Study on Mix Proportion Design and Compressive Strength of Environment-Friendly Three-Admixture Concrete

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Abstract: In this paper, the environment-friendly three-admixture concrete was prepared by using straw powder (rice husk powder) to replace cement by 6% and 8%, silicon powder by 10% and fly ash by 20%, respectively, and the effects of straw powder (rice husk powder), silicon powder and fly ash on the compressive strength of concrete were studied. Through the comparative analysis of the compressive strength of 9 groups three-mixed concrete blocks, the compressive strength of concrete reached the highest when the content of straw powder (rice husk powder) was 6%. On the basis of the current mix design formula of ordinary concrete, the strength formula of environment-friendly three-mixed concrete with correction coefficient was given, and the optimum substitution amount of straw powder (rice husk powder) was put forward.

1. Introduction

As a great agricultural country in the world, China is rich in crop resources. However, the amount of straw resources, the waste after the crop production in China, occupies the first place in the world and the utilization rate of them only reaches 33%. Since 1994, although the amount of straw produced in China has fluctuated, it has shown an overall upward trend, which should exceed 640 million tons up to now, and a large amount of straw waste cannot be utilized. A large amount of straw is used as heating fuel for burning or landfill in rural areas, and the waste gas produced by burning not only pollutes the environment, but also wastes resources, which affects human life and comfort. Moreover, stacked straw is easy to cause fire, burning straw will cause double pollution of environment and atmosphere, so how to use straw reasonably and environmentally has important practical significance.

Li Jinghui, et al. [1] studied the reliability of building application of straw environmental protection materials and the application performance of straw in building materials, and concluded that adding a certain proportion of plant fiber into cement can improve the toughness, heat preservation and fracture resistance of materials; Li Chaofei, et al. [2-4] added rice straw to experimental concrete, and made a series of studies and found that it has good mechanical properties. At the same time, the present research situation of straw plant fiber in concrete was introduced. Geng Rui, et al. [5] explored the mechanical properties of straw fiber reinforced concrete in Sichuan area, and found that the water consumption of strip straw was slightly larger than that of powdered straw, and the compressive strength of the specimen reached the maximum when 6% rape straw powder and fly ash were mixed into the experimental concrete. Literature generally uses single straw powder to study its influence on mechanical properties, and straw composition is slightly different due to regional influence, and straw size and shape are also different. Therefore, this paper selected four kinds of ground fibers, such as corn straw powder, wheat straw powder, rice straw powder and rice husk powder, and mixed them with fly ash and silicon powder at 6% and 8%, respectively, to study their influence on the compressive strength of environment-friendly...
three-mixed concrete, and put forward the best mixing amount.

2. Test Materials and Schemes

2.1. Test materials
1) Silicon powder: 92% domestic silicon powder of Henan Borun Casting Material Co., Ltd.;
2) Corn straw powder: the experimental powder of 20 mesh broken corn stalk powder produced by Surui Straw Processing Factory;
3) Wheat straw powder: 20 mesh crushed wheat straw experimental material straw powder produced by Surui Straw Processing Factory;
4) Dry straw fiber rice straw: produced by Yutai Jiayao Agricultural Products Co., Ltd, and the specification is 0.5-1;
5) Grinding rice husk: 80 mesh low moisture dried and dust removed rice husk powder produced by Chutian bran powder processing factory in Badong County, Enshi Prefecture, Hubei Province;
6) Cement: "Miaolong" brand P.O 42.5 grade cement produced by Jilin North Cement Company is adopted;
7) Coarse and fine aggregate:
   Natural crushed stone: the maximum particle size is 20 mm, the apparent density is 2680 kg/m³, and the water content is 0%;
   Natural sand: medium sand with qualified gradation, apparent density of 2600 kg/m³ and water content of 0%;
8) Fly ash: fly ash produced by Tienan Heating Company in Yanji City, Jilin Province;
9) Water reducer: polycarboxylic acid water reducer from the northern building materials market
10) Water: tap water.

