Experimental study on the foundation of soft soil solidification formula based on the Design - Expert software search

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Abstract: Xuan city + 1100 kv search for converter station in Anhui province, in the process of foundation treatment, there is a cloth with a large number of lacustrine soft soil can not reach the need of engineering construction, so we want to cure the soft soil. By combining ratio of blast furnace slag (GGBS), gypsum, exciting agent CaO as a main curing agent for combination of reinforcing soft soil, the indoor unconfined compressive strength test, the influence factors on blast furnace slag, exciting agent and dosage of gypsum as impact factors, response value is 7 d and 28 d unconfined compressive strength of solidified soil, the experimental method is the Box - Behnken. The results show that the 7 d gypsum and the interaction of the blast furnace slag is obvious; 28 d exciting agent and gypsum interaction is obvious. By the analysis plaster, CaO, GGBSIn 7 d optimal proportion is 3.71%, 3.62%, 12.18%, the actual strength of the solidified soil age 1479.33 kPa; 28 d optimal proportion was 4.08%, 4.50%, 11.6%, the actual strength of the solidified soil age 2936.78 kPa. In the soil and the water curing effect of GGBS solidified soil, thereby GGBS this is a kind of new solidification material that can be used as the engineering foundation treatment of soft soil stabilizer has a certain value.

1 Introduction

Soft soil curing is the most widely used in soft soil area of foundation reinforcement method [1]. The search on the water rich silt muddy clay or [2]. Granulated blast furnace slag powder (GGBS) has the potential of hydration activity, hydration products the same as the cement, can replace cement as curing agent of lacustrine soft soil. The graining blast furnace slag powder to replace or partly replace cement as soft soil curing agent can improve the effect of soft soil curing, reduce the project cost [3, 4]. Box - Behnken method was applied to the development of the soft soil firming agent formula, analysis of three kinds of additive to slag powder interaction law of GGBS, CaO and plaster, established between additives and intensity target function model, and then determine the curing agent and the optimal formula of compound excitation agent between.

2 Test Design

The Box - Behnken experimental design [5] the three factors (X1, X2, X3), three levels (1, 0, + 1) arrangement test, test, a total of 2 K (K - 1) + C0, one of the factor K said number, C0 said center sites repetitions, the test K = 3, C0 = 5. Using the Design Expert software was carried out on the experimental data fitting, second-order experience model is set up. Model can be described as:

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$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} X_i X_j + \sum_{i=1}^{k} \beta_{ii} X_i^2$$

Type: Y to predict response values; As a constant; As the linear coefficient; As the interaction coefficient; As the square coefficient; K factor number.In this experiment, variable factors of GGBS respectively (X1), CaO (X2) and gypsum (X3), the third level respectively described as - 1, 0, + 1, as shown in table 1. Box - Behnken method is adopted to establish the test design, by age 7 d and 28 d instars of unconfined compressive strength as the response value, in order to test and test arrangement and test the results are shown in table 2.

Table 1 independent variables and their code level

variable	code	The coding level		
		-1	0	1
GGBS	X1	8	11	14
CaO	X2	2	3.5	5
gypsum	X3	2	3.5	5

Table 2 three factors three levels of Box - Behnken test design scheme

The no.	factors			Response values	Response values
	X1	X2	X3	Y7/kPa	Y28/kPa
1	1.0（14）	1.0（5）	0.0（3.5）	1289	1860
2	1.0（14）	-1.0（2）	0.0（3.5）	1317	1599
3	0.0（11）	0.0（3.5）	0.0（3.5）	1445	2735
4	0.0（11）	0.0（3.5）	0.0（3.5）	1468	2772
5	0.0（11）	-1.0（2）	1.0（5）	1166	1552
6	0.0（11）	0.0（3.5）	0.0（3.5）	1453	2752
7	-1.0（8）	1.0（5）	1.0（3.5）	1059	1575
8	-1.0（8）	0.0（3.5）	1.0（5）	1254	1706
9	0.0（11）	1.0（5）	1.0（5）	1282	2942
10	1.0（14）	0.0（3.5）	-1.0（2）	1291	2163

3 Test Results and Data Analysis

3.1 Establishment and Analysis of the Model

Using software Design - Expert, table 2 test results for quadratic polynomial regression fitting, table 3

