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Porous Asphalt Pavement

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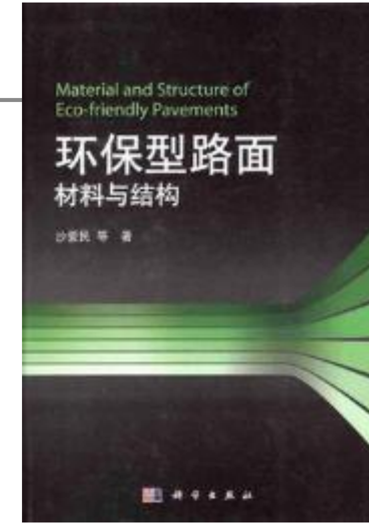
Introduction

Porous asphalt pavement is a special asphalt mixture with a void content of 18% or more, can allow stormwater runoff to penetrate inside the pavement.

OGFC	Open graded friction course	USA
PFC	Permeable friction course	USA（Texas）
PA	Porous asphalt	Most of Europe
DA	Drainage asphalt	Italy
OGA	Open graded asphalt	Canada, Australia
OGPA	Open graded porous asphalt	New Zealand
OPA	Open pore asphalt	Germany
ZOAB	Zeer open asphalt beton	Netherlands



Porous asphalt pavement

Rutting under heavy load, loose and raveling and pore clogging hinder its popularization and application in heavy-load and high-speed field.

	Coarse aggregate	Fine aggregate	Filler	Asphalt
AC	60%	30%	5%	5%
SMA	75%	15%	10%	6%
PA	84%	12%	4%	5%

