

Optimization Research of Mechanical Properties of Modified Concrete Based on Queuing Scoring Method and Matrix Analysis Method

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Abstract

In order to study the optimal combination of mechanical properties of modified concrete under multiple indicators, the orthogonal test results of rubber particle basalt fiber fly ash modified concrete were analyzed using queuing scoring method and matrix analysis method, with rubber particle substitution rate, basalt fiber content, and fly ash content as factors, compressive strength, splitting tensile strength, flexural strength, tension-compression ratio, and bending-compression ratio as indicators. The results indicate that the order of influence of various factors on the mechanical properties of modified concrete is rubber particle substitution rate, basalt fiber content, and fly ash content. The optimal combination of mechanical properties of modified concrete based on the queuing scoring method is A1B2C1, with a rubber particle replacement rate of 5%, a basalt fiber content of 4%, and a fly ash content of 10%. The optimal combination of mechanical properties of modified concrete based on matrix analysis method is A1B3C1, with a rubber particle substitution rate of 5%, a basalt fiber content of 6%, and a fly ash content of 10%.

Keywords

Modified Concrete; Queuing Scoring Method; Matrix Analysis Method; Rubber Particle; Basalt Fiber; Fly Ash.

1. Introduction

At present, numerous scholars have conducted extensive research on the modification of concrete materials in order to improve their strength, ductility, toughness, crack resistance, impact resistance, and durability. Xue Gang et al. [1] studied the effects of water cement ratio and rubber particle (RP) content on the flexural performance of rubber concrete under temperature conditions of -30 °C and 20 °C. The results showed that after adding RP, the failure of concrete changed from brittle failure to ductility; When the water cement ratio is 0.35, the low-temperature flexural strength with RP content of 10%, 20%, and 30% is 1.15, 1.22, and 1.30 times that of the room temperature flexural strength, respectively; With the increase of RP content, the flexural ratio under normal and low temperature conditions gradually increases, indicating that the toughness is gradually enhanced. Both Wen Yang et al. [2] and Hao Yunhong et al. [3] found in their experiments that the compressive strength, flexural strength, and impact resistance of concrete cubes increase with the decrease of RP particle size. The study by Yang Zhishuo et al. [4] showed that when the content of Basalt Fiber (BF) was 2 kg/m³, the cube compressive strength, axial compressive strength, splitting tensile strength, and flexural strength of C120 ultra-high strength concrete increased by 10.9%, 14.1%, 11.0%, and 10.2%, respectively. Li Dan et al. [5] studied the effect of different BF content on the impact resistance of concrete through drop hammer impact test and dynamic bending impact test. The results showed that when the BF content was 3.15 kg/m³, the number of initial cracking impacts of

concrete was 92, an increase of 74 compared to plain concrete; The number of destructive impacts was 117, an increase of 92; The difference in the number of impacts from initial cracking to destruction is 25, an increase of 18; The impact energy is 2030.3 N·m, which is 4.9 times that of plain concrete; The impact ductility index is the highest, which is 166.7% higher than that of plain concrete. Wei Ke's research shows that the compressive strength of concrete decreases continuously with the increase of freeze-thaw cycles. However, when the fly ash (FA) content increases from 0% to 30%, the compressive strength loss after 200 freeze-thaw cycles decreases from 24.4% to 22.5%, indicating that an appropriate amount of FA has a certain effect on improving the durability of concrete. Scholars such as Liu Yushan from Anhui University of Science and Technology [7] comprehensively considered the above three factors and studied the effects of RP substitution rate, BF content, and FA content on the compressive, splitting tensile, and flexural strength of modified concrete, and determined the optimal strength combination of modified concrete. Tang Jiajun et al. [8] believed that the optimal strength combination of concrete is different from the optimal ductility and toughness combination, and it is unreasonable to only analyze the optimal strength combination. Therefore, based on literature [7], they analyzed the effects of RP substitution rate, BF content, and FA content on the tensile compression ratio and flexural compression ratio of modified concrete, and obtained the optimal ductility and toughness combination of modified concrete.

