Study on Preparation Technology and Antifreeze Performance of Slag Micropowder Pumice Lightweight Aggregate Concrete

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Abstract. To study the influence of the amount of slag micropowder and the mixing ratio on the frost resistance of slag micropowder pumice lightweight aggregate concrete, the LC35 concrete was prepared with S95 grade slag powder, cement, ordinary sand and pumice as raw materials. The slow-freezing method was used to study the failure mode of the sample and the change of mass and compressive strength loss rate. The results show that the mass loss rate of slag micropowder pumice lightweight aggregate concrete after freezing and thawing cycles is small, and the loss of freeze-thaw strength is high. This mainly due to the destruction of aggregate pumice. Meanwhile, because of the Micro-filling effect of slag powder, the tensile strength has an effect of increasing the compactness of the concrete, and can effectively reduce the damage caused by the freeze-thaw cycle to the concrete.

1. Introduction

The raw materials used in traditional concrete not only consume a lot of energy in the production process, but also cause serious pollution to the environment. Taking ordinary Portland cement as an example, it needs to calcine limestone to 1400 degrees, which not only consumes a large amount of limestone and coal, but also 1kg of ordinary Portland cement will emit 0.66~0.82kg CO2 in the production process [1]. In China, the discharge of industrial solid waste, including slag and steel slag, continues to increase, causing serious pollution to the environment. Filling the concrete with some potentially active waste as a cementing agent reduces the amount of cement and realizes the comprehensive utilization of waste [2]. Slag micronized pumice lightweight aggregate concrete is a lightweight aggregate concrete prepared from pumice coarse aggregate. Pumice is one of the lightweight aggregates that has been studied in recent years. It is a mineral formed by magma cooling after volcanic ash eruption. The porosity is large, the density is small, and the main component is SiO2. It is widely distributed in northern China and has good economic performance [3][4]. The use of pumice as a coarse aggregate in concrete effectively avoids the opening of mountain and gravel, protects the original ecological environment and reduces environmental pollution.

In China, the winter in most parts of the north is relatively cold and lasts for a long time. Many buildings will have a very serious external surface and even internal structure after several years or more years of freezing and thawing. Destruction poses a threat to the people’s personal property and security. The frost resistance of concrete for buildings is very necessary for cold regions in China, and the research on frost resistance can directly reflect the multiple durability indexes of concrete used, such as impermeability, thermal insulation properties and interior of concrete tensile properties, etc.

In this paper, the S95 grade slag powder is used to replace the cement, and the coarse aggregate pumice is used to replace the stone. The slag micropowder pumice light aggregate is prepared and
tested for its frost resistance. Exploring the effect of pumice as a lightweight aggregate of concrete, after several freeze-thaw cycles, the failure mode, quality and compressive strength loss rate of the test piece, and the amount of slag micropowder and water-binder ratio on the slag micropowder pumice lightweight aggregate concrete.

2. Preparation Process of Slag Micropowder Pumice Lightweight Aggregate Concrete

2.1. Raw Material

The S95 grade slag powder produced by Runfa Mineral Products Processing Factory of Lingshou County, Shijiazhuang City, Hebei Province, is used in this research. Its main components are CaO, Al2O3 and SiO2, and the total content is over 90%. The performance indicators are shown in Table 1.

| Test items                  | standard requirement | actual data |
|-----------------------------|----------------------|-------------|
| density, g/cm³              | ≥2.8                 | 2.89        |
| Specific surface area, m²/kg| ≥400                 | 425         |
| 7-day activity index, %     | ≥75                  | 78          |
| 8-day activity index, %     | ≥95                  |             |
| Loss on ignition, %         | ≤3.0                 | 0.60        |
| Chloride ion content, %     | ≤0.06                | 0.036       |
| Liquidity ratio, %          | ≥95                  | 102         |
| Water content, %            | ≤1.0                 | 0.28        |

The cement is made of 42.5 grade ordinary Portland cement produced by Zhangjiakou City Jinyu Cement Co., Ltd. in Hebei Province. The physical performance indexes are shown in Table 2.

| Cement strength (MPa) | Fineness m²/kg | Setting time (min) | Compressive strength (MPa) | Flexural strength (MPa) |
|-----------------------|----------------|-------------------|---------------------------|-------------------------|
| 42.5                  | 347.0          | 110 175           | 3d 25.4                   | 3d 5.5                  |

