Component optimization of porous permeable brick in "sponge city" based on rainfall area division

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Abstract. The present study aims to prepare resin-based permeable bricks with micron-sized pores using fine aggregate with a particle diameter of 0.08mm-0.6mm and bisphenol-A epoxy resin, a polymer binder. The rainfall area of China was divided into 5 levels by using ArcGIS and Geoda geographic analysis software; The performance indexes of key components of resin-based permeable brick were selected by correlation with relevant standards, and the performance of materials was adjusted and designed according to the corresponding performance indexes, so as to meet the design requirements of "Sponge City". The main method of material design is to adjust the key parameters of raw materials, such as aggregates, binder materials and admixtures, by using Image Pro Plus software and SEM and other test methods, so as to optimize the selection of "graded" aggregates and admixtures for different performance requirements scenarios to achieve the material selection goal. The highest permeable rate of resin-based permeable brick is $6.22 \times 10^{-2} \text{cm/s}$, and the maximum compressive strength is more than 60MPa.

1 Introduction

In the process of global urbanization, more than 50% of the world's population live in cities ([11]). The rapid development of economy and the acceleration of urbanization have brought convenience to human beings, but also brought serious environmental pollution, resulting in many urban diseases. The urban diseases are "Heat island effect" and "Urban waterlogging". The heat island effect is caused by human factors, which changes the local temperature, humidity, air convection and other factors on the urban surface, and then causes the urban microclimate change; Urban waterlogging refers to the phenomenon of waterlogging disaster in the city due to the heavy precipitation or continuous precipitation exceeding the urban drainage capacity. The causes include the objective concentration of precipitation, imperfect drainage facilities and lagging drainage system construction. Therefore, urban climate and hydrological problems restrict the further development of the city, so it is urgent to find a reasonable solution in the process of urban construction and governance.

Based on the above reasons, China proposes to build a "Sponge City". "Sponge City" is a special appellation in China, and there are many different appellations for such urban pollution control programs in the world ([2-8]). BMP for Stormwater Management in the United States is also called Low Impact Development (LID); Sustainable Drainage System (SuDS) in the United Kingdom; Water Sensitive Urban Design (WSUD) in Australia and Low Impact Urban Design & Development (LIUDD) in New Zealand, etc.

Considering that urban environmental governance is a systematic project, it is necessary to find a fit point in a specific field, and the problem of "precipitation-pervious-drainage" in urban hydrology is just the key. When the rainwater enters the river through the urban drainage system, it will increase the pressure of the urban drainage system; while the rainwater that cannot be drained will generate a large amount of water on the road surface, which will lead to the frequent occurrence of urban flood. In addition, a large number of pollutants on the road enter the river with the runoff through the urban drainage pipe or overflow under the rain wash, forming a typical urban rainfall runoff pollution, which is the main non-point source pollution source in the city, and has a serious impact on the urban ecological environment. These are mostly environmental problems caused by hardened pavement ([9, 10]). These environmental problems are mainly caused by urban waterlogging, traffic paralysis, water pollution, etc. caused by the lack of water seepage when facing the precipitation ([11-15]). A large number of studies show that ([16]), compared with impermeable pavement, permeable pavement can alleviate surface runoff, supply underground water, purify pavement rainwater, improve urban thermal environment, absorb urban noise, improve urban surface soil ecological environment, etc. ([17-19]).

In this context, permeable brick is widely used as an efficient permeable pavement material in China. In the construction of pavement system, permeable brick is a part of the system, which has the following advantages: 1. Good water permeable performance, which can make rainwater quickly penetrate into the ground, supplement soil water and groundwater, maintain soil moisture, and
improve the living conditions of urban ground plants and soil microorganisms; 2. It can absorb water and heat, adjust the temperature of local space on the ground humidity, large-scale application can adjust the urban microclimate and alleviate the effect of urban heat island; 3. It can reduce the pressure of urban drainage and flood control, prevent the pollution of public waters and make the road free of water, etc. Permeable brick is mainly divided into three types: cement-based permeable brick, sintered permeable brick and resin-based permeable brick. Their main materials are aggregate and binder. However, the first two kinds of permeable bricks have some defects, such as: the production and maintenance cycle of cement-based permeable bricks is long, the quality is low; the energy consumption of sintered permeable bricks is very high, and the secondary pollution is serious. Therefore, the use of resin based permeable brick has become the mainstream.

