Research on influencing factors of rubber concrete performance based on grey correlation theory

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Abstract. Based on the experiment and grey system theory, the influence on slump and compressive strength of rubber concrete are analyzed systematically under the rubber grain gradation mass, the content of rubber grain substitution and whether the rubber surface is pretreated. The influence rule of each factor on the slump and compressive strength is consistent. The influence order is as follows: The mass percentage of rubber particle grading is more than the amount of rubber particle replacing, which is more than whether the rubber surface is pretreated. The mass percentage of rubber particle grading and the amount of rubber particle replacing is more than 0.6 and whether the rubber surface is pretreated that is less than 0.6. In view of this situation, considering whether the assignment condition of rubber surface pretreated is reasonable, this problem needs further study. The results of this paper provide a theoretical reference for the main factors concerned in the mix design of rubber concrete.

1. Introduction

Compared with ordinary concrete[1], rubber concrete has the characteristics of light weight, sound insulation and heat preservation, strong durability, impact resistance and good ductility[2,3,4], and improves the concrete the weight, impact resistance performance and brittleness of high shortcomings[5]. Because of its many advantages, rubber concrete has a broad prospect in road engineering, anti-crash guardrail, railway concrete sleeper, shock absorption foundation, important military buildings, nuclear industry buildings, pipeline roadbed and building walls with special requirements on heat insulation and sound insulation and so on.

However, according to the research results of Khatib Z K et al.[6]: The greater the mixing amount of rubber particles is, the smaller the slump of concrete is. When the equal volume of rubber particles replaces the fine aggregate by 40%, the slump is basically zero. According to the research results of A. Benazzouk et al. [7]: The slump increased with the increase of rubber content. The study of Gholampoura et al.[8]: the compressive strength of rubber concrete decreases rapidly with the increase of rubber content. Fattuhi et al. [9] found that the impact of fine rubber particles on the compressive strength of concrete is greater than that of coarse rubber particles, but Topu [10] believes that the reduction of the compressive strength of concrete made of coarse rubber particles is greater than that of fine rubber particles. Lu Shasha et al. [11] researches that the same rubber powder content showed a decreasing trend in compressive strength with the increase of particle size, and the total
mixing amount is the same. The larger the rubber particle size is, the smaller the slump is. With the same particle size, the greater the mixing amount of rubber powder, the smaller the slump.

Based on the above research results of rubber concrete working performance and mechanical properties, the main factors affecting the slump and compressive strength of rubber concrete are the pretreatment of rubber surface, the amount of addition and the grading of rubber particle size. However, various factors influence each other, and the influence degree of each factor on the slump and compressive strength of rubber concrete are uncertain. In this paper, the grey correlation analysis method is used to study the influence degree of each influencing factor on the slump and compressive strength, which can provide reference for the special requirements of rubber concrete preparation and application.

2. Raw material and test design

2.1. Raw material condition

Cement: PO42.5 cement from Guizhou Bijie Jiangtian Cement Co., Ltd., fineness 4%, standard consistency 26.3%, initial setting time 175 min, final setting time 225 min, fluidity 235 mm, 3-day flexural strength 5.9MPa, compressive strength 31.7MPa.

Gravel: high-quality mechanical limestone gravel of Guizhou Rock High-Tech New Material Co., Ltd., particle size 5-22mm continuous grading, apparent density 2718kg/m³.

Sand: high-quality mechanized sand from Guizhou Rock High-Tech New Material Co., Ltd., with fineness modulus 3.4, moisture content 2.1%, Mb value 1.0, and apparent density of 2736kg/m³.

Stone powder: mechanized limestone powder from Guizhou Rock High-Tech New Material Co., Ltd., with 86% calcium carbonate and 10% fineness, other technical indexes meet the requirements of the regulations.

Rubber particles: 3-6 mm (A), 1-3 mm (B), apparent density 1196 kg/m³.

Water: city tap water.

Water reducing agent: 9% low concentrated carboxylic acid water reducing agent from Guizhou Kezhijie Co., Ltd.

2.2. Test design

Taking C30 concrete as an example, the mixture ratio is: cement 260Kg, gravel 955Kg, sand 910Kg, stone powder 90Kg, water 170Kg, admixture 6.3kg, and apparent density 2391.3kg/m³.

The experiment was divided into three parts:

- The surface of rubber particles is not modified (denoted by 0), the replacement rate of machine-made sand is 5%, 10%, 15% and 20%, according to the same volume of graded rubber particles respectively (the mass incorporation ratio is A:(A+B)≥95%). The Specimen number are RC1-RC4.

- Unmodified surface of rubber particles (denoted by 0). When the gradation change of rubber particles (percentage of incorporation mass is shown in Table 2), replacing machine-made sand by 10% equal volume of graded rubber particles. The Specimen number are RCD1-RCD4.

- Modification of rubber particles (expressed as 1, see Table 2 for details). The solution was soaked in 3% NaOH solution for 2h, then washed repeatedly with clean water and dried naturally. The replacement rate of machine-made sand is 5%, 10%, 15% and 20%, according to the same volume of graded rubber particles respectively (the mass incorporation ratio is A:(A+B)≥95%). The Specimen number are RCE1-RCE4.

