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Effect of Different Admixtures on Pore Characteristics, Permeability, Strength, and Anti-Stripping Property of Porous Concrete

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Abstract: To solve the problem of insufficient strength and durability of porous concrete pavement, seven different admixtures were used in this study so that the above properties could be optimized. The strengthening effect of admixtures on the strength and anti-stripping property of porous concrete was evaluated. The effects of different admixtures on the pore characteristics, strength, and anti-stripping of porous concrete were analyzed with CT tomography technology. The relationship between the pore characteristics of porous concrete and its strength, the anti-stripping property, was explored separately, and the correlation between the strength and anti-stripping property was also investigated. The addition of admixtures affected the pore characteristics of porous concrete, and there was no significant correlation between them. The strength of porous concrete was improved by the addition of admixtures, but the addition of different admixtures had different effects on the improvement of strength. Meanwhile, there was no significant correlation between the strength and pore characteristics. Adding admixtures could improve the anti-stripping property of porous concrete, however, different admixtures had different improvement effects. The effect of porosity on anti-stripping property was limited, while the pore number and equivalent aperture had no effect. There was no obvious correlation between the strength and anti-stripping property of porous concrete prepared with different admixtures.

Keywords: porous concrete; pore characteristics; permeability; strength; anti-stripping property

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1. Introduction

As a kind of functional ecological material, porous concrete has good properties of permeability, improving water quality, recharging the groundwater, reducing pavement-tire acoustic noise, and mitigating the urban heat island effect [1–8]. Due to the above excellent ecological properties, porous concrete has been widely used in urban squares, ecological trails, road shoulders, pathways, parking areas, expressway service area, and other areas [9–13]. The large-scale use of porous concrete has been proven to bring good ecological, social, and economic benefits [8]. The good ecological performance of porous concrete was based on its large number of voids inside. However, the strength and durability of porous concrete are also seriously reduced by these voids [8,14,15].

The environmental properties, mechanical properties, durability properties, and internal pore characteristics of porous concrete are largely determined by the factors of aggregate gradation, aggregate type, admixtures, water to cement ratio, cement to aggregate ratio, mixing, forming, and curing method [1,9,14–17].

As one of the important ecological properties, the permeability of porous concrete is usually measured by the falling-head test method and constant-head test method [1,8,9,16]. Although the test methods and devices of permeability adopted by different scholars in the previous studies may be different, it has been demonstrated that when the other conditions were the same, the permeability of porous concrete was increased with the increase of porosity and aggregate particle size, and decreased with the increase of specimen thickness [16]. Zhang used the two methods to test the permeability of porous concrete with different mix ratios. It was found that the permeability obtained by the falling-head method was much larger than that obtained by the constant-head method. Nevertheless, there was a good positive correlation between the permeability obtained by the two methods and the porosity [1,16].

For the optimization and improvement of the mechanical properties of porous concrete, methods such as reducing the porosity, using high-quality aggregate and high-grade cement, optimizing the mixing ratio, and adding admixtures, were often used [3,9,13–17]. However, reducing the porosity will affect the ecological property of porous concrete, and with the improvement of environmental protection requirements, the cost of high-quality aggregate has risen sharply [16]. Besides, the use of high-grade cement will also increase the construction cost [15,16]. In addition, after the mix proportion optimization, the addition of appropriate admixtures has become an effective method to significantly improve the mechanical properties of porous concrete without significantly reducing the porosity [3,14,15]. Zhang divided the commonly used admixtures of porous concrete into four categories: inorganic admixtures, polymer admixtures, fiber admixtures, and nano admixtures; the influence mechanism and ruler of different admixtures on the strength of porous concrete were combined [16]. Previous studies have found that the addition methods of admixtures in porous concrete mainly include a single admixture or a simple combination of two admixtures, and the studies on the composite addition of multiple admixtures in porous concrete were not in-depth [3,14,15,18].

For the evaluation of the durability of porous concrete, the freeze-thaw cycle performance of its materials was mostly used [16,18–24]. The relative value of the dynamic elastic modulus, mass loss rate, and strength loss rate of porous concrete after the fixed freeze-thaw cycles was taken as the evaluation indexes of its freeze-thaw cycle property [16,25,26]. However, some scholars pointed out that the relative dynamic elastic modulus and mass loss rate were not applicable in the evaluation of frost resistance of porous concrete [16]. The stripping of surface particles of porous concrete pavement materials under tire friction and impact can also be considered as insufficient durability. The research on the anti-stripping property of porous concrete was still insufficient [15,16]. As one of the essential diseases of porous concrete, surface looseness, threshing, and pit not only affect its appearance, but also significantly reduce its operation life [15]. Some scholars have tested the anti-stripping property of porous concrete regarding to the Cantabro scattering test method for asphalt concrete to evaluate its durability, and it was found that the Cantabro scattering test method was also feasible in porous concrete [15,18,19].

The internal pore characteristics of porous concrete was generally considered to affect its ecological properties, mechanical properties, and durability [15,16,27–40]. There are two main ways to obtain the internal pore characteristics of porous concrete at present: the slice method and the industrial CT scan [16]. Two-dimensional cross-sectional images of porous concrete were obtained by the two methods, and then the different pore characteristics were obtained through image processing and analysis [15,16]. The pore characteristics of porous concrete can be divided into two-dimensional (2D) and three-dimensional (3D) pore characteristics [16]. The 2D pore characteristics include porosity, pore number, pore area, equivalent aperture, and fractal dimension [28–31]. The 3D pore characteristics include connected porosity, pore size distribution, pore connectivity, pore tortuosity, pore throat, and pore topological structure [15,30–32]. It was found that the aggregate gradation had the most significant influence on the pore characteristics of porous concrete [29]. With the aggregate gradation changing from coarse to fine, the porosity, equivalent aperture, and pore connectivity presented an increasing trend, but the uniformity of pore distribution became worse [29]. Besides, the larger the volume ratio of aggregate in porous concrete, the larger the porosity, the connected porosity, and the dispersion of pore distribution inside [27,34]. The studies on the correlation between the pore characteristics and properties of porous concrete mainly focus on the influence of pore characteristics on its permeability, compressive strength, and freeze-thaw cycle property. The results presented that the different pore characteristics had different effects on its different properties [32–40].

From the above, the current studies of porous concrete focus on the effect of the mix ratio and single admixtures added to its ecological properties, mechanical properties, durability properties, and pore characteristics. However, the studies only paid attention to the significant improvement effects of multi admixtures compound on the strength, but the attention of anti-stripping property was insufficient. In addition, there was no adequate understanding on whether the compound addition of multiple admixtures have a great impact on the internal pore characteristics of porous concrete and affect its permeability under the same grading conditions or not. Therefore, it is very necessary to study the effect of compound admixtures on the pore characteristics, strength, and anti-stripping property of porous concretes, which were prepared with the same aggregate gradation.