However, since the sponge city was built in 2012, there are still many deficiencies in the national overall urban planning, such as the imbalance of construction caused by the climate difference between the north and the south, the irrationality of construction caused by the selection of the same construction system, and the exclusiveness of manufacturing and selection caused by the differences in the origin of materials. However, the "Six Words Policy" of "Sponge City" of "infiltration, stagnation, storage, purification, utilization and drainage" is often mixed together, and there is no very obvious boundary. Based on this, it is necessary to implement the sponge city plan of "adjusting measures to local conditions" for different regions according to different rainfall and material properties. On the basis of the above logic, this study conducted an in-depth study on the selection scheme of "sponge city" in accordance with the classification of "macro; meso; micro", and formulated a specific guidance scheme according to the reasonable combination of these three levels. The main research contents are as follows:

- Macro research: collect the rainfall data of each city in recent 10 years in China, and divide the rainfall area in China; Meso research: study the permeable brick based on resin and obtain the regulation scheme for the permeable and mechanical properties; Micro research: study the admixtures to obtain the further regulation method.

2 Experimental

2.1 Raw material

Binders and aggregates are the main materials for making resin-based permeable pavement. Admixtures are chemical substances that can significantly improve the performance of permeable bricks.

2.1.1 Aggregate

The aggregate is 10 kinds of natural sand with similar particle size but different distribution obtained from different regions in China. Their particle size is controlled within 0.08mm-0.6mm by vibrating screen.

2.1.2 Binder materials

Binders: bisphenol-A epoxy resin, white transparent viscous liquid, epoxy value is 0.44, industrial brand is E44; Amine curing agent (adduct of diethylenetriamine and butyl glycidyl ether), industrial grade is 593, relative density is 0.985, viscosity (25°C) is 90 - 150mPa·s, total amine value is 500 ~ 700mgKOH/g. In a dry environment at room temperature, the 1-day strength can reach 90% of the maximum value.

2.1.3 Admixture

The additives were selected from four aspects: alcohol additives, filler additives, reaction additives and water-resistant additives, and the macro performance of permeable brick was tested to explore the influence of different additives on the epoxy resin binder material system. For the convenience of research, the above additives are classified according to the molecular weight and functional differences as shown in Fig. 1:

2.2 Sample preparation

For the preparation of resin-based permeable bricks (RBPB for short), firstly, the aggregates shall be weighed according to the formula and poured into the mixer, epoxy resin and curing agent shall be added, and then the mixture shall be placed in the mixer for 240s until the materials are well mixed. In order to make the pores well-distributed, samples need to be vibrated. The mix proportion is shown in Table 1.

![Fig1. Admixture selection scheme (a) according to different functional groups (b) according to molecular weight (c) according to functional group characteristics](image)

| Weight fraction (wt%) | Composition | Sand | Resin | Curing agent |
|-----------------------|-------------|------|-------|--------------|
| 94.3                  | 4.4         | 1.3  |       |              |

When the total volume of porous materials is constant, the mechanical properties increase with the increase of the content of binder materials, but the water permeability will decrease. Through some exploration experiments, it was found that the proportion of the total mass of resin and curing agent accounting for 6% of the aggregate can meet the requirement of the mechanical properties, water...
permeability and cost better. So the proportion of 6% was used for subsequent research and the proportion of curing agent and resin is as follows: \( \text{m (curing agent)} : \text{m (resin)} = 3:10 \).

2.3 Methods

2.3.1 Test methods for water permeability and mechanical properties of RBPB

The test methods and indicators of water-permeable properties of permeable materials are based on GB/T 25993-2010 ([20]) for ordinary permeable brick. The permeability coefficient \( K(\text{cm} \cdot \text{s}^{-1}) \) is calculated by the formula as shown in Eq(1). The compressive strength of the samples was measured by using a universal testing machine at a crosshead speed of 2 mm/min([21]) . The flexural strength was measured according to the loading rate of 0.04MPa/s ~ 0.06MPa/s ([22]) .

\[
K = \frac{QL}{AHt}
\]  

(1)

2.3.2 Test method for porosity

The porosity measurement method refers to the experimental method of Jiang ([23]) , and the calculation is as follows:

\[
\varepsilon = \frac{m_{12} - m_{22}}{V \cdot \rho_w} \times 100\%
\]  

(2)

Where \( \varepsilon \) represents porosity, \( m_{12} \) represents the wet weight of permeable brick, \( m_{22} \) represents the dry weight of permeable brick, \( V \) represents the apparent volume of permeable brick, \( \rho_w \) is the density of water.

