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Study on influence of foamed light soil admixture based on orthogonal test

Huang Hongbin
(University of Shanghai for Science and Technology, Shanghai 200093, China)

Abstract
As a new building material, foam lightweight soil has the characteristics of high mobility and light weight, and meets the contemporary environmental protection and green requirements. Nowadays, foamed lightweight soil is mainly used for soft foundation treatment. In this paper, the influence of each additive material on the properties of foamed lightweight soil is studied and analyzed by orthogonal design test. Using orthogonal test as an experimental method, the purpose of seeking the optimal combination of influencing factors and their levels through less test times is achieved, and the performance of foamed lightweight soil is improved, so as to expand its practical engineering application.
Key words: *foam lightweight soil;orthogonal design test;water-solid ratio;contect of fly ash;contect of mineral powder*

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I. INTRODUCTION

With the construction of expressways, problems such as bridge jump, instability of high embankment, poor settlement of new and old subgrade[1], freeze-thaw damage in cold areas are becoming more and more serious[2]. Most of the coastal areas are silt coastlines, which are characterized by high water content, large porosity, low density, low strength, high compressibility, low permeability, medium sensitivity and so on. This kind of soil is slow in drainage and consolidation and poor in foundation stability.

In recent years, a new soft foundation treatment method, that is, the use of cast-in-place foam lightweight soil subgrade filling method, has gradually developed. Because of the characteristics of light weight and high fluidity of foamed light soil, it becomes a subgrade structure measure for soft soil foundation treatment. Because of its light weight, it can reduce the weight of subgrade structure to reduce the settlement of subgrade. Because of its high mobility, the integrity and stability of the subgrade is improved, which is similar to the effect of foundation reinforcement engineering, but the engineering practice is much simpler, and the construction period is greatly shortened[3].

In addition to foaming agent, cement[4] is the main raw material used for foamed light soil. However, with the deepening of research on foamed light soil, in order to further improve the scope of engineering application of foamed light soil, its raw materials are gradually developed, such as fly ash[5]. Different admixtures and their dosage have different effects on the performance of foamed light soil[6].

In this paper, three factors of water-solid ratio, fly ash content and mineral powder content are selected, each factor has five levels, and orthogonal test is carried out. Through range analysis of the results, the best combination of foam light soil properties is obtained[7][8].

II.Method of test

Orthogonal experiment[9] was used in this experiment. According to the rules of orthogonal table, multiple factors affecting the test results and multiple levels corresponding to each factor were selected, and then each specific test in the orthogonal table was tested and theoretically analyzed. The significance of influence of different factors at different levels on the test results could be analyzed by range analysis or variance analysis, and finally the optimal test mix ratio was selected. Its whole has "orthogonality, representativeness, comprehensive comparability"[10].

In this test, L25(5^3) orthogonal table was selected to study the influence of three factors, namely water-solid ratio, fly ash content and mineral powder content, on the mechanical properties of light foamed soil. The flow value, compressive strength, flexural strength and water absorption of light foamed soil samples were tested through cross test, and then the range analysis was carried out on the test results. The influence charts of horizontal convection value, 7-day compressive strength and 28-day compressive strength of different factors were drawn, so as to obtain the optimal water-solid ratio, the optimal fly ash content and the optimal mineral powder content, namely the optimal mix ratio of foamed light soil. This orthogonal test can reduce the number of tests to 25[11].

2.1 Orthogonal design parameters

Three factors of water-solid ratio, fly ash content and mineral powder content were selected in this test, and five levels were selected for each factor. Therefore, the orthogonal table L25(5^3) is selected, as shown in Table 1 below.

Column number	1	2	3
factors	A	B	C
Experiment number	Water-solid ratio	Fly ash（%）	Mineral powder（%）
1	1（1:2.10）	1（0）	1（0）
2	1	2（10）	2（5）
3	1	3（20）	3（10）
4	1	4（30）	4（15）
5	1	5（40）	5（20）
6	2（1:2.15）	1	2
7	2	2	3
8	2	3	4
9	2	4	5
10	2	5	1
11	3（1:2.20）	1	3
12	3	2	4
13	3	3	5
14	3	4	1
15	3	5	2
16	4（1:2.25）	1	4
17	4	2	5
18	4	3	1
19	4	4	2
20	4	5	3
21	5（1:2.30）	1	5
22	5	2	1
23	5	3	2
24	5	4	3
25	5	5	4

Tab. 1 Orthogonal experimental design parameters

2.2 Test material consumption

According to the code[12], the wet density of light foam soil designed in this experiment should be between 500 and 1100kg/m^3, and 550kg/m^3 can be selected, among which, the standard foam density is 40kg/m^3 and the cement density is 3000kg/m^3. The specific materials are shown in Table 2 below.

