Experimental Study on the Flexural Strength of Marble Industrial Powder Concrete

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Abstract. The flexural strength and cube compressive strength of marble industrial powder concrete were studied by orthogonal test method. 25 orthogonal test groups and 1 contrast test group with the mineral admixture content 0% were designed to carry out the flexural and compressive tests. The strength of concrete with different substitution rate and fineness is obtained, and the mechanism of influence on each strength is analyzed. The experimental results show that the concrete flexural strength is reduced by the addition of marble powder, but it can meet the requirement of engineering application when the substitution rate is less than 10%. According to the orthogonal test, the main factor affecting the flexural strength of marble industrial powder concrete is the substitution rate of marble powder, and the secondary factor is the fineness of marble powder. The effect of marble powder on the flexural strength and compressive strength of concrete is basically the same. The ratio of flexural strength to cubic compressive strength of marble powder concrete with different substitution rate and fineness is 0.16.

1. Introduction

With the continuous development of marble industry, the usage of marble is increasing. In the process of mining, transportation, grinding and cutting, a large number of solid waste is produced, such as waste powder, waste pulp and other solid wastes. A block of marble rock mass of 15-20 tons, will be lost of 70% in the process of mining, cutting, grinding and so on [1], which are caused by solid waste. The problem of environmental pollution is becoming more and more prominent [2]. More and more countries recognize that marble industry solid waste is a worldwide problem [3].

A lot of studies have been carried out on marble solid waste concrete. It is found that marble powder can improve the properties of cement-based material [4-6]. Chemical analysis and particle size analysis show that marble powder is inactive material only plays the filling effect[7]. But in the end stage of hydration, the marble powder has hydration activity with a certain proportion[8]. It is found that the mechanical properties of concrete can be increased with a certain proportion of marble powder [9], but some study consider it may reduce the mechanical properties [10-11]. The replacement rate of marble powder instead of cement within 10%[11-13] can meet the standard requirements. Some
scholars point out that the best replacement amount of marble powder is 15%[14-16]. And marble powder can improve the durability of concrete[17].

In this study, five kinds of Hezhou marble industrial powder contain three kinds of pure powder and two kinds of waste powder were selected, and the quality of the marble industry powder concrete was made by replacing the cement with the quality of the cement. The effect of 2 factors on the 28d strength of the marble powder and the fineness of the marble powder was analyzed.

2. A Experimental Study

2.1. A Test Material

Cement: P.O 42.5, produced by Huarun Fuchuan cement Plant. Its physical properties are shown in Table 1.

| Table 1. Physical properties of cement |
|---------------------------------------|
| Name | Apparent density/(g·cm⁻³) | Specific area/(m²·kg⁻¹) | Setting time/min (initial | final | 3d | 28d | 3d | 28d |
| P·O42.5 | 3.11 | 327 | 158 | 5.4 | 7.4 | 26.3 | 43.3 |

Fine aggregate: River sand collected in Wuzhou. The fineness modulus is 2.7 belongs to the medium sand. The physical properties are shown in Table 2.

| Table 2. The physical properties of sand |
|------------------------------------------|
| Apparent density/(kg·m⁻³) | Loose packing density/(kg·m⁻³) | Compact packing density/(kg·m⁻³) | Sediment percentage(%) |
| 2781 | 1420 | 1560 | 1.4 |

Coarse aggregate: Artificial crushed stone with the maximum diameter of 25mm. The physical properties of the aggregate are shown in Table 3.

| Table 3. Physical properties of the coarse aggregate |
|--------------------------------------------------|
| Apparent density/(kg·m⁻3) | Loose packing density/(kg·m⁻3) | Compact packing density/(kg·m⁻3) | Sediment percentage(%) | Crushing index (%) | Needle particle substitution rate(%) |
| 2717.4 | 1460 | 1550 | 0.98 | 11 | 4.04 |

Water: the test uses tap water for daily use in Hezhou.
Marble powder: the manufacturer of marble powder in Hezhou City, the chemical composition is shown in Table 4.

| Table 4. The chemical composition of marble powder |
|--------------------------------------------------|
| Name | Fe₂O₃ | MgO | CaO | TiO₂ | Al₂O₃ | SiO₂ | K₂O | Na₂O | Loss ignition |
| Artifical marble waste powder | 0.052 | 13.854 | 34.131 | 0.195 | 0.675 | 4.001 | 0.078 | 0.365 | 46.65 |
| Marble cutting waste powder | 0.004 | 9.311 | 46.437 | 0.099 | 0.042 | 0.019 | 0.053 | 0.125 | 43.22 |
| Pure powder | 0.012 | 8.853 | 47.239 | 0.134 | 0.009 | 0.031 | 0.007 | 0.204 | 44.14 |
2.2. Test Process
Three standard specimens of 150mm × 150mm × 550mm were made in each group, after 24 hours of molding the mold was removed, curing 28 days in the standard curing room (temperature 20 ±3 °, humidity > 90%). The flexural strength test was carried out according to the standard of test method for “mechanical properties of ordinary concrete (GBP / T 50081-2002)” . The test section span of 450 mm was tested on the universal testing machine. The cube specimens was made and its compressive strength was tested for 28 days; at the same time, a group of specimens with a cement substitution of 0% was made as the experimental contrast group.

