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Application of Porous Road Materials in Sponge City Construction

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To discuss the application of porous road materials in sponge city construction. The effect of porosity on mechanical properties was observed by an analysis of the porosity and mechanical properties of 5 groups of porous asphalt concrete test pieces at 15℃ and 20℃ respectively and by comparison of porosity and mechanical properties between these 5 groups. As porosity increases, the mechanical properties of test pieces decrease; as temperature rises, their mechanical properties decrease, too. This could be used for reference during material selection in subsequent sponge city construction. Porous road materials could act as the sponge in sponge city, and their selection is closely associated with their mechanical properties. In short-term application, these materials would contribute to drainage and sewage control; in long-term application, they would save on expenses and benefit to urban construction.

1. Introduction

Sponge city refers to a city that can be "elastic" like sponge under the influence of environmental changes and natural disasters. In rainy seasons, it can absorb, save, make infiltrate, and purify water (Liu et al., 2015). Then, it "releases" water for reuse whenever required. It makes the most of original terrain in rainwater saving, natural infiltration, water purification by vegetation and wetland. Measures such as sunken greenfield, permeable pavement, green roofs, and so on can significantly reduce "thermal island effect", urban flooding and runoff pollution (Li et al., 2017). Among these measures, permeable pavement creates an opportunity for porous road materials that have advantages of environmental protection, noise absorbing, multiple pores, light weight, air permeability and good water permeability (Wang, 2016). Porous road materials can be applied to waters and coasts of river, lake, seaside, etc. playing a part in sand stabilization, embankment reinforcement, and water and air permeability. Currently, porous road materials are frequently used in sponge city construction at home or abroad (Zhang, 2017). In this paper, we studied the porous asphalt concrete among porous road materials.

2. Literature Review

Currently, as economy develops, the urban built up area increases rapidly. At the same time, extreme weather occurs frequently and the urban storm sewer system bears an increasing stress (Li et al., 2017). Concomitant urban flooding and water pollution are common problems which most cities are faced with. Besides troubling citizens, these problems restrict economic development and test the governing capacity of governmental sectors (Lin et al., 2016). The Ministry of Housing and Urban-Rural Development published Technical Guidelines on Sponge City Construction—Low Impact Development Storm Sewer System Construction (on Trial) formally in November 2014, signifying that the sponge city had been one of national strategies (Li et al., 2017). The construction concept of sponge city—an integrated solution based on China's actual conditions—would contribute to solving many problems such as urban flooding and water saving in China (Zhang et al., 2017). Risks of urban storm sewer system and flood control project in defending disasters increase due to the high ground hardening, poor water permeability, changes in underlying surface, and rise in ground runoff coefficient of the urban built up area. One of the optimal choices to alleviate current road water-logging is to make rainwater infiltrate into the earth surface by means of porous road materials (Yu et al., 2017).

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Porous road construction alleviates urban ponding, taking roads as the support for drainage and water saving and breaking through the traditional urban storm water control system “centered on drainage” (Ren et al., 2017). Traditional pavement is made of non-porous materials, and rainwater can only infiltrate via sewer pipes. Since “water seepage” is one of the basic functions of sponge city, porous pavement is the best choice to alleviate poor storm water leading and to realize the low impact development storm sewer system. Moreover, the green material attribute of porous materials happens to coincide with the “green development” in “the 13th five-year plan”. Porous road materials will be of great application value in sponge city construction.

3. Method

For the experimental road asphalt, relative density is about 0.982g/cm3, and softening point and penetration index are in the allowable range. Experimental stones are limestone rubble in the laboratory, consisting of 5 gradations of particle graded crushed stones and a certain amount of fine aggregate such as mineral powder and fine sand. Their particle composition is given in Table 1.

Heat and stir the prepared stones and asphalt respectively 20 minutes by using the inter-laboratory asphalt mixer. Take them out. Compact the material 75 times by using CNC Marshall automatic compaction device. Then, make them into standard Marshall test pieces, of which the size should comply with the standard, minimum 4 in each group. After demolding, cool the test pieces down in water bath. Measure the cracks of demolded test pieces with HC-CK102 crack width gage. By comparison, it could be known that cracks are wider and wider with the increase of gradation. For test pieces with lower gradation, the crack width is mainly 1.00~1.10mm; for test pieces with higher gradation, the crack width is mainly 3.20~4.10mm.

Table 1: Aggregate Particle Grading Composition

Aggregate particle gradation					
Agglomerate Grain Mesh (round hole)/mm	5 kinds of gradation plan aggregate sieve margin /%				
	A	B	C	D	E
2.5~5	0	10	8	20	40
5~10	10	20	27	30	30

4. Results and discussion

4.1 Calculation of porosity of specimen

According to the above method, the experiment data of 5 groups of test pieces are summarized in Table 2.

