Strength Performance Test of Permeable Concrete

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Abstract: In this paper, the correlation of strength performance of water permeable concrete with reinforcement, fine aggregate , 42.5 cement and solid C30 is studied by field test. First of all, according to the relevant literature and field experimental research data to construct the contents of field experiments, then the effective data statistical analysis. The following results were found from the study :1, The amount of permeable concrete rubber is 350~430 kg/m3, For each additional 40 kg/m, Concrete strength can improve a strength grade, and the permeability and compressive strength can meet the requirements of experimental C30. 2. if the initial and ease of the mixture is similar, The more obvious the enhancement effect is, The lower the permeability coefficient of permeable concrete, The reinforcing agent promotes the cohesion of fresh permeable concrete, It can ensure the uniformity of aggregate wrapped in slurry; On the other hand, the reinforcement component in the enhancer promotes the density of the slurry, Reduced inter-aggregate defects, The strength of concrete increases. 3. with the increase in sand rates, The compressive strength of permeable concrete also increases, Because of the fine aggregate, Increased number of contact points between the promotion, At the same time, the thickness of cement mortar wrapped outside the record is also significantly increased, Increased bondability between aggregates, More dense inside, So that the strength of permeable concrete greatly increased, So adding a proper amount of fine aggregate is beneficial to the strength of permeable concrete, But not too much, Otherwise, it would make the permeable concrete dense, Loss of its permeable function.

Keywords: permeable concrete; test analysis; strength performance

INTRODUCTION

Permeable concrete is a kind of porous concrete. The common permeable concrete can be divided into cement permeable concrete, asphalt permeable concrete and so on. By looking into the appearance effect, it can be divided into ordinary permeable concrete, colored permeable concrete and exposed permeable concrete, etc. Besides, it can also be divided into ordinary permeable concrete pavement, landscape permeable concrete pavement and bearing permeable concrete according to its function. Permeable concrete is composed of a series of connected pores and the skeleton of solid concrete, which has porous structure with water permeability. In the construction, it mainly depends on the cementation material wrapped on the surface of aggregate. After the slurry is hardened, the aggregate particles are cemented together to achieve the design strength of concrete. In order to improve the compressive strength, flexural strength and durability of permeable concrete, the micro and macro structure of permeable concrete are systematically studied to further explain its performance and physical along with mechanical properties. So as to formulate the relevant specifications and standards of mix design, construction, maintenance and management of permeable concrete, to promote the application in a comprehensive range.

Zhu elaborated the working performance, mechanical performance and durability in the discussion of the influence of reinforcer on the performance of permeable concrete. From the layered test method of permeable concrete, he found that the reinforcer can effectively improve the slurry segregation and sinking of permeable concrete under the same slurry fluidity, and improve the stability of concrete during transportation. The mechanical performance of permeable concrete can be enhanced by adding reinforcer1. The reinforcer can also effectively improve other performance of permeable concrete to a certain extent.

Due to permeable concrete needs to have both permeable performance and certain strength, the balance between the two factors must be considered in the selection of aggregate type and particle size. In the study of permeable concrete performance and influencing factors, Zhang expounded the importance of diameter and compressive strength of raw aggregate. He believed that the effect of using single graded aggregate with smaller diameter in the preparation of permeable concrete was better22. The diameter of aggregate will directly affect the internal pores of permeable concrete, for instance, the pores formed by the accumulation of aggregate with small diameter are often smaller than that of large diameter. From the perspective of compressive strength, aggregate with small diameter has better performance. From a structural point of view, for a certain volume of permeable concrete, the number of particles of using small-sized aggregate must be greater than that of large-sized aggregate. Therefore, there will be more number and area of contact points between the aggregates, creating higher compressive strength5.
How to improve the strength performance of permeable concrete? The purpose of this paper is to design the mix proportion scheme of permeable concrete in experiments through field tests. Research questions are given below:
The strength performance of C30 concrete was tested by literature data and field test.
Through the experiment of mixing permeable concrete with reinforcing agent, to find out the influence of the proportion of reinforcer on the strength of permeable concrete.
Through the experiment of mixing permeable concrete with aggregate, to find out the influence of aggregate diameter's changing on the strength of permeable concrete.
The research flow of this paper is as follows: Chapter 2 literature review, Chapter 3 research hypotheses proposed after experiments, Chapter 4 results and discussion, and Chapter 5 conclusions and suggestions.