The coarse aggregate pumice is made of light aggregate pumice from Zhangjiakou area, with a continuous grade of 4.75-20mm. The physical properties are shown in Table 3.

| Apparent density (kg/m³) | Bulk density (kg/m³) | Crushing indicator(%) | Mud content (%) | Water absorption rate(%) |
|--------------------------|----------------------|------------------------|----------------|-------------------------|
| 1707                     | 861                  | 38.1                   | 0.1            | 17.8                    |

In this paper, ordinary sand is used, the particle gradation is good, and its physical performance index is shown in Table 4.

| Fineness modulus (kg/m³) | Apparent density (kg/m³) | Bulk density (kg/m³) | Mud content (%) |
|--------------------------|--------------------------|----------------------|-----------------|
| 2.5                      | 2604                     | 1425                 | 3.5             |
The water reducing agent adopts the polycarboxylate superplasticizer produced by Zhangjiakou Haifeng New Building Materials Co., Ltd., which is translucent and viscous liquid, and the water reduction rate is as high as 28.7%. The specific performance indicators are shown in Table 5.

| Chloride | Na2SO4 | Alkali content | formaldehyde | Gas content | Bleeding rate ratio |
|----------|--------|----------------|--------------|-------------|--------------------|
| 0.025    | 2.30   | 1.4            | 0.007        | 2.9         | 0                  |

2.2. Mix Ratio Design
According to the design of mix design in JGJ51-2002 of Lightweight Aggregate Concrete Technical Regulations, according to the equal mass replacement method, the slag micropowder content is 30%, 45%, 50% respectively; the design water-to-binder ratio is 0.28, 0.30, 0.32 The sand ratio was 32%, 34%, and 38%, and the initial test mix ratio was determined. According to the designed 8 sets of ratios, 24 pieces of 100mm X 100mm X 100mm cube test pieces were produced, and the standard compressive strength of the cube was measured by the standard curing method. The conversion coefficient was converted into the cubic standard compressive strength, and the 7d compressive strength was used. The index and the concrete test piece are compared with the appearance quality to determine the best mix ratio. The mix ratio parameters are shown in Table 6.

| Serial number | Water to glue ratio | Mineral powder content(%) | cement kg/m³ | Mineral powder kg/m³ | pumice kg/m³ | sand kg/m³ | Water kg/m³ | Admix -ture kg/m³ |
|---------------|---------------------|---------------------------|--------------|----------------------|--------------|-------------|-------------|-------------------|
| C1            | 0.28                | 30                        | 312          | 168                  | 746          | 586         | 133         | 4.8               |
| C2            | 0.28                | 45                        | 264          | 216                  | 746          | 586         | 133         | 4.8               |
| C3            | 0.28                | 50                        | 240          | 240                  | 746          | 586         | 133         | 4.8               |
| C4            | 0.30                | 45                        | 247          | 203                  | 757          | 595         | 133         | 4.5               |
| C5            | 0.32                | 45                        | 231          | 189                  | 768          | 603         | 133         | 4.2               |

2.3. Preparation Process
Because the slag micropowder pumice lightweight aggregate concrete adopts coarse aggregate pumice with large porosity, large variability and small density than cement mortar, delamination phenomenon is easy to occur in the vibrating and transportation process of the mixture. Therefore, in the preparation of the modified concrete, the pumice is first pre-wetted. The slag micronized pumice lightweight aggregate concrete has relatively small self-weight, and the dry apparent density is about 1850kg/m³. Because the lightweight aggregate pumice particles are extremely irregular and the friction between them is very large, the vertical mixer cannot stir the concrete. Uniform, combined with the above reasons, the mixing of the slag micronized pumice lightweight aggregate concrete adopts the horizontal shaft forced mixer, and the mixing time is appropriately increased. The water absorption of the aggregate is very hard to the quality of the concrete, so the excess moisture of the pre-wet lightweight aggregate pumice is drained before the aggregate is placed, and the draining time is kept at 30 minutes. The feeding sequence is an extremely important part in the slag micropowder pumice lightweight aggregate concrete, and due to the water absorption problem of the pumice, in addition to the pre-wet pumice accident, the mixing materials are evenly stirred and then the polycarboxylic acid water reducing agent is added. The specific preparation process is shown in Figure 1.
Figure 1. Preparation process of slag micropowder pumice lightweight aggregate concrete.

