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Optimization of Porous Concrete containing Admixtures on Lighten Road

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Abstract. As a new-type material for pavement structure, porous concrete has aroused a broad attention and discussion all around the world on the preparation technology and optimization design. The choice of material ingredient and its proportion of porous concrete have been discussed and corresponding tests had been done. Porous concrete were tested compressive strength and flexural strength by adding two kind different concrete admixtures including ZS-3 and Etonish845. The results indicated gradation and particle size of aggregate and ratio of aggregate to cement are the key factors affecting porosity and compressive strength of porous concrete; concrete admixtures such as ZS-3 and Etonish845 can improve the properties of the porous concrete. Porous concrete is suitable for lighten road in strength and permeable ability.

Introduction

In recent years, «Sponge city construction technical guide» was released by housing construction, which aim was to build a permeable, retaining, aquiferous, purified, useful, drainage city and to make the city collect and reuse the rain like the sponge [1]. With the development of the city, city area is much bigger than old one. However impervious surface coverage rate is more 30% than construction land. Water use is growing but the water repetition rate of our country is only 20%, which is lower 30% than international average value [2]. In addition, the city would be flooded with rain owe to the mistake of urban duct. What's more, the flood with pollutants in the roads would polluted the underground water. It would add the sewage treatment cost and make the social burden heavier [3]. It is necessary to make a kind of concrete which is suitable for lighten roads. The concrete not only relieve the pressure on urban drainage facilities, but also solve a part of environment issues.

This paper seek for mixture ratio of concrete suitable for lighten roads via doing lots of experiments. We explored the influence factors of porous concrete by adding different kinds of admixtures and changing the content of coarse aggregate. The permeable road which made by porous concrete have some functions such as porous, noise reduction, anti-skating, cooling. The road can relieve urban water shortage and heat island phenomena, conserve and protect of water resources.

Materials and Mix Proportion

Materials. Cement: P•O 42.5 cement made in WEIHAI concrete corporation in Taizhou Jiangsu China; Sand: riverine sand, fineness modulus is 2.46, bulk density is 1480kg/m^3, gradation is qualified; Coarse aggregate: made from natural stones, aggregate size range from 5 to 16.5mm; Admixtures: a, ZS-3 made by Jiangsu University suitable for porous concrete road. The admixture is a tan suspensions which pH is 4.5. ZS-3 can promote the hydration reaction of cement, add durability of the concrete and improve the strength of concrete. In addition, ZS-3 can keep the concrete permeability and uniformity and improve the internal and surface acidity, the ability of chemical resistance and biological compatibility, etc. b, Etonish845 made from Germany and it is a white powder. The admixture is similar to ZS-3, but can improve interlocking capability between the coarse aggregates and bond action of the cement paste which can significantly increase the flexural strength of concrete.

Mix Proportion. The mix proportion in the experiment keep the quality of the cement and sand constant. We can achieve the different mix proportion by changing water and admixture. The dosage of admixture is based on the percentage of the cement quality.

Table 1. Mix proportion of porous concrete.

W/C	Cement/kg/ m^3	Sand/ kg/ m^3	coarse aggregate/ kg/ m^3	Water/L	ZS-3/%	Etonish845/%
				65	4	0
0.3	250	100	1420	60	4	2
				55	4	4
				70	4	0
0.32	250	100	1420	65	4	2
				60	4	4
				75	0	4
0.34	250	100	1415	70	2	4
				65	4	4
				80	0	4
0.36	250	100	1415	75	2	4
				70	4	4

Experiments

Method. According to the design of the mix proportion above. It is necessary to make some steps to make the concrete. Step 1: Before the coarse aggregate, cement and sands in need were put into the blender, the blender stirred 25s with nothing. Step 2: Pour half the water into the blender and keep the blender stir 60s. Step 3: The rest water and admixture were poured into the blender during the blender stir about 180s. Step 4: Spade the concrete into the mold with 3 layers. Each layer was needed to insert 11times lightly. After the mold was vibrated 3 times, knock the surface of the concrete with mallet. Step 5: Wipe the cement paste which W/C is 0.35 on the top of the concrete. Step 6: Remove the mold from the concrete in the after of the concrete were conserved in the standard curing room.

