Study on Compressive Strength of Concrete Mixed by Steel Slag Powder and Fly Ash

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Abstract. Using steel slag powder and fly ash to replace cement can promote the secondary utilization of industrial solid waste and protect the ecological environment. Besides, fly ash can save costs, improve workability and improve the later strength of concrete. Four groups of concrete test blocks were tested by the combination of the two to replace cement, and the concrete appearance and compressive strength of the test blocks in different periods were tested. The experimental results show that: 1. Under the premise that the total amount of composite substitution is 40%, increasing the content of steel slag powder can effectively improve the compressive strength of concrete, but excessive addition and substitution will make it counterproductive. 2. Steel slag is regarded as overburned Portland cement clinker, which can be used as auxiliary cementing material to improve the activity of cement, while fly ash can improve the workability of concrete and improve the later strength of concrete. 3. The recommended optimal composite substitution ratio is cement: steel slag powder: fly ash = 12:5:3.

1. Introduction
Environmental pollution has been around the whole society, and has been put on the agenda by various countries. With the rapid development of China's industry and the revitalization of the old industrial base in Northeast China, the industrial solid waste represented by steel slag, slag and fly ash will inevitably grow rapidly[1]. Using fly ash as cementitious materials to prepare concrete can improve the workability of concrete, reduce the heat of hydration, and improve the later compressive strength and durability. Steel slag is regarded as overburned Portland cement clinker because of its hydraulic cementitious products, dicalcium silicate and tricalcium silicate, which can be used as auxiliary cementitious materials. These industrial wastes can replace part of cement clinker and improve the activity of cement[2]. Concrete, with its characteristics of high strength, long life and high bearing capacity, has become a widely used material in civil engineering, and has been widely used[3] in construction[4], road[5] and other fields. At present, China's annual production of concrete is more than 2 billion m³. Adding industrial solid waste into concrete to replace cement and other cementitious materials can improve the comprehensive utilization rate of solid waste, effectively protect the environment and meet the national sustainable development strategy, and has become a hot topics of research[6]. Based on this, this paper takes the solid waste of iron and steel industrial - grinding fine steel slag powder, coal solid wastes – grade II fly ash as the research object, on the premise of guarantee the quality of engineering, through literature analysis and test research, composite substitute part of cement equally and try to match the concrete, the compressive strength test, put forward the best mixture ratio of the composite cement replaced by steel slag powder and fly ash, and the compressive strength of the concrete mixed formula with correction coefficient.
2. Test materials and Plans

2.1. Test materials

Steel slag powder and fly ash composite substitute cementitious material to prepare concrete, whose property is green concrete. First of all, the code for "design of proportion of ordinary concrete" (JGJ55-2011) was selected to select the test materials.

(1) natural coarse aggregate: the gravel of Yanji city, Jilin province with a grain size of 5-20mm continuous grading was selected;
(2) natural fine aggregate: river sand from Yanji city, Jilin province;
(3) fly ash: grade II fly ash by Tienan heating company, Yanji city, Jilin province;
(4) cement: the "Miaoling" brand ordinary Portland cement produced by Jilin North Cement Co., Ltd. was selected with the strength grade of 42.5Mpa;
(5) steel slag powder: steel slag powder produced by Qiqihar JiangHua Building Materials Manufacturing Co., Ltd.
(6) water: tap water.

Slump and extension degree are important indexes to evaluate the fluidity, water retention and cohesion of concrete mixtures. This method is simple, practical and convenient for field operation. This test was carried out in "Standard for performance test methods of ordinary concrete mixtures" (GB/T50080-2016).

2.2. Concrete mix design

In order to study the effect of steel slag powder and fly ash on the strength and performance of concrete, According to the formula for strength of concrete preparation in accordance with "Specification for mix proportion design of ordinary concrete" (JGJ55-2011):

\[ f_{cu,0} = f_{cu,k} + 1.645\sigma \]

Among them:
- \( \sigma \) —— Standard deviation of concrete compressive strength (N/mm²);
- \( f_{cu,0} \) —— Concrete preparation Strength (N/mm²);
- \( f_{cu,k} \) —— Standard value of compressive strength of concrete cube (N/mm²).

Concrete specimens with different amounts of steel slag powder and fly ash were prepared, as shown in table 1.