Table 2: Specific experimental data

	Quality/g	After the water quality/g	Diameter/cm	Height/cm	Drainage quality/g	volume/m³	Porosity/%
A	546.1	602.3	10.258	4.615	220.6	381.405	27.4
B	545.4	603.1	10.256	4.615	228.5	380.183	24.7
C	545.3	608.2	10.260	4.608	235.4	380.976	21.7
D	545.6	613.8	10.236	4.640	242.1	383.846	19.2
E	545.7	616.9	10.220	4.648	260.8	381.292	12.9

In porosity measurement, considering the capillary pores where water cannot flow, weigh a test piece and record the value m1. Measure its diameter, height, and other lengths with vernier caliper. Calculate its volume V. Then, put thetest piece into the vacuoscope containing water. Under pressure, water would flow into capillary tubes, decreasing the error. Saturate the test piece in a vacuum saturator to make air out. 2h later, take it out of the saturator and drain off surface water. The criterion is that no water remains on the horizontal table when the test piece is taken away from it. Weigh the dry test piece by using a scale, and record the value m2. Then, put the test piece into a big measuring cylinder full of water. Measure the weight, m3, of water extruded. Porosityp=l-(m3+m2-m1)/V.

4.2 Calculation of mechanical properties

Since fatigue cracking is also one of the most common damages of bituminous pavement, researchers focus on the fatigue property of bituminous mixture at all times. During service, bituminous pavement withstands the wheel load repeatedly, so its stress or strain stays in a crossover changing state for long, decreasing the structural strength of pavement little by little. When the load action repeats certain times, the affected pavement will produce a stress exceeding the structural resistance of pavement after decrease in structure strength. Then, the bottom of pavement will present fatigue cracking. Under the continuous load action, cracks expand to the road surface and form fatigue cracks. In this paper, the mechanical properties of test piece and the compressive strength of bituminous mixture were determined through uniaxial compression test. For the formed 5 groups of test pieces with each gradation, the unconfined compressive strength test and compressive modulus test were done by using MTS-810 material testing system, in combination with optimal asphalt content, at 15℃ and20℃. Prior to the tests, the test pieces were preloaded with dual-wave type dynamic load 200 times, under a pressure of lkN. The loading time was 0.1s, and interval was 0.9s. When the result was stable, the triangle-wave type test load was applied. Loading speed: lkN/s; unloading rate: 5kN/s; loading interval: 30s.

4.3 Mechanical performance measurement results

The results of above uniaxial compression test are given in Table 3, 4, and the trend analysis of their changes is shown in Figure 1-4.

Table 3: 15℃ uniaxial compression test results

Porosity/%	Compressive strength/MPa	Compressive modulus/MPa
12.9	2.53	465.54
19.2	2.37	428.52
21.7	2.11	355.12
24.7	1.54	264.53
27.4	0.76	151.24

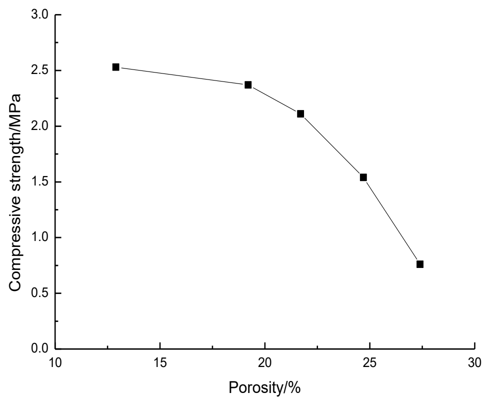

Figure 1: Relationship between porosity and compressive strength at 15℃

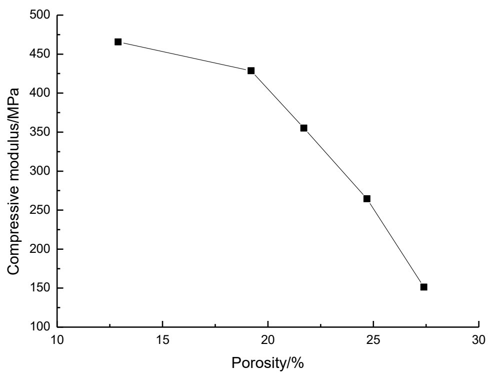

Figure 2: The relationship between porosity and compressive modulus at 15℃

Table 4: 20℃ uniaxial compression test results

Porosity/%	Compressive strength/MPa	Compressive modulus/MPa
20.9	2.35	442.52
21.8	2.16	408.35
22.3	1.72	332.12
24.5	1.36	240.54
26.8	0.54	132.48