AC

- Strength
- Stability
- Durability

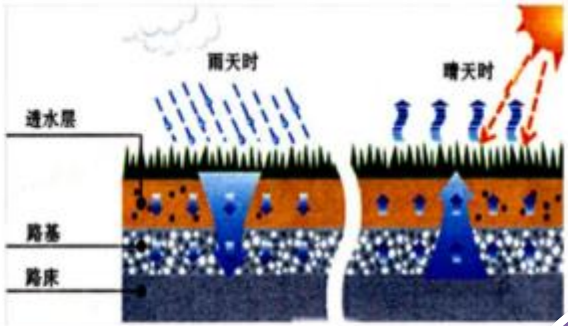
PA

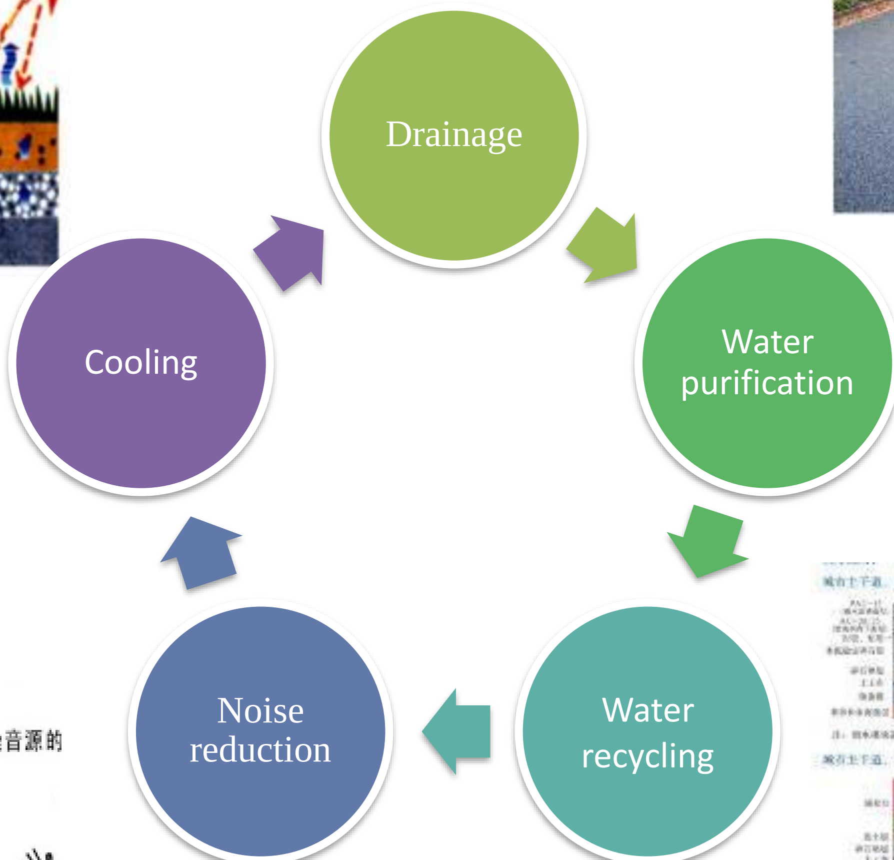
Need

- **Strong aggregate**
- **Better binder**

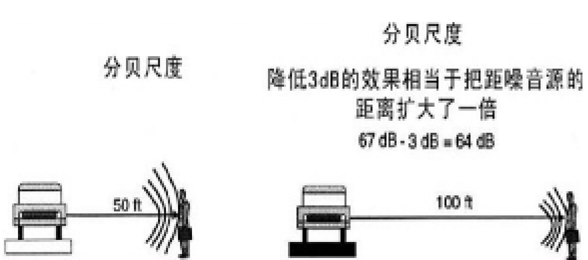
沙爱民. 环保型路面材料与结构[M]. 科学出版社, 2012.

Ecological function of Porous Asphalt Pavement





In China, porous asphalt pavement also be used as an effective method to alleviate stormwater runoff in Sponge City.



The Application of Red Mud as Filler in Porous Asphalt Pavement

Porous asphalt pavement

Current improvement methods

- **Excellent coarse aggregate**: mechanical properties and morphological parameters. (**high cost, difficult to achieve**)
- **Highly viscous modified asphalt**: improved adhesion, high temperature performance and aging resistance. (**High cost, energy waste** caused by rising compaction temperature, **poor workability, and shortened transportation distance**);
- **Porous Asphalt Mixture with Fine solid waste as filler**
  - ✓ Enhance performance
  - ✓ Lower cost
  - ✓ Reuse of waste

Red mud

- Red mud is a type of solid waste generated when the aluminum is produced by the Bayer process.
- In China, the production of 1-ton alumina will produce 0.8 ~ 1.5 ton red mud.
- In 2011, China's red mud output is about 70.0 million ton, what’ s more the cumulative stockpile is about 400 million ton.



Materials

TABLE 1 High Viscosity Asphalt Properties

Test item		Unit	Specifications	Results
Penetration@25℃,100g , 5s		0.1mm	20~40	38
Penetration Index		1	≥0.0	+0.17
Ductility@5℃, 5cm/min, cm		cm	≥20	22
Softening Point, $T_{R\&B}$		℃	≥82	93.5
Flash Point		℃	≥230	326
Solubility		%	≥99	99.8
Storage Stability@163℃, 48h, Difference between softening point		℃	≤2.5	2.0
Elastic Recovery@25℃		%	≥95	95.1
RTFOT Residue (163℃,85min)	Weight Change	%	±1.0	+0.01
	Ductility@5℃, 5cm/min	cm	≥15	16
	Penetration Ratio	%	≥70	73.7
Dynamic Viscosity @60℃		Pa·s	≥20000	709875
SHRP PG		1	PG 76-22	PG 76-22

TABLE 2 Limestone ore powder and red mud properties

Sample	Density (g/cm³)	Source	Chemical Composition (%，w/w)							
			Al_2O_3	SiO_2	Fe_2O_3	Na_2O	CaO	MgO	K_2O	TiO_2
Red Mud	2.97	Henan, China	44.82	28.07	6.91	0.19	0.60	0.48	2.75	2.80
Limestone ore powder	2.73	Shanghai, China	0.89	4.04	0.39	0.007	51.13	0.52	0.091	0.044

The Preparation of Asphalt Mortar

1. Asphalt binder was first heated up to 185℃ till it became liquid.
2. A corresponding amount of **filler** according to FB **was added in three times** with equal amount, while a 5-min shearing procedure using an agitator with a shearing rotor was applied at 185℃ after each adding; **the shearing speed is 4000r/min and the total shearing time is 15 minutes**.
3. Rheological properties of these mortar **should be tested immediately**.
4. To eliminate the effect of shearing procedure on the comparison of rheological properties between asphalt and asphalt mortar, the asphalt also was sheared at 185℃ with a speed of 4000r/min for 15 minutes.

