Experimental study on the influence of temperature on compressive strength of non-spontaneous combustion coal gangue aggregate concrete

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Abstract. In Pingxiang mining area of Jiangxi Province, a large amount of non-spontaneous combustion coal gangue is piled up into mountains, which not only occupies the land, but also seriously pollutes the ecological environment. In order to solve this problem and improve the utilization rate of coal gangue, the study of coal gangue without spontaneous combustion in Pingxiang mining area was carried out, and the differences of chemical composition, physical characteristics and thermal activation characteristics of coal gangue were analyzed. On this basis, the coal gangue was used as coarse aggregate instead of some natural stones, and the influence of different temperatures on the compressive properties of coal gangue aggregate concrete was studied. The results show that the compressive strength of gangue concrete is lower than that of ordinary concrete at room temperature. At high temperature, under the influence of secondary hydration of cement and thermal activation of gangue, the compressive strength of concrete test blocks in each group presents an upward trend before 400℃, and reaches its maximum strength at 400℃, among which the mechanical strength of concrete with 30% gangue coarse aggregate is the best. This study provides a basis for the resource utilization of coal gangue in Pingxiang.

1. Introduction
Pingxiang mine, located in western Jiangxi Province, is the largest coal producing area in South China and has nearly 14,826.3 acres of abandoned mines. Coal mining produces a lot of gangue, which is seriously abandoned and forms a continuous gangue mountain, which not only wastes resources, but also causes serious pollution to the surrounding environment [1-3]. With the rapid development of the construction industry, the market demand for construction aggregate is high, but the price of natural aggregate is expensive [4-5]. Moreover, the exploitation of a large amount of natural aggregate is contrary to the green development concept of "clear water and green mountains are gold and silver mountains" in China, while coal gangue, as a mineral resource, has similar properties to natural stone and can be applied in the field of architecture [6]. The existing coal gangue resources are used in various directions, but the overall dosage is low and the utilization rate is low [7-9]. Coal gangue is mostly used to fill Mined-out area or generate electricity. Many scholars have studied the influence of physical and chemical properties of gangue on the compressive strength of concrete [10-12], but they mainly focus on self-ignition coal gangue with good activity. Due to its relatively intact crystal shape
and low activity, non-spontaneous combustion coal gangue is usually activated by physical or chemical methods before application \cite{13-14}. Ordinary concrete does not bear high temperature \cite{15-17}, and building damage after fire is a major factor in casualties. However, the study on the performance change of non-spontaneous combustion coal gangue concrete at high temperature is not exhaustive \cite{18}.

In order to effectively solve the problem of large amount of coal gangue accumulation in Pingxiang mining area, the properties of non-spontaneous combustion coal gangue were analyzed in this paper, and the chemical composition, physical characteristics and thermal activation characteristics of the coal gangue were obtained. On this basis, the coal gangue is used as coarse aggregate instead of some natural stones, and further study the influence of different temperatures on the compressive properties of coal gangue concrete, providing a basis for the resource utilization of pingxiang coal gangue.

2. Test Section

2.1. The raw material

The cement adopts conch brand P.O. 42.5 ordinary Portland cement. Coal gangue without spontaneous combustion is taken from Pingxiang mining area of Jiangxi Province. The fineness modulus of natural fine aggregate was 2.3 of river sand, and the grain size was 0~4.75mm. The natural coarse aggregate takes gravel with a diameter of 4.75~20mm and is continuously graded to meet the requirements of "Construction Pebble and gravel" (GB/T14685-2011). The chemical composition, physical properties and thermal activation properties of raw materials are shown in Table 1, Table 2, and Table 3 respectively.

The chemical composition of coal gangue is shown in Table 1. Non-spontaneous combustion coal gangue is mainly composed of quartz and kaolinite, and the content of active ingredients is relatively low when undisturbed, while the content of active ingredients reaches a higher level when the activation temperature increases from 700°C to 800°C. As can be seen from Table 2, compared with natural aggregates, coal gangue has a larger crushing index and lower crushing resistance, but higher porosity and moisture content. In Table 3, specimens M0, M6, M7, M8 and M9 respectively represent cement mortar specimens caused by coal gangue powder after activation at different temperatures, while P0 represents ordinary cement mortar specimens. The results show that the mechanical strength of coal gangue after activation at 700 °C-800 °C is good.

2.2. Block preparation

The non-spontaneous combustion coal gangue was selected for crushing, and the coarse aggregate diameter was separated to 4.75~20mm. Strength grade C40 and water-cement ratio 0.45 are designed according to JGJ-55-2000 "Design Code for Mix Proportion of Ordinary Concrete" and JGJ51-2002 "Technical Code for Light Aggregate Concrete", with specific coordination as shown in Table 4. In the test block number, the letters P and C respectively represent the test block of ordinary concrete and the test block of coal gangue coarse aggregate. The figures 0.3 and 0.6 respectively represent the aggregate admixture. The test blocks are divided into three types, each with 30 blocks, a total of 150 blocks, the size of which is 100mm×100mm×100mm. They are cured for 28d after mold release for subsequent tests.
Table 3. The compressive strength (MPa)

| The sample | Flexural strength | The compressive strength |
|------------|------------------|-------------------------|
| M0         | 3.91             | 23.53                   |
| M6         | 5.46             | 32.43                   |
| M7         | 7.13             | 35.2                    |
| M8         | 6.33             | 39.13                   |
| M9         | 5.63             | 27.43                   |
| P0         | 6.28             | 45.92                   |