The queuing scoring method is a commonly used multi-index optimization method for concrete, which can easily and quickly determine the optimal combination scheme [9]; Matrix analysis is an orthogonal experimental result processing method that avoids subjective factors and has high data reliability [10]. Based on this, this article, based on the research of Liu Yushan from Anhui University of Science and Technology [7], takes RP substitution rate, BF content, and FA content as factors, compressive strength, splitting tensile strength, flexural strength, tensile compression ratio, and flexural compression ratio as indicators, and uses queuing scoring method and matrix analysis method to study the optimal combination scheme of mechanical properties of modified concrete under multiple indicators, providing reference for the optimization research of mechanical properties of modified concrete.

2. Test Overview

$L_9(3^3)$ orthogonal experimental scheme is designed, and three factors are selected: RP substitution rate (factor A), BF content (factor B), and FA content (factor C), each corresponding to three levels. The experimental factors and levels are shown in Table 1. The particle size of RP used in the experiment is 1-3 mm, which is used to replace some sand; The length of BF is 18 mm, the aspect ratio is 1200, the density is 2650 kg/m³, and the tensile strength is 4800 MPa; FA is grade I fly ash used to replace some cement. The test results of 28-day compressive strength, splitting tensile strength, flexural strength, tensile compression ratio, and flexural compression ratio of modified concrete are shown in Table 2.

Table 1. Test factors and levels

Level	Substitution rate or dosage of each factor/%		
	Factor A	Factor B	Factor C
1	5	2	10
2	10	4	15
3	15	6	20

Table 2. Experimental results [7]

Test number	Orthogonal combination	Compressive strength /MPa	Splitting tensile strength /MPa	Flexural strength /MPa	Tension compression ratio / $\times 10^{-2}$	Flexural-compressive strength ratio / $\times 10^{-2}$
1	A1B1C1	40.02	4.51	9.38	11.27	23.44
2	A1B2C2	41.81	4.94	9.66	11.82	23.10
3	A1B3C3	38.03	4.40	9.14	11.57	24.03
4	A2B1C2	36.95	4.01	7.74	10.85	20.95
5	A2B2C3	36.18	4.07	8.02	11.25	22.17
6	A2B3C1	36.82	4.48	7.98	12.17	21.67
7	A3B1C3	28.15	3.08	6.76	10.94	24.01
8	A3B2C1	32.04	3.62	7.90	11.30	24.66
9	A3B3C2	31.71	3.63	7.54	11.45	23.78

3. Calculation of Queuing Scoring Method

The queuing scoring method ranks the experimental results in a single indicator, scores the experimental results, and then sums up the scores under each indicator to transform the multi-indicator problem into a single indicator problem. The higher the total score, the better the combination. This article sets the maximum value for each indicator as 10 points and the minimum value as 1 point, and determines the scores for other values using interpolation [11]. Considering the large amount of computation, this article uses SPSS software for interpolation calculation, and the calculation results are shown in Table 3. According to Table 3, the second group had the highest total score of 43.83 points among all experimental groups; The total score of Group 7 is the lowest, at 13.04 points.

Table 3. Calculation results of queuing scoring method

Test number	Orthogonal combination	Compressive strength /points	Splitting tensile strength /points	Flexural strength /points	Tension compression ratio /points	Flexural-compressive strength ratio /points	Sum /points
1	A1B1C1	8.82	7.92	9.13	3.86	7.04	36.78
2	A1B2C2	10.00	10.00	10.00	7.61	6.22	43.83
3	A1B3C3	7.51	7.39	8.39	5.91	8.47	37.66
4	A2B1C2	6.80	5.50	4.04	1.00	1.00	18.34
5	A2B2C3	6.29	5.79	4.91	3.73	3.96	24.68
6	A2B3C1	6.71	7.77	4.79	10.00	2.75	32.02
7	A3B1C3	1.00	1.00	1.00	1.61	8.42	13.04
8	A3B2C1	3.56	3.61	4.54	4.07	10.00	25.78
9	A3B3C2	3.35	3.66	3.42	5.09	7.87	23.38

