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Research on the Application of Orthogonal Analysis in the Preparation of Foam Concrete

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Abstract

Orthogonal experiment is an important experimental design method, widely used in the field of engineering, science and statistics, which can select a number of representative test conditions in a larger number of test conditions, and through the data of these several experiments, to find the better target conditions, i.e., the optimal or better program. This paper describes the application of orthogonal experimental analysis in the preparation of foam concrete, through the four-factor three-level proportion analysis of foam concrete optimal proportion to carry out the study, the experimental results show that: the optimal proportion of ceramic foam concrete is 25% of ceramic granule mixing, the foaming agent mixing amount of 0.3, the amount of fly ash mixing amount of 20%, at this time, the ceramic compressive strength of the foam concrete in the range of 1.79~2.22MPa The compressive strength of ceramic foam concrete is 1.79~2.22MPa, and the apparent density is 700~800kg/m3.

Keywords

Orthogonal Experiment; Foam Concrete; Compressive Strength; Apparent Density.

1. Introduction

In the fields of engineering, science and statistics, experimental design plays a crucial role in order to deeply understand and optimize the performance of complex systems. However, traditional experimental methods often require a large number of experiments, consume a lot of time and resources, and limit the progress and efficiency of research. Therefore, how to obtain accurate and reliable experimental results in as few trials as possible has become an important issue. In order to solve this problem, Orthogonal Analysis has emerged as an efficient and reliable experimental design method. Orthogonal experiments effectively reduce the number of trials by systematically designing experimental protocols and are able to extract the effects of key factors on response variables. The aim of this study is to optimize the mixing ratios in the preparation of foam concrete and design an application study to compound the desired target properties. In this thesis, firstly, we will introduce the basic principle and design method of orthogonal experiment. Then, by designing and experimenting foam concrete mixing ratios with four factors and three levels, we will explore the application of orthogonal experiments under different factors and derive the optimal or better experimental mixing ratio scheme, and finally, we will summarize the results of the study and look forward to further research and application of orthogonal experiments in the future.

2. Basic Principles and Design Methods

The basic principle of orthogonal experiment is to make the factors independent of each other by choosing an appropriate experimental design, and to be able to effectively identify and assess the effects of each factor on the index being measured[1]. It utilizes a certain number of tests to arrange and combine different factors and levels, so as to achieve as many as possible to observe the combined effects of different factors and levels, and eliminate the influence of other factors interference.

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Common orthogonal experimental design methods include: orthogonal table method, Taguchi method, box-behnken design, center group and design, Latin square design method, etc. Experimental design methods mainly include the following aspects:

(1) Selection of factors: by understanding the characteristics and needs of the system or problem, a set of factors affecting the indicators to be measured is selected, as well as several levels of each factor.

(2) Application of orthogonal table: according to the number of factors and levels, choose the appropriate orthogonal table, combine the different levels of each factor and construct the test matrix.

(3) Experimental execution: according to the experimental program designed by the orthogonal table, carry out each test in turn and record the data obtained.

Data analysis: Through the method of statistical analysis, derive the degree of influence and interaction relationship of each factor and level on the measured index.

3. Preparation of Foam Concrete

3.1 Section of Test Materials

Cement: P-O 42.5 grade cement produced by Tangshan Fengrun XX; micro-silica powder: silica content (mass) of 96%, the average particle size of 0.1 ~ 0.3; ceramic granules: basic parameters as Table 1; foam agent: animal protein composite polymer-type blowing agent, the basic performance of Table 2; fly ash: the test selection of II grade fly ash; water reducing agent: the use of polycarboxylic acid high-efficiency water reducing agent, water reduction rate of 20.1%. 20.1%.