3. Results

3.1. Orthogonal Test Analysis of Flexural Strength
The results of the analysis and analysis of experimental data by orthogonal test design L25 ( 5 2 ) are shown in Table 5. The 28d flexural strength of 28d is up to 6.06 MPa , which can be applied to ordinary concrete structure engineering .

| subject                        | No | substitution rate(%) | $f_t$(MPa) | $f_{cc}$(MPa) | $f_t/f_{cc}$ |
|-------------------------------|----|----------------------|------------|--------------|--------------|
| cement                        | 0  | 0                    | 5.38       | 35           | 0.176        |
|                               | A1 | 5                    | 5.27       | 33.8         | 0.156        |
| mesh                          | A2 | 10                   | 5.53       | 33.2         | 0.152        |
| powder                        | A3 | 15                   | 4.53       | 31.1         | 0.146        |
|                               | A4 | 20                   | 5.23       | 29.9         | 0.150        |
|                               | A5 | 25                   | 5.23       | 27           | 0.156        |
|                               | A6 | 5                    | 5.7        | 35.8         | 0.159        |
| 600 mesh powder               | A7 | 10                   | 5.03       | 38.1         | 0.159        |
| Mesh                          | A8 | 15                   | 5.23       | 32.6         | 0.160        |
| powder                        | A9 | 20                   | 4.83       | 29.6         | 0.163        |
|                               | A10| 25                   | 4.5        | 25.9         | 0.174        |
|                               | A11| 5                    | 5.17       | 35.4         | 0.157        |
| 400 mesh powder               | A12| 10                   | 5.65       | 35.5         | 0.159        |
| mesh                          | A13| 15                   | 5.4        | 34           | 0.159        |
| powder                        | A14| 20                   | 5.57       | 27.1         | 0.189        |
|                               | A15| 25                   | 4.77       | 26.2         | 0.182        |
| Artificial marble waste powder| A16| 5                    | 5.87       | 34.7         | 0.169        |
|                               | A17| 10                   | 5.23       | 32.8         | 0.159        |
| waste                         | A18| 15                   | 4.8        | 30.5         | 0.157        |
| powder (AW)                   | A19| 20                   | 4.57       | 22.9         | 0.200        |
| Marble                        | A20| 25                   | 3.8        | 21.6         | 0.176        |
| Cutting waste                 | A21| 5                    | 5.53       | 34.3         | 0.161        |
| waste                         | A22| 10                   | 5.23       | 35.4         | 0.162        |
| powder (CW)                   | A23| 15                   | 5          | 32           | 0.157        |
|                               | A24| 20                   | 5.13       | 29.9         | 0.163        |

$f_t$: flexural strength  $f_{cc}$: compressive strength

3.2. The Significance Analysis of Concrete Mix Ratio - The Range Analysis
Through calculation, the analytical table of 28d flexural strength of marble industrial powder concrete is obtained, which is shown in Table 6.
Table 6. Range analysis of 28d flexural strength

|   | Factor A | Factor B |
|---|----------|----------|
| $\bar{k}_{ij}$ | 5.936    | 5.588    |
| $k_{ij}$ | 5.264    | 5.54     |
| $k_{ij}$ | 5.3      | 4.996    |
| $k_{ij}$ | 4.854    | 4.77     |
| $k_{ij}$ | 5.126    | 4.354    |
| $R$ | 1.082    | 1.234    |

From the results of range analysis, it can be concluded that the primary and secondary order of the influencing factors of the 28d flexural strength of marble industrial powder concrete is B and A. That is, the substitution rate of marble powder plays a leading role, and the particle fineness of marble industry powder plays a secondary role.

3.3. The Influence Factor Level Analysis

In order to analyze more intuitively the influence of various factor levels on the 28d flexural strength of marble industrial powder concrete, the curves of the relationship between the level of each factor and the flexural strength of powdered concrete in marble industry were drawn, such as figs. 1 and figs. 2.