Table 3 7 d and 28 d second-order analysis of variance of model equations

Sources of	7d			28d		
variance	The F value	P values	The coefficient of	The F value	P values	The coefficient of
Model	21.78	0.0003	1452.80	15.04	0.0009	2752.20
X1	48.05	0.0002	110.13	16.38	0.0049	305.88
X2	5.42	0.0527	37.00	17.70	0.0040	318.00
X3	9.86	0.0164	49.88	13.47	0.0080	277.38
X1 X2	1.42	0.2726	-26.75	0.22	0.6557	-49.75
X1 X3	5.56	0.0504	-53.00	0.37	0.5623	-65.00
X2 X3	0.021	0.8891	-3.25	5.01	0.0602	239.25
X12	34.24	0.0006	-128.15	34.78	0.0006	-614.35
X22	55.67	0.0001	-163.40	33.24	0.0007	-600.60
X32	23.06	0.0020	-105.15	6.64	0.0367	-268.35

Note: the 7 d model R2 = 0.9655; 28 d model R2 = 0.9508. By analysis of variance, the age of 7 d and 28 d of age model were significantly (P = 0.0003, 0.0009), showed that fitting model and the actual situation is very good. The analysis of the significance level, on the basis of the 7 d age, of various factors on the strength of solidified soil were significantly linear effect and surface effect, X1X3 interaction significantly; 28 d age, of various factors on the strength of the linear effect and surface effect are significant, X2X3 interactions are significant. For 7 d results of the regression analysis, through the Design - no significant Expert software rejecting X1X2, X2X3, second order model is as follows:

$$Y7=1452.80+110.13X1+37.00X2+49.88X3-53.00X1X3-128.15X12-163.40X22-105.15X32 \quad (2)$$

$$Y28=2752.20+305.88X1+318.00X2+277.37X3+239.25X2X3-614.35X12-600.60X22-268.35X32 \quad (3)$$

3.2 Interaction and Curing Mechanism Analysis

From the above analysis, when the ages of 7 d GGBS interactions with gypsum, in the heart of the type (2) X2 fixed at zero level, then get the GGBS and the influence on the strength of interaction between gypsum content of the response surface and contour plot.

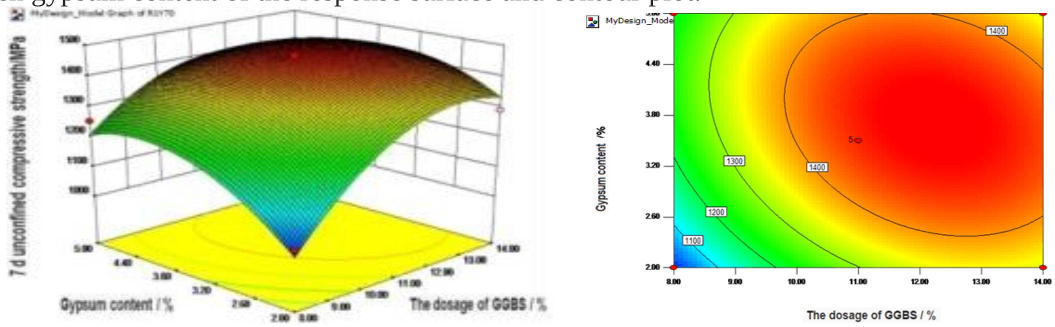

Figure 1 GGBS and plaster for 7 d (the strength of the interaction of the response surface and contour plot

You can see by the above, when the dosage of 8% ~ 8% of GGBS, Y7 increases with the increase of dosage of gypsum, and when the dosage of 12% ~ 12% of GGBS, Y7 increases with the increase of dosage of gypsum present first after the change trend of decrease; Additionally, the strength of solidified soil also increases with the increase of the dosage of gypsum, first, then decreases. This is because when the outside a small amount of gypsum as addition agent to the granulated blast furnace slag, plaster of SO42 - can destroy the mesh structure of GGBS, release the vitreous body structure of Ca2 +, Si2 + plasma, thereby promote the hydration of GGBS, and at the same time of hydration products of GGBS will continue to generate ettringite reaction with gypsum. Ettringite is a kind of natural gas hydrates dilatability, occurred in the process of forming its volume expansion, can effectively fill soil intergranular pore [6]. And ettringite can has a unique structure characteristics and hydration calcium silicate (CSH) constitute a special kind of mesh structure, the mesh structure effectively improve the soil strength [7]. For the age of 28 d, CaO interactions with gypsum, X1 in type (3) fixed to the zero level, then get CaO and impact on the strength of interaction between gypsum content response surface and contour plot.

