Experimental research on modified polymer concrete

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Abstract

A sort of high performance modified polymer concrete was needed to develop as while as the maturing and function defecting of concrete become one common issue for dam engineering, coffering engineering and foundation engineering of hydraulic structure. In order to researching the composite additive of polymer concrete and the influence of silica fume mixing proportion on polymer concrete, A series of orthogonal tests were processed. Firstly, an optimum mixing proportion of the composite additive was proposed, the antifoaming agent is 1.5% of polymer emulsion, the water reducing agent is 1.2% of cement and the stabilizing agent is 3% of polymer emulsion. Secondly, the result shows that the compressive strength, rupture strength and splitting tensile strength of polymer concrete firstly increases and then decreases with the increase of the mixing amount of silica fume and the mechanical properties will be optimized at mixing amount of 12%. Thirdly, compared with ordinary concrete, the modified polymer concrete raised the compressive strength 11.2%, the rupture strength 8.3%, splitting tensile strength 11.4% and improved the impermeability 4.4 times on the 28th day. Finally, the action mechanisms of the modified polymer concrete are analyzed.

Keywords: Modified polymer concrete, orthogonal test, impermeability, splitting tension strength, composite additive

1 Introduction

Polymer concrete is one kind of geopolymer cementitious material, which can be fast setting under normal temperature or under water, self-levelling, well flexible after solidifying, high impermeability and strong cohesive force. Based on these advantages, great attention was paid in the field of water conservancy projects at home and abroad and it has been widespread use in dam engineering, coffering engineering, reinforcement dam engineering and foundation engineering of hydraulic structure [1]. While the ordinary concrete cannot be directly used widely because it is own defects, such as low bonding and rupture strength, big brittleness, bad flexible and durability. Since 1950s, Polymer concrete was applied to the field of construction engineering. Polymer concrete material got more popularization and application after 1970s following the appearing of impregnated polymer concrete. Plenty of studies have been carried out refer to mixing proportion theory, working performance, basic mechanical property, micro mechanical property, durability and structural character. Accordingly, both theoretical research and engineering application about polymer concrete have been promoted [2]. This paper proposed a new high performance modified polymer concrete. Experimental researches on the composite additive of polymer concrete and the influence of silica fume mixing amount to the performance of polymer concrete have been conducted.

2 Raw material selection

2.1 CEMENT

Ordinary Portland cement with strong brand 42.5 grade produced in Jiaozuo city in Henan province is selected. The main chemical constitution is listed in Table 1.

TABLE 1The main chemical constitution of cement (%)

SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	LOSS	f-CaO
21.84	3.30	5.23	2.76	65.23	0.19	0.92

2.2 POLYMER EMULSION

Polymer acrylate emulsion (PAE) produced by Jinyuan building materials factory in Taiyuan city and provided by Oriental tai bo chemical technology company in Qingzhou city in Shandong province is selected in this research, with milky white viscous liquid, minimum film formation temperature 8℃, solid content 50%, glass transition temperature 12℃.

2.3 AGGREGATE

Fine aggregate is Xinyang sand with fineness modulus 3.0. Coarse aggregate is gravel produced in Yuntai mountain in Jiaozuo city with continuous grading 5~25 mm diameter, gravel accounts for 60%, 20~40 mm diameter gravel accounts for 40%. The performance index of aggregate is listed in Table 2.

TABLE 2 Performance index of aggregate

Aggregate types	Stacking density, kg/ m^3	Performance density, kg/ m^3	Silt content,%	Moisture content,%
Fine aggregate	1566	2650	1.8	2.5
Coarse aggregate	1520	2670	0.26	0.095

2.4 ADDITIVE

High efficiency water reducing agent (FDN-8000) is used with water-reducing rate of 22%. Organic silicon

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antifoaming agent (L-1000) is adopted with polysiloxane as the main material produced by Shanghai li qi auxiliary chemicals company. Stabilizing agent (Modified emulgator OP-10 of W106) belong to non-ionic surfactant is employed produced by Sichuan xiang he coating company.

2.5 SILICA FUME

Silica fume, greyish-white powder with volume-weight 150~200kg/m^3 produced by Shanghai ai ken company, is mixed using external addition method. Its Chemical composition is shown in Table 3.

TABLE 3 Chemical composition of silica fume

Items	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	pH
Average value	85~94%	1.0±0.2%	0.9±0.3%	0.7±0.1%	0.3±0.1%	1.3±0.2%	neutral

Fineness of Silica fume is detected by using laser particle size analyzer. The result shows that the average grading is about 1.5μm. Figure 1 shows the laser particle size of silica fume.