The objective of this study is to analyze the influence of compound admixture of various admixtures on 2D pore characteristics, strength, and anti-stripping property of porous concrete. The pore characteristics of porous concrete were obtained by industrial CT equipment in the laboratory of school of transportation at Tongji University, Shanghai, China (the scanning internal is 0.2 mm, and the resolution of CT scanning is 1200 dpi × 1200 dpi) and Image J software (Image Processing and Analysis in Java, developed by the National Institutes of Health, Maryland, American). The porosity of porous concrete obtained by different methods was compared. Besides, the correlations between pore characteristics and permeability, strength, and anti-stripping property were analyzed. In addition, the relationship between the strength and anti-stripping property of porous concrete was investigated.

2. Materials and Methodology

2.1. Materials

Basalts aggregates with particles sizes of 2.36~4.75 mm and 4.75~9.5 mm were selected as the coarse aggregate to produce pervious concrete in this study, and the physical properties were shown in Table 1. The 42.5 Ordinary Portland was selected as the main binder materials, and the main chemical compositions is shown in Table 2. Tap water from the laboratory was used to prepare the pervious concrete specimens. Superplasticizer (SP), silica fume (SF), micro-silica (MS), slag (SL), nano-silica (NS), graphene oxide (GO), and carbon nanotube (CNT) were selected as the admixtures added in porous concrete to improve the property (as shown in Figure 1).

Table 1. Partial physical properties of the basalt.

Aggregate	Size mm	Density g/cm^3	Bulk Density g/cm^3	Porosity %	Crushing Value %	Content of Flat and Elongated Particles %
Basalt	2.36~4.75	2.889	1.666	42.3	20.20	-
	4.75~9.5	2.906	1.699	41.5	11.55	6.54

Table 2. Main chemical composition of cement (W/%).

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
P.O 42.5	21.60	2.35	0.20	63.0	2.0	2.80	4.0

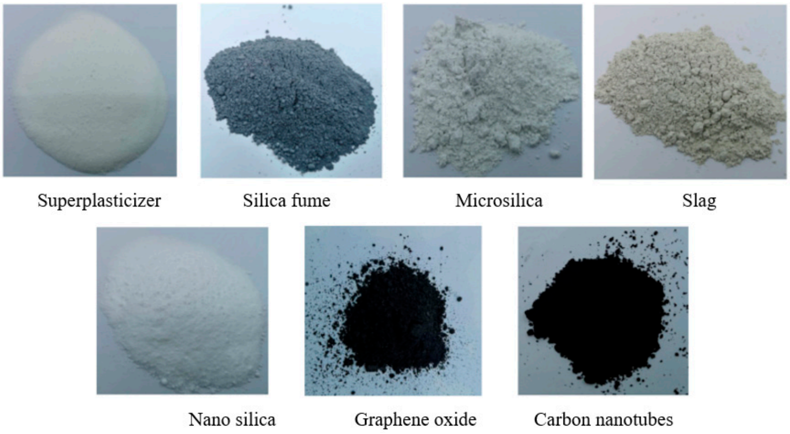

Figure 1. Appearance of the admixtures.

2.2. Mix Proportion

The porous concrete mixture was prepared with basalt aggregate, P.O 42.5 cement, different admixtures, and water. The mix proportion scheme of porous concrete is shown in Table 3, including one control group, seven groups of single admixture added, five groups of double admixture added, and two groups of triple admixture added. Due to the few samples of double and triple admixtures of porous concrete, they were collectively called porous concrete with composite admixtures in this paper.

Table 3. Mix proportion of porous concrete.

Mixture Type	Aggregate Size (mm)		Per m^3 of Porous Concrete (kg/m^3)								
	2.36~4.75	4.75~9.5	Cement	Water	SP	SF	MS	SL	NS	GO	CNT
ND			440	132.1							
SP			472	99.1	0.944						
SF			414	132.1		26.4					
MS			418	132.1			22				
SL			352	132.1				88			
NS			436	132.1					4.4		
GO			440	132.1						0.044	
CNT	164	1529	440	132.1							0.22
SP + SL			352	92.4	0.944			88			
SP + GO			472	99.1	0.944					0.044	
SF + MS			392	132.1		26.4	22				
SF + SL			326	132.1		26.4		88			
SF + NS			411	132.1		26.4			2.2		
SP + SL20% + GO0.0075%			352	92.4	0.944			88		0.033	
SP + SL25% + GO0.01%			330	92.4	0.944			110		0.055	

2.3. Specimen Preparation

The porous concrete specimens were prepared by the China Standard CJJ/T 135-2009 Technical Specification for Pervious Cement Concrete Pavement at the laboratory [26]. The cylinder porous concrete specimen with a diameter of 100 mm and height of 50 mm was prepared to test the porosity, pore characteristics, permeability, and anti-stripping performance. The cube specimen with a size of 100 mm × 100 mm × 100 mm was prepared for the compressive strength test, and the cuboid specimen with a size of 100 mm × 100 mm × 400 mm was prepared to test the flexural strength. Besides, in order to make the test results more reliable, five replicate specimens were prepared for each test groups to obtain the reliable mean values.

2.4. Porosity

The porosity of porous concrete was tested by the underwater gravity method. The cylinder specimens should be immersed in water that exceeds 24 h to make the specimen saturated before being measured. After throwing out the flowing water and wiping the surface of the specimen with a wet towel, we weighed the specimen in the air immediately. We then put the specimen into the drainage bucket, and recorded the weight in the water when the weight of the hydrostatic balance was stable. The porosity of porous concrete could be calculated by the two different weights of the specimens in air and water, as in the following Equation (1) [41]:

$$p = \left[1 - \left(\frac{(m_1 - m_2)/\rho_w}{v}\right)\right] \times 100\%, \tag{1}$$

where p is the porosity of porous concrete; m_1 is the weight of porous concrete in the air, g; m_2 is the weight of porous concrete in the water, g; ρ_w is the density of water, g/cm^3; v is the volume of porous concrete, cm^3.

2.5. Pore Characteristics

The internal pore characteristics of porous concrete were obtained by industrial CT scanning at School of Transportation Engineering of Tongji University. Image J software was used to analyze the two-dimensional image to obtain the 2D pore characteristics such as porosity, pore number, and equivalent aperture. The mean value of 11 sections with an interval of 4 mm from top to the bottom (from 0.5 cm to 4.5 cm on the upper forming surface) was regarded as the pore characteristics value of the specimen. Part of the image processing process was shown in Figure 2.

