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The Application of Rubber Aggregate-Combined Permeable Concrete Mixture in Sponge City Construction

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Abstract: Permeable concrete is a new type of pavement material, which can effectively improve the urban flood discharge system, and is of great significance to the construction of sponge city. In order to optimize the use effect of permeable concrete and improve the application value of permeable concrete in permeable road engineering, the combination of rubber aggregate and permeable concrete is proposed, and the mix ratio of rubber permeable concrete mixture material is designed, which is applied to the engineering of pavement in Hunan Province, and its comprehensive pavement performance is analyzed and evaluated. The results show that the rubber permeable concrete has the best performance when the water cement ratio is 0.3, the designed porosity is 15%, the rubber particle size is 16 mesh, the rubber content is 15% and the coarse aggregate ratio is 4:6. The removal rates of suspended solids and metal pollutants are 0.65 and 0.72, respectively, which are increased by 0.23 and 0.19, respectively, compared with ordinary permeable concrete. This shows that rubber permeable concrete improves the ecological benefits of permeable concrete pavement, gives full play to the economic benefits of waste rubber products, reduces the construction cost of permeable concrete pavement, and provides assistance for promoting the construction of sponge city.

Keywords: rubber aggregate; permeable concrete; permeable road; sponge city

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1. Introduction

With the development of urbanization, the contradiction between urban water demand and urban water replenishment has become increasingly prominent. In order to solve the problems of water shortage, urban waterlogging and groundwater level decline caused by the water crisis, the concept of sponge city came into being [1]. The core of sponge city is urban rainwater management. Through the construction of urban infrastructure, rainwater can be stored when it rains and released when it is dry, so as to promote the comprehensive and effective utilization of rainwater and establish a “breathing city” [2,3]. Vincevica-Gaile and other scholars proposed to use industrial wastes and by-products as substitutes for traditional materials in view of the limitations of peatland soil on the implementation of sponge city construction projects, which successfully improved the stability of the soil [4]. Krauklis et al. believed that fiber-reinforced composites inject new vitality into the reinforcement market and are conducive to the protection of the ecological environment [5]. In the construction of sponge city, the improvement of surface permeability is one of the key steps, and the construction of permeable roads is very important. Permeable concrete, as an environmental load-reducing material, has good water permeability and climate adaptability, can absorb most of the surface precipitation, and effectively relieve the flood discharge pressure of the urban drainage system. At the same time, permeable concrete reduces the damage of hardened ground to the ecological environment, and more ground gaps can also absorb dust, which is conducive to reducing urban dust pollution and promoting a virtuous circle of regional ecology [6,7].

In the process of urbanization, a large number of waste tires have been produced in the field of automobile manufacturing. These waste rubber materials are difficult to degrade naturally, and incineration and landfill will do some harm to the environment. Many scholars have conducted plenty of research on its reuse. Mahmoud and other scholars aim to effectively improve the performance of wet rubber roof panels by adding super absorbent polymers to rubber and using free radical polymerization technology to synthesize them [8]. Milad et al. applied waste tire rubber powder to asphalt pavement construction and used it as asphalt modifier, successfully improving the comprehensive performance of asphalt pavement [9]. The addition of rubber aggregate in the preparation of concrete is conducive to improving the strength of concrete, enhancing its impact resistance and durability, and optimizing its comprehensive performance. However, in actual operation, the performance of pervious concrete is poor due to the change of rubber aggregate content and other factors. To improve the application value of rubber aggregate in permeable concrete, this paper takes a pavement project in Hunan Province as an example to analyze the mix ratio of rubber permeable concrete mixture material, so as to improve the comprehensive performance of permeable concrete and provide reference for the preparation and application of green ecological concrete material. At the same time, it makes up for the lack of research on the combination of rubber and sponge city construction, and enriches the theoretical research on rubber concrete.

2. Construction Design of Pavement Engineering

2.1. Overview of Pavement Engineering

A ground engineering project in Hunan Province is a bicycle lane and hiking trail located in the urban area. The road runs from north to south, with a total length of 6014 m, a road width of 65 m, a ground elevation of 28.4–35.6 m and a relative height difference of 7.2 m. There are mainly lakes, farmland, ponds and vegetable fields along the road, with few mountains and relatively flat overall terrain. Miscellaneous fill is distributed on the surface of the project area, with yellow-brown and grayish yellow color, loose and slightly wet soil, mixed with a small amount of construction waste and domestic waste; Below it is clay, which is yellow-brown, black-gray and grayish-brown in color. The soil layer is thin, the soil is moist, and contains plant roots and a small amount of humus. By surveying the geological conditions along the line, it is found that the soil structure along the line is stable, the plant coverage is wide, the ecological environment is good, and there are no geological problems such as debris flow, landslide and collapse, and wind and sand. The climate of the surface project belongs to a continental mid-subtropical monsoon humid climate, with a hot summer and cold winter. The climate changes greatly during the year, and the annual average temperature is between 16–19 °C. The annual sunshine hours are about 1300–1700 h, concentrated in July–September, and the annual precipitation is about 1200–1500 mm, concentrated in spring and summer [10,11]. By observing the hydrological conditions along the surface engineering in the last three years, it is found that the main source of surface water is precipitation, which is mainly distributed in low-lying areas such as lakes, ponds and ditches. The accumulated water lasts for more than 15 years, and the average water depth and width are 1.8 and 0.2 m, respectively. Groundwater mainly comes from precipitation and surface water recharge, and its types are mainly pore-confined water and stagnant water. The buried depth of pore-confined water is 1.2–8.3 m, and the annual variation range of water level depth is 2.5–3.3 m, in which the highest water level depth and the lowest water level depth are 32 and 24.7 m, respectively, and they appear in summer and winter, respectively. Stagnant water mainly occurs in the upper clay layer, with strong permeability and poor water richness.

