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Design of Mix Ratio of Polymeric Aluminum Chloride Waste Residue to Prepare Static Pressed Brick

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Abstract

The orthogonal test of L16 (44) was designed with four levels set under each factor, and the orthogonal method was used to analyze the effect of L16 (44) on the surface layer of static pressed brick, and the optimal formula was obtained. The results show that it is reasonable for PAC waste slag to replace 10% ~ 20% of cement, and the maximum replacement amount should not exceed 20%. The compressive strength of the surface layer of static pressed brick increases with the increase of the ratio of glue to bone, increases first and then decreases with the increase of silica sol content, and has no significant change with the content of emulsion powder. Taking the 28-day compressive strength of static pressed brick as the index, the optimal formula of quartz sand surface was obtained by orthogonal test as follows: glue to bone ratio 1:3, water to glue ratio 0.32, emulsion powder content 1%, silica sol content 1%, compressive strength up to 39.7 MPa.

Keywords

PAC Waste Slag; Concrete Static Pressure Brick; Mix Ratio Design.

1. Introduction

Polymeric Aluminum Chloride (PAC) is a commonly used water purifier with excellent flocculation properties[1-3]. It has the characteristics of fast settling speed, strong adaptability in water temperature, PH value and organic matters[4, 5], and is widely used in the field of water treatment[6, 7].The raw materials for the production of PAC are mainly aluminum hydroxide, bauxite, calcium carbonate powder, hydrochloric acid, etc. A certain amount of PAC waste residue will be produced in the production process. The main components are SiO2 and Al2O3 after harmless treatment. Its properties are similar to those of polymerized ferric sulfate aluminum waste slag and red mud, so it has a broad prospect of application in the field of construction materials. PAC waste residues lack effective utilization, and are still mainly disposed of in landfills or heaps, which cause great harm to the environment. The use of PAC waste residue for brick making is an effective treatment approach.

In the design of mix ratio, the amount of cementing material is the key factor affecting the compactness and mechanical strength of the product. When the amount of cement is too little, it is difficult to effectively bond the coarse and fine aggregates, and the cementation effect is insufficient, resulting in the low strength of the product. Too much cement will lead to the increase of cost and the occurrence of caustic soda[8]. In the study of Wang Song[9], as the amount of cement added increases, the compressive and flexural strength also increases first and then decreases slightly. Liu Junjie [10]used 10 MPa, 15 MPa, 20 MPa, 25 MPa and 30 MPa pressure to form specimens with the same ratio, and found that the compressive strength first increased rapidly with the increase of molding pressure, and then tended to be gentle when it reached 20 MPa. The surface layer of static pressed brick usually does not contain coarse aggregate, but mainly fine aggregate. Usually fine sand or ultra-fine sand is used to prepare the surface layer. The prepared surface layer is smooth and beautiful, but there is a problem that it is easy to crack and powder. Studies have shown that adding silica sol can

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significantly improve the compressive and flexural strength of concrete[11, 12]. Hani[13] added nano-sio2 into self-compacting concrete and found that the greater the water-cement ratio, the higher the compressive strength. Wang[14] studied the mechanical properties and microstructure at 25℃, 200℃, 400℃ and 600℃ through static load test, scanning electron microscope and X-ray diffraction, and found that the addition of nano-sio2 improved the high temperature properties of concrete at different temperatures. The addition of nano-sio2 to concrete is conducive to the improvement of mechanical properties. On the one hand, the addition of nano-sio2 can improve the early hydration reaction[15], and on the other hand, nano-sio2 can fill the interfacial transition zone between aggregates and improve the compactness[16]. Therefore, it can be preliminarily judged that it is feasible to introduce nano-sio2 into the preparation of static pressed brick surface layer to improve the mechanical properties. Dispersible emulsion powder is a polymer that can be stirred with water to re-form a stable emulsion with similar properties as before drying. Redispersible polymer emulsion powder is usually used with cement, gypsum, lime, etc., which helps to improve durability, water resistance, toughness[17], mechanical strength[18], cohesivenessand other properties. It is widely used in the fields of waterproofing, insulation coating, bonding mortar, tile adhesive and asphalt[19], which can improve the bond and cohesion of concrete and enhance the flexural strength. The above research shows that silica sol and emulsion powder can be used to improve the strength of concrete and improve the early hydration reaction of concrete.[20] However, they are all applied in plastic concrete with good fluidity, and there are few examples in dry hard concrete with poor fluidity and static pressing, and the specific effect needs to be verified.