Table 4. Concrete test block mix ratio (kg/m³)

| The sample | Cement | water | Natural sand | Natural stone | Coal gangue |
|------------|--------|-------|--------------|---------------|-------------|
| P          | 406    | 185   | 610          | 1220          | 0           |
| C₀.3       | 406    | 185   | 610          | 855           | 366         |
| C₀.6       | 406    | 185   | 610          | 490           | 732         |

2.3. Test plan

2.3.1. High temperature test.
Before the test, the test block was dried on the surface and put in an oven at 105°C to dry to a constant weight to prevent the test block from bursting during the high temperature test. At room temperature (20°C), heating began. The target temperature was set at 200°C, 400°C, 600°C and 800°C, respectively, the heating rate was 6°C/min, after 2h of heat preservation, it is cooled naturally.

2.3.2. Compressive strength test.
The test was carried out in accordance with the provisions of the "Test Standard for Mechanical Properties of Ordinary concrete" (GBT50081-2002). The compressive loading parameter was set as 0.6mpa /s, and each group was tested for 3 times, the average value was taken and multiplied by the size conversion factor of 0.95 as the final experimental result.

3. Results analysis

3.1. Failure characteristics of different test blocks at the same temperature
As shown in Figure 1, the failure patterns of each group are consistent. After careful observation of the specimens destroyed by compression, it can be seen that the broken places of ordinary concrete specimens are all the cementing surfaces of natural stones and cement bases. The stones themselves are basically not broken, and their forms are still intact. After the concrete with gangue coarse aggregate is destroyed, the fracture section passes through the gangue coarse aggregate but bypasses the stone. The analysis shows that the crushing index of coal gangue is 2.04 times of that of the stone, which is more easily broken than the stone. In the case of compression, the strength of stone itself is greater than that of cementing strength between stone and surrounding cementing strength, while that of gangue with surrounding cementing strength is greater than that of gangue itself.

3.2. Failure characteristics of the same test block at different temperatures
As shown in Figure 2, before 400°C, the section of cement base is relatively smooth, dense, obvious effect of the fracture section on aggregate, cement powder gradually after 400°C, the aggregate spun off from the cement base, breaking in to aggregate and cement cementation basic body surface or cement, rough section. This indicates that when the temperature exceeds 400°C, the cement-based pulverization of concrete is serious, which is the main reason for the specimen to break and seriously affects the compressive strength of concrete.
3.3. Pressure-displacement variation characteristics of each block

As shown in Figure 3, it can be seen that the compressive fracture characteristics of gangue coarse aggregate concrete are similar to those of ordinary concrete test blocks. Due to the standard shape of the specimen used in the test, it can be seen from the x-coordinate values corresponding to the curve slope, the highest point and the turning point of the curve in the figure that: the concrete specimen at 200℃ has the maximum rigidity, the concrete specimen at 400℃ has the maximum strength, and the concrete specimen has better plasticity at 600℃.

3.4. Variation characteristics of compressive strength of each block

As shown in Figure 4, before 400℃, the compressive strength of each group showed an upward trend, and reached its maximum strength at 400℃. After 400℃, the compressive strength declined. At normal temperature, the compressive strength of ordinary concrete specimens is the highest. With the increase of temperature, the strength of gangue concrete increases rapidly. When the temperature exceeds 400℃, the strength of ordinary concrete decreases at the fastest rate, and the concrete strength with 30% gangue coarse aggregate is the highest. Through analysis, it can be seen that the high temperature before 400℃ causes the secondary hydration of cement, and a large number of active substances generated by the thermal activation of coal gangue play the role of volcanic ash in water, which improves the bonding strength of aggregate and cement base. After 400℃, the cement base inside concrete gradually becomes powder, and the cementation strength between cement base and aggregate is weakened, which is the main reason for the decline of concrete strength. However, the cement strength of gangue concrete is higher than that of ordinary concrete specimens under the influence of the reaction of active ingredients in gangue.
4. Conclusion

(1) At room temperature, the compressive strength of gangue concrete is lower than that of ordinary concrete.

(2) Under high temperature, the concrete test blocks of each group are affected by secondary hydration of cement and thermal activation of gangue. The compressive strength of each group presents an upward trend before 400°C and reaches its maximum at 400°C. After 400°C, the compressive strength decreases due to cement-based pulverization.

(3) In high temperature environment, concrete with 30% gangue coarse aggregate has the best compressive performance. Replacing part of natural aggregate with non-spontaneous combustion coal gangue as concrete aggregate can not only solve the problem of large amount of gangue accumulation, alleviate the supply demand of natural aggregate market, but also improve the working performance of concrete to a certain extent, which has high practical value in the field of non-metallic building materials.

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