2.2. Construction Process

According to the geological and hydrological conditions of the pavement project, the construction scheme of permeable concrete pavement is selected, and through the comparative analysis between different construction schemes, the construction design is continuously adjusted to improve the feasibility and effectiveness of the construction scheme and promote the smooth development of permeable road construction. The development of pavement engineering projects should strictly abide by the building construction technology and specifications, such as the "Code for Load of Building Structures", "Technical Regulations for Application of Permeable Concrete Pavement in Hunan Province" and "Standards for Safety Inspection of Building Construction", and should reasonably arrange construction projects in the rainy season, and select appropriate mechanical equipment and temporary facilities to improve production efficiency and reduce production costs [12–15]. At the same time, leaders, managers and construction personnel are set up, in which managers play the role of coordination and command, not only to master the construction situation, but also to actively participate in the contact and coordination of relevant units, such as design, and adjust the construction plan in time. According to each step involved in the construction process, they also must set up corresponding management personnel, who should coordinate the cross construction between various types of work according to the relevant construction standards and specifications, adjust the construction technology and process, and ensure the safety of personnel and engineering quality in the construction process. Construction personnel are responsible for guiding site construction, supervising construction quality and checking construction safety. Because construction personnel play a vital role in the whole construction project, before carrying out construction, it is necessary to carry out skills training for all construction personnel, strengthen the cultivation of post responsibility consciousness of construction personnel, and lay the foundation for the smooth progress of the pavement project.

Before the construction of permeable roads, in order to confirm the construction site leveling and "three links and one leveling", after height difference measurement, angle measurement and distance measurement, the positions of middle pile and side pile are determined by lime powder, and the pile intervals in horizontal curve and straight line are 10 m and 20 m, respectively. The main elevation is controlled by setting elevation lines, and indicator piles are set up to ensure the safety and order of the construction site [16,17]. At the same time, the base construction has reached the elevation, all buried pipelines have been buried, and the base rolling has been completed. After determining the construction scope, the subbase should be cleaned manually to ensure its surface is clean. After setting protective measures around the subbase, the lower seal coat should be laid with hot asphalt. The asphalt must be heated to 150 °C and sprayed evenly on the subbase by the asphalt distributor. Aiming at the missing and oversprinkling parts, the uniformity of asphalt distribution is ensured by manual cleaning. In order to ensure the construction safety and completion effect of pavement engineering, the permeable concrete material is controlled by using a building formwork structure to reduce the external load of concrete material. In the process of erecting templates, the height difference between templates must not exceed 6 mm.

After the formwork is erected, the rubber aggregate permeable concrete material should be prepared, which is a key step in the pavement project construction. According to the way of adding rubber aggregate, the production of rubber asphalt can be divided into a dry process and a wet process. The difference between the two processes is reflected in the way the asphalt and rubber aggregate are combined. In the wet process, the rubber aggregate is directly added to the asphalt, and the concrete material is prepared by mixing. In the dry process, the rubber particles with large diameters are selected as the basic materials, and the combination of rubber and asphalt materials is achieved by spraying. Compared with the dry process, the wet process can improve the viscosity between asphalt and rubber, reduce the fatigue of concrete, and significantly improve the performance of concrete materials. Therefore, the preparation of rubber pervious concrete materials by wet process is studied, the forming process of rubber permeable concrete is shown in Figure 1.

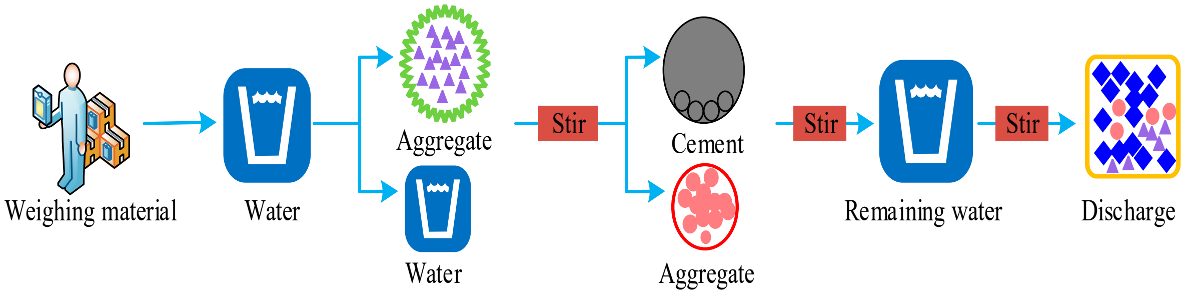


Figure 1. Forming process of rubber aggregate periodic concrete.

From Figure 1, the molding of rubber permeable concrete includes two links: feeding and mixing. Among them, the feeding should be carried out strictly according to the mixture ratio of permeable concrete materials, and the first feeding must be over-weighed to ensure the quality of concrete materials. Wet the mixing equipment with a small amount of water; then, put in aggregate and most of the water to stir for 30 s; then, put in cement and other aggregates to stir for 1 min and 30 s; finally, put in all the remaining water, and stir again for 90 s to discharge. The mixing of rubber aggregate permeable concrete must be completed by machine, not manually. The mixture must meet the conditions of uniform mixing, uniform color, grasping by hand and being able to form a ball without touching hands, which shows that the discharge effect meets the requirements.

