Research on compressive strength of recycled cement mortar after high temperature

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Abstract: In order to study cube compressive strength of recycled fine aggregate cement mortar after different temperatures, with the affect parameters between replacement rate of recycled fine aggregate and temperature, 45 standard cube test blocks were designed and produced to carry out compressive strength test. The failure process and failure mode of test blocks were observed. Ultimate compressive strength of cube blocks were measured, the relations between cube compressive strength and the replacement rates of recycled fine aggregate under different temperatures as well as the relations between cube compressive strength and temperatures under different replacement rates were all analyzed, the influence change parameters made on cube compressive strength was discussed. The results showed: the failure process and the failure mode of recycled fine aggregate cement mortar and the failure process and the failure mode of nature is similar; when the temperature reached 400\textdegree C, the block has no burst phenomenon, but the colour of block into a dark pink; with the increase of recycled fine aggregate, the mass lose rate of block is increase; effect different temperature make on cube compressive strength of test block is not obvious when temperature keeps same for 3h.

1. Introduction

At present, resource waste is very serious in our country, according to statistics [1], China's construction waste has occupied 30\% - 40\% of municipal waste, of which 50\% - 60\% is waste concrete. Due to the rapid development of urbanization, a large number of construction waste, produce great harm to the environment, to protect environment and save resources, realize sustainable development, the scientific use of construction waste is urgent[2-3]. Our country building sand have increased in recent years, natural resources are close to run out, continued exploitation will inevitably lead to environment, cost, security and other issues, etc[4]. Make the construction waste to be recycled, then after the program processing such as crushing, screening, cleaning, drying and part or all of the aggregate instead of natural aggregate to make recycled building materials[5-6]. After the mixture of crushing fine aggregate instead of natural fine aggregate and cement and water to make new building materials is called recycled cement mortar[7]. Construction waste recycling can reduce the consumption of natural aggregate, relieve the pressure on the per capita possession of resources, improve the economic and environmental benefit will have a positive effect[8-10].

In recent years, the studies of the recycled cement mortar performance have a certain size. Yang Z S et al[11] have studied construction waste’s recycled mortar mechanical performance, the results
have showed that the block strength of recycled aggregate can meet the requirement, grain composition has app on the strength. But they didn't explain the high temperature’s effect on the block. Xu M et al[12] studied the stress-strain relationship of the uniaxial compression for the recycled cement mortar prism specimen(70.7mm×70.7mm×216mm) after high temperature, the results showed that different recycled fine aggregate replacement rate of mortar at high temperature after surface color changes obviously, more than 400 degrees, the quality tends to be stable. Under same temperature, with the increase of replacement ratio of recycled fine aggregate, the peak stress and elastic modulus decreases, peak strain and ultimate strain increases gradually. However, there are few reports on the standard cube test block after high temperature.

In this paper, forty five cement mortar with recycled fine aggregate of the standard cube test block were made in 3 different temperatures, the recycled cement mortar cube test block of uniaxial compressive strength test. Analysis of the same substitution rate under the condition of cube compressive strength changing with temperature, and at the same temperature as the cube compressive strength of recycled fine aggregate replace rate of change, in order to provide reference for the preparation of recycled cement mortar, and disaster control.

2. Test profiles

2.1. Test raw materials

The four components of cement, recycled fine aggregate, sand and water according to a certain proportion was made recycled fine aggregate cement mortar. The cement is 42.5 grade P.O cement of Jiaozuo strong production; reinforced concrete beams with recycled fine aggregate from the Henan Polytechnic University structure test hall has been destroyed, crushing, screening, grading, cleaning, drying and other processing procedures, the particle size in the range of 0.5~5mm, the bulk density is 1321kg/m³, as shown in Fig. 1 (a); the sand to the natural river sand, its bulk density is 623kg/m³, as shown in Figure 1 (b); by mixing water into ordinary tap water.

2.2. Mix ratio

The standard test block of cement mortar with strength grade of M15, this experiment has produced 5 kinds of standard cube recycled fine aggregate cement mortar test block with different substitution rate. Among them, the cement mortar specimen was seem as reference block (N) when the replacement is 0%, 25%, 50%, 75%, 100% and four kinds of different substitution rate test blocks (RM25, RM50, RM75 and RM100) as contrast test block, according to JGJT 98-2010 "with mortar than the" design rules of mix design, mix design test as shown in table 1.

| Test block type | cement (kg/m³) | Water (kg/m³) | Aggregate(kg/m³) |
|-----------------|----------------|---------------|------------------|
|                 | Light sand     | Ordinary sand |                  |
| N               | 370.0          | 310.0         | 0.0              |
| RM25            | 370.0          | 310.0         | 155.8            |
| RM50            | 370.0          | 310.0         | 311.5            |
| RM75            | 370.0          | 310.0         | 467.3            |
| RM100           | 370.0          | 310.0         | 623.0            |