![Figure 1. The flexural strength with substitution rate](image1)

![Figure 2. The flexural strength with marble fineness](image2)

From the above figures, it can be found that with the increase of marble powder substitution rate (factor B), the 28 days flexural strength of the marble industrial powder concrete is decrease, and with the increase of powder fineness of marble industry (factor A), the 28 days flexural strength of marble industrial powder concrete decreased first and then increased. It was found that the optimum ratio is A1B1.
3.4. Comparison of Flexural Strength and Cube Compressive Strength of Marble Powder

From the data in Table 6, it can be seen that the flexural strength of the concrete with different fineness and substitution rate of marble industrial powder has obvious changes, and the flexural strength of all the specimens is lower than that of the control group. The flexural strength of 3000 mesh marble concrete decreases with the increase of the substitution rate of the concrete, and the value of the flexural strength is very close when the substitution rate exceeds 10%. The flexural strength of artificial marble waste powder concrete also showed a downward trend with the increase of the substitution rate, but the decrease range of the flexural strength first decreased and then increased, that is, the flexural strength decreased rapidly then slow down and then decreased rapidly. The flexural strength of other kinds of powdered concrete increases first and then decreases with the increase of the substitution rate, and the decreasing amplitude decreases with the increase of the substitution rate. The flexural strength of 600 mesh marble concrete with 10% substitution rate was 6.06 MPa, which was 1.6% lower than that of the control group, and the minimum flexural strength of 25% artificial marble waste concrete was 3.8 MPa, which was 38.3% lower than that of the control group. The change law is basically consistent with the change trend of concrete compressive strength.

Table 6 shows that the ratio of flexural strength to cube compressive strength of marble industrial powder concrete is about 0.16, and the average ratio value of measured flexural strength to cube compressive strength is 0.16.

4. Discussion

The reason for the change of flexural strength of pure powder concrete in marble industry is that when the inert calcite crystal replaces the cement, the effective cement-based composition in the concrete decreases and the water-binder ratio increases. The water-binder ratio is the most important factor affects the strength of concrete material, which leads to the lower flexural strength than the control group. In theory, the flexural strength of concrete mainly depends on the weakest tensile strength at the bottom of the concrete specimen, that is, the transition zone of aggregate interface. In fact, because of the existence of tiny cracks in concrete, the specimen is easy to develop from the tiny cracks when the specimen is destroyed. The calcite particles in the powder can be dispersed into the concrete system and filled in the cement particles under the condition of low content. The inert calcite crystal provides the crystal nucleus for the hydration of the cement. The inert calcite crystal provides the crystal nucleus for the hydration of the cement and forms a dense calcium silicate gel around the calcite crystal. The calcium silicate gel aggregates with each other and is filled with calcite. So that the concrete is more dense, the cement hydration effect is better, when the substitution rate is 5%, the marble powder is evenly diffused between the cement particles. But because of the limited amount of cement, the best filling effect can not be achieved. However, the increase of the degree of enrichment between cement particles decreases the internal porosity of concrete, so the flexural strength of 10% concrete is higher than that of 5%. 3000 mesh powder, and the decreasing trend is moderate. The main reason is that the particle size of 5um powder is too fine to fill between the particles of 30um, the amount of material needed for filling is large, but the quantity of filling can not meet the requirement of filling when the substitution rate of 30um is low, but the effective cement-based material is reduced when the filling effect is better when the substitution rate of 30um is high. As a result, its strength is decreasing. However, the flexural strength of artificial granite waste powder concrete is decreasing continuously, and the decreasing trend is accelerated with the increase of the substitution rate. The main reasons are as follows: first, the reduction of effective gelling materials increases the water-binder ratio, while macroscopically reduces its flexural strength. The other is that the long chain structure of the unsaturated resin of artificial granite waste powder results in the formation of low strength granular aggregates due to the agglomeration and isolation from cement paste.

5. Conclusions

Through the bending and compression tests of 26 marble industrial powder concrete specimens with different proportions, the following conclusions are obtained:
The concrete flexural strength is reduced by adding marble powder into the concrete. However, it can meet the requirement of engineering application when the substitution rate is less than 10%.

From the orthogonal test, the main factor affecting the flexural strength of marble industrial powder concrete is the amount of marble powder. The secondary factor is the fineness of marble powder. The effect of marble powder on the flexural strength and compressive strength of concrete is basically the same. The ratio of flexural strength to cube compressive strength of marble concrete with different substitution rate and fineness is 0.16.

6. Acknowledgement
This paper is Supported by Systematic Project of Guangxi Key Laboratory of Disaster Prevention and Engineering Safety (2019ZDX003).

7. References
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