Study on the Influence of the Pre-Wetting Time of Ceramsite and the Floating Beads Content on the Property of Lightweight High-Strength Concrete

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Abstract. The influence of different ceramsite pre-wetting time and the floating beads content on the properties of lightweight high-strength concrete was studied in this paper. The results showed that as the pre-wetting time increased, the absorption rate of ceramsite continued to increase, reaching a saturated state at 12 h with 36.14% water absorption rate; the concrete slump/expansion degree is increased significantly, and the growth rate decreased gradually, and the improvement was not obvious after 12 h; the 7 d strength of concrete saw an obvious downturn, and the strength dropped by 10.4% at 12 h, after which the decline was basically stable; the 28 d strength, 28 d strength growth rate and 7 d-28 d strength growth rate all showed a steady upward trend, which reached 61.18 MPa, 12.4% and 29.73% respectively at 12 h, and the growth rate was basically stable afterwards; as the floating beads content increased, the concrete dry density, slump/expansion degree, 7 d and 28 d strength all showed a significant decline trend.

1. Introduction
As the construction industry of China continues to transform and upgrade toward low energy consumption, high environmental protection, and high quality[1], lightweight high-strength concrete has become an important research direction in modern concrete field with broad market prospects because of its low density, high compressive strength, and good thermal insulation properties[2-3].

At present, the main functional material components, such as ceramic pellets and floating beads, are used to prepare lightweight high-strength concrete. On the one hand, ceramic pellets are porous structural materials with the advantages of light mass, high strength and low thermal conductivity[4-5], which can be used to replace traditional aggregates and reduce energy consumption in construction[1]. But this porous structure has high water absorption[6], which will affects the work performance and mechanical properties of concrete[7-9]. On the other hand, floating beads are industrial waste, and its most important feature is low density and small fineness, which can be used as a lightweight material for concrete to replace fly ash. However, the high rate of water absorption, about 20 times that of sand, can also influences the work performance and mechanical properties of concrete.

Therefore, pre-wetting of the ceramsite was firstly made to study the effect of different pre-wetting time (PWT, Pre Wetting Time) on the water absorption rate of ceramic pellets, work performance and mechanical properties of lightweight high-strength concrete in this paper; and based on this, the effect of different floating beads content (FBC, Floating Beads Content) on dry density, work performance and mechanical properties of lightweight high-strength concrete was further investigated in this paper.
2. Design of raw materials and mix ratio

2.1. Test raw materials
The cement used in the test is Conch high-performance cement P.II 52.5; the fly ash is Huaneng II grade fly ash; the density of silica fume is 2400 kg m⁻³; the density of floating beads (FB) is 600 kg m⁻³; the silicate ceramics is composed of the mixture of quartz tailings aggregate and sand in 8:2 proportion, with a particle size distribution between 2 mm and 16 mm; the sand is medium-sized natural river sand, with a fineness modulus of 2.4; the water is running water and the water reducer is BASF high efficiency polycarboxylate acid water reducer with a solid content of 17%.

2.2. Mix ratio design
The benchmark mix ratio of lightweight high-strength concrete used in this paper (excluding the pre-wetting time of ceramsite and the floating beads content) is shown in table 1.

| Components      | Cement | Silica fume | Fly ash | Silicate ceramics | Sand | Water | Water reducer | W/C |
|-----------------|--------|-------------|---------|------------------|------|-------|---------------|-----|
| Content         | 500    | 50          | 60      | 776              | 268  | 158   | 4.75          | 0.26|

The first part is to design the mix ratio for 8 different ceramsite pre-wetting times of 0 h, 1 h, 3 h, 5 h, 8 h, 12 h, 18 h and 24 h, which are respectively marked as PWT0, PWT1, PWT3, PWT5, PWT8, PWT12, PWT18, PWT24, to study the effect of different ceramsite PWT on the performance of lightweight high-strength concrete.