2.3.3 Particle group parameter test

The optical stereo microscope and Sony ILCE-6000 24.3 megapixel camera were used to collect the image information of the sand particle group, and then the image information of the particle group is analyzed and processed with Image Pro Plus software to obtain the particle group parameters. The image collection and analysis process is shown in Fig. 2.

3 Results and discussion

3.1 Micro research

3.1.1 Pore structure analysis

SEM was used to study permeable brick, and the results are shown in Fig. 3.
Fig 3. Micrograph of permeable brick specimen. (a) Two different types of pores, (b) Roundness of particle

It can be seen from Fig. 3 that the roundness of aeolian sand particles is high, so it is reasonable to consider it as a sphere. It can be seen in the SEM image that the pores and large gaps caused by the overlapping particles are very obvious. Image Pro Plus software was used to calculate more than 100,000 particles, the average roundness of this desert aeolian sand is 0.92. In addition, the pore size of the lapped pores is 30-100 microns, of which the three-particle lapped pore diameter is 30-50 microns, and the four-particle lapped pore diameter is 100 microns. Kayhanian’s ([24]) study shows that when the diameter of harmful particles is larger than 38 microns, permeable concrete will be blocked, while Siriwardene’s ([25]) study shows that when the diameter of particles is smaller than 6 microns, particles in porous media will migrate with water, and a deposit layer will be formed at the bottom of porous materials to prevent water from penetrating underground. The permeable bricks prepared in this study have micron-level pores, which have smaller pore sizes than millimeter-scale permeable concrete/bricks, which can effectively block the clogging and migration of harmful particles, making the permeable pavement service life longer.

3.1.2 Admixture research

The experimental results of 13 different admixtures are shown in Fig. 4.

Adding small molecule admixtures within the range of 3%-7% will increase the porosity, and the increase of porosity is significant when carboxyl group is added in the low dosage of admixtures. Macromolecular additives have no special effect on porosity; Adding hydrophobic material will increase the porosity, indicating that the addition of hydrophobic material is conducive to the dispersion of binder materials, so that the effective porosity is improved. With the increase of additives, the porosity shows an upward trend, and then drops rapidly after reaching the highest point, which shows that additives can improve the fluidity of binder materials and disperse more evenly in the process of use, so the binder materials are not easy to block the pores, which leads to the increase of the effective porosity of the permeable materials and the increase of the connecting pores. However, if the amount of additives continues to increase after achieving the best coupling of fluidity and distribution uniformity, it will lead to the plugging phenomenon of large amount of binder material, so the porosity will further decrease.
The use of ethylamine as an additive does not affect the water permeability and mechanical properties of the permeable material, which is mainly because amine as a reactive additive only increases the concentration of the curing agent in the chemical reaction of cross-linking curing, only accelerates the reaction speed, but does not affect its functionality. There is a negative correlation between the porosity of ethanol and acetic acid and the compressive strength, which indicates that the structure of the binder material will be destroyed when the content of acetic acid is very large.

One of the highest points in Fig. 6 is that in the group with a small amount of polyacrylic acid added, its compressive strength is much higher than that of other groups, and after further adding polyacrylic acid, its strength drops rapidly, which is very special. Due to the strong polarity of the carboxyl group of polyacrylic acid, it can react with the epoxy group on both sides of the epoxy resin, and can also activate the cross-linking curing reaction. At the same time, the molecular weight of polyacrylic acid is moderate, adding it to the body-shaped macromolecules increases the structural stability, but adding more polyacrylic acid containing the carboxyl group will reduce the strength of the material.

It can be seen from Fig. 7 that the water retention rate does not change with the change of porosity after adding hydrophobic materials, and it always fluctuates within the range of 0.12-0.14, which is different from other additives. Because the hydrophobic material can’t be well wetted by water, the pores in the water permeable material added with the hydrophobic material will form a hydrophobic layer, so that the water permeable material does not have good water retention, and the water has a quick drainage effect after entering the water permeable material.