2.2. Test scheme
1) Design indicators
   The design strength grade of green environment-friendly three-mixed concrete and ordinary concrete is C30. The slump required by construction is T = 30-50 mm and sand ratio Sp = 35%.
2) Maintenance conditions
   The concrete block is placed in a standard curing room with a temperature of 20 °C and a relative humidity of over 80%.
3) Manufacture of test block
   A total of 9 groups of test blocks were made, and the group 1 was the concrete control group mixed with fly ash and silica fume; In the groups 2 to 5, straw powder was used to replace cement by 6%. In groups 6 to 9, straw powder was used to replace cement by 8%. Among them, the group 2 and the group 6 selected corn straw powder while wheat straw powder was used in the third and seventh groups. The fourth and eighth groups selected straw powder while rice husk powder was used in the group 5 and 9. All the 9 groups of test blocks used fly ash to replace cement by 20% and silica fume to replace cement by 10%.
4) Preparation strength and mixture ratio
   Refer to the Code for Mix Proportion Design of Ordinary Concrete (JGJ55-2011) of concrete preparation strength formula:
   \[ f_{cu,0} = f_{cu,k} + 1.645\sigma \] (1)
   In which:
   \( \sigma \) —— standard deviation of concrete strength (N/mm²);
   \( f_{cu,0} \) —— preparation strength of concrete (N/mm²);
   \( f_{cu,k} \) —— standard value of compressive strength of concrete cube (N/mm²).
   According to calculation, the mixing ratio of 1 m³ ordinary concrete is 215.6:201.6:684.26:1272.73 (cement: water: sand: gravel). Table 1 shows the material test coordination of straw powder (rice husk powder), silicon powder and fly ash.
Table 1. Test mix ratio of concrete materials (mixing amount is 33L)

| group | Cement /kg | Water /kg | sand /kg | Natural crushed stone /kg | Silica fume /kg | Fly ash /kg | Straw powder (rice husk powder) /kg |
|-------|------------|-----------|----------|---------------------------|----------------|-------------|-----------------------------------|
| 1     | 7.11       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0                                 |
| 2     | 6.69       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.43                              |
| 3     | 6.69       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.43                              |
| 4     | 6.69       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.43                              |
| 5     | 6.69       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.43                              |
| 6     | 6.55       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.57                              |
| 7     | 6.55       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.57                              |
| 8     | 6.55       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.57                              |
| 9     | 6.55       | 6.65      | 22.58    | 42.00                     | 1.02           | 2.03        | 0.57                              |

Note: Group 1: 0% straw powder; Group 2: 6% corn straw powder; Group 3: 6% wheat straw powder; Group 4: 6% straw powder; Group 5: 6% rice husk powder; Group 6: 8% corn straw powder; Group 7: 8% wheat straw powder; Group 8: 8% straw; Group 9: 8% rice husk powder

3. Test Equipment and Tests

3.1 Test and detection

1) slump test

The test results of slump test are shown in Table 2.

Table 2. Slump test results

| Group | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Slump | 40  | 33  | 36  | 30  | 38  | 32  | 34  | 31  | 42  |

Slump test and block making are shown in Figure 1. There will be systematic errors between the test values of concrete blocks and the prepared strength values due to the mixing of ground straw, silica fume and fly ash. The concrete was prepared with reference to the formula of the prepared strength of ordinary concrete, the unsatisfactory artificial vibration and curing conditions.

A) slump of ordinary concrete

B) vibrating screeding

Figure 1. Slump test and block making

2) Compressive strength test

After 7 days, 28 days and 56 days, the test blocks were tested at the rate of 3 kN/s on the press of Yanbian University Civil Experiment Center. The compressive strength test values of concrete test blocks are shown in Table 3.
Table 3. Test results of compressive strength of concrete block

| Group | 7d/MPa | 28d/MPa | 56d/MPa |
|-------|--------|---------|---------|
| 1     | 26.2   | 32.7    | 34      |
| 2     | 16.3   | 20.5    | 23.7    |
| 3     | 15.3   | 17.5    | 18.6    |
| 4     | 9.5    | 11.4    | 12.5    |
| 5     | 18.4   | 22.5    | 25.5    |
| 6     | 11.3   | 14.7    | 17.4    |
| 7     | 7.2    | 10.7    | 13.8    |
| 8     | 3.9    | 7.7     | 9.1     |
| 9     | 12     | 16.7    | 17.8    |