Experiment number	Water-solid ratio	Material per cubic meter						
		Fly ash		Mineral powder		Water（kg）	Cementing materials（kg）	Foam（kg）
		（%）	（kg）	（%）	（kg）			
1	1:2.10	0	0	0	0	168.206	353.232	28.562
2		10	35.323	5	17.662			
3		20	70.646	10	35.323			

4		30	105.970	15	52.985			
5		40	141.293	20	70.646			
6	1:2.15	0	0	0	0	165.513	355.852	28.635
7		10	35.585	5	17.793			
8		20	71.170	10	35.585			
9		30	106.756	15	53.378			
10		40	142.341	20	71.170			
11	1:2.20	0	0	0	0	162.905	358.390	28.705
12		10	35.839	5	17.920			
13		20	71.678	10	35.839			
14		30	107.517	15	53.759			
15		40	143.356	20	71.678			
16	1:2.25	0	0	0	0	160.377	360.849	28.774
17		10	36.085	5	18.042			
18		20	72.170	10	36.085			
19		30	108.255	15	54.127			
20		40	144.340	20	72.170			
21	1:2.30	0	0	0	0	157.927	363.233	28.840
22		10	36.323	5	18.162			
23		20	72.647	10	36.323			
24		30	108.970	15	54.485			
25		40	145.293	20	72.647			

Tab. 2 Test specific material calculation

2.3 Test sample preparation

Prepare according to the calculation results of materials used in the orthogonal test design, and dry the powdered raw materials in advance, and then use the electronic balance to accurately weigh each material (accurate to 0.1kg). Follow the principle of "a small amount of times", first pour cement, fly ash and mineral powder into the mixer, mixing for 3min, after mixing evenly, then gradually pour water slowly, continue mixing for 3min, until all materials are evenly mixed, forming cement slurry[13]. A small amount of cement slurry was taken for flow value and wet weight test, in which the flow value was measured by a smooth and seamless metal cutoff die with a diameter of 50mm and a height of 80mm. The sizes of the remaining material pouring samples are respectively compressive sample 100mm×100mm×100mm, collapsible sample 100mm×100mm×400mm and water absorption sample 100mm×100mm. (Note that foam lightweight soil is easy to form collapsing mold when pouring, and the sample is easy to fracture when demoulding. Therefore, a layer of vegetable oil should be brushed on the inner wall of the mold for this pouring. After vibration compaction, the surface of the sample is scraped and the excess slurry is scraped off. After standing for 72h, the mold can be released. During curing, it is placed into the standard constant temperature and humidity curing box with curing temperature of (20±1) ℃ and curing humidity of 95%. When the curing time for testing is reached, it can be used for test performance test[14].

III.Test results and analysis

3.1 Orthogonal test data

3.1.1 Moisture severity was measured and range analysis was performed

After the preparation of foamed light soil according to the orthogonal experimental design, its wetness was measured, and the results were shown in Table 3 below. Range analysis was performed as shown in Table 4 below.

Experiment number	1	2	3	4	5	6	7	8	9	10
Wet intensity(10^{-2}×kN/m^3)	489.67	516.67	517.67	509.33	508.67	514.67	519.00	516.67	533.00	522.67
Experiment number	11	12	13	14	15	16	17	18	19	20
Wet intensity(10^{-2}×kN/m^3)	522.67	532.67	518.33	486.00	533.00	521.33	475.00	484.50	505.33	520.00
Experiment number	21	22	23	24	25					
Wet intensity(10^{-2}×kN/m^3)	486.67	496.00	503.67	512.67	452.83					

Tab. 3 Results of orthogonal test for moisture severity(10^{-2}×kN/m^3)