Under the condition that 40% of cement was replaced by steel slag and fly ash, the content of steel slag powder and fly ash is 20%, 25%, 30% and 40% respectively, while the content of fly ash is 20%, 15%, 10% and 0% respectively. The water-cement ratio was all 0.4. After preparation, the compressive strength of concrete with different amounts of steel slag powder and fly ash was tested according to "Standard for test method of mechanical properties on ordinary concrete" (GB/T50081-2002) and "Standard for test methods of long-term performance and durability of ordinary concrete" (GB/T 50082-2009). The compressive strength was tested on 3d, 7d, 28d and 56d respectively, so as to focus on the study of later strength variation rule and the determination of the optimum mix ratio. The design of test mix ratio is shown in Table 1, and the analysis of cementing material content is shown in Fig. 1.
| Test number | Cement | Steel slag powder | Fly ash | Gravel | River sand | Water | Water/cement ratio | Note                                 |
|-------------|--------|-------------------|---------|--------|------------|-------|-------------------|--------------------------------------|
| D1          | 240    | 80                | 80      | 1159.2 | 680.8      | 160   | 0.4               | Steel slag powder20%,
|             |        |                   |         |        |            |       |                   | Fly ash20%                           |
| D2          | 240    | 100               | 60      | 1159.2 | 680.8      | 160   | 0.4               | Steel slag powder25%,
|             |        |                   |         |        |            |       |                   | Fly ash15%                           |
| D3          | 240    | 120               | 40      | 1159.2 | 680.8      | 160   | 0.4               | Steel slag powder30%,
|             |        |                   |         |        |            |       |                   | Fly ash10%                           |
| D4          | 240    | 160               | 0       | 1159.2 | 680.8      | 160   | 0.4               | Steel slag powder40%,
|             |        |                   |         |        |            |       |                   | Fly ash0%                            |

2.3. Test process and analysis
(1) Due to the angular characteristics of steel slag, it will increase the difficulty of concrete mixing and reduce the workability of concrete, thus causing many adverse effects on concrete. Therefore, steel slag powder is used instead of steel slag in the test.
(2) Because the fine density of steel slag powder is small, it can fill the concrete in the mixing process. According to its physical properties, masks should be worn during the actual mixing process to prevent excessive inhalation.
(3) After the steel slag is mechanically ground to fine, the original crystal structure can be changed to increase the activation energy of the particle surface, which can be used as the active material of cement or cement concrete. In addition, steel slag powder has good fluidity, durability, volume stability and alkali resistant aggregate reaction. Adding steel slag powder to concrete can improve the workability of concrete and eliminate alkali aggregate reaction.

3. Test detection and analysis
3.1. Slump analysis
Through the slump test, it can be concluded that under the condition of constant water-cement ratio control, the slump under the mixture ratio of D1 to D4 is 172mm to 180mm. The slump test is shown in Fig. 2.
Under the condition that steel slag powder and fly ash are mixed to replace cementing material, the workability of concrete is good and there is no bleeding. The addition of steel slag powder is beneficial to improve the performance of fresh concrete. Because of its small specific surface area, steel slag powder can change the pore size and distribution of the hydrated matrix, form a smooth moving surface between the cement paste, and play a positive role in the fluidity of the paste. As a result, compared with the concrete without steel slag powder, the concrete with it can improve the workability and increase the slump.

3.2. Concrete appearance and compressive strength of test block

3.2.1. Appearance analysis of test block
D4 concrete test blocks with steel slag powder instead of cement are shown in Fig. 3, and concrete test blocks with steel slag powder and fly ash instead of cement are shown in Fig. 4.

By comparing Fig. 3 and Fig. 4, it can be found that the concrete test block mixed with steel slag powder has more bubbles and poor surface flatness. However, the surface of the concrete using steel slag powder and fly ash to replace cement is smooth, and the number of honeycomb is obviously reduced.

3.2.2. Compressive strength analysis of test block
The compressive strength test of concrete test block is shown in Fig. 5.

The relationship between compressive strength and age of D1 concrete test block is shown in Fig. 6.
According to the relationship between compressive strength and age of group D1 in Fig. 5 and Fig. 6, the concrete strength replaced by steel slag powder and fly ash composite meets the quadratic fitting curve equation \( y = 10.11357 + 1.35212x - 0.01576x^2 \) with age, and \( R^2 = 0.95813 \).

The relationship between strength and age of test concrete blocks in groups D1, D2, D3 and D4 is shown in Fig. 7, and the relationship between compressive strength and age in group D4 is shown in Fig. 8.