The group 5, i.e., when the equivalent amount of substitute cement is 6% of rice husk powder, 10% of silicon powder and 20% of fly ash respectively, the compressive strength of the three-mixed concrete is obviously improved compared with other groups, the strength growth rate is the best, and the compressive strength is the highest in 56 days. On the basis of formula (1), the correction formula of concrete preparation strength with correction coefficient of 0.7249 is put forward as follows:

$$f_{cu,0} = (f_{cu, k} + 1.645\sigma) \times 0.7249$$

(2)

3.2. Relationship between specimen strength and age

1) Fitting curve equation

The test results are shown in Table 3. The above test values are fitted by Origin software, and the relationship between specimen strength and age is shown in Fig. 2.

![Figure 2. Relationship between specimen strength and age of concrete](image)

As shown in Figure 2, the Group 1 is the control group, that is, when the straw powder (rice husk powder) is equal to 0% of cement, the relationship between the age and compressive strength of the concrete can meet the fitting equation $y_1=20.78755x^{0.12664}$, ($R^2 = 0.96$). In Group 2, when 6% of cement is replaced by corn stalk powder, the relationship between the age and compressive strength of the concrete can meet the fitting equation $y_2=11.39627x^{0.18019}$, ($R^2 = 1$). In Group 3, the relationship
between the age and the compressive strength of the concrete can meet the fitting equation \( y_3 = 12.75432 \times x^{0.09412}, \) (\( R^2 = 1 \)). In Group 4, when the same amount of straw powder replaces cement by 6%, the relationship between the age and the compressive strength of the concrete can meet the fitting equation \( y_4 = 7.34711 \times x^{0.13196}, \) (\( R^2 = 1 \)). In Group 5, the relationship between the age and compressive strength of the concrete can meet the fitting equation \( y_5 = 13.4867 \times x^{0.15682}, \) (\( R^2 = 1 \)). In Group 6, the relationship between the age and compressive strength of the concrete can meet the fitting equation \( y_6 = 7.46281 \times x^{0.20831}, \) (\( R^2 = 1 \)). In Group 7, when 8% of cement is replaced by wheat straw powder, the relationship between the age and compressive strength of the concrete can meet the fitting equation \( y_7 = 3.8109 \times x^{0.31712}, \) (\( R^2 = 1 \)). In Group 8, when the same amount of straw powder replaces cement by 8%, the relationship between the age and compressive strength of the concrete can meet the fitting equation \( y_8 = 1.98297 \times x^{0.38578}, \) (\( R^2 = 0.97 \)). In Group 9, the relationship between the age and the compressive strength of the concrete can meet the fitting equation \( y_9 = 8.52891 \times x^{0.18854}, \) (\( R^2 = 0.96 \)).

2) Experimental analysis

According to the comparative analysis of each group in Figure 2, adding straw powder (rice husk powder) can reduce the compressive strength of concrete, and with the increase of straw powder (rice husk powder), the compressive strength of concrete shows a downward trend.

Through the comparative analysis of groups 2-5 and 6-9, it can be concluded that the priority of straw powder (rice husk powder) replacing cement in equal amount is: rice husk powder > corn straw powder > wheat straw powder > rice straw, and in Group 5, when the content of rice husk powder is 6%, the compressive strength is the best.

4. Conclusions

1) Excessive amount of straw powder (rice husk powder) is unfavorable to the development of concrete compressive strength. The appropriate addition of straw powder can meet the requirements of compressive strength of concrete and reduce the cost.

2) The priority of replacing cement was rice husk powder > corn straw powder > wheat straw powder > rice straw. The content of fitting curve equation is refined.

3) The results show that the optimum mixing ratio of three additives is 6% rice husk powder, 20% fly ash and 10% silica fume. This kind of environment-friendly concrete can be used in the reconstruction of existing buildings and new projects in cold and severe cold areas.

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