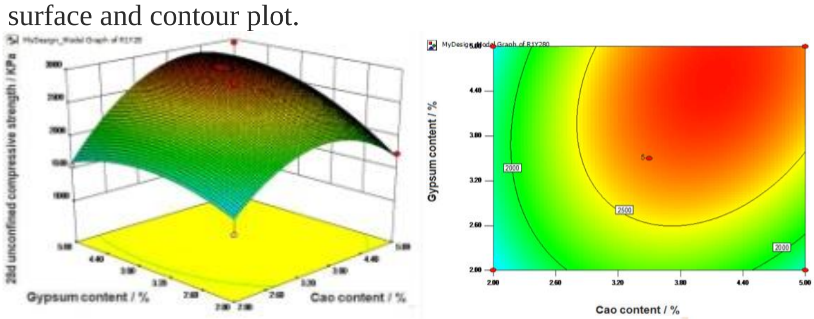

Figure 2 CaO and plaster age of 28 d in the strength of the interaction of the response surface and contour plot

As shown in figure 2, CaO and the interaction of the gypsum, when CaO content at 2% ~ 2%, Y28 increases with the increase of dosage of gypsum present first after the change trend of decrease; Additionally, the strength of solidified soil also increases with the increase of CaO content in first, then decreases.

3.3 Formula Optimization Analysis

Through the Design - Expert software for 7 d and 28 d age interaction analysis, concluded that GGBS, CaO, the optimal ratio of gypsum were 12.18%, 3.62%, 3.71% and 12.18% respectively, 4.08%, 4.50%, Y7 = 1479.33 kPa, Y28 = 2936.78 kPa.Between measured and predicted in table 4.

Table 4 Between measured and predicted

7d		28d	
The measured values	Predictive value	The measured values	Predictive value
980	1014.12	1115	913.37
1028	1006.49	1194	1286.25
1059	1085.85	1303	1527.13
1080	1097.37	1552	1603.37
1166	1197.13	1575	1797.64
1209	1171.37	1599	1525.13
1254	1212.25	1706	1840.99
1282	1271.13	1736	1684.62
1289	1308.38	1860	2161.13
1291	1332.75	2163	1898.01
1305	1326.51	2415	2452.75
1317	1234.38	2704	2752.20
1437	1452.80	2735	2752.20
1445	1452.80	2752	2752.20
1453	1452.80	2772	2752.20
1461	1452.80	2798	2752.20
1468	1452.80	2942	2717.88

4 GGBS solidified soil compared with the mechanical properties of cement stabilized soil analysis

The above test and analysis proves that GGBS, CaO and gypsum can effectively cure lacustrine soft soil, increase the strength of the soil. Engineering to the 28 d strength as a general readings, accordingly to verify GGBS, CaO and gypsum mixed curing agent in the engineering feasibility of the cement stabilized soil experiment results and the optimal ratio of 11.6%, 11.6%, 4.50% GGBS solidified soil were compared.

4.1 Solidified Soil Strength Change Law of Contrast

Using cement to reinforce the soft soil, test conditions and curing conditions the same as the above slag solidified soil, cement mixing ratio of 8%, 11% and 14% respectively, cement solidified soil moisture content of natural moisture content (32.51%), and figure 5 for soil and GGBS solidified soil unconfined compressive strength curve.

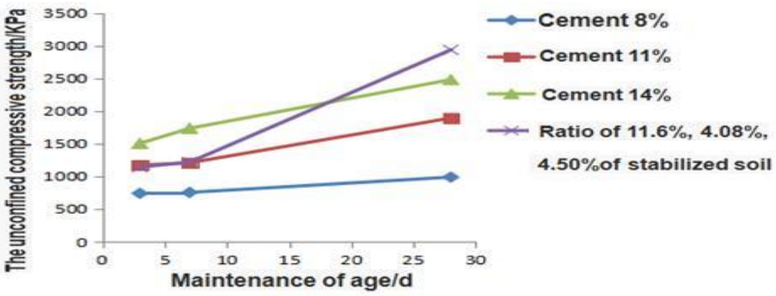

Figure 3 cement-soil and GGBS solidified soil unconfined compressive strength curve

