Study on effect of mechanical sand on mechanical properties and fractal characteristics of mortar pore structure

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Abstract. The influence of stone powder content, fly ash and other factors on mechanical properties, pore structure and fractal dimension of machine-made sand mortar were studied, and the relationship between fractal dimension and mechanical properties of mortar was explored. The research shows that with the increase of the content of stone powder, the mechanical properties of mortar and the fractal dimension of pore structure of different sizes increase; the porosity and average pore size of the mortar decrease, and the ternary of cement-fly ash-stone powder The micro-particle system can effectively optimize the pore structure distribution of the mortar; the fractal dimension of the mortar using ordinary river sand is significantly smaller than that of machine-made sand under the same conditions; with the increase of the fractal dimension of the pore structure, the compressive strength and flexural strength of the mortar continue to increase Large, the fractal dimension and the macroscopic mechanical properties of the mortar show a good correlation.

1. Introduction

Concrete is a multiphase composite material in which aggregates are cemented into a whole by cementing materials, and its interior contains pores of different sizes. The characteristics of the meso-pore structure of a material are closely related to its mechanical properties, durability and other macroscopic properties. The meso-structure of the material determines the change of its macroscopic properties. The internal pore structure of concrete is extremely complex, and the macroscopic properties of the material are not only related to porosity, but also closely related to factors such as pore shape and pore size distribution. Traditional pore evaluation parameters cannot quantitatively describe the pore roughness of different scales. Fractal theory, as a new subject to evaluate the irregularity and complexity of objects, is introduced into the research of concrete pore structure, and the complexity of concrete pore structure is evaluated by fractal dimension. At present, many fractal models are used to characterize the pore properties of materials. The more classic fractal models include space filling model, Menger sponge model, and thermodynamic relationship fractal model. Due to the different physical meanings of fractal dimensions and model construction methods between different models, many research results are quite different. Studies have shown that there are large differences in the relationship between the calculated pore fractal dimension and material properties [1-3]. However, for the remote mountainous areas in southwest my country, river sand resources are relatively scarce. The use of local ore to prepare machine-made sand for the construction of engineering projects can effectively solve the problem. The practical problem of insufficient natural river sand [4-6]. The surface of machine-made sand is rough and angular, which is significantly
different from the round and smooth appearance of river sand, which makes the pore structure characteristics of cement-based materials prepared from machine-made sand different from ordinary river sand. Therefore, based on the pore structure test data of mortar mercury intrusion test, this paper compares and analyzes the influence of machine-made sand mortar and river sand mortar on the fractal dimension of pore structure, and discusses the relationship between fractal dimension and pore structure parameters and mechanical properties of mortar.

2. Raw materials and test methods

2.1. Raw materials

The physical and mechanical performance indexes of cement are shown in Table 1; the indexes of fly ash are shown in Table 2, which meets the specification for grade I fly ash. The fine aggregate is made of sandstone machine-made sand produced by the quarry, with a fineness modulus of 2.7, a stone powder content of 5%, an MB value of 1.2, and a specific surface area of 303cm²/g; see the chemical composition of sandstone powder and fly ash table 3.

| Table 1. Physical and mechanical performance of cement |
|-----------------------------------------------|
| Parameter                                    | Value |
| Water consumption for standard consistency (%) | 24.8  |
| Free calcium oxide (%)                       | 1.2   |
| Specific surface area (cm²/g)                | 364   |
| density (g/cm³)                              | 3.23  |
| SO₃ (%)                                      | 2.7   |
| Cl⁻ (%)                                      | 0.01  |
| Alkali content (%)                           | 0.42  |
| MgO (%)                                      | 1.2   |
| Ignition loss (%)                            | 2.81  |
| Setting time (min)                           | 135   |
| Compressive strength (MPa)                   | 203   |
| 3d                                           | 26.5  |
| 28d                                          | 51.0  |

| Table 2. Properties of Fly Ash |
|---------------------------------|
| Parameter                      | Value |
| Fineness (%)                   | 9.3   |
| Water demand ratio (%)         | 90    |
| Ignition loss (%)              | 1.94  |
| Specific surface area (cm²/g)  | 311.4 |
| density (g/m³)                 | 2.19  |
| SO₃ (%)                        | 0.45  |
| Cl⁻ (%)                        | 0.007 |
| Water content (%)              | 0.17  |

| Table 3. Chemical composition of fly ash and sandstone powder |
|--------------------------------------------------------------|
|                  | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO   | MgO   | Na₂O  | K₂O  | SO₃  | IL   |
| Fly ash          | 48.91 | 28.05 | 8.85  | 2.65  | 1.03  | 0.78  | 2.08 | 0.45 | 1.94 |
| Stone powder     | 55.11 | 12.83 | 7.84  | 5.84  | 1.81  | 2.70  | 2.10 | 0.35 | 10.01|