In the second part, based on the research results of the first part, the mix proportion design was carried out for five groups of different floating beads content, including 0 kg, 30 kg, 45 kg, 90 kg and 120 kg, which are respectively marked as PWT12-FBC0, PWT12-FBC30, PWT12-FBC45, PWT12-FBC90, PWT12-FBC120, to study the influence of different floating beads content on the performance of lightweight high-strength concrete.

3. Test method
The research is divided into two parts. The first part is the influence of different pre-wetting time (PWT) on the water absorption of ceramsite, the work performance and mechanical properties of lightweight high-strength concrete; the second part is the influence of different floating beads content (FBC) on the dry density, work performance and mechanical properties of lightweight high-strength concrete.

The concrete is mixed by a horizontal-shaft mixer at one time. The test indicators are divided into four categories: rate of water absorption, dry density, slump/expansion degree and compressive strength.

The water absorption test of ceramsite shall be conducted according to Standard for technical requirements and test method of sand and crushed stone(or gravel) for ordinary concrete (JGJ 52-2019); The dry density of concrete shall be tested according to Technical standard for application of lightweight aggregate concrete (JGJ/T 12-2019); The concrete slump/expansion test shall be carried out according to Standard for test method of performance on ordinary fresh concrete (GB/T 50080-2016); The concrete compressive strength test shall be carried out according to Standard for test methods of concrete physical and mechanical properties(GB/T 50081-2019).

4. Test results and analysis

4.1. The influence of pre-wetting time (PWT) on water absorption of ceramsite and performance of concrete
According to 8 groups of concrete mixtures with different pre-wetting time mix ratio from PWT0 to PWT24, the water absorption rate of ceramsite and concrete slump/expansion degree are tested. The test results are shown in table 2 and figure1~2.
Table 2. The influence of PWT on water absorption of ceramsite and work performance of concrete

| Test number PWT | PWT (h) | Rate of water absorption (%) | Slump/expansion degree S (mm) |
|-----------------|---------|-------------------------------|-----------------------------|
| PWT0            | 0       | 0                             | 95/230                      |
| PWT1            | 1       | 10.77                         | 140/420                     |
| PWT3            | 3       | 23.35                         | 185/540                     |
| PWT5            | 5       | 34.53                         | 215/595                     |
| PWT8            | 8       | 35.36                         | 230/610                     |
| PWT12           | 12      | 36.14                         | 235/615                     |
| PWT18           | 18      | 36.14                         | 235/620                     |
| PWT24           | 24      | 36.15                         | 240/620                     |

Figure 1. The effect of PWT on the water absorption of ceramsite

It can be seen from table 2 and figure 1 that as the pre-wetting time increases (0 h~24 h), the water absorption rate of ceramsite increases, but the growth rate decreases gradually. At 12h, it basically reaches saturation state, and the water absorption rate reaches 36.14%.

Figure 2. The influence of ceramsite PWT on concrete slump/expansion degree

It can be seen from table 2 and figure 2 that the slump and expansion degree of the concrete mixture increase with the continuous increase of the ceramsite pre-wetting time, but the growth rate decreases gradually. When the pre-wetting is 12 hours, the slump degree reaches 235 mm, and the expansion
degree is up to 615 mm. After 12 h, the improvement of working performance is not obvious. The main reason is that the longer the pre-wetting time, the higher the water absorption rate of the ceramsite, and more free water is attached to the inside and the surface of the ceramsite. While the water is playing a lubricating effect, the ability to absorb water from the gelled slurry is continuously weakened, so as to improve the working performance of the concrete mixture. This improvement will become insignificant after water saturation (12 h).