The range analysis results of the total score are shown in Table 4. From the analysis of Table 4, it can be seen that the range values corresponding to factors A, B, and C are 18.69, 8.71, and 6.40, respectively. The order of the impact of each factor on the experimental indicators is $A > B > C$, that is, RP substitution rate $>$ BF content $>$ FA content; The optimal combination of modified concrete is A1B2C1, with an RP substitution rate of 5%, BF content of 4%, and FA content of 10%. Reference [7] used orthogonal analysis to show that the order of the influence of various factors on splitting tensile and flexural strength is RP substitution rate $>$ BF content $>$ FA content; The order of the influence of various factors on compressive strength is

RP substitution rate>FA content>BF content. The research results in reference [8] indicate that among all factors, the BF content (factor B) has the greatest impact on the tensile compression ratio, while the RP substitution rate (factor A) and FA content (factor C) have relatively small and similar effects on the tensile compression ratio; The order of the influence of various factors on the compression ratio from high to low is RP content>FA content>BF content. The indicators in reference [7] only consider compressive strength, splitting tensile strength, and flexural strength, while the indicators in reference [8] are tensile compression ratio and flexural compression ratio. This study comprehensively considers the above five indicators, so the research results are different.

Table 4. Calculation results of matrix analysis method

Parameter	Score of each factor/points		
	Factor A	Factor B	Factor C
k1	39.42	22.72	31.53
k2	25.01	31.43	28.52
k3	20.73	31.02	25.13
R	18.69	8.71	6.40

4. Calculation of Matrix Analysis Method

Matrix analysis is an objective data processing method that processes experimental results by setting weight matrices, without directly using the results of each group of experiments during the analysis process [12]. The calculation process is as follows:

(a) Establishment of hierarchical structure model. The hierarchical structure model typically consists of an indicator layer (Level 1), a factor layer (Level 2), and a horizontal layer (Level 3). Taking this study as an example, establish a 3-level hierarchical structure model, as shown in Fig. 1.

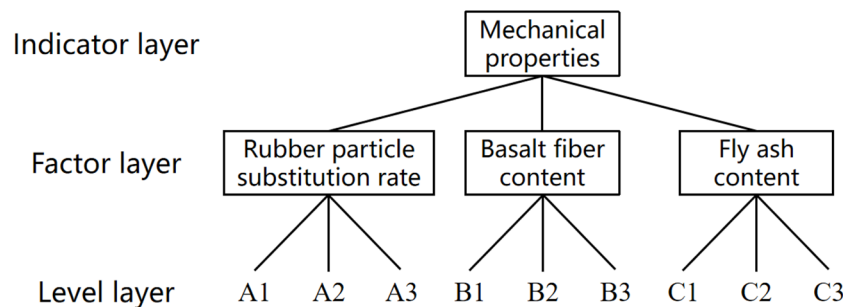


Fig 1. Hierarchical structure model

(b) Establishment of Matrix. The indicator layer matrix M is composed of the average value K_{ij} (or the reciprocal of the average value $1/K_{ij}$) of the experimental indicators at each factor and level, where i represents the factor and j represents the level. If the larger the indicator value, the better, then take the average value K_{ij} of the values in matrix M ; On the contrary, take its reciprocal $1/K_{ij}$. The factor layer matrix T is composed of the reciprocal of the sum of experimental indicators at different levels under the same factor. The product of matrix M and matrix T represents the degree of influence of a single level within a factor. The horizontal matrix S is composed of the range and sum of the range of each factor under the same indicator, and represents the degree of influence of each factor under a single indicator. The matrix W is obtained by continuously multiplying the indicator layer matrix M , factor layer matrix T , and horizontal layer matrix S . The matrix W represents the set of influence weights of each factor

and level on each indicator. For the orthogonal experimental study of m factors and n indicators, the matrices are shown in equations (1) to (3).