Compressive Strength. The method of measurement refer to the GB50081-2002 «Ordinary concrete mechanics performance test method standard», the size of the concrete is 150×150×150mm, concrete age is 7d and 28d. The compressive strength can be achieved by the below equation:

$$R = \frac{P}{A} \tag{1}$$

where, P is the pressure lead to the damage of the concrete (N); A is compression area of the concrete (mm^2); R is the compressive strength of the concrete.

Flexural Strength. The method of measurement refer to the GB50081-2002 «Ordinary concrete mechanics performance test method standard», the size of the concrete is 100×100×400mm, concrete age is 7d and 28d. The flexural strength can be achieved by the below equation:

$$f_f = \frac{Pl}{bh^2} \tag{2}$$

where, f_f is the flexural strength of the concrete (MPa); f is failure load (N); l is the span of the shifting bearing (cm); b is the breadth of section (mm); h is the depth of section (mm).

Porosity. The concrete is the porous concrete, so porosity is a remarkable character. The concrete should have been soaked about 24h in the water when the porosity of the concrete was measured, the porosity can be achieved by the below equation:

$$\rho_1 = 1 - \frac{(m_3 - m_1)\rho_W}{V} \times 100\% \quad (3)$$

$$\rho_2 = 1 - \frac{(m_2 - m_1)\rho_W}{V} \times 100\% \quad (4)$$

where, p_1 is the full porosity of the porous concrete; p_2 is the opening porosity of the porous concrete; m_1 is the mass of the dry porous concrete; m_2 is the mass of the wet porous concrete; m_3 is the mass of the porous concrete in the condition of the $20^oC \pm 2^oC$ and relative humidity is 60% ; p_w is density of the water(g/cm^3); V is the volume of the concrete sample (cm^3) [4].

Permeation Coefficient. According to the Sidney Mindness, cylindrical samples that diameter is 100mm and the height is 200mm were prepared in the experiment [5]. Permeation coefficient can be achieved by Darcy Law. In the experiment, every 3 sample needed to be measured 3 times and the results should be calculated to get the mean value. To make sure the water permeated the circular section of the sample, the sides of the samples is full of the wax in case of water permeating from the side. In this way, the permeation coefficient can be measured accurately.

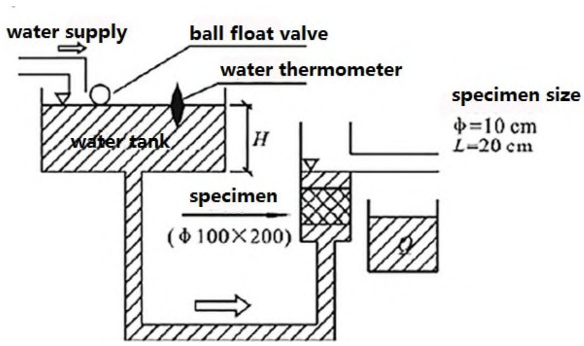

Fig. 1 Water permeability set- up for porous concrete.

The regulation of the permeation coefficient can be seen from the experiment. The permeation coefficient is in direct proportion to the height of the sample, but is inversely proportional to the cross sectional area. The permeation coefficient can be achieved by the below equation:

$$K_T = \frac{HQ}{hA\Delta t} \times \frac{\eta_T}{\eta_{15^oC}} \quad (5)$$

where, K_T is the constant head permeation coefficient when the temperature is T°C, cm/s; h is the constant head of the top of the sample, cm; Q is the water yield though the sample in the limit time,cm^3; A is the cross sectional area of the sample, cm^2; Δt is the test time, s; η_T/η_{15^oC} is the relative viscosity when the temperature of the water is T°C and 15°C.

Table 2. The viscosity ratio of Water at T°C and 15°C [5].