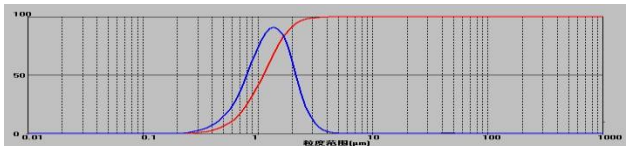

FIGURE 1 Analysis of laser particle size of silica fume

2 Experimental method

Refer to the two testing regulations including Ordinary concrete long-term performance and durability test method standard (GB/T50082-2009) and Test code for hydraulic concrete (SL352-2006), the experiment is conducted.

Compressive strength is detected according Cube test-piece with length of 100mm. Rupture strength is detected according beam test-piece with size of 100 mm×100 mm×400 mm.

Bonding strength is described by splitting tensile strength of concrete samples. The concrete test cube with length of 100mm is manufactured and conserved 28 days, then divided into two pieces using impulsion method. Polymer emulsion modified concrete is poured with one piece of the concrete in Concrete formwork beforehand, and the formwork is dismantled after 24 hours. Splitting tensile strength of the test-piece is detected after 28 days.

Chloride ion diffusion coefficient method (NEL) is adopted to analyze the ability resistance to chloride penetration.

Production process of polymer concrete is as follows.

1) Raw materials without water reducing agent should be stirred evenly by using concrete mixer (NJB-30). Then adding water and stirring for 1 minute. Adding high efficiency water reducing agent slowly and stirring for 2 minutes. Adding polymer emulsion and stirring well, then pouring the concrete mixture into slump cone. The value of collapsed slump of the polymer concrete mixture can be measured with standard test method.

2) The cube test-pieces with lengths of 100mm and 150mm and the beam test-piece with size of 100mm×l00mm×400mm should be conducted using the polymer concrete above on shaking table and surface should be smoothed. Then marking them 12 hours later and dismantling formwork 24 hours later. Curing for 3 days in curing room at temperature of 20℃ and relative humidity of 95% and dryly curing until the age of concrete. The mechanical properties of the polymer concrete can be detected.

3 Development of high performance modified polymer concrete

According to the authors previous researches, mix proportion of the polymer concrete listed as follows. Water cement ratio is 0.45, polymer-cement ratio is 10%, sand ratio is 40%, water reducing agent is 1.2% of cement content. Factors level of orthogonal test is shown in Table 4.

TABLE 4 Factors level table of complex admixture

Level	Factors		
	Water reducer / Cement	*Antifoamer / Emulsion*	*Stabilizer / mulsion*
Level-1	0.008	0.01	0.025
Level-2	0.01	0.015	0.03
Level-3	0.012	0.02	0.035

3.1 TEST RESULTS AND ANALYSIS

According to the testing regulation of ordinary concrete mechanical properties (GB/T50081-2002), mechanical properties of polymer concrete from orthogonal test is listed in Table 5.

TABLE 5 Mechanical properties of modified polymer concrete

Test number	Mechanical property (MPa)		C/R ratio
	Compressive strength (28d)	*Rupture strength (28d)*	
1	31.9	5.5	5.8
2	32.6	6.3	5.2
3	29.8	5.5	5.4
4	32.7	5.7	5.7
5	33.5	6.1	5.5
6	30.0	5.1	5.9
7	30.2	5.4	5.6
8	31.6	5.9	5.3
9	30.5	5.6	5.4

Note. C/R ration is compressive strength to rupture strength ratio.

Modified effect of the polymer concrete after curing 28 days is described by the measured compressive strength to rupture strength ratio. The result is listed in Table 6.

TABLE 6 Visual analysis table of composite additive

Items	Water reducer	Antifoamer	Stabilizer	C/R ratio
Test 1	1	1	1	5.8
Test 2	1	2	2	5.2
Test 3	1	3	3	5.4
Test 4	2	1	2	5.7
Test 5	2	2	3	5.5
Test 6	2	3	1	5.9
Test 7	3	1	3	5.6
Test 8	3	2	1	5.3
Test 9	3	3	2	5.4
Average value 1	5.467	5.700	5.667	-
Average value 2	5.700	5.333	5.433	-
Average value 3	5.433	5.567	5.500	-
Range	0.267	0.367	0.234	-

Note. C/R ration is compressive strength to rupture strength ratio.