In this paper, the influence of different cement content and forming pressure on the compressive strength of static pressed brick base was studied to provide reference for the mix ratio design. PAC waste slag was used to replace 0, 10%, 15%, 25%, 30% cement with equal mass respectively, and the mechanical properties of static pressed brick were studied. The effects of glue to bone ratio, water to glue ratio, latex powder and silica sol on static pressed bricks were studied. Based on the above research and engineering practice, the production technology and ratio design of static pressed brick were carried out.

2. Materials

(1) Cement

P.O 42.5 ordinary silicate cement was used for the test, and the main chemical composition is shown in Table 1.

Table 1. Main chemical composition of cement (%)

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Cl^-	Other
OPC	20.15	4.76	3.18	64.87	2.87	-	-	1.74

(2) Aggregate

Fine aggregates were made of machined sand with a fineness modulus of 2.7; coarse aggregates were made of building aggregates with a maximum particle size of 9.5 mm, an apparent density of 2652 kg/m3 and a crushing value of 6.9 %.

Aggregate gradation is an important factor affecting the strength of static pressed bricks. In this paper, Fuller gradation curve was used to design aggregate gradation, and the composite gradation of 70% machine-made sand and 30% stone was adopted, as shown in Figure 1.

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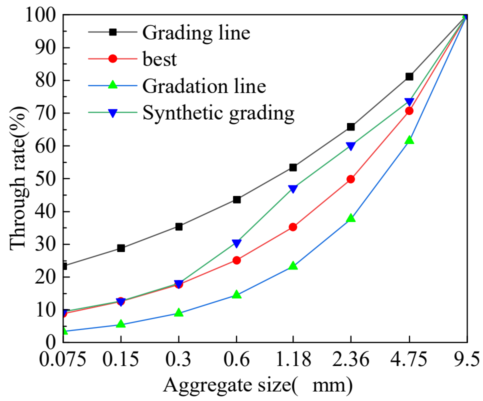

Figure 1. Aggregate grading curve

(3) Slag powder

The density of S95 granulated blast furnace slag powder is 3.09 g /cm3, and the main physical parameters are shown in Table 2.

Table 2. Physical parameters of slag powder

Index	Density (g/cm^3)	Compressive strength (MPa)		Flexural strength (MPa)	
		7 d	28 d	7 d	28 d
S95	3.09	34.1	52	6.3	9.2

(4) Silica sol

The silica sol is nano-sio2 with an average particle size of 13 nm, solid content of 30.5%, and sample purity greater than 99%. The main performance indexes of silica sol used in the test are shown in Table 3.

Table 3. Basic properties of silica sol

Product model	**appearance**	**SiO2 content**	**PH**	**Density**	**viscosity**	**Particle size**
GS - 30	Slightly opal and transparent	30.5 %	9.6	1.204 g / m^3	6.2 cp	11 nm

(5) Emulsion powder

Redispersible emulsion powder, the main performance indicators are shown in Table 4.

Table 4. Basic properties of dispersible emulsion powder

Product model	**Solid content**	**PH**	**Packing density**	**Specific surface area**
9070	99 %	8	0.468 g/m^3	460 m^2/kg

(6) White cement

P.W42.5 white Portland cement, whiteness ≥ 87, the main physical and mechanical indexes are shown in Table 5.

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Table 5. Physical and mechanical properties of white cement

index	Specific surface area (m^2/kg)	density (g/cm^3)	Setting time (min)		Compressive strength (MPa)		Flexural strength (MPa)	
			Initial set	Final set	7d	28d	7d	28d
P.W 42.5	403	3.09	163	216	29.2	46.3	4.2	5.3

(7)Quartz sand

The 18-90 mesh quartz sand used in the test has a packing density of 1416 g /cm3.