7 d/28 d compressive strength($f_{c-7}/f_{c-28}$), 28 d compressive strength growth rate($G_1$) and 7 d-28 d compressive strength growth rate($G_2$) test results of 8 groups of concrete from PWT0 to PWT24 are shown in table 3 and figure 3. $G_1=\frac{(f_{c-28}-f_{c-28})}{f_{c-28}} \times 100\%$, $G_2=\frac{(f_{c-28}-f_{c-7})}{f_{c-7}} \times 100\%$.

| Test number | PWTi | 7d Compressive strength $f_{c-7}$ (MPa) | 28d Compressive strength $f_{c-28}$ (MPa) | 28d Growth rate of compressive strength $G_1$ (%) | 7d-28d Growth rate of compressive strength $G_2$ (%) |
|-------------|------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| PWT0        | 52.63| 54.42                                 | /                                     | /                                     | 3.401                                 |
| PWT1        | 51.32| 55.63                                 | 2.223                                 | 8.398                                 |
| PWT3        | 50.11| 57.71                                 | 6.0456                                | 15.167                                |
| PWT5        | 49.17| 59.04                                 | 8.490                                 | 20.073                                |
| PWT8        | 48.25| 60.12                                 | 10.474                                | 24.601                                |
| PWT12       | 47.16| 61.18                                 | 12.422                                | 29.729                                |
| PWT18       | 46.84| 61.22                                 | 12.495                                | 30.700                                |
| PWT24       | 46.63| 61.25                                 | 12.551                                | 31.353                                |

Figure 3. The influence of ceramsite PWT on the mechanical properties of concrete

From table 3 and figure 3, it can be seen that as the ceramsite pre-wetting time increases, the early strength of concrete at 7 d presents a significant decline trend, and the reduction rate reaches 10.4% at 12 h. When the pre-wetting time exceeds 12 h, the 7 d early strength decrease is basically stable. The reason is that, as the pre-wetting time increases, the water content of the ceramsite increases, and the water absorption capacity of the concrete cementitious material system continues to decrease, so that the reduction rate of the water-cement ratio at the interface of the ceramsite-cementitious material system decreases continuously, the number and size of pores in the interface area continue to increase, and the compaction gradually decreases, which eventually leads to a continuous decrease in concrete strength.

With the increase of pre-wetting time, the 28 d strength($f_{c-28}$), 28 d strength growth rate($G_1$) and 7 d-28 d strength growth rate($G_2$) of concrete showed a steady upward trend. At 12 h, $f_{c-28}$ reached 61.18 MPa, and $G_1$ reached 12.4%, $G_2$ reached 29.73%, after 12 h, the growth trend tended to be flat. The main
reason is that as the hydration reaction continues, the water in the cementitious material system continues to lose, and the relative humidity of the cementitious system is less than ceramsite, which causes the internal water precipitation from the ceramsite to show a phenomenon of "backwater", forming the effect of "internal curing", this "internal curing" effect reaches its peak at 12 h and this is particularly obvious in the low water-binder ratio and high-strength concrete. As the pre-wetting time is longer, the internal water absorption of the ceramsite increases, and its “internal curing” ability is stronger, the acceleration and efficient of the hydration reaction will be greater, which greatly increases the 28 d strength, 28 d strength growth rate and 7 d-28 d strength growth rate of concrete. What's more, because the ceramsite shell is mainly composed of torbermite (5CaO·6SiO2·5H2O), quartz (SiO2), mullite (3Al2O3·2SiO2) and silica alumina glass, among them the silica alumina glass will react with the hydration product, such as Ca(OH)2, to form hydrated calcium silicate, which improves the structure of the interface transition zone between the ceramsite and the cementitious material system, enhances the interface bonding performance, and promotes the later mechanical properties of concrete, which is also an important reason why the concrete fracture surface penetrates the ceramsite lightweight aggregate.

4.2. The influence of the floating beads content (FBC) on the performance of concrete

It can be seen from section 3.1 that when the PWT is 12 h, the performance optimization of concrete basically achieves the maximum effect. In order to further realize the lightweight goal of high strength and high performance concrete, this study uses floating beads to reduce the dry density of concrete, and explores its influence on the work performance and mechanical properties of concrete.