Figure 1. Fine aggregate

Table 1. Mix ratio of recycled mortar
2.3. Test block fabrication, high temperature test and loading

45 block size made in this experiment are standard cube 70.7mm × 70.7mm × 70.7mm block, in 3 groups of temperature (20℃, 200℃, 400℃) conditions, each replacement rate (0%, 25%, 50%, 75%, 100%) has 3 block. The mold is used in cube steel mold standard, 24h after stripping, standard curing 28d, respectively, corresponding test block is heated to 200℃, 400℃, and keep in the constant temperature 3 hours then take out, natural cooling to room temperature, the heating device is TDL-1400F high temperature furnace, as shown in figure 2. The heating system at 200℃ and 400℃ are shown in Figure 3 and Figure 4. According to JGJ-T70-2009 "mortar test method", the test blocks under different temperature conditions are uniformly loaded, and the compressive strength is measured. Load device is the SYE-2000 type pressure testing machine, the maximum range is 2000kN, as shown in Figure 5, the test using the loading rate is 3~5kN/s.

3. Test results and analysis

3.1. Test block high temperature phenomenon

During the heating process, with the increase of the temperature, the moisture inside the test block has been evaporating, and the mortar test block has a great physical change in the process of high temperature. After the high temperature test, the two groups did not have a burst phenomenon. As shown in Figure 6, when the temperature reached 200 degrees, the color of the test block and the color of the test block at room temperature is basically no different. But when the temperature reached 400 degrees, the color of the test block had a significant change, was dark pink.

3.2. The failure process and failure mode of the test block

At the beginning of the load, test block appearance has not changed significantly, as the load increases, the occasional faint sound of colloid cracking, with increasing load, block surface produced some vertical and slightly tilted cracks parallel to the axial force direction, when the load is close to the limit load, the micro crack develop quickly, through the formation of the main crack, four vertical free
surface began to drum, final failure. Recycled cement mortar specimens under normal temperature and ordinary cement mortar damage process and form block is basically similar to that of recycled cement mortar under different high temperature after the failure process and failure form of block are similar, showing two connected four Inverted pyramid. At different temperatures, the failure modes of all replacement rate test blocks are shown in Figure 7 (a), (b), (c). At different temperatures, the failure pattern of the 100% replacement rate test block are shown in Figure 6 (d), (e), (f).

![Figure 7. Destruction form](image)

4. Influence factor analysis

4.1. Mass loss rate

The mass loss of the test block includes the evaporation of water, the melting of the fibre, the decomposition of calcium silicate hydrate and the decomposition of calcium carbonate[13], etc. Mass loss ratio is the ratio of the mass to the high temperature and the quality of the test block after high temperature[14]. Curve of mass loss rate $\eta$ of recycled cement mortar and the temperature $T$ are shown in Figure 8, the relation curve between the mass loss rate $\eta$ and recycled fine aggregate replacement rate is $r$ as shown in figure 9.

![Figure 8. Mass loss rate and temperature curve](image)

![Figure 9. Mass loss rate and replacement rate curve](image)
Figure 8 shows that with the increase of temperature, the mass loss rate of N type test block gradually increased. RM25, RM50, RM75, RM100 test block mass loss rate increased. Related to 20°C, at 200°C, N and RM25, RM50, RM75, RM100 block mass loss rate increases were 8.2%, 8.4%, 8.6%, 9.9%, 11.7%; related to 20°C, at 200°C, RM25, RM50, RM75, RM100 type specimen mass loss rate increases were 3.70%, 4.90%, 7.60%, 9%, 10.30%. The increases of mass loss rate of each replacement rate test block in the range of 20~200°C are significantly higher than that in the range of 200~400°C. For the reason, this is because most of the water at the 20~200°C has been evaporated, only a small part of the water evaporated at 200~400°C.

Figure 9 shows that when the replacement rates were 0%, 25%, 50%, 75%, 100%, 200 degrees corresponding block mass loss rates were 8.2%, 8.4%, 8.6%, 9.9%, 11.7%, 2.4%, increased by 2.4%, 15.1%, 18.2%; at 200°C, the corresponding block mass loss rate was 11.9% 13.3%, 16.2%, 18.9%, 22%, 21.8%, increased by 11.8%, 16.7%, 16.4%. With the increases of replacement rate of recycled fine aggregate, the mass loss rate increases gradually. The reason is that with the increase of the replacement ratio of recycled fine aggregate increased gradually, the number of test block within the pore and micro cracks increases gradually, the free water that did not participate in the hydration of cement became more, at the same temperature, free water evaporated and lost[15-16].