2.2. Mix ratio of mortar

The mixing ratio of the influence of stone powder on the performance of mortar is shown in Table 4. A1~A4 are sandstone machine-made sand. Since the stone powder content of machine-made sand is 5%, A1 is directly prepared by machine-made sand. The other three groups are prepared by sieving 8%, 11% Stone powder content of machine-made sand. A5 is ordinary river sand. The fineness modulus of river sand is 2.7, which is the same as that of machine-made sand.

| Table 4. Mortar mix proportion |
|---------------------------------|
| Numbering | cement (kg) | Fly ash (kg) | sand (kg) | water (kg) | Stone powder content (%) |
| A1        | 450         | —            | 1350      | 225        | 5                       |
| A2        | 450         | —            | 1350      | 225        | 8                       |
| A3        | 450         | —            | 1350      | 225        | 11                      |
### 2.3. Experimental test

According to "Cement Mortar Strength Inspection Method" (GB/T 17671-1999), the mortar and pure mortar samples were subjected to standard curing, and the 7-day and 28-day compressive strength and flexural strength of the mortar samples were measured, and the 1.5-year-old test The compressive strength of the mortar during the period. At the age of 28 days, after testing the mechanical properties of the mortar, take the core of the cement mortar, dry it in a vacuum drying oven at 105°C for 24 hours, cool it in a vacuum dryer, and then conduct MIP analysis.

### 3. Results and discussion

#### 3.1. The influence of stone powder and fly ash on the mechanical properties of mortar

The influence of stone powder and fly ash on the mechanical properties of mortar is shown in Figure 1.

![Figure 1. Influence of stone powder and fly ash on mechanical properties of mortar](image)

It can be seen from Figure 1 that with the increase of stone powder content, the mechanical properties of machine-made sand mortar at different ages have increased. Under the premise of the same mortar mix ratio, when the stone powder content in machine-made sand increases from 5% to 11%, the machine-made sand The compressive strength of the mortar at the age of 1.5 years increased by 7.9 MPa. In addition, sandstone powder has a certain influence on the development of early mechanical properties of mortar. Machine-made sandstone powder can accelerate the early hydration of mortar. When the content of stone powder is 5-11%, the 7-day compressive strength of the mortar has reached 28 days. 90% of A5 ordinary cement mortar is only 81%, indicating that sandstone powder can promote the early hydration process of cement-based materials. In addition, the addition of fly ash to the cementitious material has a greater impact on the mechanical properties of machine-made sand for 7 days, but the impact on the 28-day age is not significant, especially at the age of 1.5. The mechanical properties of coal ash mortar are significantly improved, which is 17.9 MPa higher than that of A2 without fly ash, which is much higher than that of machine-made sand mortar without fly ash. This is mainly due to the low pozzolanic activity of fly ash in the early stage. It mainly reflects the micro-aggregate effect and the particle filling effect, while the later period is the volcanic ash effect. The mechanical properties of machine-made sand mortar of different ages are obviously better than those of cement mortar prepared from ordinary river sand, which may be due to the granular effect of machine-made sand.