The mixture shall be transported to the paving floor mat in time for paving, and the mixture shall be covered with striped cloth during transportation to avoid water loss. Mixed paving adopts short-section paving. In the paving process, slow and uniform paving should be ensured, and the paving coefficient should be 1.2 to ensure that the paving thickness is consistent with the design thickness [18,19]. After paving, tamp it and cover its surface with plastic film to ensure the compactness and strength of the permeable concrete. The permeable concrete base course is leveled and rolled by means of roller combined with manual screed. During leveling, the plate surface at the joint must be flat and the formwork surface clean. For the leakage of pressure, the manual feeding method should be adopted for leveling. After leveling and rolling, the concrete grinder is used for grinding operation. The grinding standard is that there is no slurry accumulation, the surface is flat and the rubber aggregate is evenly distributed. Due to the large gap of pervious concrete, paving, leveling and rolling operations should be carried out in the morning and evening to slow down the loss of water. Because of the large porosity of permeable concrete, its water volatilization speed is fast. In order to avoid the problem of material performance reduction caused by rapid hardening of cement paste, it is necessary to carry out sprinkler curing after the pouring of rubber aggregate permeable concrete road, which is based on the full coverage of plastic film [20–24]. The maintenance period is 1–2 weeks, watering and curing at least twice a day to keep the road surface moist. About 4 days after the porous concrete is dried and formed, the sealing agent shall be painted on its surface to avoid problems such as pore blockage caused by pollutants in the environment and improve the durability and aesthetics of the concrete. The construction process of permeable pavement engineering is shown in Figure 2.

From Figure 2, the construction of pavement project mainly includes two modules: pre-construction preparation and construction process quality control, in which pre-construction preparation includes the determination of construction principles, personnel, materials and equipment, and construction control includes eight steps, such as construction lofting, lower seal laying and formwork erection. Through the process design and quality control of the whole construction process, the smooth development of pavement engineering is promoted, and the pavement performance of permeable roads is guaranteed.

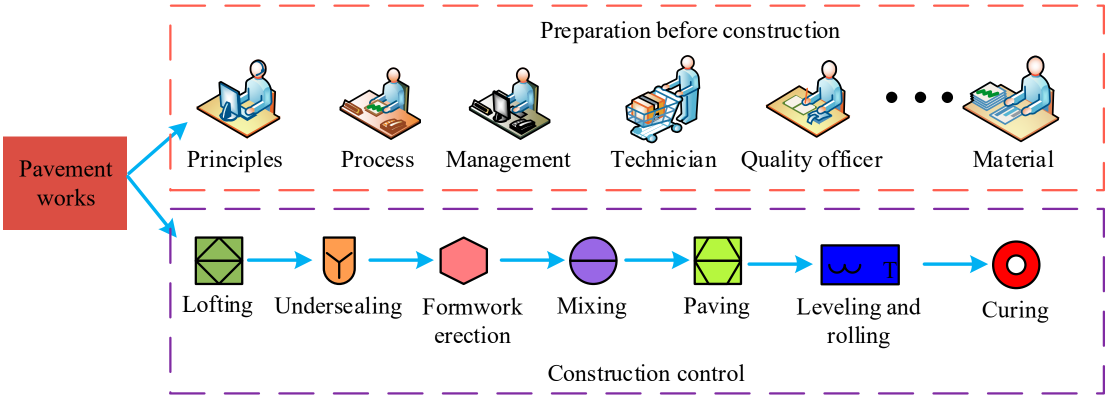


Figure 2. Construction process of pervious road payment works.

2.3. Selection of Raw Materials for Rubber Permeable Concrete

As a new type of concrete, rubber concrete treats waste rubber materials and mixes them into concrete as aggregates, giving full play to the advantages of rubber aggregates, such as high elasticity, good abrasion resistance, strong tear resistance and heat resistance; improving the shortcomings of pervious concrete, such as poor impact resistance, low strength and short life cycle; improving the use effect of pervious concrete materials, and promoting the protection of the urban ecological environment, and thus, promoting urban sustainable development. In the course of pavement project construction, different raw materials have different properties, which will affect the physical and mechanical properties, permeability and stability of permeable concrete, and directly determine the quality of pavement engineering. Therefore, according to the relevant standards and regulations, combined with the actual situation of the project, the pavement project should choose the appropriate mixing materials. Rubber permeable concrete material is mainly composed of water, cement, aggregate, admixture and reinforcing agent. According to the JGJ 63 standard of Concrete Water Standard, tap water is selected for the water needed in the process of mixing and curing of mixed materials [25]. The strength of cement in the mixed materials should not be less than 42.5 grade, and the storage and use of cement should be distinguished according to the standards of brand, grade and production date, and the phenomenon of cement mixing should not occur. According to the industrial standard “General Portland Cement” GB175 [26,27], P.042.5 ordinary Portland cement is selected for the pavement project, and its related indexes are tested by the GB1345-2005 negative pressure screen method and Reich method. The basic performance indexes of P.042.5 ordinary Portland cement are shown in Table 1.

From Table 1 that the standard consistency water consumption, setting time, stability, fineness and strength of P.042.5 ordinary Portland cement meet the construction requirements of pavement engineering projects, and can be used as raw materials of rubber aggregate permeable concrete.