LITERATURE REVIEW

SIGNIFICANCE OF PERMEABLE CONCRETE

Reduce the burden of the drainage system. After the rainstorm, the phenomenon of waterlogging is common in cities. If the permeable concrete pavement is used, its special pore structure can make the rainwater quickly infiltrate into the ground, to avoid the occurrence of waterlogging phenomenon, so as to reduce the burden of pavement drainage system; Alleviate the heat-island effect,referring to urban high temperature. The porous structure o can make the capillary water in the bedding soil cool down through natural evaporation and other transpiration after rainfall, thus effectively to alleviate the heat-island effect. It also has the function of sound absorption and noise reduction. The traffic noise pollution is becoming more and more serious. The use of permeable concrete meeting the requirements of road strength and durability can play the role of sound absorption and noise reduction, so as to reduce noise pollution. The main principle is that the sound wave propagates to the concrete through the pores, so that part of the sound energy is converted into heat energy and finally digested6. Besides, it can improve the ecological environment. Permeable concrete has been widely used in pavement and slope protection. While taking into account the use requirements, it also has the conditions to improve the growth of ground and underground animals, plants, and microorganisms, so as to improve the ecological environment1,3.

APPLICATION OF PERMEABLE CONCRETE

Permeable concrete has been studied and applied in developed countries for nearly 30 years. In 1979, near a church in Sarasota, Florida, USA, a parking lot was built with no-fines porous concrete for the first time, and the patent of permeable concrete was obtained. Then, New Mexico and Utah in the United States used no-fines concrete as pavement surface material for parking section. Germany has been committed to the improvement of impermeable pavement since 1980s, and its goal is to transform 90% of the urban pavement into permeable pavement by 2010. Freiburg in the south of Germany is a famous ecological city today. More than 10 years ago, Freiburg proposed the plan of building an ecological city,

which completely demolished all the hardened ground (except roads) in the city and replaced it with various forms of permeable ground. As a result, the groundwater level of Freiburg gradually rose, and the vegetation could be completely free from artificial irrigation and lush7.

At the beginning of this century, China has successively carried out the application of permeable concrete. In Hangzhou, permeable engineering materials have been widely used in the urbanization construction in addition to the canal pollution control project since 2005. According to an uncompleted statistic, by 2007, the area of permeable concrete laid in Hangzhou reached 300,000 square meters. In Beijing, the pavement of water-permeable engineering materials in the construction of Olympic venues alone reached more than 100,000 square meters. At the seminar of providing the water environment design ideas for the Olympic Park, an expert proposed that one of the most important designs of the Olympic Park should be making the ground have a good function of rainwater infiltration. In Shanghai, permeable concrete pavement was widely used in the construction of new and reconstructed parks. It was widely used in the construction of Shanghai World Expo and Special Olympics training base in 2010. The Ministry of Construction is also vigorously promoting permeable concrete materials, which marks that urban construction has gradually stepped out of the misunderstanding of hardening, to show people a new kind of ground laying with environmental, ecological and water resources protection functions.

MATERIALS AND CONSTRUCTION

1. Materials

According to the strength requirements of concrete design, 42.5# ordinary portland cement should be used for permeable concrete with strength above C20. The structure layer stone should be hard, durable and clean. The diameter of stone is within 2.4-13.2mm4. The diameters of the stones are uniform and meet the strength requirements. To check the volume of stone powder in the surface layer, the manual method can be used on site. That is, first wet your hand with water, then put your hand into the stone pile, grab a handful of stones, check the volume of stone powder adsorbed on your hand after releasing the stones, to determine whether it is suitable for construction with visual method. It is required to reach into the stones with one hand for deeper than 30cm. Permeable concrete additives are specially used. The operator needs to check whether the additives are moist and whether the actual weight is consistent with the label on the package. Clean water is used for concrete mixing, which can be drunk by people. See Table 1 for performance index of aggregate.

2. Construction technology

For foundation treatment, the construction personnel should first inspect the foundation, pay attention to issues such as height and compactness, and deal with the partial non-compliance. For concrete mixing, the mixing of permeable concrete must be carried out in strict accordance with the mix proportion, and no wrong feeding is allowed. The first feeding must be weighed, and then marks can be made in the feeding mechanical container. The feeding shall be referenced to the standard. As for the feeding sequence, 1/2 stones are put into the hopper of the mixer first, then cement and additives are put in, and then another 1/2 stones are put in. That is, it is more appropriate to keep the cement and additives in the middle of the stones. For mixing method, the aggregate and 50% water should be added to the mixer for 30-second mixing, then the cement, reinforcer and additives should be added for 40-second mixing, and finally the remaining water should be added for longer than 50-second mixing. For transportation of finished materials, the finished mixed materials shall be transported to the construction site in time after they are discharged from the machine. And it is better to transport them to the construction site within 10 minutes. If the air temperature is higher than 30 ℃, the concrete must be covered to keep moisture, so as to prevent moisture evaporation which will affect the construction quality. According to the construction regulations of permeable concrete, the transportation time from the machine to the construction site should not exceed 30 minutes. In the later stage, the permeable concrete must meet the indicators in Table 2, Table 3 and Table 4.

