | 10.00 | 7.51         | 6.97         | 44.48 |
| 14  | 7.86     | 5.77  | 6.60  | 4.15         | 4.27         | 28.65 |
| 15  | 3.39     | 3.45  | 2.88  | 3.96         | 2.54         | 16.21 |
| 16  | 2.78     | 1.62  | 1.82  | 1.89         | 1.38         | 9.49  |

Table 4. Range analysis of queuing scoring method

| Parameters | Factors | A      | B      | C      |
|------------|---------|--------|--------|--------|
| $k_1$      |         | 19.15  | 24.74  | 10.36  |
| $k_2$      |         | 20.86  | 24.82  | 14.54  |
| $k_3$      |         | 21.55  | 18.77  | 24.33  |
| $k_4$      |         | 24.71  | 17.93  | 37.03  |
| $R$        |         | 5.56   | 6.88   | 26.67  |

Note: $k$ is the average value of the total scores of the corresponding factors, and $R$ is the range.

4. Verification of queuing scoring method

In order to verify the applicability of the queuing scoring method, the orthogonal test data in literature [7] and literature [8] were scored respectively, and the results are shown in Table 5 and Table 6.

Table 5. Scoring results of literature [7]

| Parameters | Factor A | Factor B | Factor C | Factor D |
|------------|----------|----------|----------|----------|
| $k_1$      | 25.37    | 28.22    | 37.96    | 44.03    |
| $k_2$      | 35.30    | 33.12    | 32.20    | 30.01    |
| $k_3$      | 32.09    | 31.42    | 22.60    | 18.72    |
| $R$        | 9.94     | 4.90     | 15.35    | 25.32    |

Note: Factors A, B, C and D correspond to fiber length, cement dosage, sand ratio and water cement ratio.

Table 6. Scoring results of literature [8]

| Parameters | Factor A | Factor B | Factor C |
|------------|----------|----------|----------|
| $k_1$      | 8.55     | 18.98    | 21.03    |
| $k_2$      | 20.60    | 22.02    | 22.48    |
| $k_3$      | 36.35    | 24.51    | 22.00    |
| $R$        | 27.80    | 5.53     | 1.46     |

Note: Factors A, B and C correspond to steel fiber, polypropylene fiber and fly ash.
According to the analysis of Table 5, the influence of various factors on each index of concrete from large to small is D > C > A > B, that is, water cement ratio > sand ratio > fiber length > cement dosage. The best combination of concrete is A2B2C1D1, which is roughly the same as the analysis result in literature [7]. According to the analysis of Table 6, the influence of each factor on each index of concrete from large to small is A > B > C, that is, steel fiber > polypropylene fiber > fly ash, and the best combination of concrete is A3B3C2, which is consistent with the analysis results in literature [8].

To sum up, when using queuing scoring method to analyze the results of orthogonal test, we can accurately determine the size relationship of the influence of various factors on the index, and quickly select the best combination scheme of concrete.

5. Conclusions
In this paper, the results of RAC orthogonal test were analyzed by queuing score method, and the effects of RA substitution rate, FA substitution rate and SF incorporation rate on RAC compressive strength, splitting tensile strength, flexural strength, tension compression ratio and folding compression ratio were studied. The conclusions are as follows.

(1) When the RA substitution rate is 100%, FA substitution rate is 0%, and SF incorporation rate is 1.8%, the total score of RAC is the highest, and the mechanical properties of RAC are better.

(2) The influence of each factor on RAC is SF incorporation rate > FA substitution rate > RA substitution rate, and the best combination of RAC was A4B2C4.

(3) The queuing score method can accurately determine the relationship between the influence of various factors on the index and the optimal combination of concrete in orthogonal test.

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