T°C	0	1	2	3	4	5	6	7	8	9
0	1.575	1.521	1.470	1.424	1.378	1.336	1.295	1.225	1.217	1.182
10	1.149	1.116	1.085	1.055	1.027	1.000	0.975	0.950	0.925	0.902
20	0.880	0.859	0.839	0.819	0.800	0.782	0.764	0.748	0.731	0.718
30	0.700	0.685	0.671	0.657	0.654	0.632	0.620	0.607	0.596	0.584
40	0.574	0.564	0.554	0.544	0.535	0.525	0.517	0.507	0.498	0.490

Results

The Impact of the W/C on Porous Concrete Performance. The impacts of the W/C on porous concrete performance are presented in Table 3. The compressive strength decreased after increased with the increased of the water cement ratio (W/C). When the W/C is 0.32 and the content of the ZS-3 is 6%, the compressive strength increased up to the peak value. The compressive strength of porous concrete including interlocking between the coarse aggregate and the sticky effect of the cement mortar [6]. The main reason that the compressive strength was not up to peak value when W/C is 0.30 is water is not enough. The workability of the cement mortar is low and the thickness of the harden cement layer is thin are the reasons of the cement mortar can't wrap the coarse aggregate. In the same time, the porous concrete is hard concrete which W/C is low. That can make it difficult stir the concrete and make amount of coarse aggregate that carrying more cement mortar sink in the bottom of the mold. As a result, the compressive strength of the concrete's bottom is high, and the top is low. Thus, the compressive strength is not up to the peak value. When the W/C is 0.32, the cement mortar of the workability is enough and can wrap the coarse aggregate. The spot bond would change into surface bond. That would enhanced the density and compressive strength to the peak. However, the harden cement mortar layer would thicker with the W/C is higher. Through keep the sticky effect of the cement mortar, the interlocking between the coarse aggregate would decreased. In this condition, the whole structure would form suspend dense structure and the compressive strength of the concrete would decreased.

Table 3. Effect of ratio water to cement on properties of porous concrete.

No.	W/C	ZS-3 /%	Compression area A / m²	7d Press P/KN	7d Strength N/ MPa	28d Press P/KN	28d Strength N/ MPa	Porosity ρ_2 /%	Permeation coefficient cm/s
P1		2		491	21.8	529	23.5	12.9	0.098
P2	0.30	4		520	23.1	576	25.6	14.2	0.165
P3		6		561	24.9	596	26.5	13.2	0.111
P4		2		526.5	23.4	596	26.5	10.8	0.038
P5	0.32	4		538	23.9	606	26.9	11.1	0.044
P6		6	$2.25\times$	574	25.5	648	28.8	11.0	0.042
P7		2	10^{-2}	488	21.7	504	22.4	10.1	0.026
P8	0.34	4		511	22.7	536	23.8	10.4	0.031
P9		6		554	24.6	596	26.5	10.0	0.025
P10		2		466	20.7	495	22.0	9.1	0.015
P11	0.36	4		497	22.1	533	23.7	10.2	0.028
P12		6		534	23.7	576	25.6	9.6	0.020

In the conclusion, the porosity of the concrete would decreased after increased with the increase of the water cement ratio (W/C). The workability of the cement mortar would be better when W/C increase. In this case, some voids would be blocked and make the porosity decrease when the compressive strength increase. However, when the W/C is keep increasing, the cement mortar which make concrete lost the ability of permeation and it would block the voids of the structure. As a result, the compressive strength and porosity are opposite relation. It is the key to keeping the balance of the compressive strength and porosity.

The Impact of the Admixture on Porous Concrete Performance. The physical and mechanical properties can be seen in Table 3 is optimum when W/C is 0.32. The chapter studied on the effect of the admixtures on the properties of porous concrete in the condition of the W/C is 0.32 and the size of coarse aggregate is 5~16.5mm.

