Experimental study on the frost resistance and thermal conductivity of Environmental fair-faced concrete

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Abstract. For fair-faced concrete buildings and structures, the secondary recycling of agricultural and industrial wastes can achieve both green energy saving and heat preservation, save costs, and protect and promote ecological and resource environments. In this paper, to fully recycle agricultural waste and industrial waste, the new type of fair-faced concrete was prepared by triple doping of fly ash, slag and rice husk ash, and three sets of concrete thermal conductivity test blocks and two sets of freeze-thaw test blocks were prepared and tested for thermal conductivity and mass loss rate. The test results showed that the thermal conductivity of the new fair-faced concrete is 0.9644 W/(m·K) on average, and the mass loss rate was 1.825 and 2.575 after 25 and 50 freeze-thaw cycles respectively, which meet the requirement of less than 5%. The new type of fair-faced concrete has good energy saving and durability, and can be applied in construction projects in cold regions.

1. Introduction

Fair-faced concrete or architectural concrete is known as decorative concrete because of its highly decorative effect. In developed countries, the fair-faced concrete has been widely used for construction. However, due to the limitation of construction technology, China is still unable to promote fair-faced concrete widely. At the same time, national and industry specific standards have not been formulated completely[1].

During the 75th session of the United Nations General Assembly, China set a goal to achieve carbon neutrality by 2060. Building operations account for 28% of global greenhouse gas emissions, while building materials and construction alone account for 11%. Therefore, it is important to reduce building energy demand at source, improve the energy efficiency of building equipment and systems, and improve and upgrade the concrete process appropriately. In the study of Chi Zhaokun, Zhao Xian et al., admixed with fly ash and mineral powder within a certain proportion can improve the concrete's workability, increase the slump of concrete and reduce slump loss, which can effectively protect the environment while improving the workability of concrete and reducing the cost of concrete[2]. In rural areas, rice husk is only regarded as a cheap fuel, which has a bad impact on the environment, which is also a great waste of resources and does not meet the trend of sustainable development, it is necessary to study the recycling of rice husk ash. In the study of Liang Shiqing, Sun Bosheng et al. rice husk ash concrete has good compactness and is very beneficial to prevent corrosion of reinforcing steel in reinforced concrete buildings in maritime engineering[3]. Three doped concrete can not only reduce the amount of cement and production costs more, but also help to save energy and reduce environmental...
pollution, in the case of conditions permitting, ready-mixed concrete enterprises should use three doping processes as far as possible[4].

2. Test materials and scheme

2.1. Test materials
In accordance with the "Specification for mix proportion design of ordinary concrete" (JGJ55-2011), test materials were selected.

(1) Cement: "Miaoling" brand ordinary silicate cement, strength grade 42.5Mpa, produced by Jilin Province North Cement Co.

(2) Natural fine aggregate: river sand from Yanji City, Jilin Province; it is medium sand with an apparent density of 2600 kg/m³ and a moisture content of 0%.

(3) Rice husk ash: low-moisture drying and dust removal rice husk powder from Badong County, Enshi Prefecture, Hubei Province is selected.

(4) Natural coarse aggregate: crushed stone from Yanji City, Jilin Province is selected; the maximum particle size of the crushed stone was 30 mm, the apparent density is 2680 kg/m³, and the moisture content was 0%;

(5) Slag: selected s90 level powder, its specific surface area is 429 m²/kg, and its density is 2.9 g/cm³;

(6) Fly ash: selected secondary fly ash produced by Tienan Heating Company in Yanji City, Jilin Province.

(7) Water reducing agent: polycarboxylic acid water reducing agent of Fang Sheng Building Material Company of Yanji City, Jilin Province.

(8) Water: Tap water

2.2 Proportion design and test block making
Formulation of green fair-faced concrete strength grade ratio. Referring to the formula of "Specification for mix proportion design of ordinary concrete" (JGJ55-2011).

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

\( \sigma \) - standard deviation of concrete strength (N/mm²).  
\( f_{cu,0} \) - concrete formulation strength (N/mm²).  
\( f_{cu,k} \) - standard value of concrete cubic compressive strength (N/mm²).

