Experimental study on Mechanical Properties of green and environmental friendly self-compacting recycled concrete

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Abstract: By replacing cement with 5% of ground rice husk powder, 4% of corn stalk powder and 30% of fly ash, and replacing natural aggregate with 25% recycled aggregate, the Mechanical Properties of green and environment-friendly self-compacting recycled concrete were studied. The experimental results show that the early strength of the concrete is lower than the common self-compacting concrete. However, the strength of 56 days is up to the design requirement and the volume stability is good. According to the test value of the compressive strength of the concrete block, the curve equation of the relationship between the compressive strength and the age is put forward, and it provides a reference for similar concrete mix proportion design.

1. Introduction
The research of self-compacting concrete in China is relatively late compared with other countries. The research and application of self-compacting concrete began in the early 1990s. At present, China is deeply studying the improvement technology of self-compacting concrete. Zheng Huaxin [1] proposed that under the premise of meeting the same quality requirements, self-compacting concrete is more material saving, money saving, time saving and labor saving compared with ordinary concrete. Therefore, it is of great significance to study self-compacting concrete. With the development of the times, more and more attention has been paid to the research of green environment-friendly concrete and its structural design and construction. Among the components of ordinary self-compacting concrete, replacing part of cement and natural aggregate with agricultural and industrial wastes in equal amount is the focus of research on green self-compacting concrete.

Rice hulls, the waste left over from rice processing, are seen as a cheap fuel. However, this kind of treatment not only causes pollution to the environment, but also is a huge waste of resources, which is not in line with the concept of sustainable development. Rice husk powder is a kind of active material of volcanic ash with excellent performance. The main component of it is SiO₂ gel particles. Huang [2] et al. showed that rice husk powder can enhance the compressive strength and permeability resistance of concrete. Corn straw is one of the main raw materials of roughage for livestock, which is rich in nutrients and available chemical components. It can be used as a good building insulation material, and because of its light weight, it can effectively reduce the self-weight of building materials. Chen Deng [3] showed that straw would reduce the compressive strength and thermal conductivity of concrete, and the performance of concrete mixed with straw powder was better than that of concrete mixed with straw strips. Recyclable aggregate is the stone material obtained by crushing concrete of construction waste. Liu Zhilong [4] et al. showed that the greater the replacement rate of recycled aggregate is, the smaller
the fluidity of concrete is. The compressive strength of concrete decreases with the increase of aggregate replacement rate. De Brito [5] et al. pointed out that when the replacement rate of recycled aggregate is less than 25%, the compressive strength of concrete will not be significantly changed. Chen Yi [6] proposed that in coarse aggregate, the larger the proportion of particles with a particle size of 10-20mm, the total surface area of aggregate would decrease, thus improving the fluidity of self-compacting concrete.

At present, there are few studies on green and environment-friendly self-compacting concrete. Wan Huiwen et al. [7] conducted a mix ratio design study of self-compacting concrete on the basis that rice husk ash was mixed to replace 8.2% cement, and its concrete strength, self-compacting property and other properties could meet the design requirements. Wu Chunyang [8] showed that the best performance was achieved when the replacement rate of recycled coarse aggregate was 50%. In this paper, through literature analysis and research, rice husk powder 5%, corn straw 4%, fly ash 30% of the same amount to replace the cement, and recycled aggregate 25% of the same amount to replace the natural aggregate, to further study the green environmental protection type of self-compacting recycled concrete mix design and mechanical properties.

2 Self-compacting concrete

Self-compact Concrete (SCC) means that under its own gravity, it is able to flow and be dense, filling the formwork completely even with the presence of dense steel, and achieving good homogenization without additional vibration. Compared with ordinary concrete, self-compacting concrete has many advantages, it can ensure the good compaction of concrete, improve production efficiency, improve the working environment and safety, increase the freedom of structural design, reduce the overall cost of the project and many other advantages. But at the same time, the durability of self-compacting concrete after hardening is very limited, especially in cold climate. Moreover, there are many unstable bubbles in self-compacting concrete. The high fluidity self-compacting concrete compares with the ordinary concrete, the material requirements of high fluidity self-compacting concrete are more strict, and the drying shrinkage is larger.