Table 1. Basic parameters of ceramic granules

Particle size/mm	Apparent density/kg/m3	Bulk density/kg/m3	Cylinder compression strength/MPa	1h water absorption/%
10-35	750	442	2.1	11

Table 2. Foaming agent properties

Density/g/mL	Settling distance/mm/h	Water secretion	Dilution factor	Foaming power
1.04	13	72	40	16

3.2 Experimental Program

Table 3. Orthogonal factor table

Numble	A (ceramic granule mixing)	B (Blowing agent dosage)	C (Fly ash admixture)	D (Silica Fume Admixture)
1	15%	0.1	10%	5%
2	25%	0.2	20%	10%
3	35%	0.3	30%	15%

There are many factors affecting the performance of vitrified foam concrete, in order to determine the optimal value of each factor and the order of influence of the primary and secondary, designed a four-factor, three-level orthogonal test, the range of each factor admixture is as follows: vitrified granule admixture 15%~35%, foaming agent admixture 0.1~0.3, fly ash admixture 10%~30%, and silica fume admixture is 5%-15%. The orthogonal factor table is shown in Table 3. where the pottery mixing amount is the volume percentage of the pottery foam concrete, the fly ash mixing amount is the mass percentage of the equivalent replacement of cement, the blowing agent mixing amount is the volume percentage of the pottery foam concrete, and the silica fume mixing amount is the mass

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percentage of the equivalent replacement of cement. According to the mixing amount of each factor, the ceramic foam concrete proportion design and test results are shown in Table 4. (The compressive strength and dry apparent density in the table are obtained by taking the arithmetic average of 3 test blocks in each group).

Table 4. Experimental design and results

Test No.	Ceramic granule	Foaming agent	Coal ash	Silica fume	7d compressive strength/Mpa	28d compressive strength/Mpa	Apparent density/kg/m3
P-1	15%	0.1	10	5	1.51	1.74	618
P-2	15%	0.2	30	10	1.60	1.65	799
P-3	15%	0.3	20	15	2.72	2.96	750
P-4	25%	0.1	30	15	1.72	1.93	732
P-5	25%	0.2	20	5	1.66	1.75	701
P-6	25%	0.3	10	10	1.90	1.92	720
P-7	35%	0.1	20	10	1.85	1.95	759
P-8	35%	0.2	10	15	1.62	1.70	790
P-9	35%	0.3	30	5	1.22	1.56	750

4. Sensitivity Analysis of Factors

In orthogonal analysis, each sensitivity analysis is a commonly used statistical method for assessing the extent to which different factors affect the output of a system. It can help determine which factors have a significant impact on the performance, reliability, or effectiveness of a system so that these factors can be focused on during the design or optimization process. Some of the commonly used methods are main effects analysis, interaction analysis, analysis of variance, and sensitivity indicator analysis. These various sensitivity analysis methods can help to determine which factors in the system have an important impact on the output results, so as to guide further optimization, design, or adjustment.In this paper, we use Analysis of variance (ANOVA) means to analyze and adjust the experimental results.

4.1 Sensitivity Analysis of Factors Affecting Compressive Strength

The orthogonal test results of 28d compressive strength of each factor of each level for the mean and extreme difference, the calculation results are shown in Table 5, from which it can be seen that the extreme difference of the A factor (ceramic grains) is the smallest, followed by the B factor (blowing agent), the D factor (silica fume), and the largest is the C factor (fly ash), the sensitivity of the factors to the compressive strength of the largest to the smallest for the C-D-B-A, which suggests that the C factor for the compressive strength of the control of the main role[1].

Table 5. Compressive strength extreme difference analysis table

Number of horizontal groups	Ceramic granules (A)	Foaming agent (B)	Fly ash (C)	Silica fume (D)
K1	2.12	1.87	1.79	1.69
K2	1.87	1.72	2.22	1.84
K3	1.74	2.15	1.71	2.19
Extremely poor	0.38	0.43	0.51	0.50