In the process of slump test, the concrete ratio was adjusted appropriately, and the measured slump was T=155mm. Finally, the test fits of ordinary C30 green fair-faced concrete was obtained as shown in Table I.

| Cement | Water | Sand | Gravel | Fly ash | Rice husk ash | Slag | Water Reducer |
|--------|-------|------|--------|---------|---------------|------|--------------|
| 220    | 233   | 785  | 1060   | 70      | 30            | 20   | 1.67         |

The concrete test blocks were made by mechanical mixing in the test process, and the fresh concrete after mechanical mixing is then manually turned over several times to ensure its uniformity, with a mixing time of 2 to 3 mm. Before molding the mixed concrete, machine oil is needed to paint the inner wall of the mold to ensure a smooth surface of the test block.

The mixed concrete mix was loaded into four freeze-thaw test molds of size 100mm×100mm×400 mm and three heat-conducting molds of size 300mm×300mm×30mm, and then compacted using a vibrating table. After the specimen is formed, the upper surface is smoothed along the mold opening. After the test pieces were demolded, the test blocks were obtained as shown in Fig. 1 and Fig. 2.
3. Experimental scheme

3.1. Frost resistance testing test
The test uses the KDR type concrete fast freeze-thaw machine as shown in Figure 3 using the water freezing and thawing method, the thickness of the water layer around the specimen is 3mm. The freezing temperature is 6°C-17.8°C, the thawing temperature is 17.8°C-6°C. The allowable deviation of the limit temperature is ±1.7°C, and freezing and thawing cycle shall not be less than 2 hours, not more than 4 hours, the conversion time between freezing and thawing does not exceed 10min, thawing time is not less than 1/4 of the whole freezing and thawing cycle time. The refrigeration workpiece is F22, circulation medium for the No. 2 antifreeze, circulation medium from the lower left into, upper right out, freezing point-35°C, its main component is ethylene glycol, weight concentration of 50%, specific gravity of 1.07 by weight.

Referring to GB/T 50082-2009 "Standard for test methods of long-term performance and durability of ordinary concrete". The freeze-thaw test used four freeze-thaw specimens placed as shown in Figure 3, and the mold was demolded 2 d after the final setting of concrete, then the freeze-thaw specimens were cured in the standard curing room for 24 d, and then immersed in water for 4 d. During the freeze-thaw cycle test of the specimens, the quality of the specimens was monitored, and the mass loss rate of the specimens was measured with a balance of 0.1g accuracy; the specimens that had completed the set number of freeze-thaw cycles were weighed after wiping off the water on the surface, and the curve of the mass loss rate of concrete and the number of freeze-thaw cycles was made. The frost resistance of the specimens was measured, and the average value of the test data of four blocks were taken as the test results.

3.2. Thermal conductivity test
The test uses the DRH-300 thermal conductivity tester as shown in Figure 4, the thermal conductivity is measured in the range of 0.010–2W/(m)-K, the measurement accuracy <1%; hot surface temperature measurement range: room temperature ~99.99 °C, temperature resolution 0.01°C; cold surface temperature measurement range: 0~60°C, temperature resolution 0.01°C, the test room temperature 20~25°C. Keep the dry state of thermal conductivity test environment, set the control temperature of hot
plate to 35°C, the control temperature of cold plate to 15 °C, the temperature difference between hot and cold plate is 20 °C; start the power supply, start the test, after a period of time, the test data is stable convergence, the test equipment automatically stops, the system displays the specific value of thermal conductivity.

According to the test requirements of "insulation material steady state Determination of thermal resistance and related characteristics: protective thermal plate method" (GB/T 10294-2008)[7] and at the same time, to avoid the uneven surface of the test block resulting in gaps when in contact with the plate, the test mold was made of custom-made wooden stencil. Three thermal conductivity blocks were used for the test, and the average value of the test data of the three blocks was taken as the test results after standard curing for 28 d. The same three blocks were used to study the relationship between water immersion time and thermal conductivity of green fair-faced concrete, and the specific water immersion time was 0, 0.5, 1, 2, 4, 8, 12, 18, 24, 36, 48 and 72 h. After each specimen was continuously immersed in water to determine the thermal conductivity, the average value of the three blocks was taken as the test results.

4. Test results and analysis

4.1. Analysis of frost resistance data

The mass loss rate of green fair-faced concrete specimens is calculated according to equation (2).

\[ \Delta W_n = \frac{G_0 - G_n}{G_0} \times 100\% \quad (2) \]

\( \Delta W_n \) — mass loss rate of concrete specimens after \( n \) freeze-thaw cycles (%).

\( G_0 \) — mass of the concrete specimen before the freeze-thaw cycle (g).

\( G_n \) — mass of the concrete specimen after \( n \) freeze-thaw cycles (g).