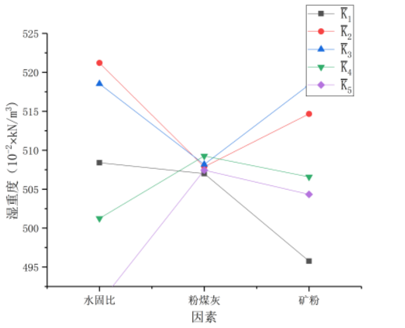
Evaluation index	Water-solid ratio	Fly ash content	Mineral powder content
$\bar{K}_1$	508.40	507.00	495.77
$\bar{K}_2$	521.20	507.87	514.67
$\bar{K}_3$	518.53	508.17	518.40
$\bar{K}_4$	501.23	509.27	520.00
$\bar{K}_5$	490.37	507.43	506.57
Optimal level	A_2	B_5	C_4
R_j	30.83	2.27	22.63
Primary and secondary order	A C B		

Tab. 4 Range analysis of wet - heavy results by orthogonal test

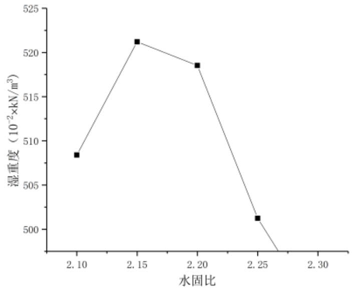
Note: K_1、 $\bar{K}_2$、 $\bar{K}_3$、 $\bar{K}_4$、 $\bar{K}_5$ are the mean values of the five-level orthogonal test respectively, and R_j is the range.

Wet weight refers to the weight of unit volume of the material in the state of flow before hardening, so it is also called wet bulk density (unit: kN/m^3), according to the specification[15], wet weight is maintained in the range of 5.5~6.5kN/m^3 is more reasonable. The influence of different factor levels on humidity severity obtained by the orthogonal test is shown in Figure 1. As can be seen from the figure, the wet weight increases with the increase of fly ash content, while the water-solid ratio and mineral powder content have an optimal coordination on the influence of wet weight. In this test, when the water-solid ratio is 2.15, the wet weight reaches the maximum. When the mineral powder content is 10%, the wet weight reaches the maximum.

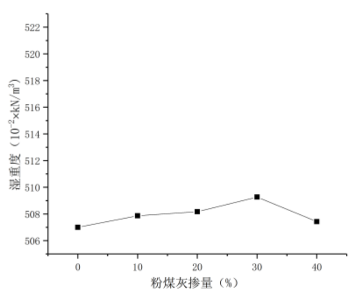
According to the range analysis of the results of the wet-weight orthogonal test, combined with Figure 1(a), it can be seen that the water-solid ratio and mineral powder content have significant influences on the wet-weight of foamed light soil, among which, the mineral powder content has the most significant influence, followed by the water-solid ratio, while the fly ash content has little influence on the foamed light soil.



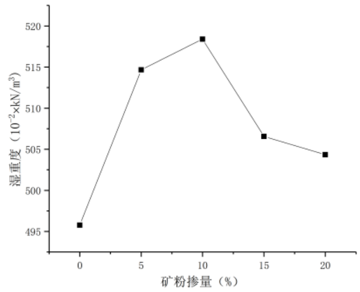
(a)The influence of different factors on humidity severity



(b)The influence of water-solid ratio on humidity severity



(c)The influence of fly ash content on humidity severity



(d)The influence of mineral powder content on humidity severity

Figure 1 The influence of different factors on humidity severity

3.1.2 Measure mobility and carry out range analysis

After the foam light soil was prepared according to the orthogonal experimental design, its mobility[16][17] was measured, and the results were shown in Table 5 below. The range analysis was shown in Table 6 below.
Fluidity is used to measure the fluidity of foamed light soil, that is, flow value. According to the rules. The flow value should be controlled between 160~190mm.