EXPERIMENTAL RESEARCH HYPOTHESES

HYPOTHESIS OF SELECTING C30 MIX PROPORTION

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At present, permeable concrete is widely used in occasions like pedestrian crossing, landscape pavement and parking lot. The porous structure of permeable concrete makes its strength generally low, and the general design grade is marked between C15 and C20, so it is necessary to design a C30 foundation mix proportion hypothesis, and use a company's reinforcer SR. See Table 5 for details.
The permeable concrete belongs to the dry and hard concrete, and the slump is generally lower or almost zero, so its working performance mainly lies in the working state of its aggregate surface paste. Under the condition that the workability of permeable concrete can not be evaluated quantitatively, the fullness of slurry is tested by hand holding. On the premise of keeping the same amount of reinforcer in the mix proportion, the permeable concrete is made into a ball by controlling the water consumption, then the later compressive strength can be observed. See Table 6.
Experimental summary: Based on the above experiments, it is concluded that under the premise of equal workability, with the increase of slurry dosage, the strength of permeable concrete increases gradually. Within the range of 350-430kg/m3 glue material dosage, the strength of permeable concrete can be improved by almost one grade for every increase of 40kg/m glue material dosage. And the permeability and compressive strength can meet the requirements of C30 experiment .

HYPOTHESIS OF SCREENING REINFORCER

Based on the hypothesis of C30 permeable concrete mix proportion adding reinforcer, the reinforcer with the best compressive strength is selected by screening the compressive strength of different reinforcers on the premise of ensuring the similar workability (brightening and squeezed into a ball by hand) of permeable concrete mixture. The performance test is shown in Table 7.
Experimental summary: On the premise of similar initial workability (brightening, squeezed into a ball by hand) of the mixture, the compressive strength of RS is 31.4MPa, which is obviously higher than that of other reinforcers by at least one strength level. Followed by the compressive strength of GZ, which is 28.6MPa. Although the permeability of PRC and GX is high, the 28-day compressive strength is much lower. The more obvious the enhancing effect of the reinforcre on the compressive strength is, the lower the permeability coefficient of the permeable concrete is. The reason for above "contradiction" is that, on the one hand, the reinforcer promotes the cohesiveness of the fresh permeable concrete, which can ensure the uniformity of the slurry wrapped aggregate. On the other hand, the reinforcing component in the reinforcer promotes the compactness of the slurry, reduces the defects between the aggregates, improving the strength of the concrete.

EXPERIMENTAL ANALYSIS OF THE EFFECT OF FINE AGGREGATE ON THE STRENGTH OF PERMEABLE CONCRETE

Although the permeable concrete uses the best graded aggregate, there is still a relatively large porosity. If the remaining voids can be filled as much as possible on the premise of ensuring its good permeability, the permeable concrete will become denser and obtain greater strength. There are many ways to improve the strength of concrete, and fly ash is generally used, which can play a good role in strengthening the transition area. But because the strength of fly ash is relatively low, it is not suitable for large-scale use. Therefore, add more economic and reliable sand to improve the strength of permeable concrete in this paper. See mix proportion in Table 8.
The sand ratios are 0, 5% and 10% respectively. The early workability of permeable concrete mixture is similar by adjusting the dosage of reinforcer (squeezed into a ball by hand), and the later compressive strength can be observed. The performance test is shown in Table 9.
Experimental summary: With the increase of sand ratio, the compressive strength of permeable concrete also increases. Because the existence of fine aggregate increases the number of contact points. At the same time, the thickness of the cement mortar wrapped outside is also significantly improved, which increases the cohesiveness between aggregates and makes the interior denser so that greatly improves the strength of permeable concrete. Therefore, adding appropriate amount of fine aggregate is beneficial to the strength of permeable concrete. However, it should not be increased too much, otherwise it will cause the permeable concrete too dense to lose its permeable function, of which 5% is the best. To sum up, the three hypotheses were verified by the method of experimental analysis. The experimental results of adding reinforcer, fine aggregate, water and other materials in C30 permeable concrete mixing meet the strength requirements. Applying the traditional concrete theories to permeable concrete engineering can meet the grading requirements of C30 permeable concrete with different strength.