According to the selection of rubber aggregate, the waste tires of a tire factory are used as raw materials, and crushed by crushing machinery. Different grades of rubber aggregate are separated by screening equipment, so as to improve the purity of rubber aggregate. After cleaning and dust removal, the rubber aggregate is black powder in appearance, its density is 1150 kg/m^3, its apparent density is 1106 kg/cm^3, its average particle size is 1.1 mm, its maximum particle size is 2.3 mm, and its water absorption rate is less than 10%. According to JT/T 797, the performance index of rubber aggregate was tested [28], and the physical and chemical technical indexes of rubber aggregate were obtained, as shown in Table 2.

Table 1. P.042.5 Basic performance indexes of ordinary Portland cement.

Test Items			Prescribed Standards	Detection Result		
Requirement of normal persistence (%)			/	26.8		
Setting time (min)	Initial setting time		≥45	196		
	Final setting time		≤600	354		
Stability			No bending and crack	Qualified		
Fineness (%)			≤10	3.3		
Strength (MPa)	Compressive strength	3D	≥16.0	18.9	19.5	21.7
				20.0		
		28d	≥32.5	43.9	46.5	41.8
				44.0		
	Flexural Strength	3D	≥3.5	4.9	4.6	5.0
				4.8		
		28d	≥5.5	6.8	6.5	6.3
				6.5		

Table 2. Physical and chemical technical indexes of rubber aggregate.

Test Items		Prescribed Standards	Detection Result
Chemical technical indicators	Carbon black content (%)	≥30	42
	Hydrocarbon content (%)	≥50	58
	Ash content (%)	≤9%	8
	Acetone extract (%)	≤18%	15
Physical and technical indicators	Water content (%)	<1	0.7
	Fiber content (%)	<1	0.6
	Metal content (%)	<0.04	0.026
	Relative density	1.09–1.35	1.25

The chemical technical indexes of rubber aggregate in Table 2, its carbon black content, hydrocarbon content, ash content and acetone extract all meet the requirements, and its physical technical indexes such as water content, fiber content, metal content and relative density value are also within the specified range, which indicates that the rubber aggregate can be used as raw material of rubber aggregate permeable concrete.

In view of the selection of coarse aggregate, because the coarse aggregate of rubber aggregate permeable concrete is required to be clean and free of foreign matter, have strong durability, hard texture and compact structure, limestone crushed stone is selected as the coarse aggregate in this pavement project, with a compact packing density of 1.704 g/m^3, an apparent density of 2.780 g/m^3, a soft stone content of 0.8% and a water absorption rate of 6.5%. The selection of fine aggregate needs to meet the conditions of dryness, cleanliness, purity and elegance. River sand is selected as fine aggregate in this pavement project, with a compact packing density of 1.549 g/m^3, an apparent density of 2.657 g/m^3, a maximum particle size of 5 mm, a light matter content of 0.9% and a water absorption rate of 7.6%. By observing the technical indexes of coarse aggregate and fine aggregate, it is found that both of them can meet the relevant standards such as JTG E42, which is suitable for the preparation of rubber aggregate permeable concrete [29–32].

After determining the raw materials of the rubber permeable concrete, it is necessary to design the mix ratio among the materials, which is one of the most important steps in pavement engineering construction. Different from traditional concrete materials, permeable concrete materials have higher requirements on the bonding thickness between aggregates and the content of cement paste. According to the "Technical Specification for Permeable Cement Concrete Pavement" CJJ/T135 and other relevant regulations and calculation standards, the parameters of mixture preparation are determined [33–36]. In unit volume of rubber pervious concrete, the cement paste dosage V_p is calculated as shown in Equation (1).

$$V_p = 1 - \beta \times (1 - \lambda_c) - R_{void} \tag{1}$$

In Equation (1), β, λ_c and R_{void} represent the control operator, the tightly packed porosity and the design porosity of the coarse aggregate, respectively. The cement consumption W_c and water consumption W_w per unit volume are calculated in Equation (2).

$$\begin{cases} W_c = V_p \times \frac{\alpha_c}{(R_{w/c}+1)} \\ W_w = W_c \times R_{w/c} \end{cases} \tag{2}$$

In Equation (2), α_c represents the mass of cement per unit volume, and $R_{w/c}$ represents the weight ratio of the amount of water and cement in the mixed material. On the basis of bulk density, the amount of coarse aggregate per unit volume, W_G is calculated as shown in Equation (3).

$$W_G = \gamma \times \delta_G \tag{3}$$

In Equation (3), γ represents the control coefficient, which is responsible for correcting the amount of coarse aggregate, and δ_G represents the bulk density of coarse aggregate. In order to ensure the construction quality of pavement engineering, it is necessary to test the specimens formed after the preparation of mixed materials. The evaluation indexes include the permeability coefficient, strength and porosity, which are used to test the permeability, mechanical properties and compactness of the specimens. According to the test method [33] specified in the GB/T50081 Standard for Test Methods of Physical and Mechanical Properties of Concrete, the calculation of the permeability coefficient K_T is shown in Equation (4).

$$K_T = \frac{QD}{SHt} \tag{4}$$

In Equation (4), t represents the time, Q represents the overflow water at t, S, H and D represent the surface area, water level difference and thickness of the specimen, respectively. The strength F_c of rubber pervious concrete is calculated as shown in Formula (5).

$$F_c = \frac{F_1}{A} \tag{5}$$

In Equation (5), F_1 represents the load of the specimen when it reaches the ultimate compressive strength, and A represents the area under pressure of the specimen. The calculation of porosity P is shown in Equation (6).

$$P = (1 - \frac{m_a - m_b}{\rho V}) \times 100\% \tag{6}$$

In Equation (6), ρ and V respectively represent the density of water and the volume of the specimen, while m_a and m_b respectively represent the mass of the specimen after drying and in water.

