Study on low temperature performance of recycled concrete

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Abstract: Recycled concrete is a product of the recycling of building materials. It has the characteristics of low cost and large demand, and its application in engineering is gradually expanding. However, there are still many unclear problems in the performance of recycled concrete in cold regions. In order to solve this problem, this paper puts forward the performance research of recycled concrete under low temperature condition, and designs the recycled concrete low temperature structure model through the ratio of recycled concrete materials and experimental construction. According to its indexes, the changes of its cryogenic antifreeze performance, compressive strength, stiffness stability and other aspects are compared and analyzed. The comparative experimental results show that when the air content of recycled concrete is gradually reduced, the insulation effect is reduced, the strength of recycled concrete is reduced, the frost resistance is also reduced, the durability and stability is poor, and the frost resistance is poor. With the continuous increase of displacement and load seismic force, the crack of recycled concrete gradually changes, the stiffness decreases faster, the stiffness degrades to a greater extent, and the low temperature seismic performance is poor.

1. Introduction

At present, China has the largest number of new buildings in the world, and recycled concrete is widely used in construction engineering as a product of recycling. However, the continuous development of building demand puts forward more requirements on the durability and strength of recycled concrete, which requires that production materials are easy to obtain, low manufacturing cost and wide application range [1,2]. With the development of building materials, the types of recycled concrete gradually increase and the application areas become more and more extensive. Therefore, it is extremely urgent to study the performance test of recycled concrete building structures in some special alpine regions [3,4], which has gradually become one of the main topics concerned by scholars at home and abroad. In the cold region of northeast and northwest China, the seismic performance of recycled concrete building structure will change greatly under the condition of low temperature. In this paper, the change of low temperature performance of recycled concrete is studied by experiments.
2. Experimental study on low temperature performance of recycled concrete

2.1. Experimental materials and instruments

2.1.1. Experimental raw material

The reclaimed aggregate used in the experiment was provided by Nanjing Fuyuan Resources Utilization Co., LTD. According to the results of field investigation, the raw material of the company's reclaimed aggregate comes from the construction waste generated by the urban reconstruction in Nanjing, mainly used building materials in the 1970s and 1980s. Compare its composition and performance with that of ordinary concrete, as shown in Table 1 and Table 2.

| Table 1 raw material chemical composition vector |
|-----------------------------------------------|
| recycled aggregate (%) | cement mortar (%) | square one stone (%) | fly ash (%) | Colloid material (%) |
| 50 | 16 | 20 | 10 | 4 |

| Table 2 Comparison of density performance between recycled concrete and concrete aggregate |
|-----------------------------------------------|
| aggregate type (%) | water absorption (%) | crush index (%) | tight density (kg/m³) | apparent density (kg/m³) | bulk density (kg/m³) | moisture content (max) | moisture content (min) |
| recycled aggregate | 4.7 | 18.1 | 1458 | 2588 | 1299 | 5.9 | 2.6 |
| natural stone | 0.68 | 10.7 | 1590 | 2601 | 1411 | 0.89 | 0.37 |

The mixture ratio of concrete and recycled concrete mixing mixture and its compressive strength test are shown in Table 3.

| Table 3 Recycled concrete aggregate and pressure resistance test |
|-----------------------------------------------|
| sample | Replacement rate of reclaimed aggregate (%) | The ratio of aggregate Cement: water: Mortar: Natural aggregate: recycled aggregate | temperature setting 'C |
| S1 | 0 | 480:160:530:1120:0 | -5°C——35°C |
| S2 | 50 | 480:181:530:520:580 | -5°C——35°C |
| S3 | 100 | 480:200:530:0:1200 | -10°C——45°C |
| S4 | 100 | 480:200:530:0:1200 | -10°C——45°C |

2.1.2. Experimental apparatus

1) Maintenance box: HBY-40B cement recycled concrete thermostat produced by Xianxian Tianjian Instrument Co., LTD.