### 4.2. Cube compressive strength

According to JGJ-T70-2009 "mortar test method", the failure load of recycled cement mortar specimens with different replacement rates at different temperatures was obtained in 3 groups. Calculated and obtained the cube compressive strength of each specimen, as shown in table 2

#### Table 2. Cube compressive strength (Mpa)

| Specimen category | Replacement rate |
|-------------------|------------------|
|                   | 0%   | 25%  | 50%  | 75%  | 100% |
| 20°C Measured strength | 17.47 | 16.50 | 13.32 | 9.15 | 14.30 |
| Error              | <15% | >15% | <15% | >15% | >15% |
| Represent strength | 17.36 | 11.51 | 12.33 | 14.22 | 14.30 |
| Cube compressive strength | 22.57 | 15.00 | 16.03 | 18.49 | 18.59 |
| 200°C Measured strength | 11.9  | 15.04 | 14.93 | 13.12 | 11.45 |
| Error              | <15% | >15% | <15% | >15% | <15% |
| Represent strength | 12.32 | 13.29 | 14.49 | 10.02 | 10.20 |
| Cube compressive strength | 16.02 | 17.28 | 18.84 | 13.03 | 13.26 |
| 400°C Measured strength | 11.09 | 15.92 | 18.81 | 10.84 | 11.17 |
| Error              | >15% | <15% | >15% | <15% | <15% |
| Represent strength | 18.13 | 16.36 | 16.52 | 12.28 | 11.94 |
| Cube compressive strength | 23.57 | 21.27 | 21.48 | 15.96 | 15.52 |

Note: Cube compressive strength calculation refer to JGJ-T70-2009 "mortar test method". When the difference between the maximum value or minimum value of strength in group with middle one less than 15% of the median value, take the average of three; when the difference between the maximum value or minimum value of strength in group with middle one more than 15% of the median value, take the median value; when the difference between the maximum value, minimum value of strength in group with middle one more than 15% of the median value, the group data is not valid.

Table 2 shows that under each replacement rate, the cube mortar test block withstand different temperatures, the compressive strength reached the design strength. For all kinds of temperature, under different recycled fine aggregate replacement rate, the cube compressive strengths of recycled cement
mortar are shown in figure 10. For various replacement rates, with the change of temperature, the cubic compressive strength of recycled cement mortar is shown in Figure 11.

![Figure 10. Cube compressive strength under different substitution rates](image1)

![Figure 11. Cube compressive strength at different temperatures](image2)

Figure 10 shows that when the replacement rate was 0%, the compressive strength of cube test block at 20°C and 400°C was not significant different, and are significant higher than the recycled cement mortar cube compressive strength. But at different temperature, there is no good regularity between the compressive strength of recycled cement mortar and the replacement ratio of recycled fine aggregate. One reason is that discrete type of cement mortar; the two is increasing the recycled fine aggregate will reduce the compressive strength, big water binder ratio made the compressive strength decreased, mutual coupling, cross effect at cubic compressive strength; three is the temperature and time insufficient let the internal structure no obvious change.

Figure 11 shows that in the range of 20–200°C, when replacement ratio is 0%, 75% and 100%, with the increase of temperature, compressive strength of test block reduced, when the replacement ratio is 25% and 50%, with the increase of temperature, compressive strength of test block improved. In the range of 200–400°C, with the gradual increase of temperature, the compressive strength of recycled cement mortar test block has a certain improvement, the smallest increase is 2.26%, the maximum increase of the amplitude can reach 7.54%. In the range of 20–400°C, with the increase of
temperature, the compressive strength of the test block is not obvious. One reason is that the temperature is insufficient and the constant temperature time is short, the internal structure of the test block is not destroyed; the two is due to the large discrete type of recycled cement mortar.

5. Conclusions
With increasing temperature, the change of surface features of recycled fine aggregate cement mortar block in the early stage was not obvious, but when the temperature increased to 400℃, block color became dark pink from gray, blocks did not have burst phenomenon.

Recycled cement mortar and ordinary cement mortar blocks damaging process and form are similar, showing two connected four Inverted pyramid;

With the increase of the replacement rate of recycled fine aggregate, the mass loss rate of recycled cement mortar increased. At different replacement rate, the mass loss rate of the test block at 400℃ increased to that at 200℃ in different degrees. When the replacement rate was 100%, the mass loss rate increased to 10.30%;

In the range of 20~400℃ and 3 hours under the conditions of constant temperature, with the increase of temperature, the law of compressive strength of recycled cement mortar test block is not obvious. It is suggested that further research should be done before the extension and application of recycled cement mortar. For example, the temperature range extended to 20~800℃, or the constant temperature time extended to 8 hours, or each group produced 6 or even 9 of the same parameters of the test pieces, and so on.

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