3. Quality Control of Rubber Permeable Concrete Pavement

3.1. Raw Material Proportion Design of Rubber Permeable Concrete

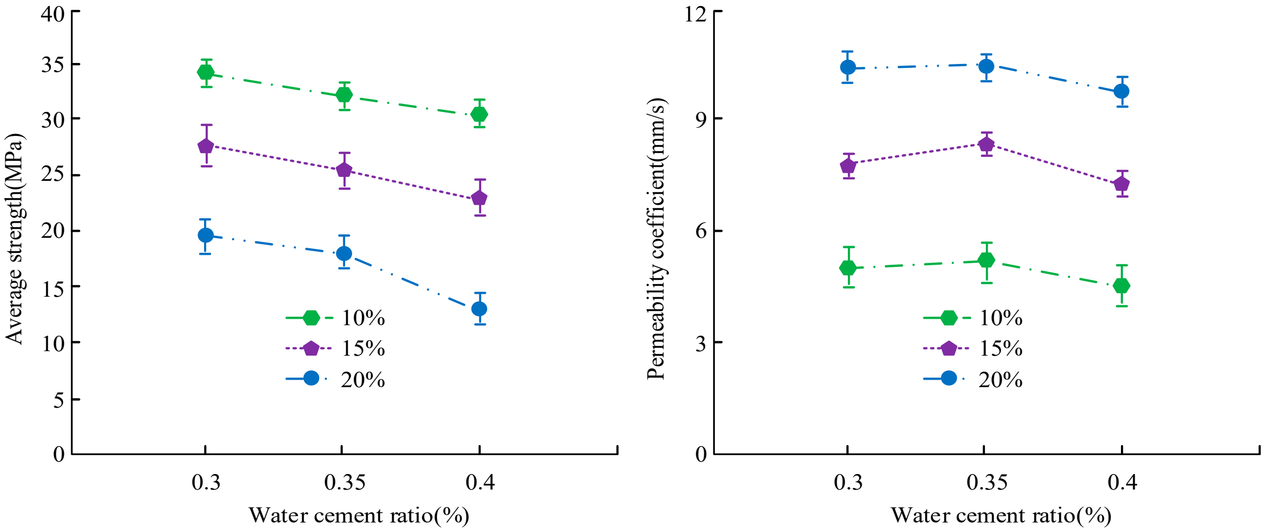
In the process of high-temperature mixing of rubber aggregate and asphalt, the rubber aggregate will undergo changes such as desulfurization and degradation, producing harmful substances such as polycyclic aromatic hydrocarbons. These harmful substances will enter the human body through the respiratory tract, skin and other channels, seriously endangering personal life safety. In order to improve the safety and availability of rubber concrete materials, the concentration of toxic chemicals in rubber concrete materials shall be controlled within 10% according to relevant standards to reduce the harm of rubber concrete materials to human beings and the environment. Three groups of experiments were designed to study the performance of rubber aggregate permeable concrete under the influence factors of water cement ratio, particle size and content of rubber aggregate and coarse aggregate ratio, which were represented by A, B and C, and the optimal mixture ratio design was determined through comparative analysis. The material dosage of unilateral rubber aggregate permeable concrete under each experimental setting is shown in Table 3.

Table 3. Material consumption of past concrete with one cubic meter of rubber aggregate.

Number	Water Cement Ratio (%)	Porosity (%)	Particle Size of Rubber Aggregate	Rubber Content (%)	Material Consumption (kg/m^3)			
					Rubber	Crushed Stone	Cement	Water
A1	0.3	10	16	15	50	1535	783	200
A2	0.3	15	16	15	50	1535	640	186
A3	0.3	20	16	15	50	1535	510	159
A4	0.35	10	16	15	50	1535	759	229
A5	0.35	15	16	15	50	1535	619	180
A6	0.35	20	16	15	50	1535	495	162
A7	0.4	10	16	15	50	1535	730	237
A8	0.4	15	16	15	50	1535	598	195
A9	0.4	20	16	15	50	1535	463	158
B1	0.3	15	16	0	19	1697	489	163
B2	0.3	15	16	5	16	1680	489	163
B3	0.3	15	16	10	34	1587	489	163
B4	0.3	15	16	15	51	1476	489	163
B5	0.3	15	35	0	18	1685	489	163
B6	0.3	15	35	5	15	1674	489	163
B7	0.3	15	35	10	33	1573	489	163
B8	0.3	15	35	15	50	1451	489	163
B9	0.3	15	80	0	17	1660	489	163
B10	0.3	15	80	5	14	1649	489	163
B11	0.3	15	80	10	31	1553	489	163
B12	0.3	15	80	15	49	1426	489	163
C1	0.3	15	16	15	50	1425	623	190
C2	0.3	15	16	15	50	1439	623	190
C3	0.3	15	16	15	50	1458	623	190

