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Orthogonal Test of Characteristics of Complex Cememting Material of FGD Gypsum-Fly Ash

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Abstract. Orthogonal test method is used to study the effect of the mineral admixtures on the performance of FGD gypsum-fly ash complex cementing material. On the basic experiment, the effect of the traditional alkali and salt admixtures added to the complex cementitious system is discussed, the factors effecting on performance of the FGD gypsum were analyzed. Based on the experimental results, the best mix proportion was determined. Finally, the basic performance of complex cementitious material was tested. The experimental results show that the performance of FGD gypsum which is activated through adding the compound admixtures was similar with the ordinary interior wall materials. The strength and water resistance of FGD gypsum complex cementing material can be greatly enhanced by adding cement, quicklime and slag powder, and effect of cement is largest, and slag smallest. The performance of the gypsum complex cementing material also can be improved after incorporation of a few of chemical admixture on the basis of adding mineral activators.

Introduction

At present, Output of FGD gypsum produced in Power Plant in China has reached more than 500 million tons. The National Power Company of China estimated that the annual output of FGD gypsum all over China will be more than 20 million tons in the end of 2010, and about 360 million tons of FGD gypsum will be produced in Zhejiang Province each year. The number means that proper utilization of FGD gypsum is very important and valuable, which will directly influence the economic benefits and environmental benefits of power plant [1]. However, application of FGD gypsum in China is not satisfactory now and the application field is limited. Therefore, research on performance and application of the raw gypsum produced in power plant is very necessary and urgent [1]. In this paper, FGD gypsum and fly ash were used as the main raw material, and effect law of the mineral admixtures and chemical activators on the performance (such as strength and water resistance) of FGD gypsum-fly ash complex cementing material (noted as FGD-FACB) is studied and the optimal proportion was finally determined. The research work presented here can not only make direct use of the raw gypsum in production of wall material, but also be propitious to reach the purpose of energy-saving, recycling and improvement of economic and environmental benefits [2-3].

Raw Materials

The raw materials such as FGD gypsum, fly ash and slag are all produced in Ningbo Beilun Power Plant. FGD gypsum is a kind of powder with pale yellow color, whose water ratio is about 15.6% and there is surplus content of more than 8.0% with 0.175mm square mesh sieve. Slag powder is dark grey and surplus content is more than 0.5% with 0.246mm square mesh sieve. Cement is ordinary Portland cement with 32.5 grade. Effective calcium content of CaO is more than 70% and degree of fineness is 80 mesh. The chosen chemical activators are NaOH, $CaCl_2$, Na_2SiO_3 and K_2SO_4 , etc.

The basic mix proportion of FGD gypsum-fly ash complex cementing material is that FGD gypsum: fly ash=50:50, Water aggregate ratio is 0.35, FDN water-reducing agent is 0.5% and SC retarding admixture is 0.3%. The content of chemical elements of main raw materials used here is listed in Table 1.

Table 1 Content of chemical elements of major raw materials (%)

Chemical elements	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	SO_3	Na_2O	K_2O	Others
Content in FGD gypsum	1.50	0.80	0.29	0.10	41.40	55.43	0.01	0.20	0.27
Content in fly ash	52.20	30.79	6.34	0.03	5.72	-	0.01	0.26	4.65

Experimental Results and Analysis

According to the previous tests [3-5], effect of the mineral activators such as cement, lime and slag powder and the chemical activators such as sodium hydroxide, calcium chloride, sodium silicate and potassium sulfate on strength, softening coefficient and apparent density of the cementing materials is tested and analyzed here with using the method of orthogonal test. The test results are as follows:

Effect of Mineral Activators on Properties of the Complex Cementing Material. Proportion is designed according to orthogonal table of three factors and three levels of L9 (33), the main mineral activators of cement, lime and slag are selected as the key influence factors. The test results of 28d compressive strength, 56d compressive strength, density and softening coefficients of the complex cementing material for different mineral activators are obtained and shown in Table 2. It is noted that the fundamental raw materials of the complex cementing material is FGD gypsum and fly ash which is presented above.

Table 2 Orthogonal experimental results for analysis of effect of mineral activators

No.	C /%	CA /%	S /%	28d strength /MPa	56d strength /MPa	density /kg/m^3	Soft coeffi-cient
1	5	1	3	2.90	3.50	1403	0.55
2	5	3	5	3.70	4.20	1424	0.55
3	5	5	10	3.00	3.90	1476	0.57
4	10	1	5	5.20	5.70	1448	0.58
5	10	3	10	6.00	7.00	1535	0.60
6	10	5	3	4.90	5.90	1423	0.60
7	15	1	10	3.60	4.70	1625	0.55
8	15	3	3	5.10	6.60	1559	0.56
9	15	5	5	4.80	5.40	1587	0.57

It is seen from Table 2 that the strength and softening coefficient of FGD gypsum and fly ash complex cementing material can be improved by adding appropriate amount of Portland cement, quicklime and slag powder. The further range analysis show that strength and softening coefficient of the complex cementing material increase significantly with cement, and effect of quicklime and slag on them is less than cement. However, effect degree of slag on the apparent density is greater than quicklime.