3. Study on Frost Resistance of Slag Micronized Pumice Lightweight Aggregate Concrete

3.1. Experiment Method
The freeze-thaw cycle test uses the slow freezing method. The specific test method steps are as follows:

The concrete test block after curing for 28 days in the curing room is taken out from the standard curing room. The test piece is placed in the drying box for drying, and then the weighed spring is used. The minimum graduation value is 5g, and the test block is used. The mass is weighed and the data is recorded for later comparison. After measuring the quality, put it into a large water basin prepared in advance (the water surface is 20 mm or more above the upper surface of the test piece) and soak it in water for 4 days.

After the concrete test block is immersed for 4 days and the water is sufficient, remove it from the water basin and wipe the surface of the test block with a dry towel.

The test uses refrigerator as the freezer, and the temperature of the refrigerator is adjusted to \(-20\pm2\)°C (measuring the temperature in the refrigerator every day with a thermometer to prevent the temperature from changing too much, affecting the later data of the concrete specimen), brushing The test block isolation net is more convenient for layering in the test block, and will not cause the test block to be bonded due to freezing and thawing.

Always observe and record the failure mode of the concrete test block in time.

The test piece after the freeze-thaw cycle was dried, and the quality was weighed by a spring; the compressive strength test was performed on the test piece after the freeze-thaw cycle by a pressure tester.

3.2. Test Results and Analysis

3.2.1. Destructive morphology analysis
The freeze-thaw cycle 20 times of slag micro-powder pumice lightweight aggregate concrete test piece is shown in Figure 2. After 20 freeze-thaw cycles, the test piece is subjected to compression failure as shown in Figure 3. It can be seen from Fig. 2 that the appearance of the concrete specimen before and after the freeze-thaw test is basically unchanged, and the surface is still dense and smooth. The number of freeze-thaw cycles was 20, and there was no major damage to the internal structure and outer surface of the slag micropowder pumice lightweight aggregate concrete test piece, so there was no such phenomenon that the surface of the test piece became rough and the coarse aggregate was exposed or peeled off.

When the compressive strength test of the freeze-thaw cycle test piece is carried out, the damage caused by the test piece and the failure mode of the same set of test pieces which are not subjected to the freeze-thaw cycle are basically similar. When the test piece is destroyed, the concrete in the middle
part acts under pressure. The expansion began to occur, and then vertical cracks appeared around the test piece and continued to fall off as the pressure increased, and finally the upper and lower portions showed a pyramid.

![Figure 2. Specimen shape after freeze-thaw cycle.](image1)

![Figure 3. Destruction of specimen after freezing and thawing cycle.](image2)

3.2.2. Freeze-thaw quality loss rate analysis

The freeze-thaw mass loss rate is shown in Table 7. There are 4 sets of test pieces (C1, C2, C4 and C5). After 20 freeze-thaw cycles, the quality of the test pieces has increased correspondingly, and the increase range is between 0.02% and 0.07%. The reason why the quality of the test piece can be increased after 20 freeze-thaw cycles is that the density of the pumice light aggregate is small and the pores are many. It is impossible to remove the air in the pore during the vibration molding of the concrete test piece. In the process of freezing and thawing, the alternating hot and cold will cause tiny pores at the interface between the aggregate and the cementitious material inside the concrete, and the air in the concrete will be continuously discharged, and then the water will continuously flow in. With the continuous entry of water, the hydration reaction inside the concrete is also continuously carried out. The chlorinated powder and the unreacted and reacted CaO in the cement react with the newly entered water to produce a large amount of Ca(OH)2. Crystal. Therefore, the quality of the test piece increased after the freeze-thaw cycle. The quality of the C3 group specimens was reduced. The results of the freeze-thaw test of the above four groups of specimens were analyzed comprehensively. Because the concrete specimens of the C3 group were unevenly mixed during the preparation process, the six specimen blocks after the concrete specimens were formed. The difference in dry apparent density is large. It has a great impact on the quality loss rate of concrete freeze-thaw test in the later stage.

