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RESEARCH ARTICLE

MIX RATIO OF GRAPHITE TAILINGS FOAM CONCRETE BASED ON ORTHOGONAL THEORY

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ARTICLE DETAILS

ABSTRACT

Article History:

Received 20 January 2024

Revised 18 February 2024

Accepted 11 March 2024

Available online 13 March 2024

In order to study the effects of water-binder ratio, fly ash content, sand-binder ratio and the amount of Graphite Tailings replacing river sand on the mechanical and physical properties of Graphite Tailings Foam Concrete (GTFC), based on the orthogonal theory, the 7d compressive strength, 28d compressive strength and porosity of graphite tailings foamed concrete were analyzed by range analysis and variance analysis. At the same time, the compressive strength and porosity of foamed concrete as performance indicators of the matrix analysis of a single proportion of optimization. The results show that among the factors affecting the compressive strength of GTFC, the content of fly ash and the water-binder ratio are the main factors, the order of influencing the compressive strength of fly ash foamed concrete is water-cement ratio, fly ash, sand-cement ratio and the amount of river sand replaced by graphite tailings, among the factors influencing the porosity of GTFC, the sand-cement ratio is the main factor, the order of influencing porosity of fly ash foamed concrete is sand-binder ratio, fly ash-water-binder ratio, graphite tailings instead of river sand, porosity and compressive strength are taken as performance indexes of foamed concrete, the optimized ratio of Matrix analysis is as follows: water-binder ratio 0.44, fly ash 40%, sand-binder ratio 0.8, graphite tailings 15% to replace river sand.

KEYWORDS

Graphite tailings foam concrete, compressive strength, orthogonal theory, matrix analysis.

1. INTRODUCTION

In order to strengthen building energy conservation and green building development, a foamed concrete with industrial solid waste as the main raw material is developed to meet the country's requirements for carbon emission reduction and circular economy in the construction industry (Hu et al., 2009; Chen and Liu, 2010). Up to now, the annual output of fly ash in Heilongjiang Province is nearly 70 million tons, but the comprehensive utilization rate is less than 30%, which brings huge pressure to the ecological environment (Liu et al., 2014; Hu et al., 2019; Zhou et al., 2008; Zhao et al., 2008). my country's graphite reserves account for more than 70% of the world's graphite reserves, of which the graphite ore reserves in Heilongjiang Province are the majority, mainly concentrated in Jixi City, Boli County, Luobei and other places in Heilongjiang Province. Large-scale graphite mining over the years has left behind a large amount of tailings. Up to now, the cumulative accumulation of graphite tailings has exceeded 100 million tons. The large accumulation of graphite tailings will not only occupy a large amount of land resources, but also cause serious ecological pollution.

As a green energy-saving building material, foamed concrete has the characteristics of light weight, heat preservation and fire resistance (Song et al., 2016; Mao et al., 2005; Zheng et al., 2019). However, due to its low strength, it is currently used as a filling material in engineering construction. Scholars have focused on the study of its combination with light steel to form a composite structure for load-bearing members (Zhang et al., 2015; Kannan et al., 2020; Chen and Guan, 2017). The mechanical properties of the material itself are not improved to achieve load-bearing. At the same time, due to the morphological effect, activity effect and micro-

aggregate effect of fly ash, the strength of concrete can be well improved, and its homogeneity and compactness can be improved (Ruan et al., 2020; Kramer et al., 2015; Luo et al., 2017). Therefore, the formulation and production process of graphite tailings foamed concrete with high strength and light weight have certain significance for promoting the development of green building materials.

Based on the preliminary design mix ratio, this paper studies the effects of fly ash content, aggregate content, and the content of graphite tailings instead of river sand on the compressive strength and porosity of foam concrete by designing orthogonal tests. SEM microscopic analysis to explore the strength formation mechanism of solid waste fly ash foam concrete. The compressive strength and porosity are used as performance indicators to optimize the mix ratio by matrix analysis method, which provides a basis for the further application of graphite tailings foamed concrete.