Through the selection of functional groups, hydrophilic and hydrophobic properties, it is found that hydrophilic small molecular substances are used as additives to modify the permeable pavement brick, and the test specimens mixed with methanol and ethylamine shows relatively good water permeability, which is named as “Class A” high water permeability and high water retention additive; The water permeable brick was modified with hydrophilic macromolecule as additive, and the soluble starch as additive. The test specimens had good water permeability and compressive strength over 40MPa, so it was named as “Class B” high strength additive; The test specimens modified by hydrophobic substances as additives did not show relatively excellent water permeability, but this kind of test block generally has high compressive strength. In general, porosity = water retention rate, but after adding hydrophobic substances, the water permeability and compressive strength over 40MPa.

3.2 Meso research

3.2.1 Aggregate division method

The distribution standard deviation $w$ in the formula reflects the dispersion degree of particle size to $x_c$. Define $\alpha$ as the aggregate distribution coefficient, which is a dimensionless quantity, the calculation formula of $\alpha$ is shown in Eq(4).

$$\alpha = \frac{w}{x_c} \quad (4)$$

Two parameters $x_c$ and $w$ in the modified Gaussian distribution function determine the particle size distribution of the particle group. From the calculation formula of $\alpha$, it can be seen that the smaller $\alpha$ is, the smaller $w$ is, and the larger $x_c$ is, which means that the particle size distribution tends to be narrow, and the most probable particle size tends to be large. Such a single aggregate grading and larger particle size will lead to the larger effective pore diameter, which is conducive to the improvement of the material’s water permeability. On the contrary, the smaller $\alpha$ means that the particle size distribution tends to be wider and the most probable particle size tends to be smaller. Aggregates with such characteristics can play a good role in pore filling, with more continuous grading and fewer pores, and better strength. As the mean value of flexural strength is 10.75MPa, which is far greater than the 3.0MPa specified in the national standard mentioned in Table 1, so it will not be discussed here.
According to the compressive strength value and permeability rate, the characteristic parameter range of 10 kinds of sands is divided as shown in Fig. 8 (a) and Fig. 8 (b). Taking the strength boundary (35MPa and 40MPa) and permeability rate boundary (0.02 cm·s⁻¹ and 0.04 cm·s⁻¹) as the standard, the compressive strength of RBPB is divided into “Ⅰ 、 Ⅱ 、 Ⅲ” three areas, and the permeability rate is divided into “A 、 B 、 C” three areas.

The characteristic parameter values of S1 and S3 are used as the classification nodes. The critical values in the two figures are compared and the intersection of them is taken. The aggregate distribution coefficient α value of aggregate is below 0.264, and the properties of RBPB prepared with it tend to be high permeable rate and low compressive strength (the compressive strength can still reach the national standard), which can be divided into high permeable aggregate(HPA for short); When the aggregate distribution coefficient α value of aggregate is above 0.8001, it is high compressive strength and low permeable rate (permeable rate can meet the national standard), which can be divided into high strength aggregate(HSA for short); When the aggregate distribution coefficient α is in the range of 0.264-0.8001, its strength and permeable rate are in a relatively balanced level, which can be divided into comprehensive aggregate (CA for short). S7 belongs to HSA, S8-S10 belongs to HPA and S1-S6 belongs to CA. The range of characteristic parameters of particle groups of various aggregates is shown in Table 2.

| Aggregate category | Permeability y/cm s⁻¹ | Compressive strength/MPa | α         |
|-------------------|------------------------|--------------------------|-----------|
| HPA               | ≥0.040                 | ≥30                      | <0.264    |
| CA                | ≥0.020                 | ≥35                      | 0.264-0.8001 |
| HSA               | ≥0.010                 | ≥40                      | >0.8001   |

There are many studies to explore the mechanical properties and water permeability of porous materials from the porosity([26-28]), but few studies from the perspective of particle group parameters. There are some defects in the design of permeable brick only by the parameters of pore. Many properties of pore have influence on the strength and permeability of porous permeable material, such as pore size, pore distribution, pore shape, etc. Moreover, the key parameters of pore structure such as effective porosity, tortuosity and connectivity are difficult to obtain and the accuracy is low. This method of judging the performance of bricks by measuring porosity is a lagging method, that is, a material must be prepared to measure its performance, so a predictive method of predictability is required. This paper proposes a method to design the various functions of porous materials in advance by obtaining the particle group parameters of aggregates, which is beneficial to selecting materials and controlling materials in advance according to the design parameters.