2) Test box: programmable constant temperature and humidity test box produced by Zhenghang Instrument equipment Co., LTD

3) Low temperature incubator: Creates low temperature conditions for experiments.
2.2. Calculation of experimental parameters
At low temperature, suppose\( Q_i \) is the total heat emitted by the cement of recycled concrete at phase \( i \); \( Q_{1i} \) is the amount of heat added to the ice water mixture at phase \( i \) when the temperature drops; \( Q_{2i} \) represents the amount of heat added to the ice water mixture at phase \( i \); \( R_q \) represents the total heat capacity of the thermostat after cement is added; \( l_i \) denotes the phase is the temperature of cement water melting for \( i \) time; \( l_0 \) represents the original temperature of cement hydration; \( \alpha \) represents the heat dissipation constant of cement in the regenerated concrete thermostat; \( E_{0,i} \) represents the area between the surrounding temperature and the cement slurry temperature curve within \( 0: i \) hours. The calculation formula of regenerated concrete cement is as follows:

\[
Q_i = R_q (l_i - l_0) + \alpha \sum E_{0,i} + Q_{1i} + Q_{2i}
\]

According to the above formula (1), experimental data of adiabatic heat release of cement can be obtained. It is assumed that the total heat release of cement hydration at low temperature; \( Q_i \) represents the heat release of cement hydration \( Q_{\text{max}} \) at low temperature within \( i \) time. The calculation formula of the hydration degree at low temperature is as follows:

\[
\mu_i = \frac{Q_i}{Q_{\text{max}}}
\]

2.3. Construction of experimental conditions
150mm×150mm×150mm cube test pieces were selected. Table 3 shows the temperature Settings of recycled concrete and ordinary concrete in the experiment, which were set at -5 ℃ --35 ℃ and -10 ℃ --45 ℃ respectively, which can meet the experimental conditions for the comparative change of the low-temperature performance of recycled concrete.

3. Low temperature performance testing and analysis
3.1. Effects of frost resistance
The low temperature of the constant temperature cryogenic chamber was set according to the above experimental conditions to test the cryogenic antifreeze performance of the recycled concrete structure model and the ordinary concrete structure model, as shown in Figure 1 and Figure 2.

![Figure 1. Recycled concrete structure model frost resistance in low temperature environment](image-url)
Figure 2 Concrete structure model frost resistance in low temperature environment

The analysis of Figure 1 and Figure 2 shows that the frost resistance of recycled concrete and ordinary concrete is related to the gas content and strength at low temperature. As shown in Figure 1, when the temperature is between -5 °C and -35 °C, under the curing of each phase of the age, when the air content is 30%, the strength of recycled concrete is increased and the frost resistance is also enhanced. With the gradual decrease of gas content, the insulation effect is reduced, the strength of recycled concrete is reduced, the frost resistance is also reduced, and the durability and stability are poor. The figure 2 shows that when the temperature is minus 5 degrees Celsius between minus 35 degrees Celsius, at each stage of age under the maintenance of air content has remained between 40% ~ 10%, under the condition of normal concrete with the gradual increase of air content and ages, ordinary concrete strength are also gradually increase, frost resistance are also gradually increase, the heat preservation effect is good, high durability and stability. It can be concluded that the frost resistance of recycled concrete is worse than that of ordinary concrete in terms of low temperature frost resistance, relatively low durability and low temperature earthquake resistance.

3.2. Compressive strength analysis

The compressive strength of the cube was tested at low temperature. According to the above ratio, ordinary concrete and recycled concrete were shaken by mixing for 24 hours and then the models were disassembled. After curing for 3d, 7d and 18d in the cabR-OABS wet temperature curing box, the wet temperature requirements were fully met. The compressive strength of each specimen was determined on 3d, 7d and 18d, and the obtained test results were shown in Table 4.

| kind                  | Density of reclaimed concrete/kg m\(^3\) | The collapse of the slump/mm | compressive strength/MPa |
|-----------------------|----------------------------------------|------------------------------|--------------------------|
|                       |                                        |                              | 3d | 7d  | 28d |
| normal concrete       | 1824                                   | 185                          | 25.6 | 40.2 | 53.4 |
| recycled Concrete     | 2346                                   | 198                          | 35  | 56.2 | 64.4 |

As can be seen from table 4, the collapse degree difference between recycled concrete and ordinary concrete is not very large, and it can meet the liquidity requirements \([5,6]\). Even though the compressive performance of ordinary concrete is lower than that of recycled concrete under different compressive strength, it can still meet the experimental conditions.