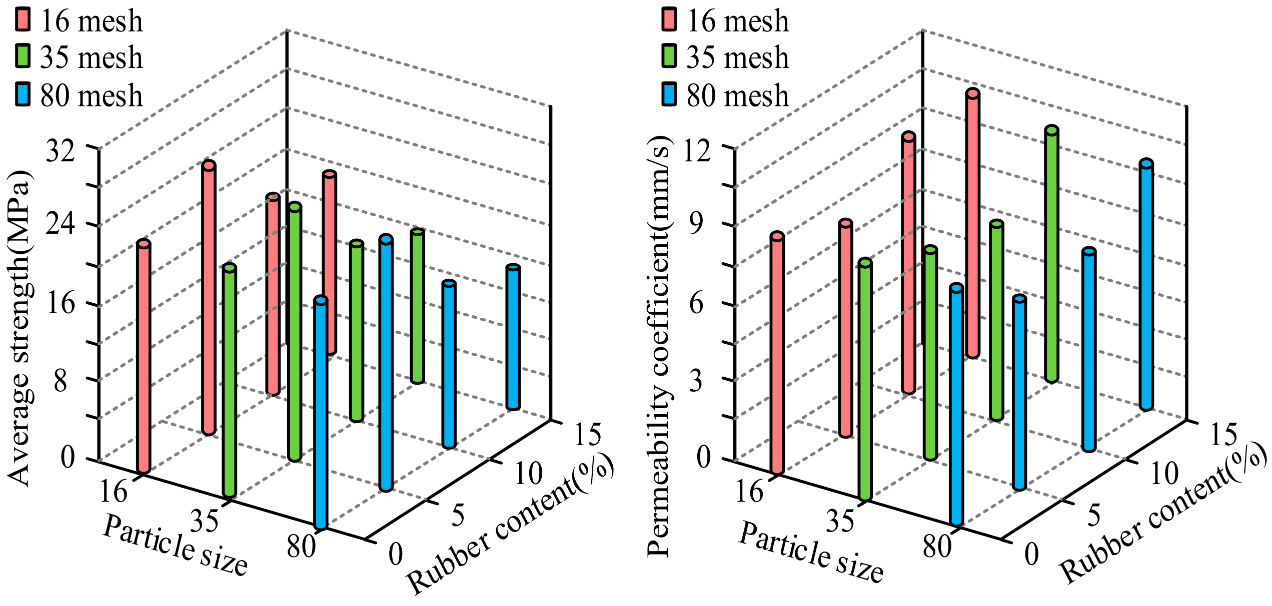
In the experiment of water-cement ratio affecting the performance of rubber permeable concrete in Table 3, the design porosity is 10%, 15% and 20%, and the water-cement ratio is 0.3, 0.35 and 0.4. In the experiment of the influence of rubber aggregate on properties, the porosity is 20%, the water cement ratio is 0.4, the rubber particle size is 16 mesh, 35 mesh and 80 mesh, and the rubber aggregate content is 0%, 5%, 10% and 15%. The ratio of 5–10 mm and 10–20 mm crushed stone is 3:7, 4:6 and 5:5 in the experiment of the influence of coarse aggregate ratio on the properties of the mixture. The performance pairs of specimens under different water cement ratios are shown in Figure 3.

In Figure 3, from the average strength point of view, with the increase of design porosity, the ability of rubber permeable concrete to resist deformation and fracture is also enhanced. At the same time, when the design porosity is the same, the strength is inversely proportional to the water-cement ratio. Taking the design porosity of 15% as an example, when the water-cement ratio is 0.3, the average strength of concrete reaches 27 MPa, which is 2 MPa higher than when the water-cement ratio is 0.4. From the perspective of the permeability coefficient, when the design porosity is 20%, the permeability coefficient of permeable concrete stays in the range of 9–12 mm/s, and reaches the highest among the three design porosities. It can be seen that when the water cement ratio is the same, the higher the design porosity, the stronger the water permeability of the material. Under the same design pore, the permeability coefficient of concrete tends to be stable, basically, with little change. It can be seen that the more internal the pore structure, the more the speed of the cement hydration reaction improves, and the further improved the strength of the concrete. Overall, when the water–cement ratio is 0.3 and the designed porosity is 15, the strength and water permeability of the test piece are higher, and the performance of the test piece is more stable than under other mixing conditions, which ensures the reliability of the pervious concrete. The performance of specimens with different rubber particle sizes and contents is shown in Figure 4.



(a) Average strength of test piece (b) Permeability coefficient of test piece

Figure 3. Performance comparison of test pieces under different water cementation ratio.



(a) Average strength of test piece (b) Permeability coefficient of test piece

Figure 4. Comparison of properties of test pieces with different rubber particle sizes and contents.

In Figure 4, under the same rubber content, when the rubber particle size is 16 mesh, the average strength and permeability coefficient of rubber permeable concrete are kept in the range of 20–28 MPa and 8–11 mm/s, respectively, and are the highest among several rubber particle sizes. When the rubber particle size is the same and the rubber content is 5%, the average strength of rubber permeable concrete is the highest, and the water permeability of concrete increases with the increase of the rubber content. When the rubber particle size is 16 mesh, the water permeability coefficient of the mixture with 15% rubber content exceeds 9 mm/s, which is 1.5 mm/s higher than with 5% rubber content. Rubber aggregate is similar to fine aggregate, which can improve the viscosity of slurry. However, rubber particle size that is too small will easily lead to pore blockage and reduce the water permeability of concrete. Overall, when the rubber particle size is 16 mesh and the rubber content is 15%, rubber aggregate can balance the strength and water permeability of concrete materials, avoid problems such as pore blockage and excessive void, improve the air permeability and water permeability of concrete materials, and its rubber permeable concrete has the best performance. The performance pairs of specimens with different coarse aggregate ratios are shown in Figure 5.

