Study on influencing factors of mechanical properties of ceramsite foam concrete based on orthogonal test

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Abstract: In this paper, orthogonal test is used to optimize the mix ratio of ceramsite foam concrete and improve the strength of ceramsite foam concrete with ceramsite content, water-cement ratio and fly ash content as the research parameters, and the compressive strength is taken as the main investigation index. The experimental results show that the content of fly ash has the greatest influence on the compressive strength of ceramsite foam concrete, the content of ceramsite is the second, and the ratio of water to cement is the smallest. Through experiment and analysis, the recommended mix ratio is as follows: the content of ceramsite is 10% ~20%, the amount of fly ash is 10% ~15%, and the ratio of water to cement is 0.4 ~0.5.

1. Introduction
Ceramsite foam concrete material is a new building material [1] at present, it integrates high strength, low density and wide application range [2]. Ceramsite foam concrete is a kind of light porous material formed by mixed mixing and curing with cement, ceramsite, fly ash, water, foaming agent and so on as the main materials [3]. Because of its environmental protection, light weight, heat preservation, sound insulation and high strength, which accords with the development direction of building materials in our country in the future, and has a broad market application prospect, the research on ceramsite foam concrete is of great significance [4]. However, at present, ceramsite foam concrete still has some shortcomings, such as poor working performance and low strength of the mixture. In this paper, the optimum mix ratio is explored through orthogonal test to improve the performance of ceramsite foam concrete.

2. Experimental materials
2.1. Cement
The strength of ceramsite foam concrete is greatly affected by the strength of cement, so it is particularly important to choose suitable cement. In addition to meeting the national standards, there should also be higher strength, faster condensation speed, and no components that impair the stability of foam [5]. Considering comprehensively, 42.5 grade ordinary Portland cement is used in this study.

2.2. Ceramsite
As the main lightweight aggregate, the ceramsite used as ceramsite foam concrete should have the characteristics of low density, thermal conductivity, water absorption and smooth surface of ceramsite without obvious defects [6]. The properties of ceramsite selected in this experiment are shown in Table 1.
Table 1 Performance index of ceramsite grain size/mm stacking density/(kg/m$^3$) apparent density/(kg/m$^3$) cylinder compressive strength/MP 1 hour water absorption/% coefficient of softing

| grain size/mm | stacking density/(kg/m$^3$) | apparent density/(kg/m$^3$) | cylinder compressive strength/MP | 1 hour water absorption/% | coefficient of softing |
|---------------|-----------------------------|-----------------------------|----------------------------------|---------------------------|------------------------|
| 10~20         | 336                         | 394                         | 1.2                              | 9.9                       | 0.86                   |

2.3. Fly ash

Fly ash, as the main industrial waste of thermal power plant and as a new type of green energy, can not only relieve the environmental pressure, replace cement to a certain extent, so as to reduce the amount of cement, but also improve the properties of materials, such as adjusting strength, improving corrosion resistance and so on.

2.4. Foaming agent

Foaming agent is an admixture which can reduce the surface tension of liquid and produce a large number of uniform and stable foam, which can be used to produce foam concrete. The foaming agent selected in this experiment is dry powder and needs to be mixed with water in the proportion of 1:30 and stirred. After mixing with water, the mixture is white, and a large amount of white flocculent foam is obtained after stirring, the density is 25kg/m$^3$, and the ph value is 6.0 ~ 8.0.

3. Experimental design and specimen fabrication

3.1. Experimental method

In this experiment, three factors and four levels orthogonal table are used to arrange the test, and the dry density is 700 kg/m$^3$. The variance analysis of various factors affecting the mix proportion of ceramsite foam concrete can be carried out by using orthogonal design, and the significant influencing factors can be obtained.

In this experiment, taking ceramsite content, water cement ratio and fly ash content as the research parameters in orthogonal test, the compressive strength of ceramsite foam concrete test block was tested, and the optimum experimental mix ratio of ceramsite foam concrete was explored$^{[1,7,8]}$.

The factor level of orthogonal test is shown in Table 2. The content of ceramsite and fly ash is the mass percentage of replacing cement, and the ratio of water to ash is the weight ratio of water consumption to cement content.