(a) Original scanned picture (b) Black and white binary picture (c) Pore marking picture

Figure 2. Pore characteristics treatment of porous concrete.

2.6. Permeability

The permeability of porous concrete was tested using the falling-head method. The test device is shown in Figure 3, and the permeability of porous concrete could be calculated by the following Equation (2) [1]:

$$k = \frac{\alpha l}{At} ln(h_1 - h_2), \tag{2}$$

where k is the permeability of porous concrete, cm/s; α is the inside cross-sectional area of water cylinder, cm^2; A is the cross-sectional area of the specimen, cm^2; l is the thickness of porous concrete, which was taken as 5 cm in this study; t is the time displayed by the stopwatch when the water level dropped from the upper recorder level to the lower water, s; h_1 is the upper water level which taken as 15 cm in this study; h_2 is the upper water level, which taken as 0 cm.

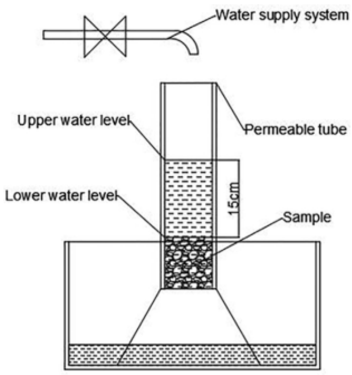

Figure 3. Falling-head permeability test device [1].

2.7. Strength

The compressive strength and flexural strength of porous concrete were tested according to the China standard Testing Methods of Cement and Concrete for Highway Engineering (JTG 3420-2020) [42]. Besides, the specimens used for testing were a non-standard size sample, therefore the test results of strength should be converted to the strength of standard size specimens through the size conversion coefficient. The compressive strength and flexural strength of porous concrete could be calculated by the following Equations (3) and (4) [42], respectively:

$$f_c = \frac{F_C}{A}, \tag{3}$$

where f_c is the compressive strength of porous concrete at 28d, MPa; F_C is the failure load of the porous concrete sample under press, N; A is the cross-sectional area of the sample, mm^2.

$$f_f = \frac{F_f L}{bh^2}, \tag{4}$$

where f_f is the flexural strength of porous concrete at 28d, MPa; F_f is the ultimate load of porous concrete sample, N; L is distance between the supports, mm; b and h is the width and height of porous concrete specimen respectively, mm.

2.8. Anti-Stripping Performance

The Cantabro Scattering Test method was chosen to evaluate the anti-stripping property of porous concrete in this research (as shown in Figure 4). The test was carried out according to China standard "Standard Test Methods of Bitumen and Bituminous Mixture for Highway Engineering" (JTG E20-2011) [43], but the partial adjustment was made according to the characteristics of porous concrete. The standard Marshall specimen was changed into a cylindrical specimen with a diameter of 100 mm and a height of 50 mm, and it was also not treated with a constant temperature water bath. The stripping mass loss rate could be calculated by the following Equation (5) [43]:

$$m_l = \frac{m_3 - m_4}{m_3} \times 100\%, \tag{5}$$

where m_l is the stripping mass loss rate of porous concrete; m_3 is the mass of porous concrete sample before stripping, g; m_4 is the mass of porous concrete sample after 300 times stripping, g.

Figure 4. Los Angeles Abrasion Tester and the morphology of porous concrete before and after scatter.

3. Results and Discussion

3.1. Porosity

The porosity of porous concrete could be obtained by two methods as mentioned previously. The first method was the underwater gravity method (M1), and the second method was the CT image processing (M2). The comparison of porosity obtained by two methods of porous concrete is shown in Figure 5. It could be seen from Figure 5 that:

(1) When the aggregate gradation and aggregate to binder ration of porous concrete were the same, the porosity of porous concrete with different admixtures added was significantly different. The difference in the porosity of porous concrete with different admixtures was within 4%, and the porosity of the porous concrete containing superplasticizer in the admixture component was obviously large. This results can be considered for the following reasons: (a) The water consumption of porous concrete, which used superplasticizer, was decreased, and the density of cement or other admixtures replacing the same mass of water was significantly higher than that of water; therefore, the volume of cement paste and the gap between aggregates that could be filled by it was significantly reduced, resulting in the large porosity of porous concrete. (b) The density of different admixtures was different (compared with cement, the density was relatively low). When using equal quality admixtures to replace cement, the volume of cement paste of admixtures with a larger amount was larger than that of the control group, and it could fill more gaps between the aggregates, therefore, the porosity of porous concrete was reduced. (c) Different admixtures had different particle sizes. Some admixtures with relative smaller particle sizes could enter the voids between cement particles during mixing, which could also affect the volume of cement paste and the porosity of porous concrete. (d) The forming and porosity testing process of porous concrete could also affect its porosity;

(2) The porosity obtained by the two methods was relatively closed. It showed that it was feasible to test the porosity by the two methods. Besides, the porosity obtained by the CT image processing method was slightly higher (within 0.5%) than the underwater gravity method. It was mainly related to the fact that the porosity obtained by the underwater gravity method did not contain closed pores.

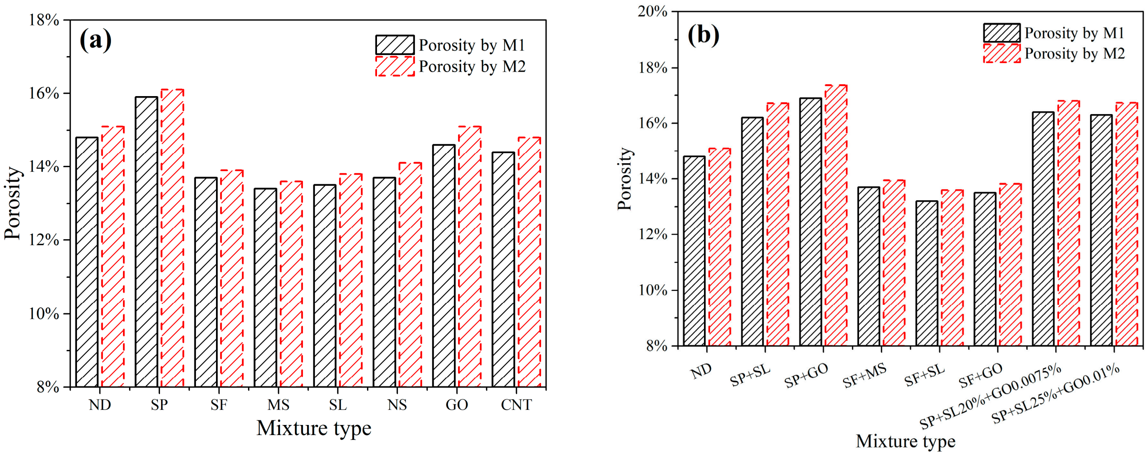

Figure 5. Comparison of porosity obtained by two methods: (**a**) single admixtures; (**b**) composite admixtures.