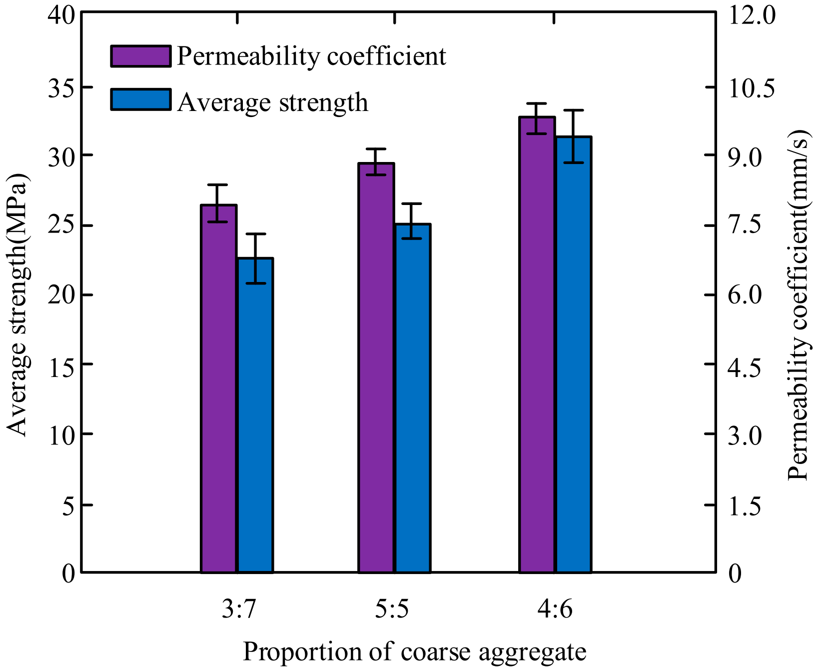
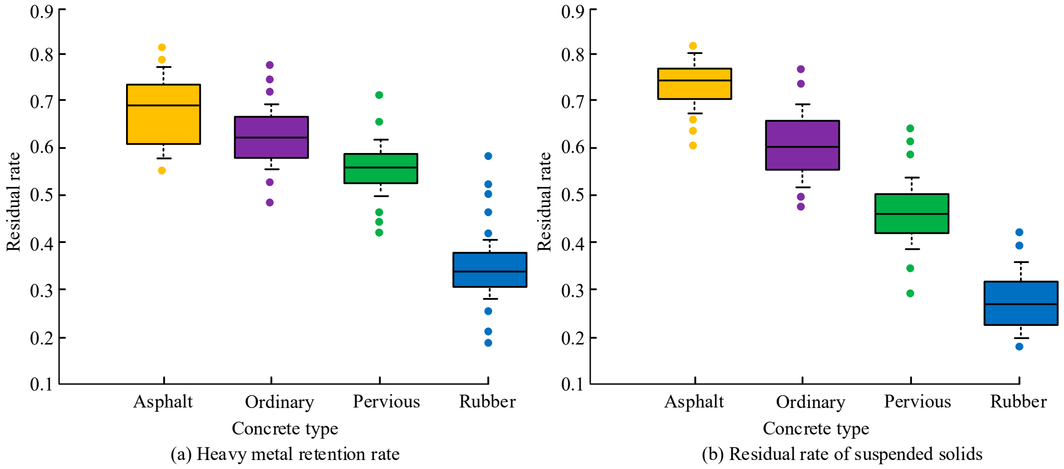


Figure 5. Performance comparison of specimens with different properties of coarse aggregate and coarse aggregate.

In Figure 5, when the ratio of coarse aggregate is 4:6, the comprehensive performance of rubber permeable concrete is the best, and its average strength reaches 32 MPa and its permeability coefficient reaches 9.3 mm/s, which is 6 MPa and 2.3 mm/s higher than that of rubber permeable concrete under the ratio of 3:7, respectively. It reaches the maximum among the three coarse aggregate proportions. When the proportion of coarse aggregate is 5:5, the comprehensive performance of rubber pervious concrete is better, but the average strength of the material is lower. It can be seen that the coarse aggregate with a large particle size plays an important role in improving the internal porosity of the material and lays a foundation for enhancing the permeability of the mixed material. However, coarse aggregate with a small particle size can strengthen the dependence among materials, especially cement paste. By improving the viscosity of mud filtrate, it can effectively prevent the phenomenon of mud plugging and avoid reducing the permeability of materials due to the sinking of cement paste.

3.2. Comprehensive Evaluation of Rubber Permeable Concrete Pavement

According to the raw material ratio experiment, a water–cement ratio of 0.3, designed porosity of 15%, rubber particle size of 16 mesh, rubber content of 15% and coarse aggregate ratio of 4 are the ideal measurements for rubber permeable concrete pavement. The preparation and construction of rubber permeable concrete materials are carried out according to the proportioning scheme of 6. Aiming at the comprehensive pavement performance test of rubber permeable concrete materials, the pavement surface temperature data were collected on 16 July 2020 to analyze the cooling performance of the mixed materials. The surface runoff water was collected, and the contents of suspended solids and heavy metal pollutants in the runoff water were obtained by water quality analyzer and Tianping instruments, and the purification performance of the mixed materials was analyzed. At the same time, asphalt concrete, ordinary concrete and permeable concrete were added as comparison. The retention rate of pollutants under different concrete types is shown in Figure 6.