As early as in the early 1970s, concrete with slight vibration has been used in Europe. However, until the late 1980s, in order to solve the contradiction between the reduction of skilled workers and the improvement of the durability of concrete structures, Japan began to study self-compacting concrete, and achieved effective results. Subsequently, Norway, France, Switzerland, Singapore and other countries have also started to study self-compacting concrete in different fields. Self-compacting concrete has been called "the most revolutionary development in concrete construction technology in recent decades".

3. Test material and scheme

3.1. Test materials

1) Cement: The cement is P.O 42.5 ordinary Portland cement of "Miao Ling" brand produced by Jilin North Cement Company;

2) Grinding rice husk powder: It is produced by ChuTian bran powder processing plant, Badong County, Enshi Prefecture, Hubei Province, 80 mesh, low-moisture drying rice husk powder;

3) Coarse and fine aggregate: natural gravel, maximum particle size of 20mm, apparent density of 2680 kg/m³, moisture content of 0%; Natural sand, medium sand, qualified grading, apparent density of 2600 kg/m³, moisture content of 0%; Recyclable aggregate is selected as the abandoned concrete test block after the test of Yanbian Municipal Testing Center for Housing and Construction, crushing by jaw crusher and screening by 20mm screen mouth;

4) Fly ash: II grade fly ash produced by Tienan Heating Company in Yanji City, Jilin Province;

5) Straw: corn straw meal;

6) Water: tap water;

7) Water reducer: polycarboxylic acid high performance water reducer produced by Jilin Fangsheng
Building Materials Co., Ltd., with a water reduction rate of 20%;
The main materials are shown in Figure 1:

![a) Corn stalk powder](image1)
![b) Rice husk powder](image2)
![c) Fly ash](image3)
![d) Recycled aggregate](image4)

**Figure 1. Test raw materials**

### 3.2. Test scheme

1) Design index: green environmental protection type self-compacti ng recycled concrete, design strength grade is C30, filling performance grade is SF1.

2) Curing conditions: the concrete test block was placed in a curing room with a temperature of 20±2 ℃ and a relative humidity of more than 80%.

3) Production of twelve 150 mm * 150 mm * 150 mm test cube, and press the rice hull powder 5%, corn straw 4%, fly ash 30% replacing cement, and the recycled aggregates according to 25% amount of replacing of natural aggregate.

4) The calculation process of mix ratio is shown in Table 1:

| Step | Calculation Process |
|------|---------------------|
| 1    | Calculate per cubic meter of coarse aggregate in concrete volume $V_g$, take 0.32 m³, calculate the aggregate mass: $m_g = V_g \times \rho_g$; |
| 2    | Calculation of mortar volume $V_m$: $V_m = 1 - V_g$. Take the volume fraction of sand in mortar $\Phi_s = 0.45$, calculate the volume $V_s$ and mass $m_s$ of sand per cubic meter; $V_s = V_m \times \Phi_s$, $m_s = V_s \times \rho_s$. Calculate the ratio of sand at a rate of 48%; |
| 3    | Calculate slurry volume $V_p$: $V_p = V_m - V_s$; |
| 4    | Calculate the formulation strength of self-compacting concrete: $f_{cu,0} = f_{cu,k} + 1.645\sigma$; Calculate the water-cement ratio $W/C = \alpha_a \cdot f_{cu} / (f_{cu,0} + \alpha_a \cdot \alpha_b \cdot f_{cu})$; |
| 5    | Determine the water consumption, get cement mass $m_c$; |
| 6    | In turn by 5%, 4% and 30% to replace cement to get mineral admixtures mass; and the mass of recycled aggregate was obtained according to the amount of 25% replaced gravel. |