2. TEST

2.1 Raw Materials

Ordinary Portland cement P.O42.5; Class II fly ash, its physical properties are shown in Table 1; Natural river sand: particle size 0~2.36mm. Foaming agent: 30% hydrogen peroxide (H₂O₂) solution. Catalyst: Manganese dioxide (MnO₂) reagent. Foam stabilizer: hydroxypropyl methylcellulose (HPMC), 200,000 viscosity. Water reducing agent: polycarboxylic acid series high-performance water reducing agent, water reducing rate is 37%; polypropylene fiber is used, and the physical properties are shown in Table 2; ordinary tap water.

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DOI:

10.26480/smmp.01.2023.19.23

Table 1: Chemical composition and physical properties of fly ash

Fineness (45 μ m square sieve)	Water content ratio	Burn the vector	SO ₃ /%	Water content	CaO/%
$\leq 30\%$	$\leq 105\%$	$\leq 8\%$	$\leq 3\%$	$\leq 1\%$	$\leq 10\%$

Table 2: Performance indexes of polypropylene fiber

Density/ (g·cm ⁻³)	Single fiber diameter/ μ m	Length/mm	Tensile strength / MPa	Modulus of elasticity /GPa	Fracture elongation /%
0.91	31	9	460	3.5	30

2.2 Experiment Method

The dry density test method of foam concrete is carried out in accordance with the provisions of "foam concrete" JG/T266-2011, and the size of the specimen is 100mm × 100mm × 100mm; foam concrete is a solid-gas two-phase porous material, and the characterization method of its porosity adopts The mass-volume direct calculation method, the size of the specimen is 40mm×40mm×40mm; the compressive strength test is carried out according to the test method specified in the industry standard "Technical Regulations for the Application of Foam Concrete" (JT)/T 341-2014), and the size of the specimen is 100mm×100mm×100mm.

2.3 Orthogonal Test

The compressive strength and porosity of graphite tailings foam concrete were used as evaluation indicators, and the GTFC mix ratio design was carried out by means of range analysis and variance analysis. In the test, 30 mg of water reducing agent, 7.5 mg of fiber, 50 mg of hydrogen peroxide, 1.5 g of foam stabilizer, and 1g of manganese dioxide were fixed.

2.3.1 Determination of factors and levels

- (1) Taking the water-binder ratio as the influencing factor of the orthogonal test of graphite tailings foam concrete (GTFC), the level is set to 0.42-0.48, and the step is divided into 0.02.
- (2) Take fly ash as the influencing factor of the GTFC orthogonal test, the level is set to 0.35-0.50, and the step is divided by 0.05.
- (3) The aggregate content was used as the influencing factor of the orthogonal test of GTFC, and the level was set to 0.6-0.9, with 0.10 as the step.
- (4) The content of river sand instead of quartz sand was used as the influencing factor of the GTFC orthogonal test, and the level was set to 0~22.5%, with 7.5% as the step.

2.3.2 Orthogonal experimental design

Design orthogonal table L16 (45) to study the influence law and significance of water-binder ratio, fly ash content, sand-binder ratio, and river sand instead of quartz sand content on compressive strength and porosity of materials. The specific test factors, The levels are shown in Table 3.

Table 3: Orthogonal, factor levels

Factors Levels	A	B	C	D
1	0.42	35%	0.6	0
2	0.44	40%	0.7	7.5%
3	0.46	45%	0.8	15%
4	0.48	50%	0.9	22.5%

3. RESULTS AND ANALYSIS

3.1 Destruction Form

The failure forms of graphite tailings foam concrete of different ages are shown in Figure 1. It can be seen from Figure 1 that due to the lateral deformation caused by vertical compression, the lateral tensile stress of the foam concrete inside the specimen reaches the ultimate tensile stress of the material itself, resulting in cracks. When the specimen reaches the

ultimate load, a penetrating crack appears in the specimen. Compared with the 28d specimen, the number of cracks in the vertical compression failure process is significantly more than that of the 28d specimen. This is because the 7d foam concrete specimen is not fully hydrated, and there is still moisture in the pores of the specimen. the aggregate accumulation effect is not optimal, and the skeleton compact structure cannot be formed inside the specimen. Under the load, the skeleton structure inside the specimen is not compact, and it is difficult to resist the external force and damage, resulting in the appearance of a large number of cracks.