(a) Heavy metal retention rate

(b) Residual rate of suspended solids

Figure 6. Comparison of pollutant retention rate under different concrete types.

From Figure 6, compared with other concrete types, rubber permeable concrete has a more significant purification effect on pollutants, the retention rate of heavy metals is about 0.35, and the retention rate of suspended solids is about 0.28, which is the lowest among all concrete types. Compared with ordinary pervious concrete, the retention rates of heavy metals and suspended solids decreased by 0.23 and 0.19, respectively. Among all concrete types, asphalt concrete has the worst purification effect, with the retention rates of heavy metals and suspended solids reaching 0.7 and 0.73, respectively, followed by ordinary concrete, with the retention rate of pollutants remaining around 0.6. It can be seen that rubber aggregate permeable concrete greatly improves the removal rate of heavy metals and suspended solids, reduces the content of pollutants in the air, and promotes the improvement of environmental quality. The temperature changes under different concrete types are shown in Figure 7.

In Figure 7, the surface temperature changes of the four kinds of concrete are consistent. In 0–15 points, the surface temperature of concrete rises continuously, reaches the maximum at 15 points, and then drops, and the temperature changes faster at night than during the day. From the overall temperature change speed, rubber aggregate permeable concrete speed change is the slowest, followed by permeable concrete. The largest temperature change range is asphalt concrete. From the temperature of each period, the highest surface temperature of rubber aggregate permeable concrete is 40 °C, and the maximum temperature difference is 13 °C. The highest surface temperature and the lowest surface temperature of permeable concrete are 45 and 27 °C, respectively. At the same time, the temperature of asphalt concrete is the highest, and its temperature difference also reaches the maximum, which is 30 °C. It can be seen that the temperature difference of rubber aggregate pervious concrete is the minimum in all periods, which indicates that it has a strong cooling function, can improve the high-temperature situation and alleviate the urban "heat island effect".

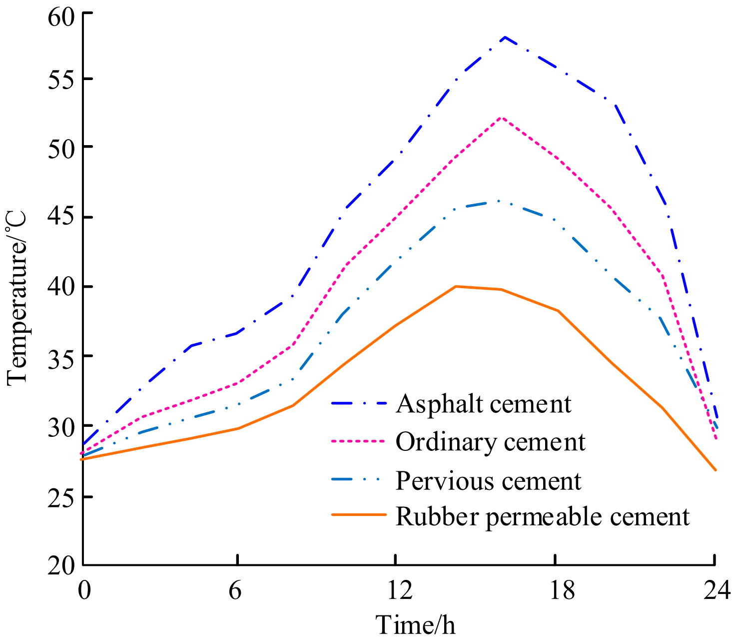


Figure 7. Comparison of temperature changes under different concrete types.

4. Conclusions

With the development of sponge city construction, permeable road, as an environment-friendly road type, has attracted more and more attention from the industry. In order to improve the comprehensive performance of permeable road, taking a pavement project in Hunan Province as an example, the preparation of rubber aggregate-combined permeable concrete mixture was designed and its performance was tested. In the mix design, when the water cement ratio is 0.3 and the designed porosity is 15%, the average strength and permeability coefficient of the specimen reach 27 MPa and 8 mm/s, respectively. When the rubber particle size is 16 mesh and the rubber content is 15%, the performance of the specimen is the best. The average strength is kept in the range of 20–28 MPa, and the permeability coefficient exceeds 9 mm/s. When the ratio of coarse aggregate is 4:6, the average strength of the specimen reaches 32 MPa, the permeability coefficient reaches 9.3 mm/s, and the bearing capacity and permeability of the specimen are the best. In the comprehensive performance test of pavement, the retention rates of pollutants under rubber permeable concrete reach 0.35 and 0.28, respectively, which are reduced by 0.23 and 0.19 respectively compared with ordinary permeable concrete. The maximum surface temperature difference is 13 °C, which is the smallest among the four concrete types. It can be seen that rubber permeable concrete can enhance the permeability of permeable concrete, improve the bearing capacity, improve the performance of permeable concrete, and provide support for promoting the improvement of environmental capacity in the region and the sustainable development of cities. Although the research has achieved some results, there are still some limitations: the study only applied rubber aggregate combined with permeable concrete mixture to urban pedestrian roads, ignoring the construction of urban traffic roads. In future research, it is necessary to further expand the application scope of mixed materials to provide reference for the construction of sponge city.

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