Effect of Chemical Activators on Properties of the Complex Cemeting Material. Upon the basis of the test for analysis of effect of mineral activators on performance of the complex cementing material presented above, the chemical activators are further added into the complex cementing material and the orthogonal experiment is conducted. The chemical activators selected are NaOH, $CaCl_2$, Na_2SiO_3 and K_2SO_4, and the test results obtained with orthogonal test method is shown in Table 3.

Table 3 Orthogonal experimental results for analysis of effect of chemical activators

No.	A/%	B/%	C/%	D/%	28d strength /MPa	56d strength /MPa	soft coefficient
1	0.3	0.5	0.5	0.5	9.10	10.40	0.60
2	0.3	1.0	1.0	1.0	9.80	11.30	0.62
3	0.3	2.0	2.0	2.0	7.40	8.70	0.58
4	0.5	0.5	1.0	2.0	9.30	10.80	0.59
5	0.5	1.0	2.0	0.5	8.30	9.90	0.61
6	0.5	2.0	0.5	1.0	8.00	10.30	0.60
7	0.7	0.5	2.0	1.0	7.60	8.90	0.59
8	0.7	1.0	0.5	2.0	8.50	9.70	0.59
9	0.7	2.0	1.0	0.5	8.70	10.10	0.58

It is seen from Table 3 that adequate chemical activators can greatly stimulate activity of FGD gypsum and fly ash complex cementing material with mineral activators, and the overall strength and softening coefficient of the complex cementing material can be improved. Results of further range analysis of the test data obtained here are shown in Table 4.

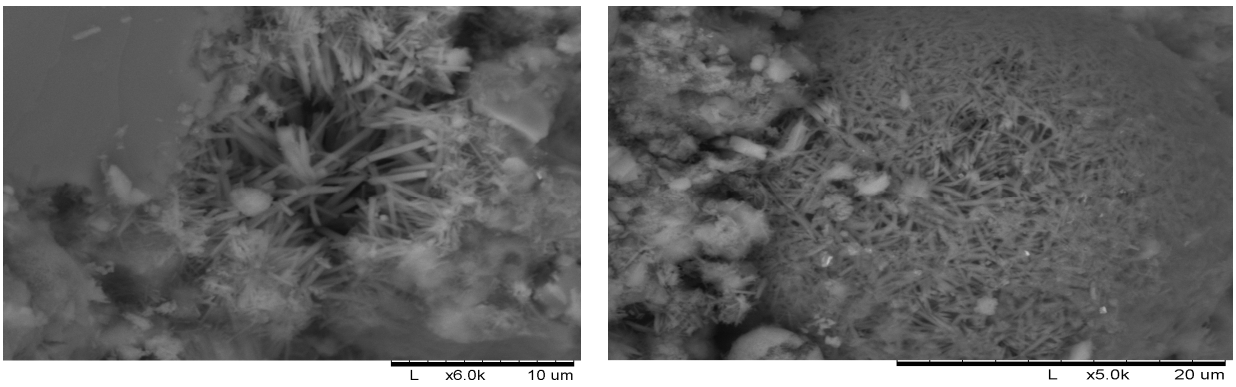
Table 4 Results of range analysis of test data

Factors		NaOH (A)	$CaCl_2$ (B)	Na_2SiO_3 (C)	K_2SO_4 (D)
28d strength	k_1	8.767	8.667	8.533	8.700
	k_2	8.533	8.867	9.267	8.467
	k_3	8.267	8.033	7.767	8.400
	R	0.500	0.834	1.500	0.300
56d strength	k_1	10.133	10.033	10.133	10.133
	k_2	10.333	10.300	10.733	10.167
	k_3	9.567	9.700	9.167	9.733
	R	0.766	0.600	1.566	0.434
Soft coefficient	k_1	0.600	0.593	0.597	0.597
	k_2	0.600	0.607	0.597	0.603
	k_3	0.587	0.587	0.593	0.587
	R	0.013	0.020	0.004	0.016

It is noted that effect of Na_2SiO_3 on strength of the complex cementing material is biggest, and then NaOH, $CaCl_2$ and K_2SO_4, respectively. Effect of $CaCl_2$ on softening coefficient of the complex cementing material is the largest, and followed by K_2SO_4, NaOH and Na_2SiO_3, respectively. However, it is also seen that effect of four chemical activators presented here on softening coefficient of the complex cementing material are all relatively smaller.

Micro-analysis of Strength and Water Resistance of the Complex Cementing material

The microstructure of hardened FGD gypsum and fly ash complex cementing material are shown in Fig.1. The results show that the main hydration products of the complex cementing material are needle-like ettringite crystals and fibrous hydrated calcium silicate gel. It is shown that the surface of fly ash is covered with a layer of vitreous round granular hydration products as shown in Fig.1 (b), but the product and the fully hydrated particles are also closely linked.



(a) (b)

Fig.1 Microstructure of FGD gypsum and fly ash complex cementing material

Summary

It is concluded that strength and softening coefficient of FGD gypsum and fly ash complex cementing material can be improved by adding appropriate amount of Portland cement, quicklime and slag powder. Adequate chemical activators can greatly stimulate activity of the complex cementing material presented here, and effect of Na_2SiO_3 on strength of the complex cementing material is biggest. However, effect of $CaCl_2$ on softening coefficient of the complex cementing material is the largest. It is seen that the main hydration products of the complex cementing material are needle-like ettringite crystals and fibrous hydrated calcium silicate gel based on SEM observation.

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