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As can be seen from Table 5, for the dosage of A factor (terra cotta), the compressive strength shows a decreasing trend and reaches the maximum value when its dosage is 15%. The reason for this phenomenon may be caused by the excess coefficient of mortar, the excess coefficient of mortar will cause the mortar layer wrapped around the surface of the grains to become thinner, constraints on the grains to reduce the deformation of the ability to reduce the grains when the external force, the grains are prone to cracks and damage and thus reduce the strength. With the increase of B factor (blowing agent) dosage, the compressive strength shows a trend of first decrease and then increase, in the blowing agent dosage of 0.3 times, the compressive strength reaches the maximum value. The reason for this may be from the K1-K2 process, with the increase in the amount of bubbles, there may be large voids and other phenomena, the concrete internal in the hydration reaction of the cement formed after the increase in the bubble skeleton thus leading to the decline in compressive strength. In the process of K2-K3 with the increase of air bubbles, the internal distribution is more uniform and thus the phenomenon of compressive strength gradually increased. With the increase of C factor (fly ash) dosage, the compressive strength shows the trend of increasing and then decreasing, and the compressive strength reaches the maximum value when the dosage of fly ash is 20%. It may be due to the fact that fly ash is an active dopant, which reacts with the hydration product CH of cement to generate hydrated calcium silicate gel, which fills the pores on the pore wall of the foamed cement and makes the pore wall also denser thus leading to an increase in the compressive strength, and the excess of fly ash makes the early hardening strength of the foamed cement lower, and at the same time, due to the doping of a large amount of fly ash will reduce the amount of cement, and the cement hydration reaction products will be reduced, which results in the front and back of the strength are smaller. With the increase of the dosage of D factor (silica fume)[2], the compressive strength shows an increasing trend, and the compressive strength reaches the maximum value when the dosage of silica fume is 15%. Silica fume is characterized by a large specific surface area, which will be adsorbed on the surface of the particles to form a dense structure leading to an increase in compressive strength.

4.2 Sensitivity Analysis of Factors Influencing Apparent Density

The orthogonal test results of the apparent density of each factor of each level for the mean and extreme deviation, the calculation results are shown in Table 6, from which it can be seen that the extreme deviation of the C factor (fly ash) is the smallest, followed by the A factor (ceramic grains), the B factor (blowing agent), and the largest is the D factor (silica fume), and the sensitivity of the factors to the compressive strength in descending order is D-B-A-C, which suggests that the C factor plays a major role in the control of the compressive strength.

Table 6. Compressive strength extreme difference analysis table

Number of horizontal groups	Ceramic granules (A)	Foaming agent (B)	Fly ash (C)	Silica fume (D)
K1	722.3	703	709.3	689.7
K2	717.7	763.3	736.7	759.3
K3	766.3	740	711.2	757.3

As can be seen from Table 6, with the increase of the mixing amount of A factor (ceramic grain), the apparent density shows a trend of decreasing and then increasing, and the apparent density reaches the maximum value when the mixing amount of ceramic grain is 35%. It is because the density of ceramic particles is small, in the preparation of the same volume of ceramic foam concrete, the more ceramic particles, the smaller its mass, so its dry density is reduced, in K2-K3 ceramic particles are evenly distributed by the slurry wrapped in a better, followed by the corresponding reaction apparent density may increase slightly; with the increase in the mixing amount of the B factor (blowing agent),

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the apparent density shows a trend of increasing and then decreasing, in the blowing agent With the increase of B factor (blowing agent), the apparent density showed a tendency of increasing and then decreasing, and reached the maximum value at the blowing agent dosage of 0.2. This is because with the increase of blowing agent dosage, at the beginning of the small pores may occur without decreasing slightly increasing phenomenon, but with the gradual increase of the dosage, the number of pores inside the foam concrete is also increased, so that the apparent density decreases more obviously, when the distribution of pores is more uniform may also show a slight increase in the trend. With the increase of C factor (fly ash) dosage, the apparent density shows an increasing trend, in the fly ash dosage of 30%, the apparent density reaches the maximum value; this is due to the low dosage of fly ash before K2, due to the hydration reaction the density may increase slightly, but with the increase of fly ash dosage, the density of the fly ash is less than the density of the cement, and replace part of the cement with fly ash, the density of foam concrete will naturally be reduced. The density of foam concrete will be reduced. With the increase of the dosage of D factor (silica fume), the apparent density shows an increasing trend, and the apparent density reaches the maximum value when the dosage of silica fume is 15%. Silica fume is characterized by a large specific surface area, which will be adsorbed on the surface of the particles to form a dense structure, leading to an increase in the apparent density.