Experiment number	1	2	3	4	5	6	7	8	9	10
Flow value(mm)	172.00	175.33	165.67	167.00	174.00	175.33	163.67	165.67	167.33	167.33
Experiment number	11	12	13	14	15	16	17	18	19	20
Flow value(mm)	175.67	170.67	167.67	163.33	167.00	171.33	152.00	167.67	161.33	165.67
Experiment number	21	22	23	24	25					
Flow value(mm)	163.67	167.33	165.33	161.33						

Tab. 5 Determination of fluidity by orthogonal test (mm)

Evaluation index	Water-solid ratio	Fly ash content	Mineral powder content
$\bar{K}1$	170.80	171.60	167.53
$\bar{K}2$	167.87	165.80	168.87
$\bar{K}3$	168.87	166.40	166.40
$\bar{K}4$	163.60	164.07	168.67
$\bar{K}5$	164.42	168.50	164.93
Optimal level	A_1	B_1	C_2
R_j	7.20	7.53	3.93

Primary and secondary order	B A C

Tab. 6 Range analysis of mobility results in orthogonal test

Note:K_1、 $\overline{K}_2$、 $\overline{K}_3$、 $\overline{K}_4$、 $\overline{K}_5$are the mean values of the five-level orthogonal test respectively, and Rj is the range.

Figure 2 The influence of different factors on the convection value

The influences of different factors on fluidity in this test are shown in Figure 2 below. As can be seen from the figure, with the increase of water-solid ratio, the flow value of foamed light soil shows an overall decreasing trend. The influence of fly ash content and mineral powder content on convection value is complicated. In this test, when fly ash content is 0, the flow value reaches the maximum, and when fly ash content is 30%, the flow value reaches the minimum. When the content of mineral powder is 5%, the flow value reaches the maximum, and when the content of mineral powder is 20%, the flow value reaches the minimum.

The range analysis was carried out on the results of the fluidity orthogonal test, and combined with Figure 2(a), it can be seen that compared with the water-solid ratio and fly ash content, the influence of mineral powder content on the convective value is the least, while the influence of water-solid ratio and fly ash content on the mobility of light foamed soil is little different.

3.1.3 Determination of unconfined compressive strength and range analysis by orthogonal test

After the foam light soil was prepared according to the orthogonal experimental design, its unconfined compressive strength[18][19] (the basic index reflecting the mechanical strength characteristics of the foam light soil[20]) was measured, and the results were shown in Table 7 below. Range analysis[21] was carried out, as shown in Table 8 below.

The influence degree of different factors in this test on 7-day and 28-day unconfined compressive strength is shown in Figure 3. In this figure, for 7-day unconfined compressive strength, the water-solid ratio has little influence, while the content of fly ash and mineral powder has significant influence. For the 28-day unconfined compressive strength, the influences of water-solid ratio, mineral powder content and fly ash content on the compressive strength decreased significantly gradually. In summary, fly ash content has a significant effect on short-term unconfined compressive strength. The ratio of water to solid has significant effect on long-term unconfined compressive strength.

Experiment number		1	2	3	4	5	6	7	8	9	10
Unconfined compressive strength(10-1×MPa)	7d	6.31	7.86	7.35	5.43	5.14	9.24	6.50	8.58	6.06	6.04
	28d	9.46	13.09	12.93	11.89	11.67	14.26	14.02	14.12	17.02	13.42
Experiment number		**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Unconfined compressive strength(10-1×MPa)	7d	11.13	8.51	6.83	4.28	5.77	8.58	6.89	8.21	8.38	6.90
	28d	17.84	12.78	14.05	10.57	16.00	14.77	12.53	12.47	13.69	9.90
Experiment number		**21**	**22**	**23**	**24**	**25**					
Unconfined compressive strength(10-1×MPa)	7d	7.07	6.29	7.77	8.33	6.13					
	28d	13.97	14.53	15.07	20.23	12.86					

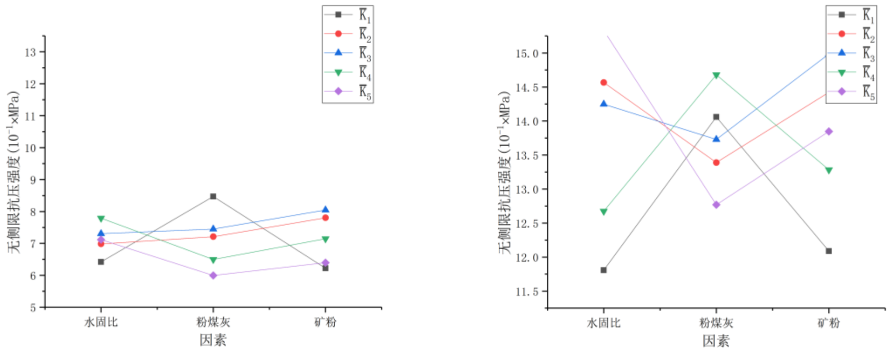
Tab. 7Test results of unconfined compressive strength by orthogonal test(10^{-1}×MPa)