- Modification of rubber particles (expressed as 1, see Table 2 for details). Gradation change of rubber particles (incorporation mass percentage is shown in Table 2). Replace machine-made sand by 10% equal volume of graded rubber particles. The Specimen number are RCF1-RCF4. The dosage of other materials remains unchanged, and 3 groups of sand are sampled in each working condition (150mm×150mm×150mm). Slump and 28 days compressive strength were measured under various working conditions. The results are shown in Table 2.
Table 1. Equal volume replacement of manufactured sand by rubber particles (unit: Kg/m³)

| Replacement rate | Rubber powder | Limestone powder | Mechanism sand | Graded crushed stone | Cement | Water | Admixtures |
|------------------|---------------|------------------|----------------|----------------------|--------|-------|------------|
| 0                | 0             | 90               | 910            | 955                  | 260    | 170   | 6.3        |
| 5%               | 18.6          | 90               | 864            | 955                  | 260    | 170   | 6.3        |
| 10%              | 37.1          | 90               | 819            | 955                  | 260    | 170   | 6.3        |
| 15%              | 55.7          | 90               | 865            | 955                  | 260    | 170   | 6.3        |
| 20%              | 74.2          | 90               | 728            | 955                  | 260    | 170   | 6.3        |

3. Grey correlation theory and result analysis[14]

3.1. Steps of grey correlation analysis

The grey correlation analysis is an analysis method based on the microscopic or macroscopic geometric proximity of behavioral factor sequences to analyze and determine the degree of influence among factors or the degree of contribution of factors (sub-sequences) to the main behavior (parent sequences). Its purpose is to seek the main relationship between the various factors in the system, find out the important factors that affect the target value, so as to master the main characteristics of things[13]. The larger the correlation value is, the greater the correlation between the subsequence and the parent sequence is. Firstly, the system behavior characteristics \( x_0 = \{x_0(k)\} \) are determined as the reference sequence (also known as the parent sequence), \( k = 1, 2, \ldots, n \). The \( x_i = \{x_i(k)\} \) is a comparison sequence, \( k = 1, 2, \ldots, n \), \( i = 1, 2, \ldots, m \). Specific calculation steps of grey correlation degree:

- Initial value of each data sequence: \( x_i(k) = x_i(k) / X_i \), \( k = 1, 2, \ldots, n \), \( i = 0, 1, 2, \ldots, m \).
- Calculate the absolute difference of the corresponding element between the subsequence of the evaluated object and the parent sequence, it is \( \Delta 0(k), \Delta 0(k) = |x'_0(k) - x'_i(k)| \), \( k = 1, 2, \ldots, n \), \( i = 1, 2, \ldots, m \).
- Calculate them: \( m = \min \min |x'_0(k) - x'_i(k)| \) and \( M = \max \max |x'_0(k) - x'_i(k)| \), \( k = 1, 2, \ldots, n \), \( i = 0, 1, 2, \ldots, m \).
- The correlation coefficients of the corresponding elements of the comparison sequence and the reference sequence are calculated respectively: \( r(x'_0(k), x'_i(k)) = (m + \xi \cdot M) / (\Delta 0(k) + \xi \cdot M) \), \( k = 1, 2, \ldots, n \), \( \xi \) is the resolution coefficient, which is 0.5.
- Calculate the correlation degree: \( r(X_0, X_i) = \Sigma x_0(k) / n \), \( k = 1, 2, \ldots, n \).

3.2. Grey correlation analysis of various factors and rubber concrete performance

The subsequence is taken as the influencing factors, such as the content of rubber particle substitution, the percentage of rubber particle gradation and whether the rubber particle surface was pretreated or not. Taking the slump and 28d compressive strength of rubber concrete as the parent sequence (see Table 2). The correlation degree between each factor and the performance of rubber concrete is calculated (see Table 3 and Table 4).

Subsequence: \( X_1 \) — the content of rubber grain substitution (%); \( X_2 \) — the percentage of rubber particle gradation mass; \( X_3 \) — Whether the rubber particle surface is pretreated; The mother sequence: \( X_01 \) — slump (mm); \( X_02 \) — 28d compressive strength (Mpa).
### Table 2. Subsequence and parent sequence

| Serial number | Subsequence | Mother sequence |
|---------------|-------------|-----------------|
| X1 | X2 | X3 | X01 | X02 |
| RC1 | 5  | 95 | 0 | 42 | 28.6 |
| RC2 | 10 | 95 | 0 | 37 | 25.2 |
| RC3 | 15 | 95 | 0 | 39 | 27.5 |
| RC4 | 20 | 95 | 0 | 48 | 23.6 |
| RCD1 | 10 | 100 | 0 | 38 | 25.6 |
| RCD2 | 10 | 75 | 0 | 32 | 22.3 |
| RCD3 | 10 | 50 | 0 | 28 | 20.4 |
| RCD4 | 10 | 25 | 0 | 25 | 18.5 |
| RCE1 | 5  | 95 | 1 | 46 | 29.2 |
| RCE2 | 10 | 95 | 1 | 48 | 28.1 |
| RCE3 | 15 | 95 | 1 | 51 | 25.7 |
| RCE4 | 20 | 95 | 1 | 54 | 24.3 |
| RCF1 | 10 | 100 | 1 | 46 | 28.6 |
| RCF2 | 10 | 75 | 1 | 43 | 26.4 |
| RCF3 | 10 | 50 | 1 | 35 | 22.5 |
| RCF4 | 10 | 25 | 1 | 27 | 20.1 |