3.2. Permeability

The permeability of porous concrete with different admixtures was presented in Figure 6. It could be clearly seen from Figure 6 that when the aggregate gradation and aggregate to binder ratio were the same, the permeability of porous concrete containing superplasticizers was significantly higher than those with other admixtures. Moreover, the permeability of porous concretes mixed with other admixtures were also slightly different from each other. It showed that when the cement cementitious materials for preparing porous concrete were different, the density could not directly determine the value of its permeability.

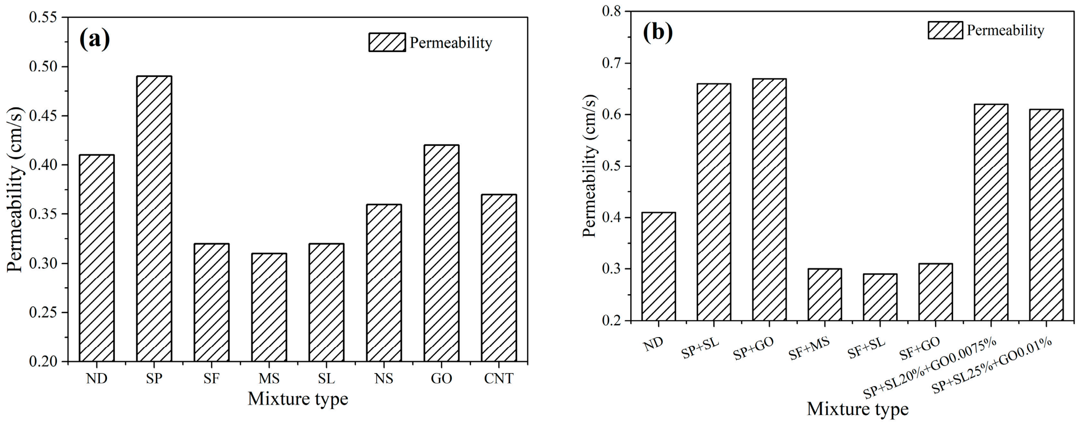

Figure 6. Permeability of porous concrete: (**a**) single admixtures; (**b**) composite admixtures.

In order to clarify the relationship between the permeability and pore characteristics of porous concrete, the relationship between the permeability and porosity, pore number, and equivalent aperture of porous concrete was analyzed, and the results are shown in Figure 7. It can be obtained from Figure 7 that:

(1) When the aggregate gradation and aggregate to binder ratio were the same, there was a significant positive correlation between the permeability and the porosity of porous concrete. The relationship equations between them were shown in Equations (6) and (7), and the correlation coefficient R^2 of both equations exceeded 0.96. It showed that porosity was the key factor that can determine the permeability.

$$k_1 = -1.10 + 10.19p, \; R^2 = 0.96, \tag{6}$$

$$k_{11} = 312.2 \times p^{3.49}, R^2 = 0.97, \tag{7}$$

where k_1 and k_{11} are the permeability of porous concrete, cm/s; p is the porosity of porous concrete.

(2) When the other conditions were the same, the permeability of porous concrete prepared with different admixtures showed an increasing trend with the increase of the pore number, but the correlation between them was not significant, indicating that the influence of the pore number on the permeability of porous concrete was limited;

(3) The permeability of porous concrete prepared with different admixtures showed a random distribution trend with the increase of equivalent aperture. It showed that the equivalent aperture had no effect on the permeability.

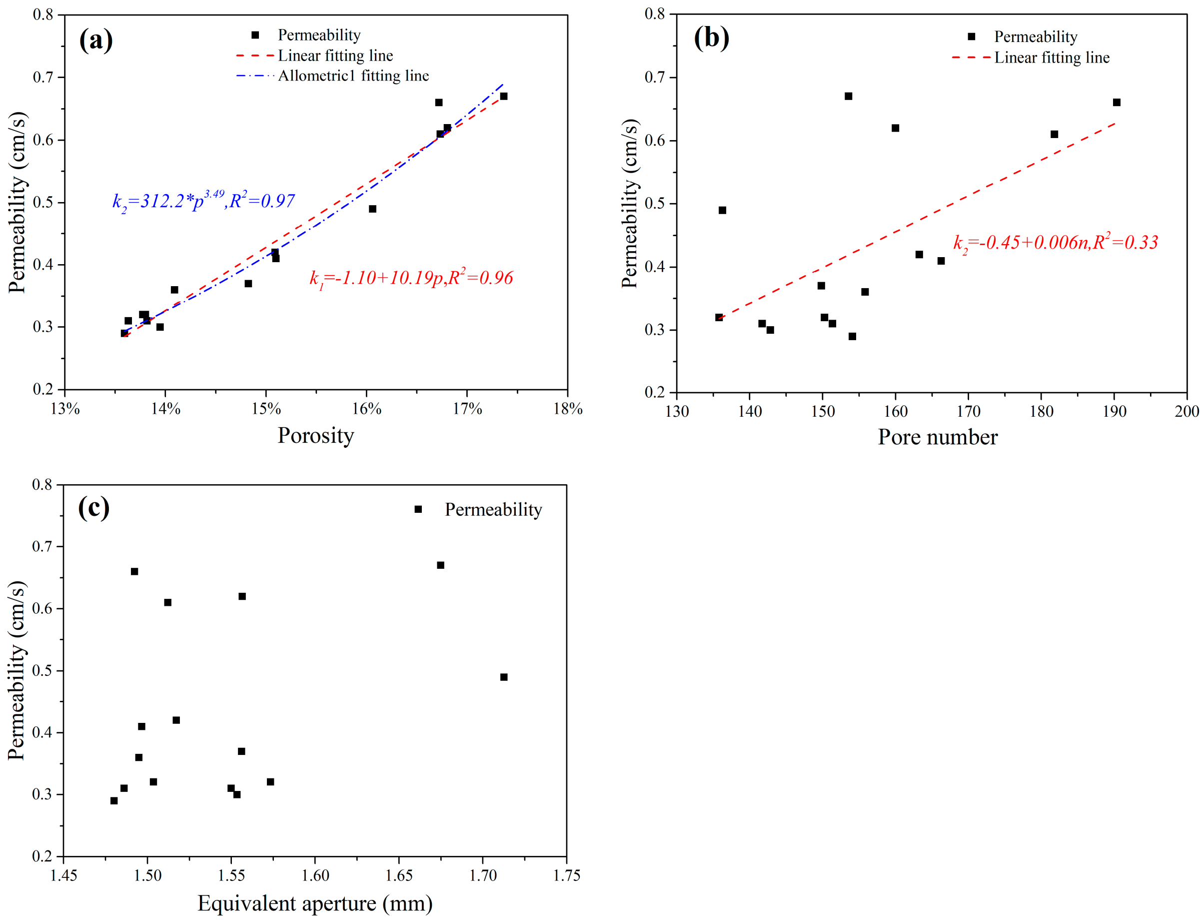

Figure 7. The relationship between permeability and pore characteristics: (**a**) porosity; (**b**) pore number; (**c**) equivalent aperture.