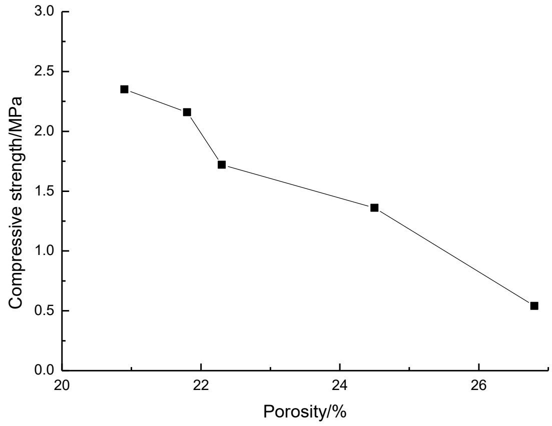

Figure 3: The relationship between porosity and compressive strength at 20℃

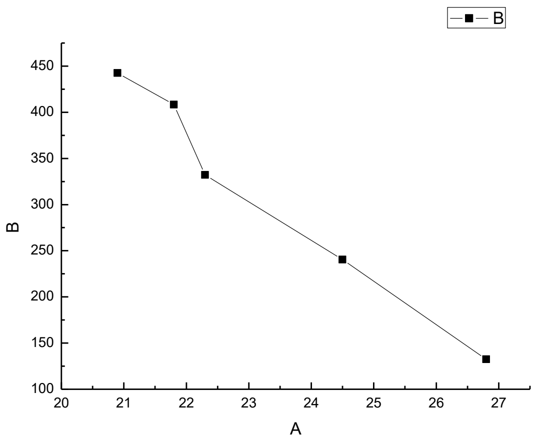

Figure 4: Relationship between porosity and compressive modulus at 20℃

From Table 3, Table 4, Figure 1, Figure 2, Figure 3 and Figure 4, it can be seen that water and air can only exist in the continuous channels of permeable bituminous mixture—a kind of porous bituminous mixture containing continuous pores. The porosity is closely associated with mechanical properties. As the experiment proves, with the adjustment in particle grading of aggregate, the porosity of plant-growing bituminous mixture increases, and its water permeability, compressive strength, fatigue property significantly decreases. Meanwhile, temperature rise makes the mechanical properties more unstable. As the temperature rises, the compressive strength and compressive modulus of test piece decrease, as shown in Figure 5 and 6.
As a step of experiment, the property comparison between 5 groups suggests that Group C is the best choice. In reality, the application of porous road materials will be influenced by many factors, and all these influence factors need be considered.

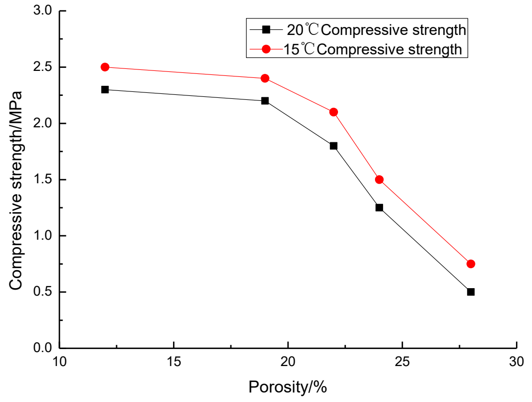

Figure 5: Relationship between porosity and compressive strength

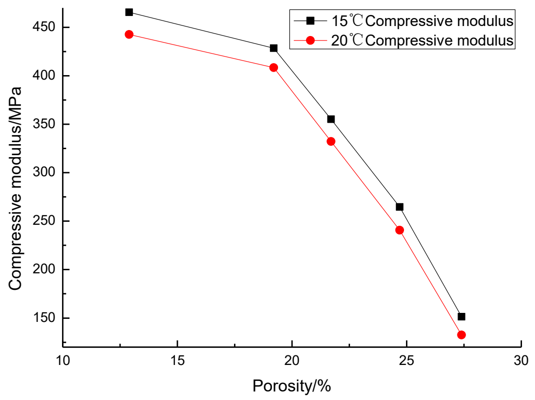

Figure 6: Relationship between porosity and compressive modulus

5. Conclusions

Porous road materials have a big advantage in low impact development of city and building of urban ecological balance. They can be used as the sponge in a sponge city and are intended for drainage and water-saving channels. As one of the large-area traffic facilities, roads play an immeasurable role in rainwater collection and digestion. Rainwater resources absorbed by road materials are available for secondary use, which is conducive to alleviating the current shortage of urban water resources. In short-term application, road materials would contribute to drainage and sewage control; in long term, they would cut down expenses and reduce construction of urban piping network.

However, porous materials still have some disadvantages, including poor stress property, contradiction between water permeability and stress property, etc. There is a big room for improvement. The drainage and water-logging prevention integrated planning involves lots of conditions, and it will be a big problem in the planned construction of sponge city in future. The research on porous road materials will focus on optimization of material gradation and selection of additives. The pore structure of asphalt is closely associated with its mechanical properties. How to complete the mechanical properties of asphalt with its structural strength assured, as well as the pore deposition treatment technique for porous bricks, the cost of sponge material, the production equipment technique, the maintenance of porous road materials, can become future research directions. Sponge city is not just a single structure, and porous road materials are one of its important links. Only if overall consideration is given to various projects, sponge city construction can come true, and a recycled urban ecosystem can be built.

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