**Figure 1: Failure patterns of graphite tailings foam concrete of different ages**

3.2 Orthogonal Range and Analysis of Variance

The compressive strength and porosity results of graphite tailings foam concrete in different test groups are shown in Table 4.

Table 4: Performance test results of graphite tailings foam concrete

Test group	A	B	C	D	Compressive strength(7d) MPa	Compressive strength(28d) MPa	Porosity %
1	0.42	0.35	0.6	0	7.6	16.4	40.8
2	0.42	0.4	0.7	0.075	5.4	14.8	47.5
3	0.42	0.45	0.8	0.15	9.5	17.6	41.6
4	0.42	0.5	0.9	0.225	5.4	14.8	48.9
5	0.44	0.35	0.7	0.15	8.5	19.4	40.0
6	0.44	0.4	0.6	0.225	9.9	21.3	41.9
7	0.44	0.45	0.9	0	11.2	18.4	47.2
8	0.44	0.5	0.8	0.075	8.9	18.1	46.0
9	0.46	0.35	0.8	0.225	11.6	18.2	43.9
10	0.46	0.4	0.9	0.15	12.6	20.2	46.0
11	0.46	0.45	0.6	0.075	10.9	16.4	41.3
12	0.46	0.5	0.7	0	6.7	13.1	44.2
13	0.48	0.35	0.9	0.075	11.5	16.9	44.4
14	0.48	0.4	0.8	0	10.9	16.5	45.7
15	0.48	0.45	0.7	0.225	9.1	14.5	41.1
16	0.48	0.5	0.6	0.15	7.0	12.1	41.5

In order to comprehensively analyze the index values of graphite tailings foam concrete under each factor level, the range analysis and variance analysis were carried out on the evaluation index results of different test groups obtained in Table 4, and the trend considering each index was drawn. The extreme poor compressive strength and variance analysis results of each test group at different curing ages are shown in Table 5 and Table 6, respectively, and the porosity extreme and variance analysis results are shown in Table 7.

It can be seen from Table 5 that according to the magnitude of the range and the variance analysis, the primary and secondary order affecting the compressive strength of 7d graphite tailings foam concrete is the water-binder ratio > the amount of fly ash > the sand-binder ratio > the amount of graphite tailings instead of river sand. According to the F value of the variance results, the 7d graphite tailings foam concrete compressive strength performance indicators, water-binder ratio, fly ash content, and sand-binder ratio are most significantly affected. This is because a large amount of fly ash reduces the hydration reaction rate of cement-based materials and takes longer time to complete setting and hardening.

Table 5: 7d compressive strength range and variance analysis

Factors	K					Source item			
	K1	K2	K3	K4	R	SS	DF	F	P
A	6.98	9.63	10.45	9.63	3.47	27.4819	3	17.43	0.021
B	9.80	9.70	10.18	7.00	3.18	25.5869	3	16.23	0.023
C	8.85	7.43	10.23	10.18	2.80	21.0819	3	13.37	0.031
D	9.10	9.18	9.40	9.00	0.40	0.3469	3	0.22	0.877

Table 6: 28d compressive strength range and variance analysis

Factors	K					Source item			
	K1	K2	K3	K4	R	SS	DF	F	P
A	15.92	19.32	16.98	15.02	4.30	41.297	3	8.28	0.048
B	17.74	18.21	16.76	14.52	3.69	32.341	3	6.49	0.079
C	16.58	15.46	17.62	17.57	2.16	12.504	3	2.51	0.235
D	16.11	16.55	17.35	17.22	1.24	4.081	3	0.82	0.563