RESULTS AND DISCUSSION

EXPERIMENTAL RESULTS

In this research, the field test method was used to explore the actual mixing of C30 permeable concrete. The experiments of putting 42.5 cement, SR reinforcer, and aggregate in mixing permeable concrete found that the proportion of aggregate is an important factor affecting the strength performance of permeable concrete. The main results are as follows:

1. Through experiments, it is proposed that within the range of 350-430kg/m3, the strength of permeable concrete can be increased by one level for every increase of 40kg/m of glue, and the permeability and compressive strength can meet the requirements of C30 experiment .
2. On the premise that the workability of the mixture is similar at the initial stage, the more obvious the enhancing effect of the reinforcer on the compressive strength is, the lower the permeability coefficient of the permeable concrete is. The reinforcer promotes the cohesiveness of the fresh permeable concrete, and can ensure the uniformity of the slurry wrapped aggregate. On the other hand, the reinforcing component in the reinforcer promotes the compactness of the slurry, reduces the defects between the aggregates, thus increasing the concrete strength.
3. Along with the increase of sand ratio, the compressive strength of permeable concrete also increases. The presence of fine aggregates increases the number of contact points. At the same time, the thickness of the cement mortar wrapped on the outside is also significantly improved, which increases the cohesiveness between the aggregates and makes the interior denser, greatly increasing the strength of the permeable concrete. Therefore, adding an appropriate amount of fine aggregates is beneficial to the strength of the permeable concrete, but it cannot be increased too much, otherwise, the permeable concrete will become too dense and lose its permeable function.

DISCUSSION

Based on the above-mentioned field test cases, the actual concrete mixing of commercial concrete companies is used for research and discussion. Therefore, it is necessary to design a basic mix proportion hypothesis of C30, and use a certain company's SR reinforcer. See Figures and Table 10 for details.

The experimental steps are that firstly to mix the concrete with the forced mixer in the commercial concrete mixing plant, then load the commercial concrete truck and enter the construction site, and then measure the plumpness of the slurry. The workability of permeable concrete can be determined by squeezing the concrete into a ball by hand. Putting the reinforcer on-site under the premise of maintaining the same amount of the reinforcer in the mix proportion, by controlling the water consumption to make the permeable concrete into a ball, and observe its later compressive strength. See Figures and Table 11.

Experimental summary: Based on the above experiments, under the premise of equal initial workability, the strength of permeable concrete increases day by day when SR reinforcer covering film is put on site. When the amount of glue is more than 350 kg/m3, the strength of permeable concrete can almost meet the requirements of experimental C30, which include the strength grade, the water permeability and compressive strength in 7 days.

Therefore, it can be concluded that both manual mixing of high performance permeable concrete and commercial-concrete-company mixing of permeable concrete can meet the designing mix proportion requirements.

CONCLUSION AND SUGGESTION

CONCLUSIONS

In this study, field test method is used to investigate the mixing of high-performance permeable concrete. In the experiment of mixing permeable concrete with cement, crushed stones and reinforcer, it is found that the ratios of reinforcer and aggregate are important factors affecting the strength performance of permeable concrete whether high-strength manual mixing or commercial concrete is selected. From the statistical analysis results, it is found that different kinds of reinforcers and aggregates can be used to prepare permeable concrete with different properties.

SUGGESTIONS

Finally, due to the limitations of the experimental conditions and the time, there are a lot of valuable research work which cannot be carried out in depth. Therefore, some of the research results need to be further clarified. It is suggested that the following three aspects can be improved in future research:

1. Strengthen the experimental verification. Increase the experimental content and the verification of precision instruments, and put forward higher-performance practical configuration.
2. Select materials form diverse channels. Use river sand, granite waste materials, marble waste materials and construction waste materials for the actual mixing experiments.
3. Time selection for commercial concrete with reinforcer. Test the influence of putting reinforcer and retarder into commercial concrete on construction and structure of permeable concrete.