3.2.2 Selection principle of binder materials

It can be seen from the above that the strength of permeable bricks increases with the increase of epoxy resin content. When the content of resin is less than or equal to 3%, the surface of aggregate can not be fully covered due to the small amount of binder material, and the high-strength cementation layer can not be formed between aggregate particles after solidification, resulting in the strength of resin based permeable pavement material can not reach the minimum strength standard of pavement material; When the amount of epoxy resin is more than or equal to 7%, excessive binder materials, in addition to fully covering the aggregate surface, will have excessive epoxy resin mixture seepage at the bottom of the mixture after mixing, filling the pores between the aggregates, so that the water permeability of the material can not meet the standard of water permeable materials.
3.3 Macro research

China is located in the east of Asia and the west of the Pacific Ocean, with tropical monsoon climate area, subtropical monsoon climate area, temperate monsoon climate area, plateau mountain climate area, temperate continental climate area and tropical rainforest climate area. In such a country that spans many climate regions, there is a great gap in the atmospheric weather conditions faced by different regions, and there are many kinds of technical measures for sponge city construction. Therefore, the principle of material selection is to "adjust measures to local conditions", which cannot be controlled and designed in one stroke. Some areas need rapid drainage, some need water storage, and some need water filtration. The most reasonable way is to arrange the selection of materials as a whole. In this context, we need to divide the national rainfall area.

3.3.1 Rainfall area data and spatial pattern

According to the precipitation data of 34 provinces, municipalities, autonomous regions and special administrative regions in 2009-2018 found by China's economic and social big data research platform, the average annual precipitation of each province in China in the past 10 years is calculated. The values are shown in Table 3.

| No | The 34 provinces, autonomous regions, municipalities directly under the central government and special administrative regions of China | Average annual precipitation in recent 10 years (unit: mm) |
|----|-----------------------------------------------------------------|---------------------------------------------------------|
| 1  | Beijing                                                         | 574.77                                                  |
| 2  | Tianjin                                                         | 566.70                                                  |
| 3  | Shanghai                                                       | 1371.29                                                 |
| 4  | Chongqing                                                      | 1193.91                                                 |
| 5  | Jiangsu                                                        | 1140.64                                                 |
| 6  | Guangdong                                                      | 1708.16                                                 |
| 7  | Sichuan                                                        | 1039.28                                                 |
| 8  | Zhejiang                                                       | 1581.13                                                 |
| 9  | Hubei                                                          | 1200.00                                                  |
| 10 | Shandong                                                       | 723.72                                                  |
| 11 | Xinjiang                                                       | 176.04                                                  |
| 12 | Anhui                                                          | 1231.00                                                 |
| 13 | Yunnan                                                         | 660.43                                                  |
| 14 | Henan                                                          | 678.97                                                  |
| 15 | Guangxi                                                        | 1709.35                                                 |
| 16 | Hebei                                                          | 533.03                                                  |
| 17 | Hunan                                                          | 1412.77                                                 |
| 18 | Shaanxi                                                        | 658.152                                                  |
| 19 | Jiangxi                                                        | 1852.98                                                 |
| 20 | Fujian                                                         | 1600                                                  |
| 21 | Shanxi                                                         | 838.425                                                 |
| 22 | Jilin                                                          | 640.84                                                  |
| 23 | Liaoning                                                       | 800                                                    |
| 24 | Heilongjiang                                                   | 577.80                                                  |
| 25 | Gansu                                                          | 410.79                                                  |
| 26 | Guizhou                                                        | 1162.26                                                 |
| 27 | Neimenggu                                                      | 319.96                                                  |
| 28 | Ningxia                                                        | 587.19                                                  |
| 29 | Hainan                                                         | 1639.00                                                 |
| 30 | Qinghai                                                        | 412.67                                                  |
| 31 | Xizang                                                         | 400.00                                                  |
| 32 | Taiwan                                                         | 1800.00                                                 |
| 33 | Xianggang                                                      | 1708.16                                                 |
| 34 | Aomen                                                          | 1790.00                                                 |