Table 2. Orthogonal experiment factor level table

| Number | Ceramsite content/% | water cement ratio | Fly ash content/% |
|--------|---------------------|--------------------|-------------------|
| 1      | 10                  | 0.2                | 10                |
| 2      | 20                  | 0.3                | 15                |
| 3      | 30                  | 0.4                | 20                |
| 4      | 40                  | 0.5                | 25                |

3.2. Specimen making

First of all, the weighing cement fly ash, ceramsite, water reducer and so on will be poured into the mixer to stir for 60s, and then the foaming agent will be stirred with the mixer. When a large number of foam similar to cotton floc appears, the foam will be poured into the mixer, then poured into tap water, stirred 120s, molded, after 24 hours of static setting, the mold is removed, then put into the standard curing room for curing, and after the specified age, the test block will be taken out for testing. The strength of concrete is tested according to the Mechanical Properties Test Standard of ordinary concrete (GB/T50081-2002).
4. Experimental results and analysis

4.1. Experimental results and range analysis

The mix ratio of the experiment and the experimental results are shown in Table 3.

| Experimental serial number | Cement /kg | Ceramsite content /% | Water cement ratio | Fly ash content /% | Water /kg | 7d compression strength /MPa | 28d compression strength /MPa |
|-----------------------------|------------|----------------------|--------------------|-------------------|-----------|-----------------------------|-----------------------------|
| 1                           | 555.30     | 10                   | 0.2                | 10                | 90.82     | 3.62                        | 7.84                        |
| 2                           | 527.35     | 20                   | 0.5                | 10                | 248.56    | 3.57                        | 7.76                        |
| 3                           | 499.63     | 30                   | 0.4                | 10                | 186.90    | 3.46                        | 7.72                        |
| 4                           | 471.60     | 40                   | 0.3                | 10                | 129.65    | 3.39                        | 7.54                        |
| 5                           | 555.30     | 10                   | 0.5                | 15                | 261.90    | 3.81                        | 8.07                        |
| 6                           | 527.35     | 20                   | 0.2                | 15                | 87.72     | 3.57                        | 7.81                        |
| 7                           | 499.65     | 30                   | 0.4                | 15                | 186.98    | 3.66                        | 7.72                        |
| 8                           | 471.50     | 40                   | 0.3                | 15                | 129.60    | 3.74                        | 7.71                        |
| 9                           | 555.36     | 10                   | 0.5                | 20                | 261.92    | 3.59                        | 7.63                        |
| 10                          | 527.40     | 20                   | 0.4                | 20                | 195.93    | 3.53                        | 7.52                        |
| 11                          | 499.33     | 30                   | 0.2                | 20                | 84.62     | 3.46                        | 7.48                        |
| 12                          | 471.50     | 40                   | 0.3                | 20                | 129.65    | 3.31                        | 7.41                        |
| 13                          | 555.33     | 10                   | 0.5                | 25                | 261.92    | 3.46                        | 7.32                        |
| 14                          | 527.80     | 20                   | 0.4                | 25                | 195.95    | 3.43                        | 7.24                        |
| 15                          | 499.60     | 30                   | 0.3                | 25                | 136.00    | 3.49                        | 7.22                        |
| 16                          | 471.33     | 40                   | 0.2                | 25                | 81.27     | 3.32                        | 7.21                        |

As can be seen in Table 4, in the analysis of the range results, the more the range (R) is, the more the influence on the compressive strength is, the primary and secondary order of the influence factors of the compressive strength of the test block is that: C>A>B, that is, the fly ash content has the greatest influence on the compressive strength of the ceramsite foam concrete, The content of the ceramsite is the second, and the water-cement ratio is the smallest; the results of the test results of the compressive strength of 7d and 28d are the same. The optimum matching ratio is 10%, the water cement ratio is 0.5, the content of fly ash is 15%, and the compressive strength of 7d and 28d is 3.8MPa and 8.07MPa, respectively.

| Experiment number | A ceramsite/ % | B water cement ratio | C fly ash/% | A ceramsite/ % | B water cement ratio | C fly ash/% |
|-------------------|----------------|----------------------|-------------|----------------|----------------------|-------------|
| K1                | 14.48          | 13.97                | 14.04       | 30.86          | 30.39                | 30.86       |
| K2                | 14.10          | 13.93                | 14.78       | 30.33          | 29.88                | 31.31       |
| K3                | 14.07          | 14.08                | 13.89       | 30.14          | 30.20                | 30.04       |
| K4                | 13.76          | 14.43                | 13.70       | 29.87          | 30.78                | 28.99       |
| R(range)          | 0.72           | 0.50                 | 1.08        | 0.99           | 0.90                 | 2.32        |