Note: X1 represents the replacement rate of machine-made sand replaced by equal volume of rubber particles; X2 represents the mass percentage of 3-6mm single grade rubber particles and 1-3mm and 3-6mm composite rubber particles; X3 denotes whether the surface of rubber particles is treated with NaOH solution.

### Table 3. The correlation degree of each influencing factor with slump and compressive strength respectively

| Serial number | Maximum/minimum difference of two levels: M=1.32, m=0 | Maximum/minimum difference of two levels: M=1.19, m=0.01 |
|---------------|------------------------------------------------------|------------------------------------------------------|
|               | r(x01,X1)  | r(x01,X2)  | r(x01,X3)  | r(x02,X1)  | r(x02,X2)  | r(x02,X3)  |
| RC1           | 0.5208     | 0.8101     | 0.3856     | 0.4638     | 0.9343     | 0.3460     |
| RC2           | 0.9462     | 0.7022     | 0.4160     | 0.8371     | 0.7710     | 0.3754     |
| RC3           | 0.6491     | 0.7417     | 0.4033     | 0.7388     | 0.8744     | 0.3550     |
| RC4           | 0.5340     | 0.9933     | 0.3545     | 0.4259     | 0.7124     | 0.3911     |
| RCD1          | 0.9134     | 0.6746     | 0.4096     | 0.8188     | 0.7271     | 0.3717     |
| RCD2          | 0.8828     | 0.8137     | 0.4517     | 0.9987     | 0.9340     | 0.4048     |
| RCD3          | 0.7785     | 0.9089     | 0.4849     | 0.9154     | 0.7726     | 0.4267     |
| RCD4          | 0.7151     | 0.6815     | 0.5132     | 0.8203     | 0.5909     | 0.4510     |
| RCE1          | 0.4827     | 0.9237     | 0.4376     | 0.4554     | 0.9706     | 0.4270     |
| RCE2          | 0.6783     | 0.9933     | 0.4526     | 0.7205     | 0.9061     | 0.4140     |
| RCE3          | 0.9214     | 0.9033     | 0.4772     | 0.6786     | 0.7913     | 0.3883     |
| RCE4          | 0.6079     | 0.8191     | 0.5046     | 0.4345     | 0.7369     | 0.3747     |
| RCF1          | 0.7151     | 0.8483     | 0.4376     | 0.7036     | 0.8509     | 0.4198     |
| RCF2          | 0.7785     | 0.8415     | 0.4168     | 0.7845     | 0.8549     | 0.3954     |
The analysis results in Table 3 show that the three factors that affect the slump and compressive strength of rubber concrete are the amount of rubber particle substitution, the percentage of rubber particle gradation mass, and whether the surface of rubber particle is pretreated. Their influence rules are basically the same. However, the percentage of rubber grain gradation mass has the greatest influence on slump and compressive strength, followed by rubber substitution content, and the influence of rubber grain surface pretreatment is the least. It is $r_2 > r_1 > r_3$.

The above analysis results provide theoretical reference for rubber concrete mix design. When considering the synergism between strength and performance of concrete, the mass percentage of rubber particle gradation is considered first. The continuous grade of rubber particle plays a major role in the performance and mechanical properties of rubber concrete. Secondly, the percentage of fine aggregate replaced by equal volume of rubber particles is controlled. The greater the amount of substitution, the more the strength of concrete decreases, the greater the percentage of rubber particle grading mass increases, and the performance of concrete will be improved. Studies by Yu Qun et al.[12] shows: After the surface pretreatment of rubber particles, the working and mechanical properties of rubber concrete are improved. In this paper, further research is needed to consider whether the evaluation is reasonable considering the influence of rubber surface pretreatment.

4. Conclusion
Based on the experiment and grey system theory, the influence on slump and compressive strength of rubber concrete are analyzed systematically under the rubber grain gradation mass, the content of rubber grain substitution and whether the rubber surface is pretreated. The influence rule of each factor on the slump and compressive strength is consistent. The order is as follows: The mass percentage of rubber particle grading is more than the amount of rubber particle replacing, which is more than whether the rubber surface is pretreated. The mass percentage of rubber particle grading and the amount of rubber particle replacing is more than 0.6 and whether the rubber surface is pretreated that is less than 0.6. In view of this situation, considering whether the assignment condition of rubber surface pretreated is reasonable, this problem needs further study. The results of this paper provide a theoretical reference for the main factors concerned in the mix design of rubber concrete.

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