(8) PAC waste slag

PAC waste slag used in this study is neutral PAC waste slag after chlorine removal. The PAC waste slag particles below 0.075mm were prepared by drying, crushing, screening and pulverizing. The morphology of PAC waste slag is shown in Figure 2.

Figure 2. PAC waste slag below 0.075mm

(9) Water

Tap water was used for the test.

(10) Water reducing agent

PCA-VI polycarboxylic acid high performance water reducer (HPPR-S), the main performance indicators are shown in Table 6.

Table 6. Performance index of polycarboxylic acid superplasticizer

Product model	appearance	Solid content	PH	density (g/cm^3)	Water reducing rate
HPWR - S	Light yellow liquid	27 %	7.0	1.07	26 %

3. Mix Ratio Design of Basic Layer

The base layer is the main structural layer which affects the basic physical and mechanical properties of static pressed brick. In this study, the cement content, water-binder ratio, micro-powder content, stone content, molding pressure and PAC waste residue content were taken as the main factors to study the effects of these factors on the apparent density, water absorption and compressive strength of the static pressed brick, and explore the law of the influence of cement content, water-binder ratio, micro-powder content, aggregate content, molding pressure and PAC waste residue on the static pressed brick.

In order to explore the effect of cement content and forming pressure on the compressive strength, water absorption and porosity of static pressed brick, the mixture ratio meeting the test requirements

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was designed with cement content and forming pressure as the control variables. The mix ratio design scheme is shown in Table 7.

Table 7. Mix ratio design of static pressed bricks

Cement content	10%, 12%, 14%, 16%, 18%, 20%
Molding pressure	3 MPa, 5 MPa, 7 MPa, 9 MPa

According to the requirements of the mix design scheme in Table 8, the compressive strength of the static pressed brick base is tested for 7 days and 28 days, and a total of 40 groups with 3 pieces in each group are 120 pieces. The material dosage of each component in the mix ratio test of the cement content group and the coarse aggregate group is shown in Table 8.

Table 8. Mix ratio of static pressed brick base

Number	Amount of material per unit volume(kg/m^3)			
	Cement	water	coarse aggregate	fine aggregate
C10	225	90	580.5	1354.5
C12	270	108	561.6	1310.4
C14	315	126	542.7	1266.3
C16	360	144	523.8	1222.2
C18	405	162	504.9	1178.1
C20	450	180	486	1134

Taking group C16 as the reference group, cement of 0, 10%, 15%, 20%, 25% and 30% were replaced by PAC waste slag, respectively, and the material dosage of each component was shown in Table 9.

Table 9. Mix ratio of static pressed brick base specimen

Number	**volume Material consumption(kg/m^3)**				
	Cement	water	coarse aggregate	fine aggregate	PAC waste slag
P0	360	144	523.8	1222.2	0
P10	324	144	523.8	1222.2	36
P15	306	144	523.8	1222.2	54
P20	288	144	523.8	1222.2	72
P25	270	144	523.8	1222.2	90
P30	252	144	523.8	1222.2	108

4. Mix Ratio Design of Surface Layer

4.1 Mix Ratio Design

In this study, the glue bone ratio, water glue ratio, latex powder and silica sol were used as the main factors to explore the effects of glue bone ratio, water glue ratio, latex powder and silica sol on static pressed bricks. Orthogonal experimental design was used to find the optimal horizontal combination of the selected factors. Using L16 (45) orthogonal design test table, 4 factor 4 level orthogonal test was carried out. The extra column in the orthogonal table was used as the error column, and the four parameters of the mix ratio, the ratio of glue to bone, the ratio of water to glue, the content of latex powder and the content of silica sol were analyzed and studied. The specific factors and level design are shown in Table 10 and Table 11. In this part, the 28-day compressive strength of test blocks is tested. There are 16 groups in total, with 3 test blocks in each group, and 48 test blocks in total. Orthogonal test is matched with Table 12.