Using ArcGIS 10.2 geographic information system, spatial interpolation analysis and three-dimensional visualization of the average annual precipitation data of China's provinces and cities in the past 10 years are shown in Fig. 10 and Fig. 11. It can be seen that the precipitation in different regions of China varies greatly, the coastal rainfall is more than that in the inland, and the rainfall in the south is more than that in the north. Decreasing from southeast coast to northwest inland is the general trend of annual precipitation spatial distribution in China.
Fig. 10. Spatial pattern analysis of average annual precipitation in recent 10 years in China using spatial interpolation method.

Fig. 11. Spatial pattern analysis of China's average annual precipitation in recent 10 years based on 3D visualization.

Fig. 11 is a three-dimensional visual analysis of the spatial pattern of China's average annual precipitation in the past 10 years. The graphic changes from (a) to (d) can directly see the height differences of precipitation in different regions of China. Fig. 11 (d) shows that although the area of southeast coastal area is much smaller than that of northwest, the absolute height of southeast coastal area in quadrant I in the positive direction of Y axis is much higher than that of northwest inland area in quadrant III in terms of rainfall. In the southeast and northwest directions, there are several areas with high and low peaks. Therefore, in the process of sponge city construction, not only the material properties need to be divided, but also the rainfall areas need to be divided throughout the country. and different permeable material system deployment schemes need to be used in different regions.

3.3.2 Division of rainfall areas in China

Using Geoda spatial data analysis software, the equal interval map method in its mapping tool is used to make the average annual precipitation distribution map of China's provinces and cities in recent 10 years, as shown in Fig. 12. According to Fig. 12, China's average annual precipitation can be divided into five grades, as shown in Table 4.
**Table 4.** Classification of average annual precipitation in recent 10 years in China

| Grade | Average annual precipitation range | provinces |
|-------|-----------------------------------|-----------|
| Level 1 | 176.040mm-5 11.428mm | Neimenggu, Gansu, Qinghai, Xinjiang, Xizang |
| Level 2 | 511.428mm-8 46.816mm | Heilongjiang, Jilin, Niaoning, Beijing, Tianjin, Hebei, Shan dong, Henan, Shanxi, Shaanxi, Ningxia, Yunnan |
| Level 3 | 846.816mm-11 182.204mm | Sichuan, Jiangsu and Guizhou |
| Level 4 | 1182.204mm-1517.592mm | Shanghai, Anhui, Hubei, Hunan and Guangdong |
| Level 5 | 1517.592mm-1852.980mm | Zhejiang, Fujian, Jiangxi, Guangdong, Guangxi, Hainan, Xianggang, Aomen, Taiwan |

From Fig. 12, we can visually observe the division of China's 5-level rainfall area, and from Table 4, we can see the average annual precipitation range of 5-level rainfall area. On this basis, the following two principles should be clear:

1. Increase the permeation rate in rainy areas, so that the maximum precipitation can meet the precipitation-permeability balance while taking into account the mechanical properties.
2. Economically applicable aggregates and binder materials are used in areas with little rain to fully reduce costs while satisfying basic performance.

According to the above principles, it is reasonable to build permeable material storehouse in different rainfall areas, but the requirements of specific pavement quantity are not within the scope of this paper.

**3.4 "Sponge city" material selection plan**

In order to promote the concept and material system of "Sponge City" in China, it is necessary to design the pavement system and material of "Sponge City" in a targeted way. Through geographical division and sponge system preset, each division can choose the road material use plan of "Sponge City" according to local conditions, so as to make the collection and utilization of rainwater and more efficient drainage. According to the research in 3.3.2, the whole country is divided into five specific rainfall areas according to the rainfall gradient, and a material storehouse needs to be established to correspond to these five rainfall areas, so that the construction of "Sponge City" can match the materials according to the area or the materials. The idea of establishing material storehouse is shown in Table 5.