$$M = \begin{bmatrix} K_{11} & 0 & \dots & 0 \\ K_{12} & 0 & \dots & 0 \\ \dots & & & \\ K_{1n} & 0 & \dots & 0 \\ 0 & K_{21} & \dots & 0 \\ 0 & K_{22} & \dots & 0 \\ \dots & & & \\ 0 & K_{2n} & \dots & 0 \\ \dots & & & \\ 0 & 0 & \dots & K_{m1} \\ 0 & 0 & \dots & K_{m2} \\ \dots & & & \\ 0 & 0 & \dots & K_{mn} \end{bmatrix} \quad (1)$$

$$T = \begin{bmatrix} t_1 & 0 & \dots & 0 \\ 0 & t_2 & \dots & 0 \\ \dots & & & \\ 0 & 0 & \dots & t_m \end{bmatrix}, \text{ Where } t_i = 1 / \sum_{j=1}^n K_{ij} \quad (2)$$

$$S = \begin{bmatrix} s_1 \\ s_2 \\ \dots \\ s_m \end{bmatrix}, \text{ Where } s_i = r_i / \sum_{i=1}^m r_i, \text{ } r_i \text{ is the range value} \quad (3)$$

(c) Calculation of matrices. This article takes the tension compression ratio as an example and uses Matlab software to explain the calculation of matrix analysis method. The range analysis results of the tension compression ratio are shown in Table 5. The values in the table are programmed in matrix form and input into the Matlab window to run the solution. The specific matrix is shown in Fig. 2.

Table 5. Range analysis results of tension compression ratio

Parameter	Tension compression ratio of various factors/ $\times 10^{-2}$		
	Factor A	Factor B	Factor C
k1	11.55	11.02	11.58
k2	11.42	11.45	11.37
k3	11.23	11.73	11.25
R	0.32	0.71	0.32

```
>> M4=[11.55 0 0;11.42 0 0;11.23 0 0;
0 11.02 0;0 11.45 0;0 11.73 0;
0 0 11.58;0 0 11.37;0 0 11.25]
T4=[1/34.20 0 0;0 1/34.20 0;0 0 1/34.20]
S4=[0.32/1.35;0.71/1.35;0.32/1.35]
W4=M4*T4*S4
```

Fig 2. Input the specific matrix in Matlab

Use the above methods to perform matrix analysis on other indicators separately, and sum up the results obtained, as shown in Table 6. According to Table 6, among the three levels of factor A, A1 has the highest impact weight on the total sum, with a weight value of 1.0466; Among the three levels of factor B, B3 has the highest impact weight, with a weight value of 0.4066; Among the three levels of factor C, B1 has the highest influence weight, with a value of 0.3149. Therefore, it can be seen that the order of the influence of various factors on the experimental indicators is $A > B > C$, that is, RP substitution rate $>$ BF content $>$ FA content; The optimal combination of modified concrete is A1B3C1, with an RP substitution rate of 5%, BF content of 6%, and FA content of 10%.

Table 6. Calculation results of matrix analysis method

Parameter	Compressive strength	Splitting tensile strength	Flexural strength	Tension compression ratio	Flexural-compressive strength ratio	Sum
A1	0.2542	0.2393	0.2486	0.0801	0.2244	1.0466
A2	0.2332	0.2146	0.2385	0.0792	0.2060	0.9715
A3	0.1949	0.1777	0.1796	0.0778	0.2303	0.8603
B1	0.0392	0.0596	0.0698	0.1695	0.0435	0.3816
B2	0.0411	0.0652	0.0775	0.1761	0.0445	0.4044
B3	0.0398	0.0647	0.0769	0.1804	0.0442	0.4060
C1	0.0669	0.0611	0.0370	0.0803	0.0696	0.3149
C2	0.0679	0.0614	0.0371	0.0788	0.0676	0.3128
C3	0.0629	0.0564	0.0352	0.0780	0.0700	0.3025

5. Conclusion

This article takes the replacement rate of rubber particles (RP), the content of basalt fibers (BF), and the content of fly ash (FA) as factors, and uses compressive strength, splitting tensile strength, flexural strength, tensile compression ratio, and flexural compression ratio as indicators to analyze and calculate the optimal combination of mechanical properties of modified concrete using queuing scoring method and matrix analysis method. The results indicate that:

- The order of the influence of various factors on the mechanical properties of modified concrete is $A > B > C$, that is, RP substitution rate $>$ BF content $>$ FA content.
- The optimal combination of modified concrete calculated by queuing scoring method is A1B2C1, with RP substitution rate of 5%, BF content of 4%, and FA content of 10%.
- The optimal combination of modified concrete calculated by matrix analysis method is A1B3C1, with RP substitution rate of 5%, BF content of 6%, and FA content of 10%.

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