Table 10. Level table of orthogonal test factors

level	factor			
	Glue ratio	water glue ratio	emulsion powder content /%	silica sol content /%
1	1:4.5	0.26	0	0
2	1:4	0.29	1	0.5
3	1:3.5	0.32	2	1
4	1:3	0.35	3	1.5

Table 11. Orthogonal test design table

level	factor				
	Glue ratio	water glue ratio	emulsion powder content /%	silica sol content /%	Error row
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

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Table 12. Mix ratio of orthogonal test

Number	**volume Material consumption**(kg/m^3)					
	Cement	**water**	**sand**	**emulsion powder**	**silica sol**	**water reducer**
M1	5	1.3	22.5	0	0.000	0.03
M2	5	1.45	22.5	0.05	0.082	0.03
M3	5	1.6	22.5	0.1	0.164	0.03
M4	5	1.75	22.5	0.15	0.246	0.03
M5	5	1.3	20	0.05	0.164	0.03
M6	5	1.45	20	0	0.246	0.03
M7	5	1.6	20	0.15	0.000	0.03
M8	5	1.75	20	0.1	0.082	0.03
M9	5	1.3	17.5	0.1	0.246	0.03
M10	5	1.45	17.5	0.15	0.164	0.03
M11	5	1.6	17.5	0	0.082	0.03
M12	5	1.75	17.5	0.05	0.000	0.03
M13	5	1.3	15	0.15	0.082	0.03
M14	5	1.45	15	0.1	0.000	0.03
M15	5	1.6	15	0.05	0.246	0.03
M16	5	1.75	15	0	0.164	0.03

4.2 Range Analysis of Orthogonal Test Results

Firstly, the results were visually analyzed. As can be seen from Table 13, M15 has the highest compressive strength of 39.7MPa among the 16 groups of tests, and its corresponding factor level combination is A4B3C2D4. The test ratio is 1:3 gel bone ratio, 0.32 water gel ratio, 1% emulsion powder content and 1.5% silica sol content. From the test results, it can be determined that the best level of glue bone ratio A is A4, that is, the glue bone ratio 1:3 is the best. The optimal formulation of the remaining parameters of the test needs to be determined by further analysis.

Compressive strength test was carried out on the surface layer test block with curing age of 28 days, and the orthogonal test results of compressive strength were shown in Table 14. Table 4-3 is the range analysis calculated according to the 28-day compressive strength test values in Table 14. The effects of gel to bone ratio, water to glue ratio, latex powder and silica sol on 28-day compressive strength of the surface layer were 18.6 MPa, 3.5 MPa, 1.0 MPa and 1.8 MPa, respectively. The greater the range R value, the more obvious the influence of the corresponding factors on the compressive strength. As can be seen from Table 4-3, the factors affecting the compressive strength from large to small are as follows: A (glue bone ratio) > B (water glue ratio) > D (silica sol) > C (latex powder), and the optimal horizontal combination is A4B3C2D3.

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Table 13. Results of orthogonal test

Number	factor					Compressive strength (MPa)
	Glue ratio	water glue ratio	emulsion powder content /%	silica sol content /%	Error row	
M1	1(1:4.5)	1(0.26)	1(0)	1(0)	1(0)	15.91
M2	1(1:4.5)	2(0.29)	2(1)	2(0.5)	2(0.5)	18.3
M3	1(1:4.5)	3(0.32)	3(2)	3(1)	3(1)	20.4
M4	1(1:4.5)	4(0.35)	4(3)	4(1.5)	4(1.5)	18.2
M5	2(1:4)	1(0.26)	2(1)	3(1)	4(1.5)	21.41
M6	2(1:4)	2(0.29)	1(0)	4(1.5)	3(1)	23.2
M7	2(1:4)	3(0.32)	4(3)	1(0)	2(0.5)	22.3
M8	2(1:4)	4(0.35)	3(2)	2(0.5)	1(0)	21.6
M9	3(1:3.5)	1(0.26)	3(2)	4(1.5)	2(0.5)	24.14
M10	3(1:3.5)	2(0.29)	4(3)	3(1)	1(0)	26.2
M11	3(1:3.5)	3(0.32)	1(0)	2(0.5)	4(1.5)	26.54
M12	3(1:3.5)	4(0.35)	2(1)	1(0)	3(1)	25.83
M13	4(1:3)	1(0.26)	4(3)	2(0.5)	3(1)	34.4
M14	4(1:3)	2(0.29)	3(2)	1(0)	4(1.5)	36.12
M15	4(1:3)	3(0.32)	2(1)	4(1.5)	1(0)	39.7
M16	4(1:3)	4(0.35)	1(0)	3(1)	2(0.5)	38.2