The Table 4 shows that the physical and mechanical properties is optimum in the case of adding 4%ZS-3 and 2% Etonish845. Under this circumstance, the compressive strength and flexural strength reach to 25.1MPa and 4.0MPa, the porosity reach to 12.4%.The flexural strength of the ordinary concrete that suitable for lighten road is up to 4MPa according to «Design Code of Highway Cement Concrete Pavement» [7]. Therefore, not only the flexural strength requested meet, but also the porosity need to be adjusted to permeate.

Table 4. Effect of ZS-3 and Etonish845 on properties of porous concrete.

No.	ZS-3%	Etonish845%	28dCompressive Strength N/MPa	28dFlexural Strength N/ MPa	Porosity/ ρ_2	Permeation coefficientcm/s
P13	0.0	0.0	16.3	1.27	12.1	0.070
P14	0.0	2.0	16.8	1.96	11.8	0.061
P15	4.0	1.5	23.4	3.50	11.9	0.064
P16	4.0	2.0	25.1	4.00	12.4	0.079
P17	4.0	0.0	25.0	3.60	11.1	0.044

The Table 4 proves that compared with the compressive strength and the flexural strength of concrete without admixture, the concrete's properties which adding Etonish845 didn't enhanced. However, the compressive strength and flexural strength of the concrete increased a lot when adding ZS-3 and Etonish845. The conclusion can be drawn that ZS-3 is the key to enhancing the compressive strength and the flexural strength of concrete. The flexural strength is up to 3.60MPa when added ZS-3 alone is lower than the flexural strength of the concrete which adding two admixtures. What's more, compare to the P13 and P14, the impact of Etonish845 on the compressive strength of the concrete is low, but on the flexural strength is high. We can draw a conclusion that the ability of the Etonish845 is mainly enhance the flexural strength. The Etonish845 is a powdery and its specific surface area is large. The Etonish845 can improve the workability of the cement mortar thus increasing the bonding points between the aggregates to enhance the flexural strength. At the same time, Etonish845 improve the strength of the cement mortar accordingly increase the compressive strength to some extent.

The Impact of the Aggregate Size on Porous Concrete Performance. The Table 5 shows that the impacts of the different aggregate size on concrete performance in the case of the W/C is 0.32, adding 4%ZS-3 and 2% Etonish845. We can see from the Tab.5 below, the porosity increase then decrease and the compressive strength and flexural strength decreased then increased in the condition of aggregates which size range from 5 to 10mm increased and aggregates which size range from 10 to 16.5mm decreased. Among them, specimen P21 has the maximum of the compressive strength and flexural strength and the minimal of the porosity.

When the size of the whole coarse aggregates are 5~10mm, the porosity is large. The strength is low due to without the large size coarse aggregates. In this time, the structure belong to the skeleton-pore structure. The strength would be high when the double sizes of the coarse aggregates were added so as to the small size coarse aggregates can be filled of the larger coarse aggregates. The compressive strength and flexural strength are the maximum when the content of the coarse aggregate that size is 5~10mm is 60% and the others which size is 10~16.5mm is 40%.In this condition, the structure is a framework dense structure. The bonding spots would decrease with the increase of the larger coarse aggregates. This is a conclusion can be drawn that the porosity will be high and the strength will be low with the content of the larger coarse aggregate increasing.

Table 5. Effect of particle diameter of aggregates on properties of porous concrete.

No.	5-10mm (%)	10-16.5mm (%)	28d Compressive Strength N/MPa	28d Flexural Strength N/ MPa	Porosity ρ_2 %	Permeation coefficient cm/s
P19	100%	0	18.8	1.88	13.5	0.126
P20	80	20	25.2	3.6	9.6	0.020
P21	60	40	25.3	4.1	9.5	0.019
P22	40	60	19.7	3.5	14.4	0.178
P23	20	80	18.1	3	16.1	0.325
P24	0	100	16.9	2.01	16.8	0.409