Through calculation, distribution and adjustment, 1 m³ concrete mix proportion such as shown in table 2:

| Water   | Cement | Sand  | Gravel | Rice husk powder | Fly ash | Corn straw | Recycled aggregate | Water reducing agent |
|---------|--------|-------|--------|------------------|---------|------------|---------------------|----------------------|
| 384     | 322.5  | 800   | 645    | 26.5            | 160     | 21.2       | 215                 | 6.5                  |

Through calculation, distribution and adjustment, 1 m³ concrete mix proportion such as shown in table 2:
4 Test results and analysis

4.1 Test

1) Slump extension detection

The concrete is stirred by manual vibration, and quickly loaded into the slump cylinder without segregation. The time from the beginning of feeding to the end of filling is within 1.5min, and no tamping or vibration is implemented. Then, lift the slump cylinder upward along the straight direction at a uniform speed. After the concrete stops flowing, measure the maximum diameter of the expanded circle and the diameter perpendicular to the maximum diameter. The time T50 for measuring the extension up to 500mm was 6'30, and the average value of the two diameters perpendicular to each other was 590mm. The slump propagation test is shown in Fig. 2.

![Fig. 2. Slump spread test](image)

2) The compressive strength test

After the blocks are completed, in 7d, 14d, 28d and 56d, respectively, the compressive strength was tested on the YAW-HNT pressure testing machine at the speed of 3kN /s. Each group was composed of three test blocks, and the average value of the three test blocks was taken as the value of the compressive strength. The compressive strength test results are shown in Table 3 below:

| Group | 7d  | 14d | 28d  | 56d  |
|-------|-----|-----|------|------|
| 1     | 13.44 | 15.06 | 18.53 | 30.21 |
| 2     | 14.01 | 15.65 | 17.92 | 31.74 |
| 3     | 13.05 | 15.97 | 17.85 | 29.69 |
| The average | 13.50 | 15.56 | 18.1  | 30.55 |

Using Origin software will test data fitting, the compressive strength of the relationship with age is shown in figure3:

From Fig. 3, it can be seen that the relationship between the compressive strength and the age of the concrete satisfies the fitting equation $y = 1.5717x^3 - 9.19x^2 + 18.628x + 2.49$.

4.2 Test analysis

By the anti-stress results show that the block in the completed 7d, 14d, 28d and 56d with the respective strength 12.54 MPa, 18.00 MPa, 23.31 MPa, 30.70 MPa, which shows an increasing trend on the whole. Compared with normal self-compacting concrete, the early strength is lower. the main reason may be the rice hull powder and corn stalk have a big water absorption, and has been in a damp status inside the block, moreover rice husk powder and corn stalk have differs greatly from cement properties resulting in slurry is not fully bonding, concrete initial setting time gets longer and longer, the strength comes more slowly. Second, the rice hull powder, corn stalks, and fly ash mixed in a certain extent will reduce the compressive strength of concrete, so compared with the ordinary self-compacting concrete, the self-compacting concrete which mixed with rice hull powder, corn stalks, fly ash and recycled aggregates
has a small compressive strength growth rate in the early, but after 28 days, the strength growth rate will improve obviously.

5. Conclusion
By using 5% rice husk powder, 4% corn straw, 30% fly ash to replace cement, and 25% recycled aggregate to replace natural aggregate in equal measure, the green self-compacting concrete is prepared, and the strength of the later stage meets the design requirements of C30 concrete. The proposed mix ratio is water: cement: sand: gravel: rice husk powder: fly ash: corn straw: recycled aggregate: water reducing agent = 384:322.5:800:645:26.5:165:21.2:215:6.5. At the same time, Origin software is used to fit the relationship between the test value of compressive strength and the age, and the curve equation obtained is $y = 1.5717x^3 - 9.19x^2 + 18.628x + 2.49$.

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