Fig.1. Automatic batching system

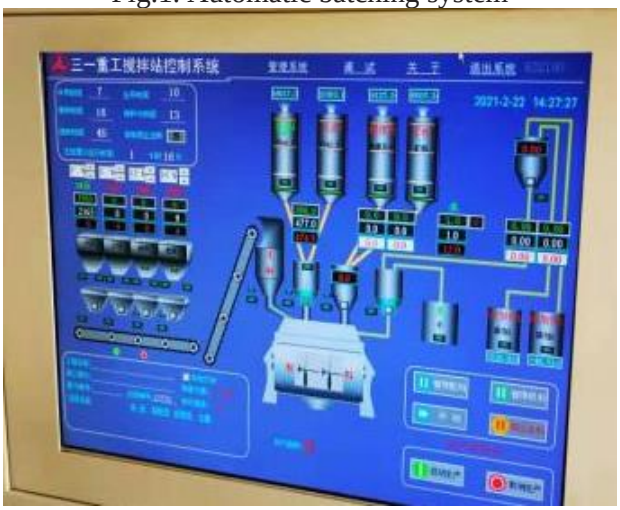

Fig.2. Automatic loading system

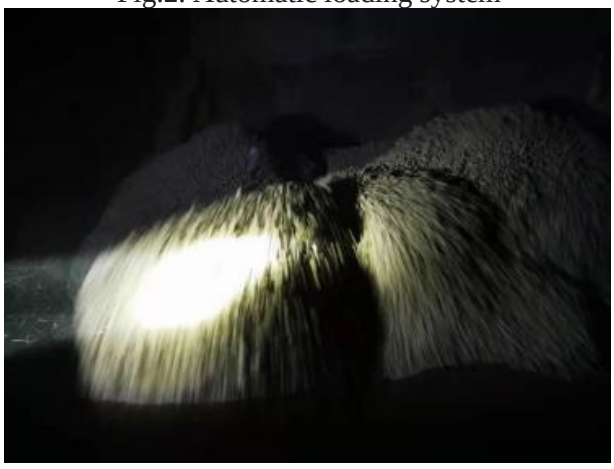

Fig.3. Forced mixer

Fig.4. Destructive use of artificial mixing layer

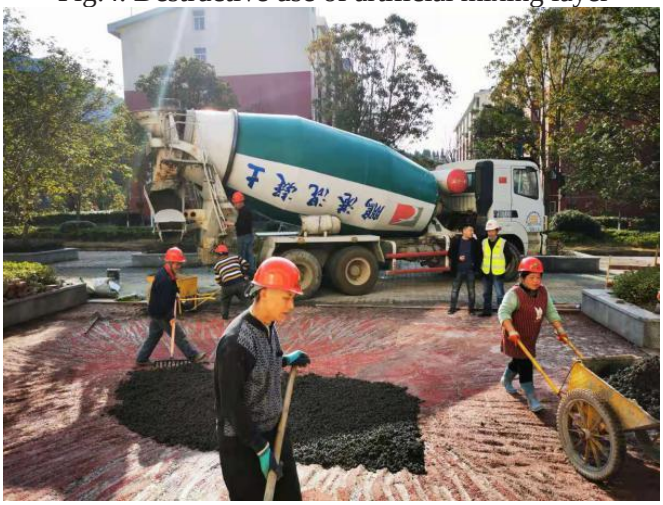

Fig.5. Commercial permeable concrete laying

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APPENDIX

Table 1. Performance index of aggregate

Items	Unit of measurement	Index 1	2	3
Diameter	mm	2.4~4.75	4.75~9.5	9.5~13.2
Crushing value	%	<15.0		
Needle-like particle content (by mass)	%	<15.0		
Mud content (by mass)	%	<1.0		
Apparent density	kg/m³	>2500		
Close stacking density	kg/m³	>1350		
Stacking porosity	%	<47.0		

Table 2. Allowable time control of permeable concrete paving construction

Construction temperature T(℃)	Maximum time allowed (h)
5≤T < 10	2.0
10≤T < 20	1.5
20≤T < 32	1.0

Table 3. Quality control of permeable cement concrete pavement surface

Items	Allowable deviation （mm）		Inspection scope		Inspection points	Inspection method
	Road	Square	Road	Square		
Altitude（mm）	±15	±10	20m	Construction unit①	1	Measure with leveling instrument
Central line deviation （mm）	≤20	—	100m	—	1	Measure with theodolite
Evenness Maximum clearance （mm）	≤5		20m	10m×10m	1	Use 3-meter ruler and feeler gauge to measure two places continuously, and take the maximum value
Width（mm）	0—20		40m	40m②	1	Measure with steel rule
Transverse slope （%）	±0.30% & no reverse slope		20m		1	Measure with leveling instrument
Height difference between shaft frame and pavement （mm）	≤3	≤5	Every shaft		1	Cross method, measuring with ruler and feeler gauge, take the maximum value