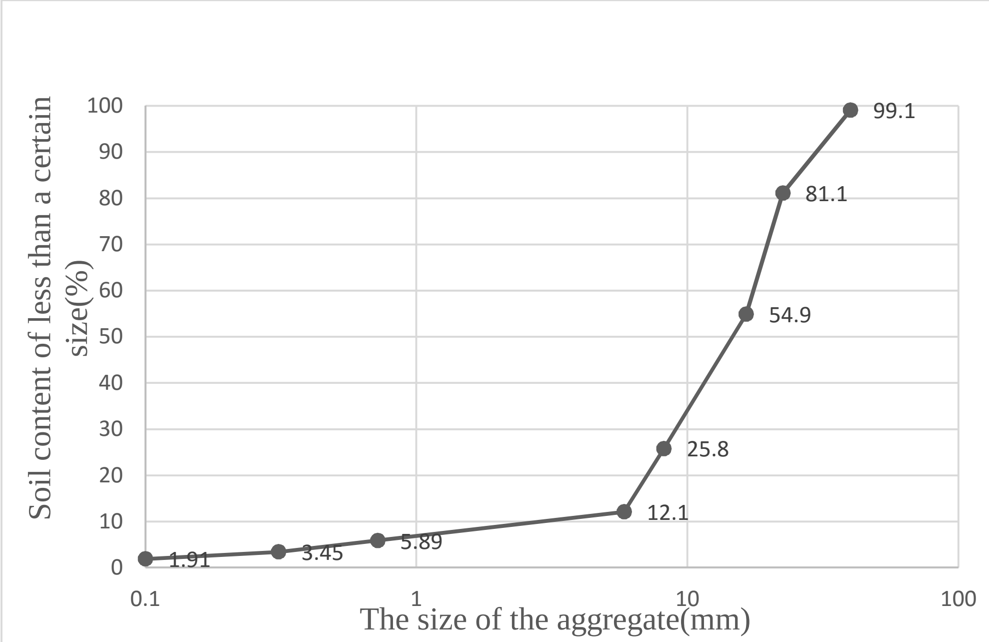

Fig. 2 Aggregate size distribution of Porous Concrete.

The grading curve of coarse aggregate can be seen in Fig. 3, d_{60}=11.5mm, d_{30}=8.8mm, d_{10}=2.5mm. K_u=d_{60}/d_{10}=4.6, K_c=$d_{30}^2/d_{10}\,d_{60}$=2.7. K_u is calculated less than 5 meaning the diameter of the aggregate is relatively uniform. In other words, the aggregates had a bad gradation. In the preparation of the porous concrete, similar size coarse aggregate should be used to form a skeleton structure to be benefit to permeate. According to Fig. 2, the size of the coarse aggregate used is 5~16.5mm. Once the larger aggregate is overmuch, the bonding spot would too little. The interlock of the aggregate is low may lead to the mechanical property poor and not suitable for porous concrete road. In the other side, the porosity would be low and hinder the permeation coefficient of the concrete when the smaller aggregate is overmuch. This experiment proved that the porosity and strength of the concrete were guaranteed when the size of the coarse aggregate is 5~16.5mm.

The Impact of the Cement Mortar Thickness on Porous Concrete Performance. The thickness of the cement mortar is affected by amount of factors such as viscosity of cement mortar, content of cement mortar and aggregate grading etc. According to pertinent literature, water reducing agent as a surfactant can reduce the surfactivity of the cement to lower apparent viscosity of the concrete [8]. The water reducing agent is the major material in admixtures of this paper. Therefore the viscosity of the paste would decreased to enhance the workability of the cement mortar. It is benefit to form cement mortar layer. In the chapter above, when the content of coarse aggregate which size is 5~10mm is 60% and which size is 10~16.5mm is 40%, the strength of the concrete is the peak value. The chapter in consequence seek the impact of the cement mortar thickness on porous concrete performance by controlling the content of the paste.

Table 6. Effect of cement mortar thickness on properties of porous concrete.