The figure 3 shows that the strength of the solidified soil increases with the increase of cement admixture, the three growth curve is almost parallel. Cement content of 8% strength of solidified soil conservation 3 d after 700 kpa, however after its strength growth rate is low, the intensity of growth curve flatten out whole, cement solidified soil strength after curing 28 d to 988 kpa, the 3-d unconfined compressive strength has reached 75% of the 28 d strength. Dosage was 11% and 14% of 8% cement solidified soil strength higher than that of cement stabilized soil, but its strength growth curve and the dosage of 8% cement solidified soil, maintained rapid growth in its early strength, cement content of 11% 3 d confining compressive strength of solidified soil strength of 28 days can reach 62%, the dosage of 14% strength of solidified soil in 3 d can reach more than 61% of 28 d. Different ratio of cement stabilized soil unconfined compressive strength experiment showed that as the growth of the curing age and the increase of the cement mixing ratio, strength of solidified soil also increases, at the beginning of the maintenance to the rapid growth of the strength of solidified soil can quickly form a certain intensity, the 3 d unconfined compressive strength of the stabilized soil basically can reach more than 60% of the 28 d strength.Ratio of 11.6%, 4.08%, 4.50% GGBS early solidified soil strength and cement content of 11% of the solidified soil, but as the growth of the curing age, slag the 28 d strength of the stabilized soil is much larger than the dosage of 11% cement stabilized soil; the 7 d compressive strength reached the 28 d strength of only 41%, compared with 60% of the soil has a larger difference; Late but slag solidified soil strength growth potential is bigger, the 28 d compressive strength increased by about 157% than 3 d.

4.2 Comparative Analysis of Solidified Soil Stress-Strain Relationship

GGBS and cement stabilized soil can effectively improve the strength of the soft soil, but the cement and GGBS also have different effects on the solidified soil. Selection after curing 28 d of cement and ratio for 11.6%, 4.08%, 4.50% of GGBS, comparing the stress strain curve of the stabilized soil is shown in figure 4:

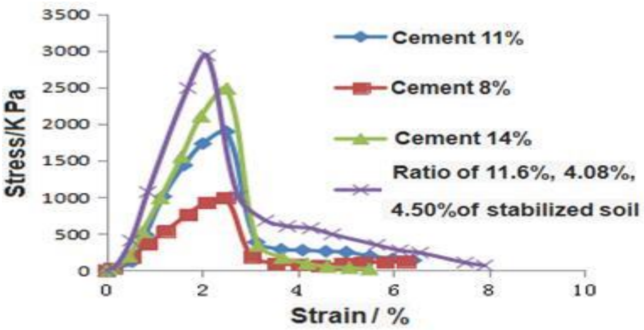

Figure 4, 28 d cement-soil compared with GGBS solidified soil stress-strain relationship curve

You can see from figure 6: three mixing ratio of cement stabilized soil stress strain curve is basically similar brittle failure, initial stress strain curves in a straight line rise, closer to the damage, the inelastic phase very short sample soon to destroy the plastic stage, strength reduced sharply. Three mixing ratio of cement stabilized soil are when the strain is about 2.5% of maximum strength, sample damage.Ratio of 11.6%, 4.08% and 4.50% of the solidified soil stress-strain curve are similar to those of cement solidified soil, but compared with the cement GGBS solidified soil strength is bigger, the stress strain curve more steep rise, when the strain is 2.1% sample is destroyed, the plastic phase is more short than cement solidified soil, destruction way closer to brittle failure. The sample destruction as shown in figure 7, damage when there is no obvious deformation, stabilized soil sample in the sample form a top-down of 45 ° seam, the destruction of soil properties is more and more close to the concrete compression failure, belongs to brittle failure.

5 Conclusion

(1) according to the analysis of variance of the regression equation, 7 d age, three factors of the strength of solidified soil were significantly linear effect and surface effect, GGBS significant interactions with gypsum; 28 d age, each factor on the strength of the linear effect and surface effect are significant, CaO significant interactions with gypsum.
(2) the Box - Behnken method to design optimization of the ratio of GGBS, and CaO, gypsum: for 7 d age, optimal mixing proportion is 12.18%, 3.62%, 3.71%, under the ratio of Y7 1479.33 kPa; For 28 d age, optimal mixture ratio is 11.6%, 4.08%, 4.50%, Y28 2936.78 kPa. Validation test results show that the predicted values and measured values close to.
(3) the cement stabilized soil and slag solidified soil, comparing the curing effect of the analysis shows that the slag can effectively cure the hefei lacustrine soft soil, the ratio of 11.6%, 4.08%, 4.50% slag solidified soil strength of 28 d can completely exceeding 14% of the mixing ratio of cement solidified soil, at the same time, the early stage of the slag solidified soil strength is lower than cement solidified soil, but the sample of the late strength growth potential is bigger.
(4) the GGBS solidified soil with cement stabilized soil stress-strain curve comparison showed that the ratio of 11.6%, 4.08%, 4.50% GGBS closer to brittle failure of the stabilized soil, the strain of 2.1% when the sample is broken, can greatly reduce the compressibility of soft soil, decrease of damage caused by deformation of soft soil.

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Reference

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