#### 3.2. Influence of stone powder and fly ash on mortar pore structure

The influence of stone powder and fly ash on mortar pore structure is shown in Figure 2.
It can be seen from Figure 2 that in the range of 5-11% of sandstone machine-made sand and stone powder content, with the increase of sandstone powder content, the porosity and average pore size of the mortar will decrease. From the perspective of the distribution of pore structure, with the increase of the content, the harmful pores and less harmful pores are reduced, while the gel pores continue to increase, indicating that sandstone powder can refine the pore structure and optimize the pore structure distribution of cement-based materials. Compared with pure Portland cement mortar, the porosity of cement-fly ash composite cement mortar A4 is larger than that of pure cement mortar A2, but the most probable pore size, average pore size and median pore size are significantly reduced. It shows that the ternary microparticle system of cement-fly ash-stone powder has a good particle accumulation effect and can effectively optimize the pore structure distribution of mortar. The porosity and average pore diameter of the mortar prepared from ordinary river sand are significantly larger than the other four machine-made mortars. The harmful pores larger than 200nm increase, and the gel pores smaller than 20nm decrease. The mechanical properties of machine-made sand are better than those of ordinary river sand mortar. In addition to the coarse particles of machine-made sand, which increases the bite force with the hydration products of the cementing material, the finer effect of the stone powder in the machine-made sand on the pore structure of the mortar also improves the mechanical properties of the mortar. One of the important reasons.

3.3. The influence of stone powder and fly ash on the fractal dimension of mortar

The influence of stone powder and fly ash on the fractal dimension of mortar is shown in Figure 3.

From the analysis of Figure 3, it can be seen that: (1) The fractal dimension of pore structure of mortar increases with the increase of the stone powder content in random sand making. Compared with the pore fractal dimension of pore size >200nm and <20nm, the stone powder content is 20 The influence of the fractal dimension of the pore structure of ~200nm is more significant. This conclusion is different from Arandigoyen et al.[7-8]. It is believed that the integral shape dimension of the pore surface decreases with the increase of the lime content in the mortar. %, while the cementitious material in this paper is kept constant, stone powder is only considered as fine particles in
machine-made sand. (2) Under the premise of a certain sandstone powder content, the composite cementing material mortar with 30% fly ash equivalent to replace the cement, the fractal dimension of the pore structure of different sizes is greater than the fractal dimension of the same condition mortar A2; (3) The fractal dimension of mortar pore structure is related to the pore size. The fractal dimension of large pores is larger than that of small pores, which is consistent with the research conclusions of Ji et al. [9]. (4) For the mortar A1~A4 with machine-made sand, the fractal dimension of the pore structure is generally larger than that of the mortar prepared by river sand. This may be due to the rough surface of machine-made sand particles and multiple edges, which makes the pore structure of the slurry more complex.

3.4. The relationship between the fractal dimension of pore structure and the mechanical properties of mortar

The relationship between the fractal dimension of pore structure and the mechanical properties of mortar is shown in Figure 4.

![Figure 4](image_url)

Figure 4. The relationship between the fractal dimension of pore structure and the mechanical properties of mortar

The pore structure characteristics of materials are closely related to their mechanical properties. Figures 4 show the relationship between the fractal dimension of the pore structure and the 28-day compressive strength and flexural strength of the mortar. From the analysis of Figures 4, it can be seen that with the increase of the fractal dimension of the pore structure of different pore diameters, the compressive strength and flexural strength of the mortar are generally increasing; the size of the fractal dimension reflects the roughness of the surface of different pore diameters. The larger the fractal dimension, the greater the pore size. The rougher the surface of the structure, the rougher pores can effectively disperse the stress concentration caused by external loads on the pore surface. Therefore, the fractal dimension of the pore structure can better characterize the macro-mechanical properties of cement-based materials.

4. Conclusion

(1) When the content of machine-made sand and gravel powder is in the range of 5~11%, with the increase of the content of powdered stone, the compressive strength and flexural strength of the mortar continue to increase. Fly ash has a certain effect on the early mechanical properties of the mortar, but the mechanical properties of the mortar are significantly improved at the age of 1.5, and the mechanical properties of the machine-made sand mortar are significantly better than the cement mortar prepared from ordinary river sand.

(2) With the increase of the stone powder content, the porosity and average pore size of the mortar are reduced, and the ternary micro-particle system of cement-fly ash-stone powder has a good particle accumulation effect, which can effectively optimize the pores of the mortar Structure distribution.

(3) With the increase of stone powder content, the fractal dimension of pore structure of mortar continues to increase; the fractal dimension of machine-made sand mortar is significantly greater than
that of ordinary river sand mortar. Compared with mortar without fly ash, fly ash is used It can significantly increase the fractal dimension of >20nm holes.

(4) With the increase of the fractal dimension of the pore structure, the compressive strength and flexural strength of the mortar continue to increase; the fractal dimension shows a good correlation with the macroscopic mechanical properties of the mortar.

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