Table 14. Range analysis of orthogonal test results

range	factor				
	A	B	C	D	e
K1	73.91	95.86	103.85	100.16	103.61
K2	88.51	104.02	105.24	100.84	102.94
K3	102.91	110.04	103.36	107.51	104.93
K4	148.42	103.83	101.30	105.24	102.27
k1	18.5	24.0	26.0	25.0	25.9
k2	22.1	26.0	26.3	25.2	25.7
k3	25.7	27.5	25.8	26.9	26.2
k4	37.1	26.0	25.3	26.3	25.6
R	18.6	3.5	1.0	1.8	0.7
Primary and secondary order	A>B>D>C				
Optimal level	A4	B3	C2	D3	
Optimal combination	A4B3C2D3				

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The range analysis results of the orthogonal test are shown in Table 15. From the range R value of 28-day compressive strength, it can be seen that the glue bone ratio A is the most important factor affecting the compressive strength, followed by the water-glue ratio B, the silica sol content D and the emulsion powder content. Glue bone has the greatest influence on compressive strength and is the most important factor affecting compressive strength. The effect of silica sol content D is stronger than that of emulsion powder C, indicating that the addition of nano-silica has a modified effect on the mechanical properties of static pressed bricks, and is better than that of the selected redispersible emulsion powder. The influence of emulsion powder content C on compressive strength is the lowest. The range of compressive strength of the four factors in Table 4-3 is greater than 0.7 in the blank column, so the test results are credible.