No.	W/C	Cement/ kg/m^3	Thickness (mm)	28d Compressive Strength N/ MPa	28d Flexural Strength N/ MPa	Porosity ρ_2 %	Permeation coefficient cm/s
P25	0.32	250	1.51	25.3	4.1	9.5	0.019
P26		300	1.77	26.1	4.2	8.8	0.012
P27		350	2.03	23.5	3.7	8.2	0.009
P28		400	2.67	19.2	3.1	7.5	0.005

According to the Table 6, the cement mortar will be thicken with the increase of the cement dosage in the condition of the W/C is constant. The compressive strength and the flexural strength would reach to the peak value when the content of the cement is 300kg/m^3. Once the content is over 300kg/m^3, the strength will decreased. As far as am concerned, the whole coarse aggregates were wrapped by cement mortar when content of the cement is 250kg/m^3. The paste can provide the interlocking and the cohesive action of the paste but the whole ability of the paste didn't released due to the thickness (1mm) of the cement mortar is not enough. This is the reason why the strength of the concrete is not up to peak value. When the content of the cement is 300kg/m^3, the thickness of the cement mortar is 2~3mm and the cohesive action is all released. In this time, the strength of the concrete increased to the maximum and the porosity and permeation coefficient were satisfy the related standard. When the content of the cement is overused, the coarse aggregates were exist in suspended state and the structure is suspended framework dense structure. The structure would lost the ability of permeate. What's more, the mechanical property would lower with the decrease of the interlocking of the aggregates.

Conclusions

(1) The grading of the porous concrete with ZS-3 and Etonish845 is: Cement: Sand: Aggregate: Water=250kg: 100kg: 1420kg: 65kg. After the experiments and analyze, the grading is suitable for lighten road such as parking, open deck and the sidewalk etc.

(2) The W/C affect the strength of the porous concrete. The compressive strength would reach to the maximum when the W/C is 0.32. The strength would decrease when W/C is over 0.32. The porosity will lessen with the increase of the W/C.

(3) The ZS-3 and Etonish845 are all improve the compressive strength and the flexural strength of the porous concrete. The physical and mechanical properties is optimum when adding 4%ZS-3 and 2% Etonish845 and its compressive strength is 25.1MPa and the flexural strength is 4.0MPa, the porosity is 12.4%.

(4) The size of the coarse aggregate affect the strength of the porous concrete. The strength would increase then decrease and the porosity would decrease then increase with the increase of the large size aggregate and decrease of the small size aggregate. In condition of the lighten road, P21 is suggested that is the content of the size is 5~10mm is 60% and the others which size is 10~16.5mm is 40%

(5) The thickness of the cement mortar has an impact on the mechanical property of the porous concrete. In addition, viscosity of cement mortar, content of cement mortar and aggregate grading are also the factors. The decrease of the viscosity of cement mortar is benefit to the increase of the thickness to improve the mechanical property. The compressive strength and the flexural strength would increase in some extent with the adding the cement when keeping the W/C is constant. However, the strength would lower due to the decrease of the interlocking when cement is overused.

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References

[1] M. Ju. The thinking about the concept, technical and policy of the sponge concept, World Water Day - Chinese water column, 3 (2015) 7-10.

[2] Z. Zhen, C. He. Urban water management, Beijing: China Water Power Press, (2003), pp. 5.

[3] J. Ma. Study on Integrated design of surface drainage and rainwater storage for environment-friendly city, Zhejiang: Zhejiang University of Technology, 2011.

[4] Z. Jiang, Z. Sun, P. Wang. Effects of Some Factors on Properties of Porous Pervious Concrete, J. Build. Mater. 8(5) (2005) 513-519.

[5] S. Mindess, J. Francis Young, D. Darwin. Concrete, Prentice Hall, 2002.

[6] Y. Sheng. Study on Mix Design of Semi-rigid Base for Concrete Pavement based on Anti-erosion Performance, Xian: Chang'an University, 2010.

[7] Technical specification for construction of highway cement concrete pavements, 1 (2014) 10.

[8] J. Bu, C. Fu. The effect of water reducing agent on fresh concrete apparent viscosity, Hebei Inst. Tech. 1 (2001) 65-68.