5. Determination of the Optimum Mixing Ratio

Compressive strength decreases with the dosage of ceramic granules, and reaches the optimum value at A1; apparent density also decreases and then increases, and reaches the optimum value at A2, followed by A1, so the optimum dosage of ceramic granules is determined in A1 and A2; intuitively, the compressive strength and apparent density of the blowing agent take the dosage of B3 when the compressive strength reaches the optimum value, so the optimum dosage of the blowing agent is taken as B3; the dosage of the fly ash takes the C2 when the The compressive strength is the largest, C1 is the second largest, the apparent density is the smallest when C1 is taken, so the optimal dosage of fly ash is determined in C1 and C2; with the increase in the dosage of silica fume, the compressive strength shows an increasing trend, and the apparent density shows a tendency to increase first and then decrease, so the silica fume dosage is the optimal value when D3 is taken.

In order to solve the above problems, the comprehensive balance method is used to determine the optimal mix ratio[3]. First of all, in the level selection to determine the level of no contradiction, in this test B3, D3 can be determined, in this level of compressive strength and apparent density and thermal conductivity are taken to the optimal value. Factor A and factor C are analyzed one by one to find the optimal mix ratio.

For Factor A, in terms of the order of precedence, the effect of Factor A on apparent density are ranked in the third place and the effect on compressive strength is ranked in the fourth place. Factor A belongs to the main influence for apparent density and factor A belongs to the secondary factor for compressive strength, therefore, the main factor is used as the level of the main selection factor. At this point, it is necessary to calculate the effect of factor A on the apparent density, with a high degree of influence prioritized, followed by a low degree of influence.

For factor C, in terms of the order of the main factors, factor C on the apparent density of the impact are ranked in the fourth place, the impact of compressive strength in the first place. Factor C belongs to the main influence on compressive strength, and factor C belongs to the secondary factor on apparent density, therefore, the main factor is the level of the main selection of factors. At this time, it is necessary to calculate the effect of factor C on compressive strength, the degree of influence is prioritized, and the degree of influence of the small second[5].

For compressive strength, when C1 is taken, the average value of compressive strength is 1.79 MPa, and when C2 is taken, the average value of compressive strength is 2.22 MPa, which rises 24.02%, which is unfavorable for compressive strength; for apparent density, when A1 is taken, the apparent density is 722.3 kg/m3, and when A2 is taken, the apparent density is 717.7 kg/m3, which falls 0.64%;

Therefore, in summary, C2A2 is taken as the optimum value and this is plotted in a table as shown in Table 7.

Table 7. Combined balance sheet for factors A and C

A/C	Average compressive strength	Mean apparent density
A_1	2.12	722.3
A_2	1.87	717.7
Percentage	Decreased by 11.79%	Decreased by 0.64%
C_1	1.79	709.3
C_2	2.22	736.7
Percentage	Increased by 24.02%	Increased by 3.86%

From the extreme difference analysis of the above test results, the preferred mix ratio of ceramic foam concrete can be preliminarily determined as A2B3C2D3. From the factor level table, it can be seen that at this time, the ceramic granule mixing amount is 25%, the foaming agent mixing amount is 0.3, the fly ash mixing amount is 20%, and the silica fume mixing amount is 15%.

6. Conclusion

(1) Orthogonal experiments have the advantages of effectively reducing the number of tests, evaluating the importance of factors, exploring the interaction of factors, optimizing the concrete proportion, and improving the stability of concrete performance and quality in the preparation of vitrified foam concrete.

(2) Through the orthogonal experimental design, the optimal proportion of ceramic foam concrete is determined as 25% of ceramic granule, 0.3 of blowing agent, and 20% of fly ash, and then the compressive strength of ceramic foam concrete ranges from 1.79 to 2.22 MPa, and the apparent density ranges from 700 to 800 kg/m3, which meets the requirements of non-load-bearing structures.

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