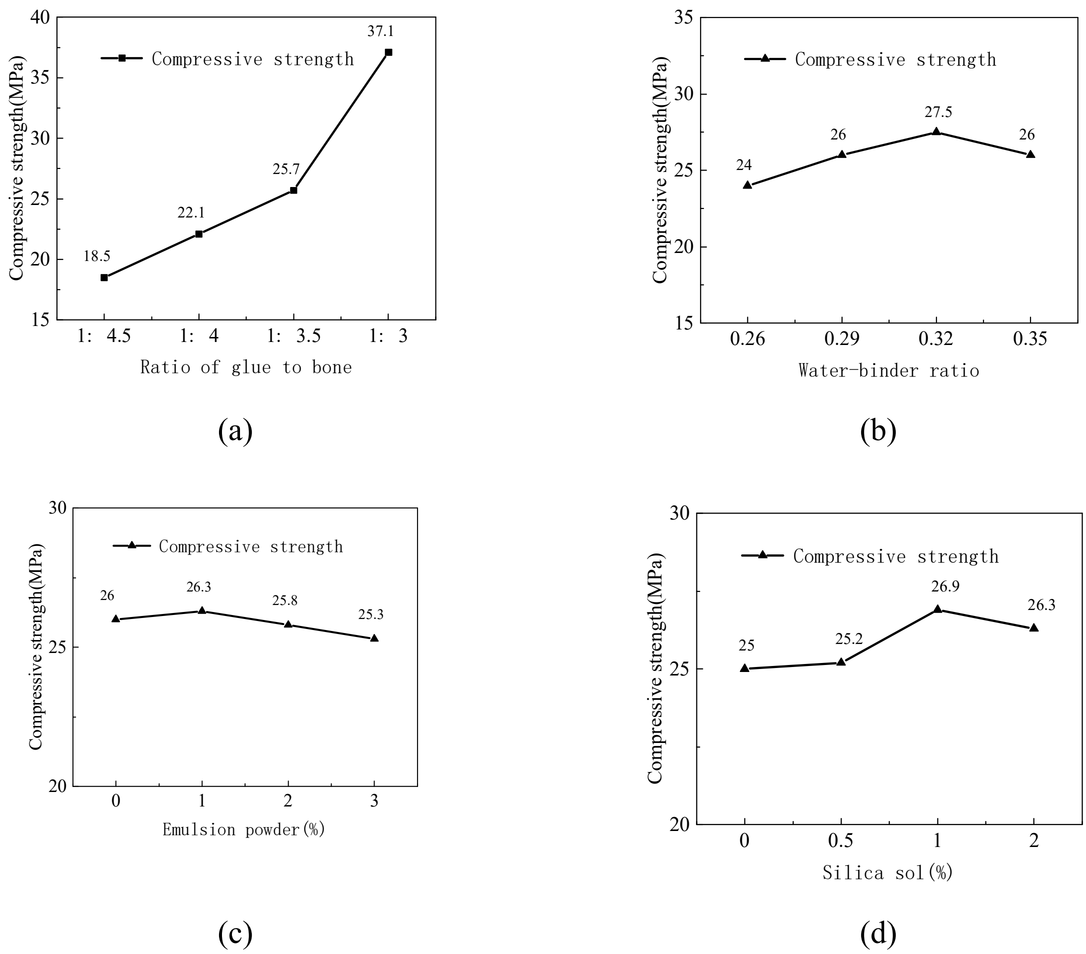

Figure 3. Compressive strength and horizontal trend of factors

As shown in Figure 3 (a), the compressive strength of the static pressed brick increases with the increase of the ratio of glue to bone, and the influence law is the same as that of the cement content on the static pressed brick in Chapter 3. Under the larger ratio of glue to bone, more calcium silicate hydrate gel is generated, which can fully cement and cover the aggregate, and the strength is high, especially in the surface layer of the static pressed brick where fine aggregate is mainly used. On the other hand, the larger the ratio of glue bone, the more cement slurry can be formed, and the larger the area and thickness of the cement paste on the surface of the aggregate, the strengthening of the aggregate also helps to improve the strength.

When the water-binder ratio is constant and the strength grade of cement is constant, the main factors affecting the compressive strength are the amount and grade of cementing material. Secondly, the water-binder ratio can affect the compressive strength of the test block by influencing the strength of the cement stone. As shown in Figure 3 (b), with the increase of water-binder ratio, the strength of the test block showed a trend of first increasing and then decreasing, and reached the maximum value when the water-binder ratio was 0.32. Due to the fixed amount of water-reducing agent, when the water-binder ratio is too low, the mix is dry, affecting the compaction effect. With the increase of the water-binder ratio, the fluidity of the mix can be improved. In the process of static pressing, the impact on the compaction effect is the most direct. With the further increase of water-binder ratio, when it reaches 0.35, the weakening effect of high water-binder ratio on cement stone becomes prominent, and the strength decreases.

In the silica sol modified static pressed brick, the compressive strength increases first and then decreases with the increase of silica sol, and the selected silica sol content can improve the compressive strength of the static pressed brick, and the optimal value is reached at 1%, and the growth rate decreases when the content exceeds 1%. The enhancement of silica sol on static pressed brick is the result of the improvement of the early hydration reaction of nano-sio2 and the filling of the interfacial transition zone between aggregates as a filler to improve the compactness. The influence of emulsion powder on compressive strength is not as obvious as that of silica sol.

4.3 Analysis of Variance of Orthogonal Test Results

Range analysis can determine the primary and secondary order of factors, but it is difficult to accurately estimate the degree of importance. Anova can distinguish the result fluctuation caused by factor level and experimental error, and serve as the criterion for evaluating the significance of factors on experimental results. This orthogonal table arrangement experiment has extra blank columns to estimate experimental error and analysis of variance, so it is not necessary to repeat the experiment.