As shown in Table 6, antifoaming agent is the greatest influence on modified effect of polymer concrete. Result shows that the C/R ratio firstly increases and then decreases with the increase of mixing amount of antifoaming agent and the modified effect will be optimal when antifoaming agent is 1.5% of polymer emulsion and the C/R ratio is minimum simultaneously. Then water reducing agent is the second greatest influence on modified effect of polymer concrete. The C/R ratio also firstly increases and then decreases with the increase of mixing amount of water reducing agent and will be minimum when water reducing agent is 1.2% of cement content. In comparison, the influence of stabilizing agent is lowest and the modified effect of polymer concrete will be best when the mixing amount of stabilizing agent is 3% of polymer emulsion.

It can be concluded from orthogonal test that the optimal mixing proportion will be B2C2A3. The best formula of composite additive is as follows. The antifoaming agent is 1.5% of polymer emulsion, the water reducing agent is 1.2% of cement and the stabilizing agent is 3% of polymer emulsion.

3.2 EFFECT OF MIXING AMOUNT OF SILICA FUME

Silica fume is employed to improve detect of low intensity of polymer concrete. The influence of mixing amount of silica fume on polymer concrete is further researched with adding different composite additives. Accordingly, the optimal amounts of silica fume could be confirmed and the high requirement of durability would be satisfied in dam engineering, coffering engineering, reinforcement dam engineering and foundation engineering of hydraulic structure.

A series of tests for compressive strength, rupture strength and splitting tensile strength of the modified polymer concrete with adding silica fume are carried out. Based on the testing regulation of ordinary concrete mechanical properties (GB/T50081-2002), the results are shown in Figure 2, Figure 3 and Figure 4.

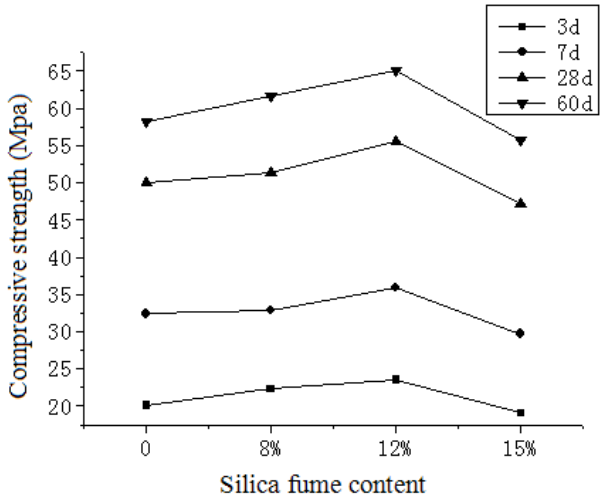

FIGURE 2 Effect of compressive strength of polymer concrete with silica fume content

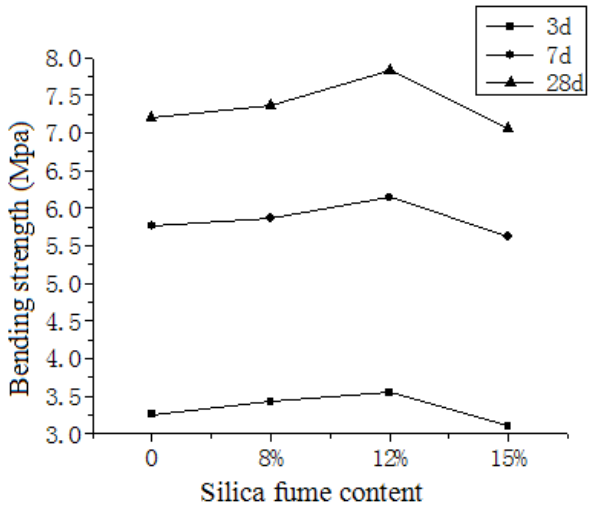

FIGURE 3 Effect of bending strength of polymer concrete with silica fume content

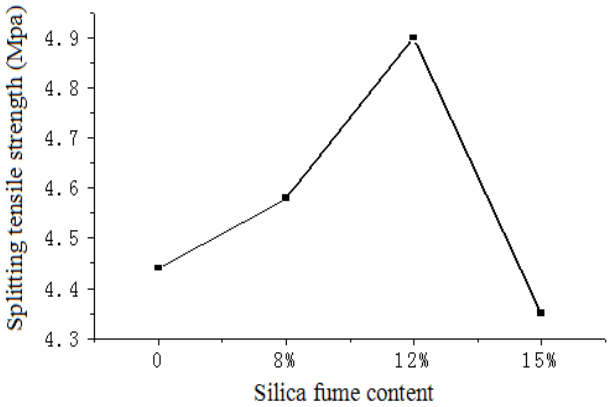

FIGURE 4 Effect of splitting tensile strength of polymer concrete with silica fume

Figure 2 to Figure 4 show that the compressive strength, rupture strength and splitting tensile strength of polymer concrete firstly increases and then decreases with the increase of the mixing amount of silica fume and the mechanical properties will be optimized at mixing amount of 12%. This is due to the particle of silica fume is smaller than that of cement which will induce cement hydration much more evenly. Generally, the calcium to silicon ratio of the gel is lower [3], named gel of calcium silicate hydrate (CSH) generated by reaction between pozzolanic silica fume and calcium hydroxide. The early shrinkage of concrete will be enlarged with the increase of mixing amount of silica fume. Because of silica fume has a very high activity when the silica fume fineness exceeds the level of 2000 m^2/kg.