Table 7: Porosity range and variance analysis

Factors	K					Source item			
	K1	K2	K3	K4	R	SS	DF	F	P
A	44.70	43.78	43.85	43.18	1.52	4.695	3	0.51	0.702
B	42.28	45.28	42.80	45.15	3.00	28.14	3	3.07	0.191
C	41.38	43.20	44.30	46.63	5.25	56.802	3	6.19	0.084
D	44.47	44.80	42.28	43.95	2.53	14.921	3	1.63	0.35

It can be seen from Table 6 that according to the size of the range and the variance analysis, the primary and secondary order affecting the compressive strength of 28d graphite tailings foam concrete is water-binder ratio > fly ash content > sand-binder ratio > the amount of graphite tailings to replace river sand. According to the F value of the variance results, the compressive strength index of 28d graphite tailings foam concrete is affected, and the water-binder ratio is the most significant. This is because fly ash has micro-aggregate effect, active effect and pozzolanic

effect. The addition of fly ash can improve the later strength of foamed concrete.

It can be seen from Table 7: According to the size of the range and the variance analysis, the primary and secondary order of affecting the porosity of graphite tailings foam concrete is the sand-to-binder ratio > the amount of fly ash > the amount of graphite tailings to replace the river sand > the water-binder ratio. According to the F value of the variance results,

the physical performance index of the porosity of graphite tailings foam concrete is affected, and the sand-to-binder ratio is the most significant. The raw materials of foamed concrete mortar are cement, water, fly ash and fine sand: when the water-binder ratio becomes larger, the cementitious material per unit volume decreases and the water consumption increases, resulting in a decrease in the density of the mortar base material, and further foaming. The porosity of concrete increases; and fly ash, as an auxiliary cementing material, has a density of about 60% to 70% of cement. If the same mass of fly ash is used to replace cement, the density of the mortar base will decrease, the greater the amount of fly ash, the lower the density, the greater the porosity; the fine sand does not react with water, and the volume occupied by the same mass is very small, which can improve the density.

3.3 Micro-Morphology Analysis

The microscopic morphology of graphite tailings foamed concrete is shown in Figure 2. It can be seen from Figure 2 that the cross-section of the 16th group of specimens with the lowest compressive strength is more hollow and the slurry structure is not dense. This is due to the fact that the cement particles the larger the particle size, the more voids in the prepared cement slurry, and the active filler cannot effectively fill the holes in the slurry. At the same time, when the amount of fly ash is too large, although the active filler fills the capillaries in the slurry, it reduces the porosity of

the capillaries is reduced, resulting in a slower secondary hydration reaction of the hydration products in the system, resulting in low structural strength. From the microscopic topography of the sixth group of specimens with the highest compressive strength, it can be seen that there are no obvious holes in the cross-section, adding an appropriate amount of river sand to form active fillers with fly ash and quartz sand, which can further improve the slurry. The compactness of the body accelerates the hydration reaction of the system and promotes the formation of more gel products.