Table 15. Analysis of variance of orthogonal test results

Source of variance	Sum of squares of deviation	Degree of freedom	Mean square	F-number	P-number
A	779.602	3.000	259.867	806.233	0.00007
B	25.376	3.000	8.459	26.243	0.01181
C	1.999	3.000	0.666	2.067	0.28310
D	9.331	3.000	3.110	9.650	0.04745
E	0.967	3.000	0.322	1.000	0.50000

Analysis of variance, also known as analysis of variance or F-test, is usually used to determine the significance of the influence of factors. This orthogonal test only observed the compressive strength for 28 days, so it was a single observation orthogonal test. The variance analysis of the compressive strength test results of the static pressed brick surface layer is shown in Table 16. For the compressive strength of the surface layer, factor A (bone glue ratio) F value is the largest, indicating that the gelatin bone ratio has a significant effect on the strength of concrete, and factors C (emulsion powder content) and D (silica sol content) are smaller than factors B (water glue ratio), indicating that factor B (water glue ratio) and factors C (emulsion powder content) and D (silica sol content) have a significant effect on the strength of concrete. The order of significance of influencing factors was A (bone glue ratio) > B (water glue ratio) > D (silica sol content) > C (emulsion powder content), and the analysis results were consistent with those of range analysis.

5. Hydrostatic Brick Production Process and Ratio

Based on the results of the above tests on base and surface, the concrete pavement bricks were prepared with machine-made sand and stone as base aggregate and quartz sand as surface aggregate.

The size of the specimen is determined according to the mold of the brick press, which is 300mm×150mm×60mm. The basic raw materials used in the test are ordinary Portland cement and machine-made sand, as well as on-site stone. The surface material is white Portland cement and quartz sand, as shown in Table 16.

Cement PAC waste slag Machine sand Quartz sand stone water whitening Agent 28d strength (MPa).

Table 16. Production mix ratio of static pressed bricks（kg/m3）

		Cement	PAC waste slag	Machine sand	Quartz sand	stone	water	whitening Agent	28d strength (MPa)
Surface course		480	-	-	1680	-	168	320	-
Basic level	C16	380	-	1588	-	280	152	-	52.4
	C15	360	-	1612	-	284	144	-	50.3
	C14	340	-	1636	-	290	134	-	46.3
	C15A10	324	36	1612	-	284	144	-	43.6

The mixture ratio of C16, C15 and C14 adjusted for the dosage of cementing material was in good mixing state, and no sticking mold or bleeding occurred. The compressive strength of 28 days curing at room temperature was 52.4MPa, 50.3MPa and 46.3MPa, respectively, and the changing trend was the same as in the above basic research test. The 28-day compressive strength was lower than 65.2 MPa in the test, mainly because the curing conditions and coarse aggregates used in the two tests were different. C15A10 is based on C15 group as the reference group, using PAC waste slag to replace 10% of cement, to prepare 28-day compressive strength of PAC waste slag 43.6MPa static pressed brick, 28-day strength reached 83.2% of the reference group, meet the requirements of the code.

6. Conclusion

(1) The study of surface layer shows that the factors affecting the compressive strength of the surface layer of static pressed brick are as follows: the ratio of glue to bone, the ratio of water to glue, the content of silica sol and the content of latex powder. Both silica sol and redispersible emulsion powder can improve the compressive strength of the brick. When the silica sol content is 1% and the emulsion powder content is 1%, the compressive strength of the quartz sand surface is the most improved. The compressive strength of the surface layer of static pressed brick increases with the increase of the ratio of glue to bone, increases first and then decreases with the increase of silica sol content, and has no significant change with the content of emulsion powder. Taking the 28-day compressive strength of static pressed brick as the index, the optimal formula of quartz sand surface was obtained by orthogonal test as follows: glue to bone ratio 1:3, water to glue ratio 0.32, emulsion powder content 1%, silica sol content 1%, compressive strength up to 39.7 MPa.

(2) Taking the C15 group as the reference group, using PAC waste slag to replace 10% cement, and using the forming pressure of 5 MPa, the benefit of preparing PAC waste slag static pressed brick is the best. The 28-day compressive strength is 43.6 MPa, which is 83.2 % of the reference group.

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