**Table 5.** Design scheme of permeable materials for "sponge city"

| Aggregate | Admixture | Performance | Type |
|-----------|-----------|-------------|------|
| Aggregate-I | Admixture-A | A I | Ultra HP | HPA |
| Aggregate-I | Admixture-B | B I | HPHS | HSA |
| Aggregate-I | Admixture-C | C I | HPDP | CA |
| Aggregate-II | Admixture-A | A II | HSHP | Plan 1 |
| Aggregate-II | Admixture-B | B II | Ultra HS | Plan 2 |
| Aggregate-II | Admixture-C | C II | HSDP | Plan 3 |
| Aggregate-III | Admixture-A | A III | CHP | Plan 4 |
| Aggregate-III | Admixture-B | B III | CHS | Plan 5 |
| Aggregate-III | Admixture-C | C III | CDP | Plan 6 |

Note: the abbreviation H means High, P means Permeability, S means Strength, DP means Drainage Promoting.

According to the previous study on aggregate and admixture, aggregate can be divided into different categories according to the particle group parameter α value of aggregate, including HPA, HSA and CA. At the same time, three kinds of admixtures with different functions are obtained in the study of admixtures, which are high permeable admixtures (HPA-A), high strength admixtures (HSA-B) and drainage promoting admixtures (DPA-C). They can modify the binder materials to some extent, so that the performance of the water permeable materials can also be improved. Therefore, according to the collocation method in Table 5, 9 different material selection schemes can be obtained as shown in Table 6.

**Table 6.** Material selection plans

| Aggregates | Admixtures | Targets | Performance | Plans |
|------------|------------|---------|-------------|-------|
| Aggregate-I | Admixture-A | A I | Ultra HP | Plan 1 |
| Aggregate-I | Admixture-B | B I | HPHS | Plan 2 |
| Aggregate-I | Admixture-C | C I | HPDP | Plan 3 |
| Aggregate-II | Admixture-A | A II | HSHP | Plan 4 |
| Aggregate-II | Admixture-B | B II | Ultra HS | Plan 5 |
| Aggregate-II | Admixture-C | C II | HSDP | Plan 6 |
| Aggregate-III | Admixture-A | A III | CHP | Plan 7 |
| Aggregate-III | Admixture-B | B III | CHS | Plan 8 |
| Aggregate-III | Admixture-C | C III | CDP | Plan 9 |

Note: the abbreviation H means High, P means Permeability, S means Strength, DP means Drainage Promoting.

From the above 9 schemes, raw material combinations with different performance characteristics can be obtained. In 5 rainfall areas or different demand scenarios, detailed screening can be carried out according to the above schemes. For example, the fifth level rainfall area is located in the southeast coastal area. Taking Hainan as an example, its annual average rainfall is more than...
1639.00mm. Therefore, the selection of permeable materials in this area obviously tends to be highly permeable, while the demand for water storage performance is not large, so the drainage promotion scheme can be selected. According to Table 6, scheme 1 and scheme 3 can be selected in the pedestrian road system, while scheme 4, 5 and 6 can be selected in the light load vehicle road system. The rainfall area in Hainan is shown in Fig. 13.

Fig13. The fifth level rainfall area -- Taking Hainan as an example

4 Conclusion

In this study, the permeable brick with permeability rate of $6.22 \times 10^{-4}$ cm/s and the compressive strength is more than 60MPa was prepared by using aeolian sand and epoxy resin adhesive materials with particle size of 0.08mm-0.6mm. After in-depth study on the aggregate and admixture of permeable brick, the performance division methods were found. By using the geographic analysis software to divide the rainfall area in China, and combining the different rainfall demand with the material bank plan reasonably, a "Sponge City" water permeable brick component material compatibility optimization plan is formed according to the local conditions. The specific conclusions are as follows:

(1) The pore shape of permeable brick are three side pore and four side pore. The pore size is 30 μm-100 μm. The micron level pore can effectively prevent large particles from blocking and small particles from migrating in the brick body, and extend the service life of permeable brick;

(2) Aggregate can be divided into three types according to particle group parameters and properties, namely, high permeable HPA, comprehensive CA and high-strength HSA; Permeable brick admixture can be divided into three types, namely, high permeable type, high-strength type and drainage promoting type.

(3) China's "Sponge City" rainfall area is divided into five levels, each of which corresponds to nine different material compatibility optimization schemes.

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