Five groups of concrete mix proportions with different floating beads contents from PWT_{12}-FBC_{0} to PWT_{12}-FBC_{120} were designed, and the dry density, slump/expansion degree and 7d/28d strength indexes were tested. The test results are shown in table 4 and figures 4~6.

Table 4. The influence of different FBC on the performance of concrete

| Test number | FBC (kg) | Dry density (kg m^{-3}) | Slump/Expansion degree S (mm) | 7d Compressive strength f_{c-7} (MPa) | 28d Compressive strength f_{c-28} (MPa) |
|-------------|---------|-------------------------|-----------------------------|-------------------------------------|-----------------------------------------|
| PWT_12-FBC_0 | 0       | 1865                    | 235/615                     | 47.16                               | 61.18                                   |
| PWT_12-FBC_30 | 30      | 1794                    | 205/550                     | 45.72                               | 59.38                                   |
| PWT_12-FBC_45 | 45      | 1771                    | 170/460                     | 44.21                               | 56.68                                   |
| PWT_12-FBC_90 | 90      | 1735                    | 140/400                     | 43.15                               | 54.62                                   |
| PWT_12-FBC_120 | 120    | 1693                    | 125/310                     | 41.43                               | 53.11                                   |

Figure 4. The influence of the FBC on the dry density of concrete

It can be seen from table 4 and figure 4 that the dry density of concrete decreases continuously with
the increase of the floating beads content. The main reason is that the apparent density of floating beads is relatively low (only 600 kg m\(^{-3}\)), which is an excellent concrete degradation component. As the floating beads content continues to increase, its volume occupancy rate continues to rise, resulting in a significant decrease in the dry density of concrete.

![Graph showing the influence of floating beads content on slump and expansion degree](image1)

Figure 5. The influence of the FBC on the work performance of concrete

It can be seen from table 4 and figure 5 that the slump and expansion degree of concrete decrease with the increase of the floating beads content. The main reason is that the floating beads have the characteristics of fast water absorption and high water absorption (approximately 20 times that of sand). With the continuous increase in the floating beads content, the water absorbed by the floating beads continues to increase, and the free water in the concrete continues to decrease, resulting in a continuous decline in the work performance of the concrete mixture.

![Graph showing the influence of floating beads content on compressive strength](image2)

Figure 6. The influence of the FBC on the mechanical properties of concrete

It can be seen from table 4 and figure 6 that as the floating beads content increases, the 7 d and 28 d strength of concrete also decreases. The main reason is that as the floating beads content increases, the water absorbed by the high water absorption rate floating beads also increases, which leads to the continuous reduction of free water in the concrete, and thus hindering the hydration reaction process of the concrete cementitious material system, and the concrete compaction is further reduced, which leads to a continuous decline in the mechanical properties of the concrete.
5. Conclusion

(1) As the pre-wetting time increases, the water absorption rate of the silicate ceramsite continues to increase, and reaches a saturated state at 12 h, when the water absorption rate reaches 36.14%.

(2) As the pre-wetting time increases, the slump/expansion degree of concrete increases significantly, but the growth rate decreases gradually. After 12 hours, the improvement of workability is not obvious.

(3) As the pre-wetting time increases, the 7 d strength of concrete shows a significant downward trend. When the pre-wetting time reaches 12 h, the strength is 47.16 MPa, with the rate of decrease reaching 10.4%, and then the rate of decrease becomes basically stable.

(4) As the pre-wetting time increases, the 28 d strength, 28 d strength growth rate and 7 d-28 d strength growth rate of the concrete all show a steady upward trend, reaching 61.18 MPa, 12.4% and 29.73% respectively when the pre-wetting time reaches 12 h, and then the growth rate turns basically stable.

(5) Under the condition of pre-wetting for 12 hours, with the increase of concrete floating beads content, the concrete dry density, slump/expansion degree, 7 d and 28 d strength all show a significant downward trend. In the actual production and application process, special attention should be paid to the determination of the best amount of floating beads content in order to meet the requirements of concrete dry density, work performance and mechanical properties at the same time.

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