The arithmetic average value of the compression results of each factor is taken, and the drawing curve is shown in the following figure.
4.1.1. Effect of ceramsite content on compressive strength
The addition of ceramsite can not only reduce the weight, but also has the characteristics of superior thermal insulation and thermal insulation, low water absorption and so on. However, ceramsite itself, as a kind of artificial lightweight aggregate, excessive amount of ceramsite will affect the overall compressive strength. It can be seen from Fig.1 that the more ceramsite content is, the more strength decreases. Therefore, it is not suitable to add too much ceramsite in the preparation of ceramsite foam concrete. It is suggested that the content of ceramsite should be controlled at 20% ~30%, which can not only play the role of ceramsite, but also ensure a certain strength. At the same time, in the course of the experiment, it is found that the particle size of the selected ceramsite should not be too large and easy to be produced when preparing ceramsite foam concrete test block. The particle size is recommended to be controlled between 10 mm and 20 mm.

![Fig.1 Effect of content of ceramsite on compressive strength(7d and 28d)](image1)

4.1.2. Effect of water-cement ratio on compressive strength
From Fig.2, it can be seen that the compressive strength of ceramsite foam concrete decreases slightly at 0.2 ~0.3 in water cement ratio, and increases at 0.3 ~0.5 in the preparation of ceramsite foam concrete. The water-cement ratio mainly affects the compressive strength by affecting the pore structure. When the water-cement ratio is small (0.2~0.3), although the strength is higher, but the mobility is poor, the encapsulation of ceramsite is uneven, and the full cement particles are united, which is not conducive to the strength growth of the test block.

With the increase of the water cement ratio (0.3~0.5), the slurry is made to have fluidity, and the light aggregate ceramsite is also wrapped uniformly, so that the internal porosity is reduced, the compressive strength [9] is improved, and the foam is also easily distributed in the slurry.

In addition, it is also found that when the water cement ratio is too large (more than 0.5), the slurry consistency decreases, the bubble is unstable, the slurry is layered, and the lightweight aggregate ceramsite floats and so on. Considering comprehensively, it is suggested that the water-cement ratio should be controlled at 0.4~0.5.

![Fig.2 Effect of water cement ratio on compressive strength(7d and 28d)](image2)
4.1.3. Effect of fly ash content on compressive strength

The effect of fly ash content on compressive strength can be seen from Fig.3. It can be seen that the strength of ceramsite foam concrete increases when the content of fly ash is 10% ~ 15%, and begins to decrease when the content of fly ash is more than 15%. This is due to the secondary hydration reaction between SiO$_2$, the chemical composition of fly ash, and Ca (OH) 2, the main product in Portland cement. Calcium silicate hydrate and calcium alginlate hydrate can be used as cementitious materials to increase the strength to a certain extent. However, after the content exceeds 15%, the strength decreases with the increase of the content, which is due to the fact that fly ash can not completely replace cement\cite{10}. Therefore, it is suggested that the content of fly ash should be 10%~15%.

![Fig.3](image.png)

The effect of the amount of fly ash on the compressive strength(7d and 28d)

5. Conclusion

(1) Ceramsite as lightweight aggregate, the content should not be too much, so as to affect the strength. To prevent the bad situation in the preparation process, the particle size range of ceramsite is within the range of 10mm~20mm.

(2) The use of fly ash can not only reduce the amount of cement, but also make up for the decrease of strength after adding ceramsite to a certain extent. More importantly, it can improve the working performance of ceramsite foam concrete.

(3) The ratio of water to cement is the key factor to affect the workability of foam and cement slurry. The water-cement ratio is too small, the liquidity is poor, the self-weight is large, and the foam loss is too much: the water-cement ratio is too large, the ceramsite floats, the fresh concrete is easy to separate, the foam stability decreases and so on.

(4) In the process of exploring the primary and secondary factors affecting the compressive strength of ceramsite content, water-cement ratio and fly ash content, the conclusion is drawn through the test of compressive strength: fly ash content has the greatest influence on compressive strength, ceramsite content is the second, and water cement ratio is the smallest. The optimum mixture ratio is as follows: the content of ceramsite is 20% ~30%, the content of fly ash is 10% ~ 15%, and the ratio of water to cement is 0.4 ~ 0.5. The actual density is about 720 kg/m$^3$.

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