Height difference between adjacent slabs（mm）	≤3	20m	10m×10m	1	Measure with ruler and feeler gauge
Straightness of longitudinal seam（mm）	≤10	100m	40m×40m	1	Measure with 20-meter wire and steel ruler
Straightness of transverse seam（mm）	≤10	40m	40m×40m		

Note: In each unit project, the 40m × 40m square grid is numbered as the basic construction unit for measurement and inspection, and the part smaller than 40m × 40m is regarded as a unit. In the basic construction unit, take 10m × 10m or 20m × 20m as the sub unit, and only one sub unit is selected for inspection within each basic construction unit; the inspection method is random sampling, that is, the basic construction unit is determined indoor, the sub unit is determined on site. Totally three points are selected, and the maximum value among the the three is counted as one point in the inspection frequency.

Table 4. Performance and inspection index of permeable cement concrete

Items		Unit of measurement	Requirements of performance	
Wear resistance (length of grinding pit)		mm	≤30	
Permeability coefficient（15℃）		mm/s	≥0.5	
freezing resistance	Compressive strength loss rate after 25 freeze-thaw cycles	%	≤20	
	Mass loss rate after 25 freeze-thaw cycles	%	≤5	
Continuous porosity		%	≥10	
Strength grade		—	C20	C30
Compressive strength（28d）		MPa	≥20.0	≥30.0
Flexural strength（28d）		MPa	≥2.5	≥3.5

Note: The tests of wear resistance and freezing resistance can be carried out according to the specific conditions and design requirements in different places.

Table 5. Mix proportion of C30 permeable concrete

No. of mix proportion	C/（kg.m^-3）	W/（kg.m^-3）	G/（kg.m^-3）	K/（kg.m^-3）	Reinforcer /kg
1	350	104	1800	80	15
2	390	115	1800	80	15
3	430	125	1800	80	15

Table 6. Test results of compressive strength and permeability of permeable concrete

No. of mix proportion	No. of specimens	Description of workability	Water permeability /（mm.s^-1）	7d strength	28dq strength
1	H1	Squeezed into a ball by hand	5.14	17.0	21.2
2	H2	Squeezed into a ball by hand	5.68	23.2	26.4
3	H3	brightening,	3.04	28.3	31.2

			squeezed into a ball by hand			

Table 7. Performance test of different reinforcers

No. of reinforcers	No. of specimens	reinforcer /kg	Description of workability	Water permeability / (mm.s^-1)	7d strength	28d strength
PRC	H4	5	brightening, squeezed into a ball by hand	1.88	25.2	27.4
GZ	H5	5	brightening, squeezed into a ball by hand	1.84	28.2	29.8
ZQ	H6	5	brightening, squeezed into a ball by hand	1.52	27.2	29.9
GX	H7	5	brightening, squeezed into a ball by hand	2.35	24.2	28.6
SR	H8	5	brightening, squeezed into a ball by hand	2.52	29.4	31.4

Table 8. Mix proportion of permeable concrete

No. of mix proportion	C/(kg.m^-3)	W/(kg.m^-3)	G/(kg.m^-3)	K /(kg.m^-3)	Reinforcer /kg
1	430	135	0	1800	0.3
2	430	133	50	1750	0.29
3	430	135	100	1650	0.27

Table 9. Performance test of different sand ratios

No. of sand ratios	No. of specimens	Description of workability	Water permeability /(mm.s^-1)	7d strength	28dq strength
1	H9	squeezed into a ball by hand	6.45	22.3	29.2
2	H10	squeezed into a ball by hand	3.3	26.3	30.3
3	H11	Brightening, squeezed into a ball by hand	2.1	28.8	32.2

Table 10. C30 permeable concrete mix proportion in commercial concrete

No. of mix proportion	C/ (kg.m³)	W/ (kg.m³)	G/ (kg.m³)	K/ (kg.m³)	reinforcer /kg
9	358	135	0	1650	15

Table 11. Test results of compressive strength and permeability of commercial mixed permeable concrete

No. of mix proportion	No. of specimens	Description of workability	Water permeability / (mm.s^-1)	7d strength	28dq strength
1	H12	Brightening and	2.64	29.5	33.5

	squeezed into a ball by hand