As can be seen from Fig. 7, in the comparison of groups D1, D2, D3 and D4, it was found that the strength growth rate of concrete test blocks in groups D1, D2 and D3 mixed with steel slag powder and fly ash was higher than that in group D4 mixed with steel slag powder alone.

Compressive strength tests were carried out on concrete test blocks at the age of 3d, 7d, 28d and 56d respectively. As can be seen from Fig. 7 and Fig. 8, the initial strength of concrete test blocks in group D4 mixed with steel slag powder instead of cement was significantly lower than that of the first three test blocks. Among them, the strength of concrete in Group D4 with only steel slag powder instead of cement satisfies the quadratic fitting curve equation \( y = 10.40573 + 0.81158x - 0.00828x^2 \) with age, \( R^2 = 0.99241 \).

The relationship between compressive strength and age of D2 concrete test block is shown in Fig. 9.

The relationship between compressive strength and age of D3 concrete test block is shown in Fig. 10.
Fig. 9 Relationship between compressive strength and age in group D2

As can be seen from Fig. 9, when the substitution rates of steel slag powder and fly ash are 25% and 15% respectively, the initial strength of concrete decreases slightly, and the later strength increases significantly when fly ash is added. In the Group D2, the concrete strength of the composite replacement cement with steel slag powder and fly ash satisfies the quadratic fitting curve equation $y=13.76727 +1.41365x -0.01596x^2$ with age, $R^2$ is 0.94046.

As can be seen from Fig. 10, when the substitution rate of steel slag powder exceeds 25% and reaches 30%, the strength of concrete decreases significantly and the later growth rate is small.

In Group D3, the strength of concrete composite substitute cement with steel slag powder and fly ash meets the quadratic fitting curve equation $y=11.63898+0.90243x-0.00953x^2$ with age development law, $R^2$ is 0.94046.

By Fig. 6, 9 and 10, contrast analysis of D1, D2 and D3 three groups of test data, and replace the cement mixed with steel slag powder is greater than or equal to 30%, the rate will reduce the compressive strength of concrete increase, but when the amount of cementitious material for cement: steel slag powder: fly ash = 12:5:3, concrete strength growth rate is the most ideal, and the compressive strength is the largest. The compressive strength value at 28d is 39.65mpa, which is 8.58mpa different from the strength value of concrete preparation calculated in formula (1). The maximum strength at 44d is 45.06mpa, which is close to the strength of concrete preparation calculated in formula (1). Therefore, on the basis of formula (1), the following strength formula for composite mixed concrete with a correction coefficient of 0.822 is put forward:

$$\sigma_{fu,0} = \left(\sigma_{fu, k} + 1.645\sigma\right) \times 0.822 \quad (2)$$

In the actual project, Group D2 is selected as steel slag powder and fly ash composite substitute cement to achieve the best substitution rate of green concrete.

Because steel slag powder itself has activity, mixing into concrete will affect the mechanical properties of concrete. When steel slag powder is mixed into concrete instead of part of cement with the same amount, the early 3d average strength of steel slag concrete will be improved slightly compared with ordinary concrete, but the 7d and 28d average strength will be significantly improved compared with ordinary concrete. The strength growth rate in the later stage is lower than that in the early stage, but the average strength of 56d is still significantly higher than that of ordinary concrete. This is because the activity of steel slag powder is relatively lower than that of cement, and its hydraulic hardness can be better developed in the later period. With the increase of mixing amount, the strength of steel slag powder decreases more obviously. By mixing with fly ash, it plays the role of mutual excitation and activation and makes the composite effect better, thus the mechanical properties of concrete can be improved.

4. Conclusion

(1) Compared with mixed steel slag powder and fly ash substituting cement with the same amount,
only mix steel slag powder makes the concrete test block has more bubbles and honeycomb in appearance, worse surface flatness, lower compressive strength growth rate, and significantly more cracks during pressure test.

(2) By substituting cement equally with steel slag powder and fly ash improve the workability of concrete and its appearance. As the content of steel slag powder increases, the strength of concrete will gradually increase, but the substitution amount will decline if it exceeds 25%. Therefore, the optimal substitution rate suggested in this paper is 25%. And the addition of fly ash could improve the late compressive strength, thus the optimal substitution rate suggested in this paper is 15%.

(3) on the basis of the current design rules for the mix ratio of ordinary concrete, a strength formula for composite mixed concrete with a correction coefficient of 0.822 is put forward in this paper.

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