3.3. Strength

3.3.1. Compressive Strength and Flexural Strength

Figures 8 and 9 presented the effects of different admixtures on the compressive strength and flexural strength of porous concrete. Figure 10 showed the correlation between the compressive strength and flexural strength of porous concrete. It could be observed from Figures 8–10 that:

(1) When the aggregate gradation and aggregate to binder ratio were the same, the added admixtures could significantly improve the compressive strength and flexural strength of porous concrete. It showed that adding admixtures was a method to effectively improved the strength of porous concrete. However, it could also be seen that different admixtures and their combinations had significant differences in improving the strength of the porous concrete. Taking the compound addition of admixtures as an example, the compressive strength and flexural strength of porous concrete

with the best combination of admixtures (SF + MS) could be increased by 52.6% (from 23.1 MPa to 35.24 MPa) and 22.8% (from 3.29 MPa to 4.04 MPa), respectively, while the compressive strength and flexural strength of the worst combination (SF + GO) could be increased by only 17.9% (from 23.1 MPa to 27.24 MPa) and 17.9% (from 3.29 MPa to 3.88 MPa), respectively;

(2) When other conditions were the same, there was a significant difference between the increase of compressive strength and flexural strength of porous concrete with different admixtures, which showed that different admixtures and their combinations had different effects for improving the strength of porous concrete. Therefore, it should not be assumed that an admixture may significantly improve the flexural strength of porous concrete just because it can effectively improve the compressive strength of porous concrete;

(3) The compressive strength to flexural strength ratio (C/F ratio) of porous concrete prepared with different admixtures was presented in Figure 10c. It can be seen from Figure 10c that the value of C/F ratio was concentrated in the range 7.0–9.0 and presented the characteristics of random distribution with the increase of porosity.

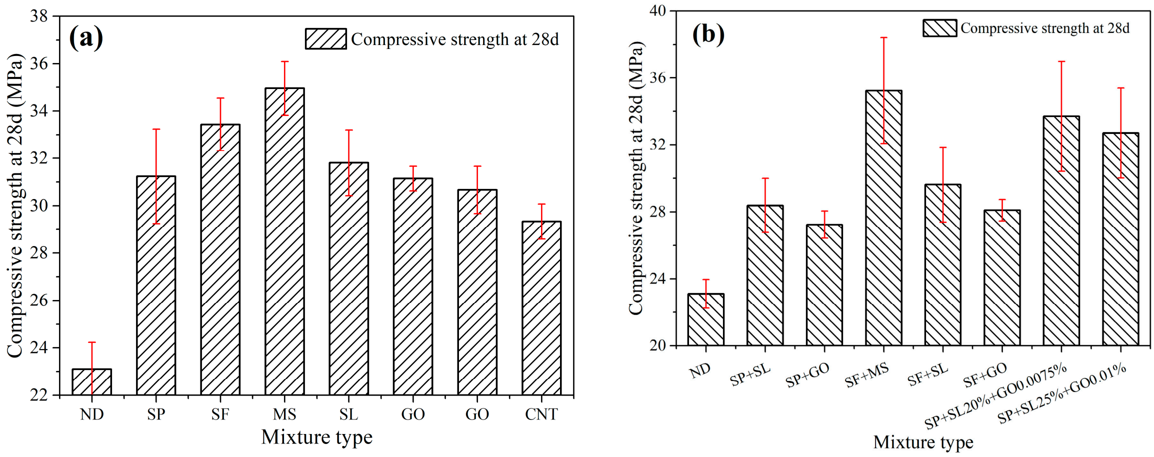

Figure 8. The effect of admixtures added on compressive strength of porous concrete: (**a**) specimen with single admixtures; (**b**) specimen with composite admixtures.

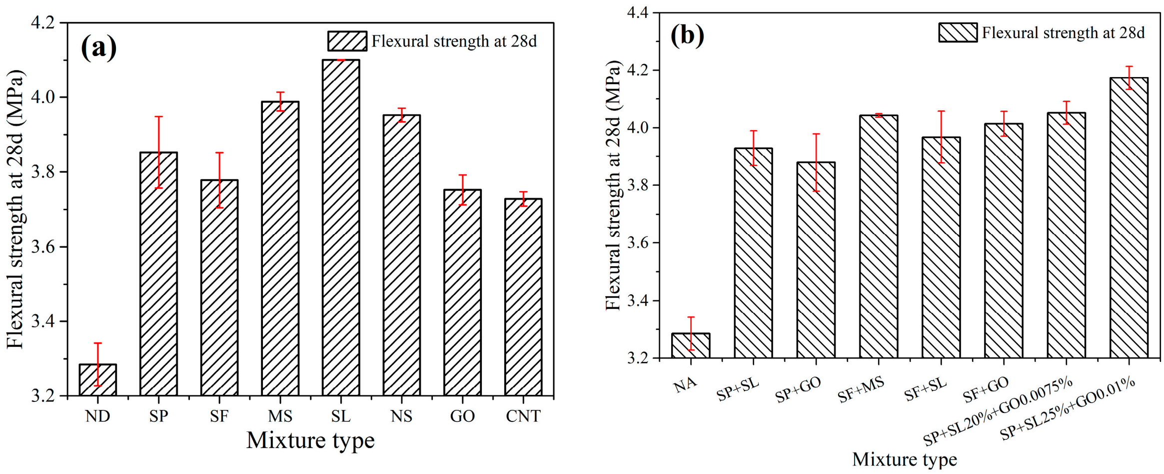

Figure 9. Effect of admixtures add on flexural strength of porous concrete: (**a**) specimen with single admixtures; (**b**) specimen with composite admixtures.