Evaluation index	7d			28d		
	Water-solid ratio	Fly ash content	Mineral powder content	Water-solid ratio	Fly ash content	Mineral powder content
$\bar{K}1$	6.42	8.47	6.23	11.81	14.06	12.09
$\bar{K}2$	6.98	7.21	7.80	14.57	13.39	14.42
$\bar{K}3$	7.30	7.45	8.04	14.25	13.73	14.99
$\bar{K}4$	7.79	6.50	7.15	12.67	14.68	13.28
$\bar{K}5$	7.12	6.00	6.40	15.33	12.77	13.85
Optimal level	A_4	B_1	C_3	A_5	B_4	C_3
R_j	1.37	2.47	1.82	3.52	1.91	2.90
Primary and secondary order	B C A			A C B		

Tab. 8 Range analysis of unconfined compressive strength results in orthogonal tests

Note: K_1、 $\bar{K}_2$、 $\bar{K}_3$、 $\bar{K}_4$、 $\bar{K}_5$are the mean values of the five-level orthogonal test respectively, and Rj is the range.

In this experiment, the influences of water-solid ratio, fly ash content and mineral powder content on unconfined compressive strength are shown in Figure 4 below. For the water-solid ratio, the 7-day unconfined compressive strength is not obvious, and the 28-day unconfined compressive strength reaches the maximum value when the water-solid ratio is 2.30, and the secondary value is 2.15. With the increase of fly ash content, the 7-day unconfined compressive strength of foamed light soil gradually decreases, while the 28-day unconfined compressive strength has little difference. When the mineral powder content is 10%, the 7-day and 28-day unconfined compressive strength of the foamed light soil reaches the maximum value in this test.



(a) Influence degree of different factors on 7-day unconfined compressive strength

(b) Influence degree of different factors on 28-day unconfined compressive strength

Figure 3 Influence degree of different factors on unconfined compressive strength

2.2 Determination of optimal mix ratio

The foam light soil used for soft soil foundation treatment not only needs to meet the requirements of filling and grouting of soft soil foundation, but also needs to ensure the smooth construction of subsequent projects. At the same time, for the actual engineering requirements, the project cost should be considered to meet the economic requirements as far as possible, which can not be ignored. Therefore, in order to meet the requirements of grouting construction, the foam light soil must have appropriate wet weight and a certain degree of mobility. In order to ensure the grouting effect and avoid the volume expansion caused by water absorption in the condensation process, the water absorption of the foam light soil should meet the engineering requirements. In order to ensure the requirements of subsequent engineering construction and application, the mechanical engineering properties (that is, unconfined compressive strength) of the foamed light soil must have a certain strength.

In summary, considering the physical and mechanical properties of foamed light soil comprehensively, the optimal mix ratio can be determined as water-solid ratio 2.15, fly ash content 20% and mineral powder content 10%. Under this mix ratio, the wet weight of foam light soil is 5.16kN/m^3, the flow value is 166.89mm, the 7-day unconfined compressive strength is 0.82MPa, and the 28-day unconfined compressive strength is 1.43MPa.

IV.CONCLUSION

(1) This paper studies the effects of water-solid ratio, fly ash content and mineral powder content on the physical and mechanical properties of foamed light soil through orthogonal test, which greatly improves the test efficiency and has a high representativeness. In addition, the orthogonal test method is adopted in this paper to reduce the adverse effects of various influencing factors as far as possible, which can effectively and accurately explore the optimal mix ratio to improve the physical and mechanical properties of light foamed soil.

(2) Among the three influencing factors of water-solid ratio, fly ash content and mineral powder content, the water-solid ratio has a significant influence on 7-day and 28-day unconfined compressive strength, fly ash content has a significant influence on convective value, and mineral powder content has a significant influence on moisture severity. Therefore, the water-solid ratio must meet the engineering requirements, the fly ash content can be increased appropriately, and the mineral powder content should not be too large.

(3) The foam light soil with added fly ash and mineral powder for soft soil foundation treatment has an optimal mix ratio: water solid ratio of 2.15, fly ash content of 20%, mineral powder content of 10%. The mixture ratio can significantly improve the stability, safety and integrity of the treated foundation.

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