| Serial number | Quality before freezing and thawing (g) | Freeze-thaw 20 times quality (g) | Quality loss rate(%) |
|---------------|----------------------------------------|----------------------------------|----------------------|
| C1            | 1895                                   | 1902                             | -0.04                |
| C2            | 1900                                   | 1905                             | -0.03                |
| C3            | 1898                                   | 1890                             | 0.04                 |
| C4            | 1865                                   | 1879                             | -0.07                |
| C5            | 1870                                   | 1874                             | -0.02                |

3.2.3. Freeze-thaw strength loss rate analysis

From the loss rate of compressive strength before and after the freeze-thaw specimen shown in Table 8, it can be known that after 20 freeze-thaw cycles in concrete time, each group of specimens has a
certain strength of compressive strength loss, which is generally distributed at 4% and Between 8%. There are several reasons for the loss of compressive strength of concrete specimens: The porosity of the pumice particles is large, and the water content of the pores in the concrete is large. After multiple freeze-thaw cycles, the volume of the water becomes larger after freezing, which causes the concrete to expand inside, alternating between hot and cold, and repeated expansion causes a large amount of interior of the concrete. The gap, the concrete tensile strength is relatively small to offset the destructive power of water freezing. As the number of freeze-thaw cycles increases, the gap will become larger and larger, and more will flow into the pores, resulting in an uncontrollable vicious cycle, further causing damage to concrete specimens by freeze-thaw. The micro-aggregate filling effect of the slag micropowder will improve the tensile strength of the concrete and also increase the compactness of the concrete (the later hydration reaction will further produce a large amount of Ca(OH)2), and the activity is better than that of fly ash. High, can increase the interface bonding ability between the aggregates. Comparing the loss rate of compressive strength of the three groups C1, C4 and C5 in Table 7, it can be concluded that with the increase of the concrete water-to-binder ratio, the internal expansion of the concrete is more serious due to the excessive moisture and pores in the early stage. Therefore, the strength loss rate of concrete is relatively large.

| Serial number | Compressive strength before freezing and thawing(MPa) | Freeze-thaw 20 times compressive strength(MPa) | Strength loss rate(%) |
|---------------|--------------------------------------------------------|----------------------------------------------|-----------------------|
| C1            | 32.04                                                  | 29.44                                       | 8.12                  |
| C2            | 38.68                                                  | 37.07                                       | 4.16                  |
| C3            | 31.46                                                  | 29.05                                       | 7.66                  |
| C4            | 33.97                                                  | 32.01                                       | 5.77                  |
| C5            | 27.83                                                  | 25.91                                       | 6.90                  |

4. Slag Micronized Pumice Lightweight Aggregate Concrete Application

The slag micropowder pumice lightweight aggregate concrete has a strength grade of LC35, a dry apparent density of no more than 1900 kg/m3, and good frost resistance. It integrates various indicators and specific application conditions of a number of representative lightweight aggregate concrete bridge projects at home and abroad, and combines the strength grade and frost resistance of the designed slag micronized pumice lightweight aggregate concrete. It is proposed to apply slag micropowder pumice lightweight aggregate concrete to bridge deck pavement and anti-shock retaining wall. It is proposed to apply slag micro-powder pumice lightweight aggregate concrete to the upper floor slab and structural wall slab of high-rise or super high-rise, to reduce the self-weight of the superstructure and the load pressure of the foundation, and also meet the requirements of new loads. Moreover, in the process of concrete pumping in super high-rises, considering that it is very difficult to block the pumping of high-rise buildings, it is advisable to use tower crane construction, then use the chute to unload the concrete to the construction site and ensure that the concrete has high fluidity.

5. Conclusions

The freeze-thaw cycle has a relatively high compressive strength to lightweight aggregate concrete. After 20 freeze-thaw cycles of slag micropowder pumice lightweight aggregate concrete, the mass loss rate of the test pieces is very small, ranging from 0.02% to 0.07%. The compressive strength loss rate is relatively large, reaching 4% to 8%.

The micro-aggregate filling effect of the slag powder can improve the tensile strength of the concrete, increase the compactness of the concrete, and effectively reduce the damage caused by the freeze-thaw cycle to the concrete.

The compressive strength loss rate of slag micronized pumice lightweight aggregate concrete increases first, then decreases and then increases with the increase of slag micropowder content.
The water-to-binder ratio will have a certain impact on the damage and compressive strength of concrete freeze-thaw cycles. As the concrete water-to-binder ratio increases, the compressive strength loss rate increases relatively.

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