The results of the frost resistance test are shown in Table II. The mass loss rate of green fair-faced concrete specimens with 25 cycles was kept at about 1.825%, while the mass loss rate of green fair-faced concrete specimens with 50 cycles was kept at about 2.575%.

| Number of cycles | A1   | A2   | A3    |
|------------------|------|------|-------|
| 25 times         | 1.86 | 1.79 | 1.825 |
| 50 times         | 2.49 | 2.66 | 2.575 |

Note: A1 is for 2 groups of specimens; A2 is for 2 groups of specimens; A3 is the average of the mass loss rate of group 1 and group 2.

![Figure 5. Analysis of the change in mass loss rate](image)

Using origin software, the above data can be analyzed to obtain the quality loss analysis graph shown in Figure 5.
From Fig. 5, it can be seen that the difference between the experimental results of A1 and A2 blocks is within a manageable range. After 25 freeze-thaw cycle tests, the mass loss rate of the specimens began to show a significant increase, while after 50 freeze-thaw cycle tests, the mass loss rate showed a small increase.

4.2. Analysis of thermal conductivity data

The green fair-faced concrete specimens were monitored by the thermal conductivity tester to obtain the test data as shown in Table 3. The final results are as follows: the average value of thermal conductivity is 0.9644 W/m-k, the average value of heat flow of specimens is 42.2676v, and the average value of thermal resistance of specimens is 0.031109m²k/w. According to the literature analysis, the range of thermal conductivity of ordinary concrete is from 1.28 to 1.51 W/m·K, so it can be obtained that the average reduction of thermal conductivity of green fair-faced concrete is approximately 31%. The test data shows that green fair-faced concrete has good thermal insulation properties compared with normal concrete.

| Test items                  | Group 1 | Group 2 | Group 3 |
|-----------------------------|---------|---------|---------|
| Thermal conductivity values | 0.9862  | 0.9547  | 0.9533  |

In the study of the relationship between water immersion time and thermal conductivity of green fair-faced concrete, the test data were analyzed by using Origin software, and the relationship between water immersion time and thermal conductivity of green fair-faced concrete can be obtained as shown in Figure 6. From Figure 6, the thermal conductivity of green fair-faced concrete increases gradually with the increase of water immersion time and tends to be stable. When the water immersion time is 0-2 h, the thermal conductivity of the specimen increases at the highest rate; when the water immersion time is 2-24h, the thermal conductivity of the specimen decreases; when the water immersion time is 24-72h, the thermal conductivity of the specimen gradually tends to be stable. The rate of water absorption of green fair-faced concrete is large in the early stage, and then the rate gradually decreases and finally reaches the saturation state when the water immersion time is 50h. The water replenishes the internal voids of green fair-faced concrete, which increases the water vapor diffusion and the heat transfer of water in the capillaries.

Figure 6. Relationship between water immersion time and thermal conductivity of green fair-faced concrete

5. Conclusion

In this paper, we use fly ash, rice husk ash, mineral powder and other industrial and agricultural wastes, and adopt the triple-doping process to carry out experimental research for the extensive engineering
application of green fair-faced concrete under the background of China's social carbon neutral target, environmental pollution reduction, energy saving, waste recycling and other policies, in view of the fact that the experimental research on the frost resistance and thermal conductivity of green fair-faced concrete in China is not comprehensive at this stage.

1. In the green fair-faced concrete frost resistance test, after 25 and 50 freeze-thaw cycles, it can be found that the difference between the two groups of specimens is small, and with the increase in the number of freeze-thaw cycles, the quality loss rate of green fair-faced concrete specimens is significantly increased, which is more conducive to the wide application of this type of green fair-faced concrete in cold regions.

2. In the test of thermal conductivity of green fair-faced concrete, the average thermal conductivity of the specimens was kept at about 0.9644 W/m·k, which is comparable to ordinary concrete. The reduction of the coefficient of thermal conductivity reached 31%. In the experiment of the relationship between water immersion time and thermal conductivity of green fair-faced concrete, the thermal conductivity of the specimens increased at a high rate at the beginning of water immersion. With the gradual extension of water immersion time, the thermal conductivity of the specimens increased at a lower rate; and after the water immersion time exceeded 24h, the thermal conductivity of the specimens gradually stabilized, and the thermal conductivity was still lower than that of ordinary concrete, which could effectively improve the thermal insulation performance of concrete with excellent thermal insulation.

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