A mixing proportion of the modified polymer concrete was proposed. Water cement ratio is 0.45, polymer-cement ratio is 10%, sand ratio is 40%, silica fume is 12% of cement, water reducing agent is 1.2% of cement, antifoaming agent is 1.5% of polymer emulsion and stabilizing agent is 3% of polymer emulsion.

3.3 PERFORMANCE OF MODIFIED POLYMER CONCRETE

Compared ordinary concrete with modified polymer concrete, results of mechanical properties and diffusion coefficient are listed in Table 7 and Table 8.

As shown in Table 7 and Table 8, the compressive strength, rupture strength, splitting tensile strength, impermeability of modified polymer concrete is superior to ordinary concrete. It increases the compressive strength by 11.2%, the rupture strength 8.3%, the splitting tensile strength 11.4% and improved the impermeability 4.4 times on the 28th day. Diffusion coefficient of chloride ion (Cl^-) in modified polymer concrete is about 0.681×10^{-8} cm^2/s, which is closed to $0.7\times10^{-8}cm^2/s$ inside the range of high performance concrete generally.

TABLE 7 Difference of mechanical properties between modified polymer concrete and ordinary concrete

Types	Compressive strength (MPa)				Rupture strength (MPa)		Splitting tensile strength (MPa)	
	3d	*7d*	*28d*	*60d*	*3d*	*7d*	*28d*	*28d*
Ordinary concrete	20.1	32.4	50.0	58.2	3.2	5.7	7.2	4.4
Modified polymer concrete	23.5	35.9	55.6	65.1	3.5	6.1	7.8	4.9

TABLE 8 Difference of coefficient of diffusion between modified polymer concrete and ordinary concrete

Types	Voltage (V)	Current (mA)	Diffusion coefficient of Cl (cm^2/s)
Ordinary concrete	4.023	1.318	3.691E-08
Modified polymer concrete	5.039	1.318	0.681E-08

4 Action mechanisms

The performance of modified polymer concrete has been improved because of the synergism of polymer emulsion with silica fume, water reducing agent, antifoaming agent and stabilizing agent. The action mechanisms is as follows.

Specific bridged bond can be formed between polymer chain, when the chemical reaction, between large mixing amount of ester group (COO-) in acrylic ester, SiO_2 and cement on surface of aggregate, $Ca(OH)_2$ generated by hydration reaction and Ca^{2+} born from hydrolyzation, is happened. That will make the whole system a net structure, enhance the compactness and increase the density of cement paste [4].

The capacity resistance to chloride penetration can be enhanced with adding silica fume. The main reason can be concluded that one is the compact effect, filling effect and pozzolanic effect of the ultrafine powder, another is reducing the porosity, improving porosity character and extending the capillary channel.

The synergism of polymer emulsion with silica fume, water reducing agent, antifoaming agent and stabilizing agent has better function during the processes of Water reduction, dispersion, plastification and homogenization. And their recombination also can make the microstructure of cement paste more homogeneous and compact and improve the pore structure. In addition, polymer emulsion can wrap around the silica fume and cement particle sufficiently, which will make net structure easier even in a lower mixing amount to restrain cracks forming and developing [5]. On macroscopic level, it means the mechanical strength increased.

5 Conclusions

1) The optimal formula of composite additive is recommend that the antifoaming agent is 1.5% of polymer emulsion, the water reducing agent is 1.2% of cement and the stabilizing agent is 3% of polymer emulsion.

2) The compressive strength, rupture strength and splitting tensile strength of polymer concrete firstly increase and then decrease with the increase of the mixing amount of silica fume and the mechanical properties will be optimized at mixing amount of 12%.

3) The compressive strength, rupture strength, splitting tensile strength, impermeability of modified polymer concrete is superior to ordinary concrete. It increases the compressive strength by 11.2%, the rupture strength 8.3%, the splitting tensile strength 11.4% and improved the impermeability 4.4 times on the 28th day.

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