3.3. Variation of low temperature stiffness of recycled concrete

The load-displacement hysteretic curves of the recycled concrete structure and the load-displacement hysteretic curves of the ordinary concrete structure are shown in Figure 3 and figure 4.
As shown in FIG. 3 and FIG. 4, the model of recycled concrete structure and the model of ordinary concrete structure are respectively analyzed. The comparison diagram of displacement hysteretic curve before and after low temperature vibration can be obtained according to the experimental comparison:

(1) It can be seen from the displacement hysteretic curve change results in Figure 4 that the recycled concrete structure model is in the elastic stage at the initial stage of loading under the condition of low temperature. When the recycled concrete structure model is resistant to seismic force, the load force and displacement show a linear state, the load form gradually increases, and the stiffness degradation is relatively obvious. With the continuous increase of displacement and load, recycled concrete cracks gradually, and the stiffness of recycled concrete decreases rapidly, indicating that the stiffness degradation degree of recycled concrete structure model is relatively large [7,8].

(2) the results seen in figure 5 displacement hysteretic curve, ordinary concrete structure model under the condition of low temperature, at the beginning of the load also belongs to the elastic stage, when the normal concrete structure model in earthquake resistance force, present a linear load and displacement, load form gradually become smaller, rigidity degeneration is not obvious, with the increase of load and displacement, ordinary concrete gradually there were signs of cracking, but slower stiffness decreases, the ordinary concrete structure model of stiffness degradation degree is smaller.

(3) the recycled concrete and ordinary concrete have pinch phenomenon, this is due to the shear deformation of inclined cracks caused by zhang, lead to sliding is bigger, can be seen from the two diagrams, recycled concrete kneading shrinkage occurs when the earthquake occurred, is caused by shear deformation zhang inclined cracks, lead to sliding is bigger, pinch phenomenon is more prominent, after the peak load, the displacement hysteretic curve is relatively stable enough, the stiffness degradation into relatively fast [9]. Fig. 5 Load-displacement hysteresis curve of concrete structure.

4.Conclusion
For buildings or structures in severe cold areas, concrete frost resistance is one of the important
indexes to evaluate the long-term durability of concrete, which determines the concrete structure. Security and long-term performance. At present, recycled aggregate has been gradually applied in practical projects, for recycled concrete buildings in cold regions, freeze-thaw. Cycle failure seriously affects the safety and long-term durability of buildings. In this article, through analysis of recycled concrete frost resistance at low temperature impact, compressive strength and stiffness degradation of recycled concrete structure under the condition of low temperature, the low temperature of the recycled concrete seismic performance compared with ordinary concrete is relatively poor, not suitable for them instead of common concrete used in seismic requirements of high building construction.

References
[1] Chen Jiguang, Liu Ling. On research progress of seismic performance of recycled concrete framework[J]. Shanxi Architecture, 2017, 43(20):36-37.
[2] Li Bowei, Zhang Yaoting. Design and seismic performance analysis of multi-layer reinforced concrete frame structure based on Pushover[J]. Architecture Technology, 2016, 47(5): 392-395.
[3] Li Bing, Meng Shuang, Ji Fengying. Finite element analysis of seismic performance of recycled concrete filled square steel tubular columns[J]. Journal of Guangxi University (Natural Science Edition) 2017, 42(1):78-85.
[4] Zheng Shansuo, Zhang Yixin, Huang Yingge, et al. Experimental study on seismic behavior of reinforced concrete frame beams in acid rain environment[J]. Journal of Building Structures, 2017, 38(9): 20-27.
[5] Guo Weishi, Qian Xiaolong. Experimental Study on Seismic Behavior of Concrete Short Columns at Low Temperature[J]. Cryogenic Architecture Technology, 2016, 38(1): 45-47.
[6] Dong Lan. Study on Seismic Performance of Recycled Concrete Energy Saving Residential Structures [J]. Building Technique Development, 2017, 44(11):3-5.
[7] GUO Hongchao, SUN Lijian, LIU Yunhe, HAO Jiping, WANG Heting. Experimental research on seismic behavior of flexible steel frame with infilling recycled concrete wall[J]. Journal of Building Structures2017, 38(7):103-112.
[8] Li Ke, Ma Weihang. Seismic Performance Analysis of Steel Frame Structure with Foamed Concrete Filled Wall[J]. Engineering and Construction, 2016, 30(2): 196-197.
[9] He Wei, Li Xiaowei, Yu Yuecan, et al. Performance changes of cement and concrete in ultra-low temperature environment and its application requirements[J]. Cement Engineering, 2017, 30(4): 26-28.