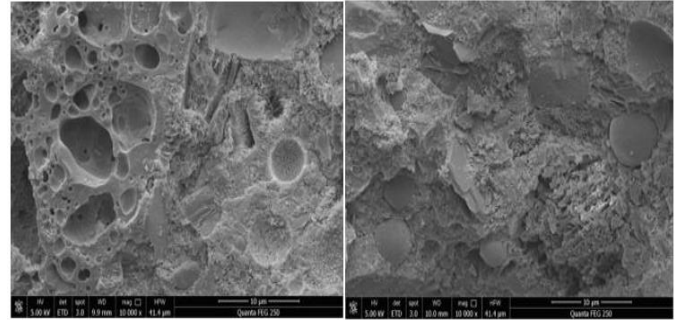


Figure 2: Microscopic topography

Table 8: Matrix calculation and analysis results

Factors	Levels	Compressive strength(7d)	Compressive strength(28d)	Porosity	Total weight
A	1	0.067095388	0.089308234	0.031578765	0.062660796
	2	0.092586826	0.108384596	0.030925289	0.077298904
	3	0.100522839	0.095241544	0.030978273	0.075580885
	4	0.092586826	0.084258609	0.030501413	0.069115616
B	1	0.086131786	0.085517508	0.058751998	0.076800431
	2	0.08525289	0.087807618	0.06292127	0.078660593
	3	0.089427645	0.080804704	0.05948162	0.076571323
	4	0.061522704	0.069992977	0.062747551	0.064754411
C	1	0.068595393	0.046823042	0.100627128	0.072015188
	2	0.057550372	0.043666194	0.105065666	0.068760744
	3	0.079252869	0.049782145	0.107740949	0.078925321
	4	0.078865325	0.049640899	0.113395525	0.080633916
D	1	0.010076159	0.026061416	0.052022966	0.029386847
	2	0.010159205	0.026777367	0.052403122	0.029779898
	3	0.010408341	0.028067696	0.049449598	0.029308545
	4	0.009965432	0.02786545	0.051408867	0.029746583

3.4 Mix Ratio Optimization of Graphite Tailings Foam Concrete

Porosity and compressive strength are important performance indicators of foam concrete. If the mix ratio is determined from a single factor and index, the results will be inaccurate. The matrix analysis method can synthesize the influence of each factor level on the test index in the form of weights. Analysis can simplify multiple indicators and simplify multi-indicator problems. The specific process of matrix analysis of foam concrete is as follows:

First, the index layer is established, and the matrix M is

$$M = \begin{bmatrix} K_{11} & 0 & \cdots & 0 \\ K_{12} & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & 0 \\ K_{1n} & 0 & \cdots & 0 \\ 0 & K_{21} & \cdots & 0 \\ 0 & K_{21} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & K_{2n} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & K_{m1} \\ 0 & 0 & \cdots & K_{m2} \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & K_{mn} \end{bmatrix} \quad (1)$$

Secondly, the factor layer matrix T is established as follows:

$$T = \begin{bmatrix} t_1 & 0 & 0 & 0 \\ 0 & t_2 & 0 & 0 \\ 0 & 0 & t_3 & 0 \\ 0 & 0 & 0 & t_4 \end{bmatrix} \quad (2)$$

Build the horizontal layer matrix E again:

$$E = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_m \end{bmatrix} \quad (3)$$

Finally, the weight matrix of the i-th indicator in the p indicators:

$$\omega_i = M_i T_i E_i \quad (4)$$

Simplify multiple indicators to get:

$$\omega = \frac{\omega_1 + \omega_2 + \cdots + \omega_p}{p} \quad (5)$$

The calculation results are shown in Table 8. It can be seen from Table 8 that among the four levels of the A factor, A2 has the largest weight; among the four levels of the B factor, B2 has the largest weight; the four levels of the C factor have the largest weight. Among the levels, C3 has the largest weight; among the four levels of the D factor, D2 has the largest weight, and the larger the weight, the higher the impact on the results. Therefore, the optimized fly ash foam concrete ratio is A2B2C4D2.

4. CONCLUSION

Among the many factors affecting the compressive strength of GTFC, the content of fly ash and water-binder ratio are the main influencing factors, and the primary and secondary order of affecting the compressive strength of GTFC is water-binder ratio > fly ash > sand-binder ratio > graphite tailings substitution River sand usage.

Among the many factors that affect the porosity of GTFC, the sand-to-binder ratio is the main influencing factor, and the primary and secondary order of affecting the GTFC porosity is the sand-binder ratio > fly ash > the amount of graphite tailings instead of river sand > water-to-binder ratio.

The porosity and compressive strength are used as the performance indicators of foamed concrete. The optimized ratio after matrix analysis is: the water-binder ratio is 0.44, the fly ash content is 40%, the sand-binder ratio is 0.8, and the graphite tailings replace the river sand content of 15%.

ACKNOWLEDGEMENT

The financial support provided by Natural Science Foundation of Heilongjiang Province (LH2022E105) and Basic Research Business Fee Project for Provincial Higher Education Institutions in Heilongjiang Province (2023-KYYWF-0473) is gratefully acknowledged.

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