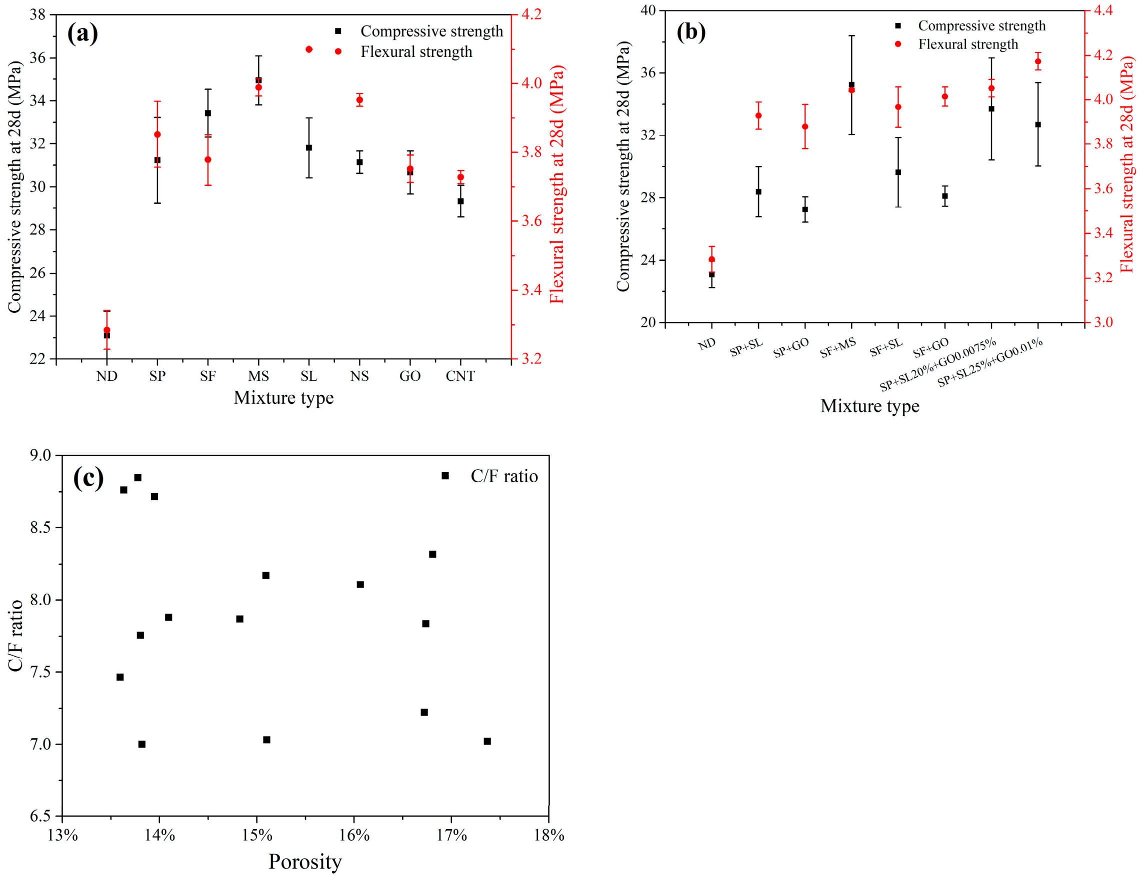

Figure 10. The relationship between compressive strength and flexural strength; (**a**) single admixtures; (**b**) composite admixtures; (**c**) C/F ratio.

3.3.2. Correlation between Strength and Pore Characteristics

The relationship between the strength and pore characteristics of porous concrete was shown in Figure 11. It could be clearly indicated from Figure 11 that the distribution of compressive strength and flexural strength of porous concrete prepared with different admixtures had no apparent rule with the increase of porosity, pore number, and equivalent aperture. This demonstrated that when the aggregate gradation and aggregate-to-binder ratio were fixed, the strength of porous concrete prepared with different cementitious materials was mainly affected by the quality of the cement mortar, but had little relationship with the pore characteristics caused by its different distribution in the porous concrete.

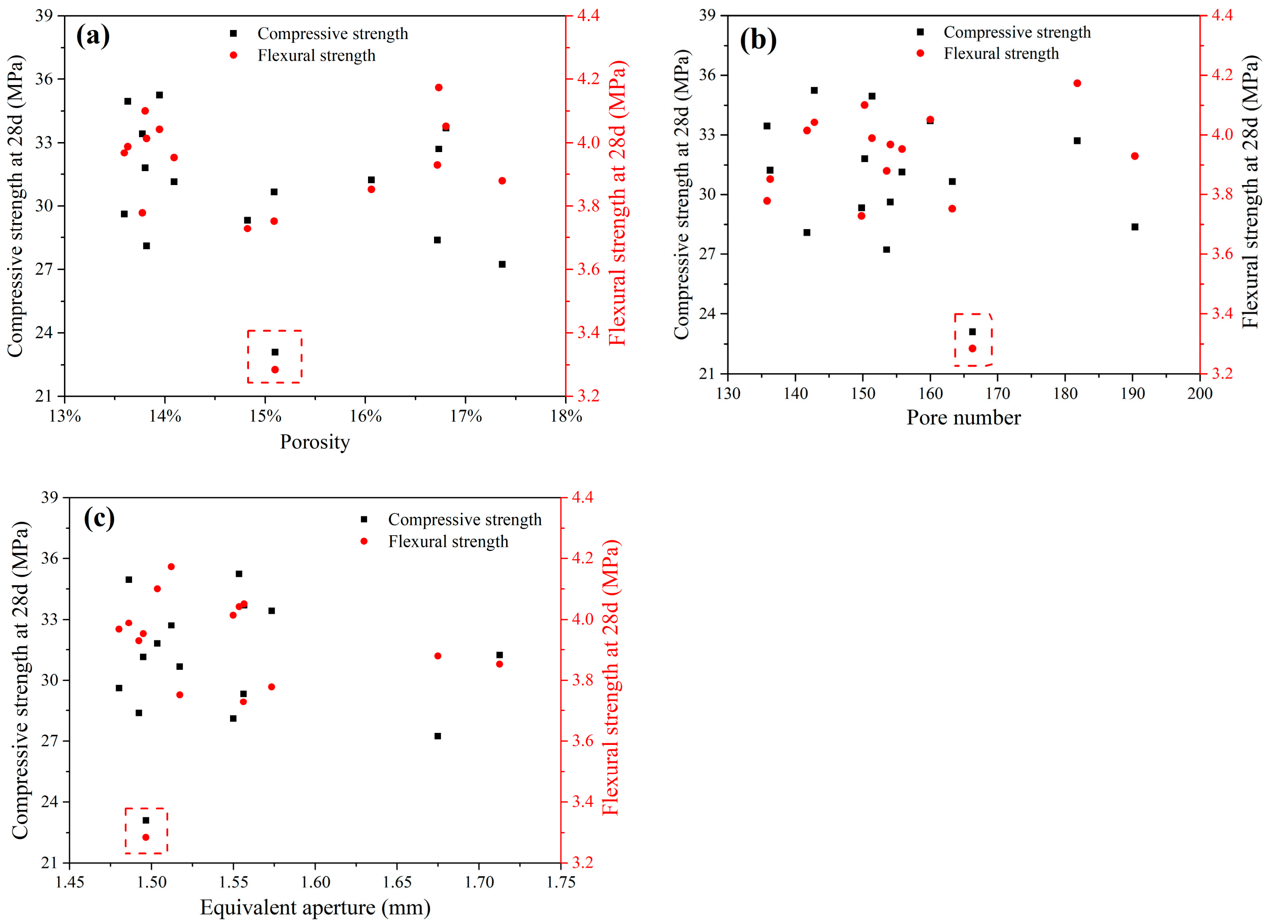

Figure 11. The relationship between strength and pore characteristics; (**a**) porosity, (**b**) pore number, (**c**) equivalent aperture.

3.4. Anti-Stripping Property

3.4.1. Mass Loss Rate

The mass loss rate of porous concrete after 300 times scatting was chosen as the index to evaluate the anti-stripping property of porous concrete, and the results was presented in Figure 12. It could be seen from Figure 12 that:

(1) It was feasible to evaluate the anti-stripping property of porous concrete by the improved Cantabro scattering test method which was used to evaluate the asphalt bonding performance of asphalt concrete, and it was not inapplicable due to the porous concrete being a brittle material;

(2) When the aggregate gradation and aggregate to binder ratio were the same, adding different admixtures into porous concrete could effectively improve the anti-stripping property of porous concrete, and the improvement effects of different admixtures were significantly different;

(3) For the porous concrete prepared with single admixtures, the anti-stripping property of porous concrete prepared with slag was the best compared with others, while the superplasticizers were the worst. The porous concrete prepared by the compound addition of admixtures also showed that the scattering mass loss rate of porous concrete containing superplasticizers was much larger than other admixtures combinations (except for the combination of superplasticizers and slag). The results showed that the slag could effectively improve the anti-stripping property of porous concrete, while the effect of superplasticizers was significantly lower than that of other admixtures. There were two reasons for the phenomenon: (a) The water consumption of porous concrete mixed with superplasticizers was greatly reduced, and the water in the mix-

ture evaporated during the molding process, especially on the upper molding surface, resulting in insufficient adhesion of the aggregate on the surface of the specimen due to the water loss of the mixture. The aggregate on the surfaces was easy to peel off during the scattering process, resulting in a large mass loss rate; (b) the porosity of porous concrete mixed with superplasticizers was relatively larger, and it meant that the thickness of cement film wrapped on the surface of aggregate was thinner, and the aggregate was easier to peel off during the scattering.

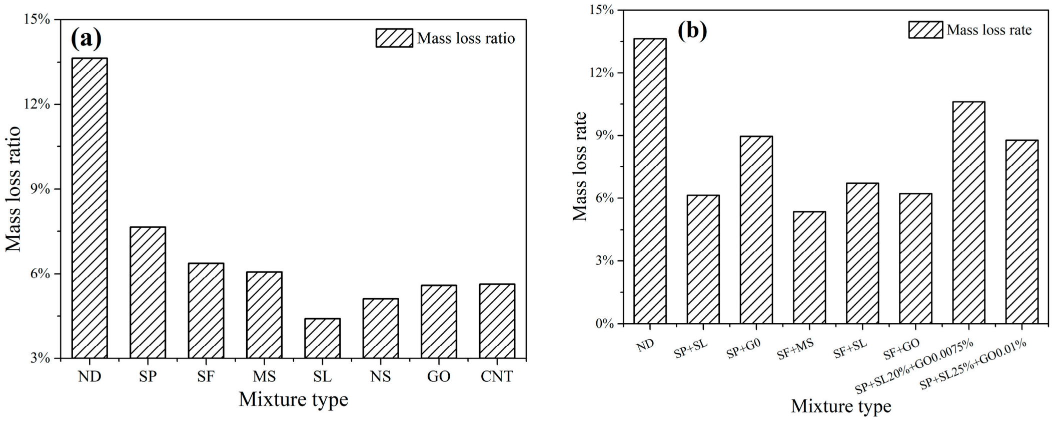

Figure 12. Mass loss rate of porous concrete with different admixtures after 300 times scattering: (**a**) single ad mixtures; (**b**) composite admixtures.

3.4.2. Relationship between Anti-Stripping Performance and Pore Characteristics

In order to evaluate the influence of pore characteristics on the anti-stripping property of porous concrete better, the correlation between the scattering mass loss rate and pore characteristics was analyzed (as presented in Figure 13). It could be seen from Figure 13 that:

(1) The mass loss rate of porous concrete showed a trend of increasing with porosity. However, the correlation between the two was weak (R^2 = 0.51), indicating that the porosity was not the only factor affecting the anti-stripping property of porous concrete, and its influence was limited. When the aggregate gradation and aggregate to binder ratio of porous concrete were fixed, the porosity could characterize the thickness of cement paste wrapped on the surface of aggregate with a certain extent. It indicated that the thickness of the cement paste wrapped in the aggregate affected its anti-stripping property. Thus, when other conditions were fixed, reducing the porosity was one way to improve the anti-stripping property of porous concrete;

(2) There was no significant correlation between the mass loss rate of porous concrete and the pore number/equivalent aperture, indicating that the two pore characteristics had little effect on the anti-stripping property. This may be related to the random distribution of the two pore characteristics among the aggregates with different cement pastes.

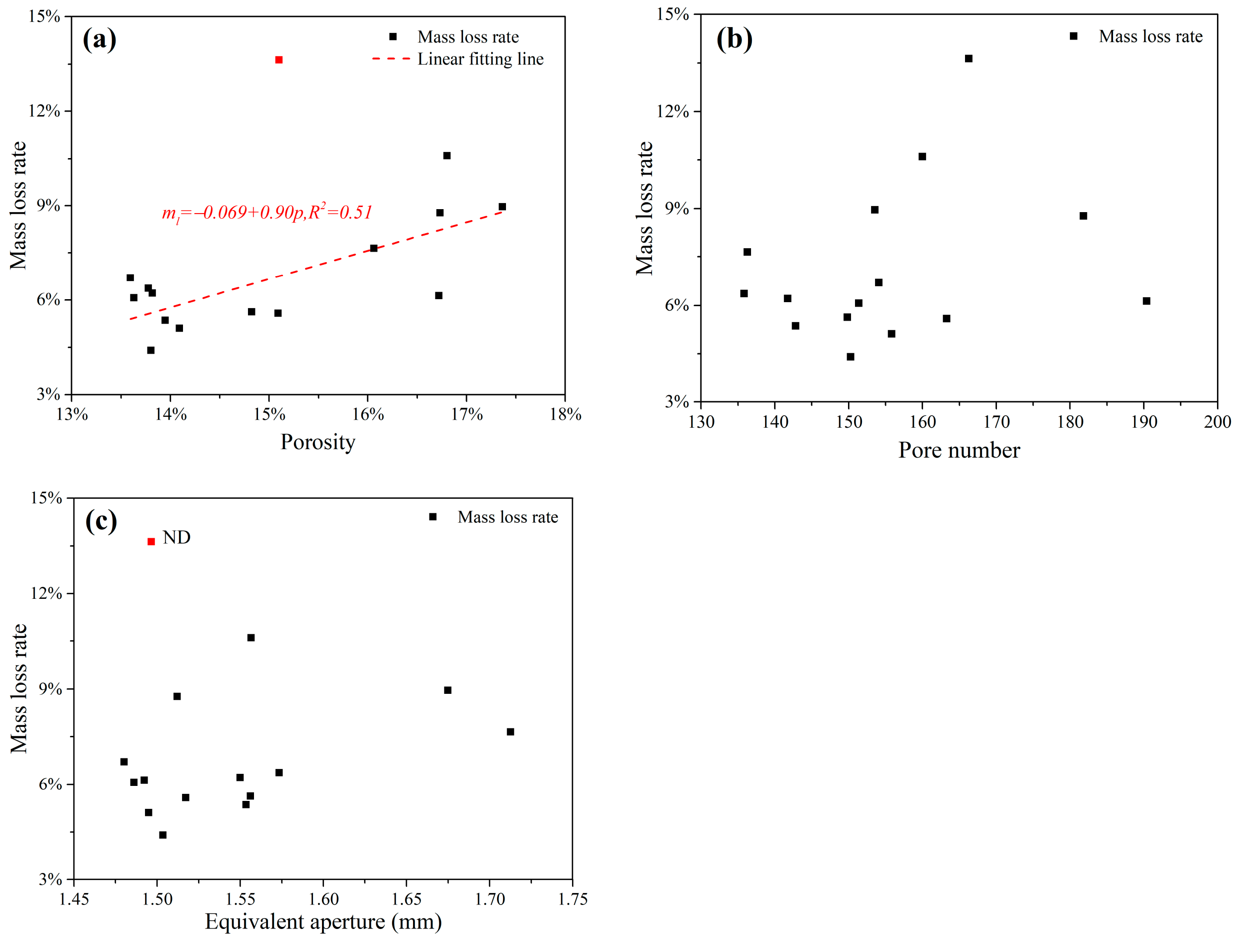

Figure 13. The relationship between the mass loss rate and pore characteristics: (**a**) porosity; (**b**) pore number; (**c**) equivalent aperture.

3.5. Relationship between Strength and Anti-Stripping Property

The relationship between anti-stripping property and strength was presented in Figure 14. The scattering mass loss rate showed a random distribution with the increase in compressive strength and flexural strength. It means that the anti-stripping property and strength of porous concrete prepared with different admixtures had no apparent relationship. Therefore, the strength and anti-stripping property of porous concrete prepared with different admixtures cannot be characterized by each other.

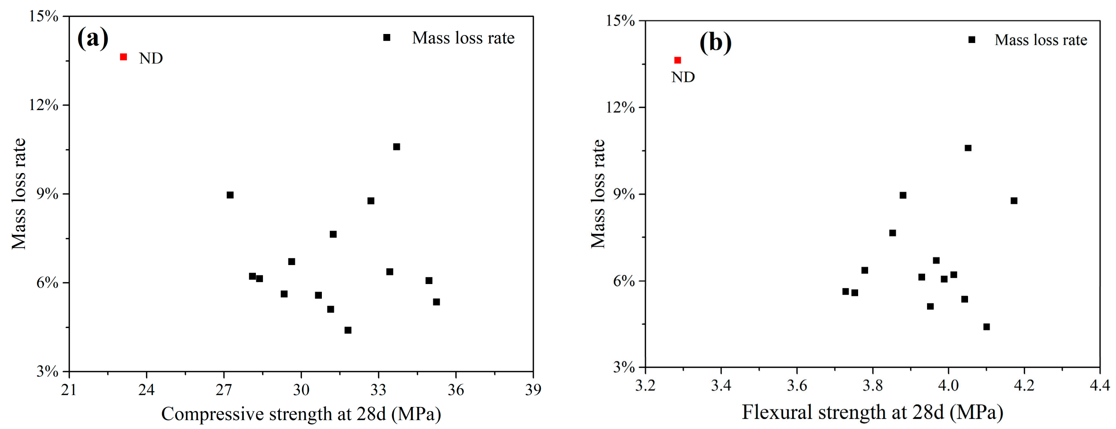

Figure 14. Relationship between mass loss rate and strength: (**a**) compressive strength, (**b**) flexural strength.

4. Conclusions

In this study, the porosity, pore characteristics, permeability, strength, and anti-stripping property of porous concrete prepared with different admixtures were experimentally examined. In addition, the relationship between permeability, strength, anti-stripping property, and pore characteristics of porous concrete, as well as the correlation between the strength and anti-stripping property, were investigated. The main conclusions are shown as follows:

(1) The porosity of porous concrete prepared with different admixtures was significantly different, indicating that when the cement mortar of porous concrete was different, the density value cannot characterize its porosity. The porosity of porous concrete obtained by the underwater gravity method was slightly lower than the CT image processing method (within 0.5%);
(2) Permeability of porous concrete made of different admixtures was obviously different (over 131%). Permeability of porous concrete had a high correlation with porosity ($R^2 \geq 0.96$), and it had no obvious relationship with the pore number and equivalent apertures;
(3) The addition of appropriate admixtures could greatly improve the strength of porous concrete, and the effect of the same admixture on the improvement of compressive strength and flexural strength was not completely consistent. The strength of porous concrete had no obvious relationship with its pore characteristics, indicating that the type of cement mortar material composed of different admixtures had a more significant impact on its strength than pore characteristics;
(4) The addition of admixtures could effectively improve the anti-stripping property of porous concrete. The anti-stripping property of porous concrete containing slag was relatively good, while that of porous concrete containing superplasticizers was poorer. Besides, the anti-stripping property of porous concrete had a weak correlation with porosity, and has no correlation with pore number, equivalent apertures, or strength;
(5) There was no significant correlation between the strength and anti-stripping property of porous concrete prepared with different admixtures.

Based on the results obtained in this study, the authors recommend the following procedures to improve the strength and anti-stripping property of porous concrete: (a) Choose the appropriate admixtures to prepare porous concrete, (b) reduce the porosity under the condition of satisfying the requirement of permeability, (c) adjust the water consumption and cement amount according to the type of admixtures added.

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