Filler-bitumen ratio is weight ratio
Weight design method.

Methodology of Asphalt/Mortar

performance index	Evaluation Index	Standard/Method	Equipment
Viscosity	Viscosity	ASTM D4402	Brookfield viscometer
High temperature performance	$G^*/\sin\delta$; J_{nr} @3.2kPa	AASHTO TP 5/ AASHTO TP 70-10	Dynamic shear rheometer
Low temperature performance	S、m	AASHTO M320	Bending beam rheometer
Adhesion/Cohesion	Binder bond strength	AASHTO TP-91	Pull-off equipment

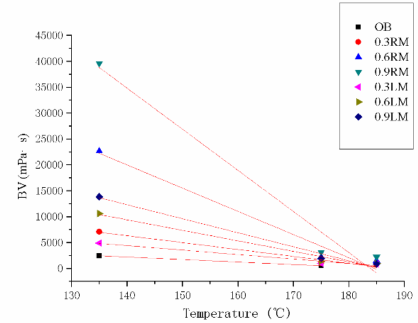
Brookfield viscometer

Dynamic shear rheometer

Bending beam rheometer

Binder bond strength test

Results and discussion (Mortar)



Item	OB	0.3RM	0.6RM	0.9RM	0.3LM	0.6LM	0.9LM
Number of Points	2	3	3	3	3	3	3
Degrees of Freedom	0	1	1	1	1	1	1
R-Square(COD)	1	0.98	0.98	0.99	0.98	0.97	0.97

FIGURE 1 Brookfield viscosity results of asphalt and asphalt mortar.

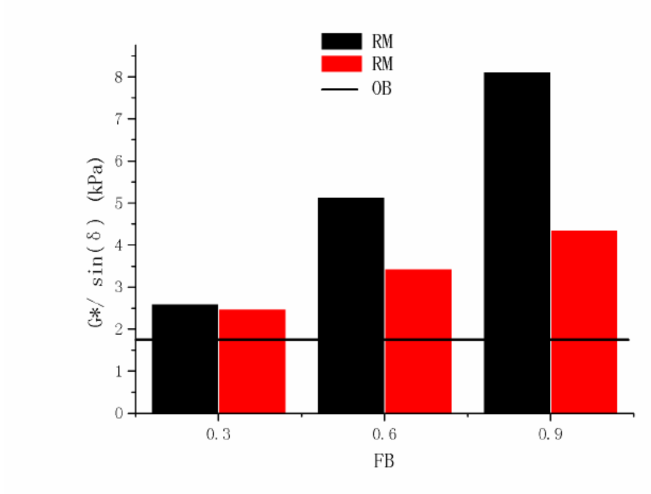
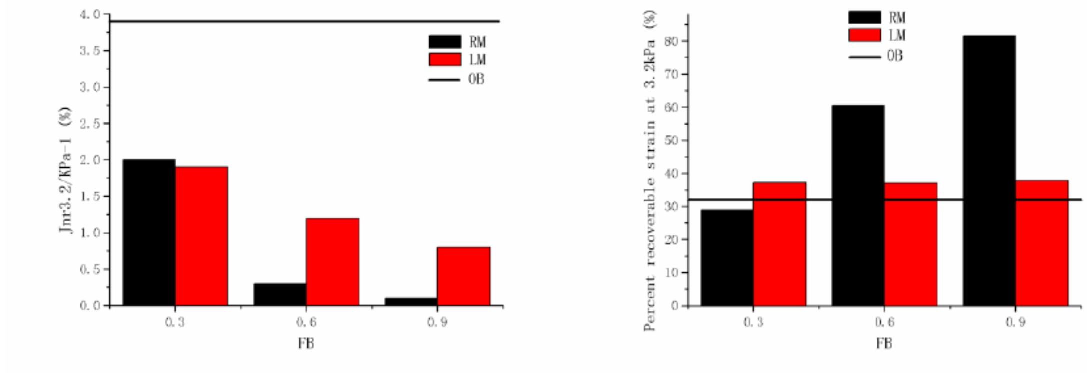


FIGURE 2 G*/ sin σ@82℃ of asphalt and asphalt mortar.

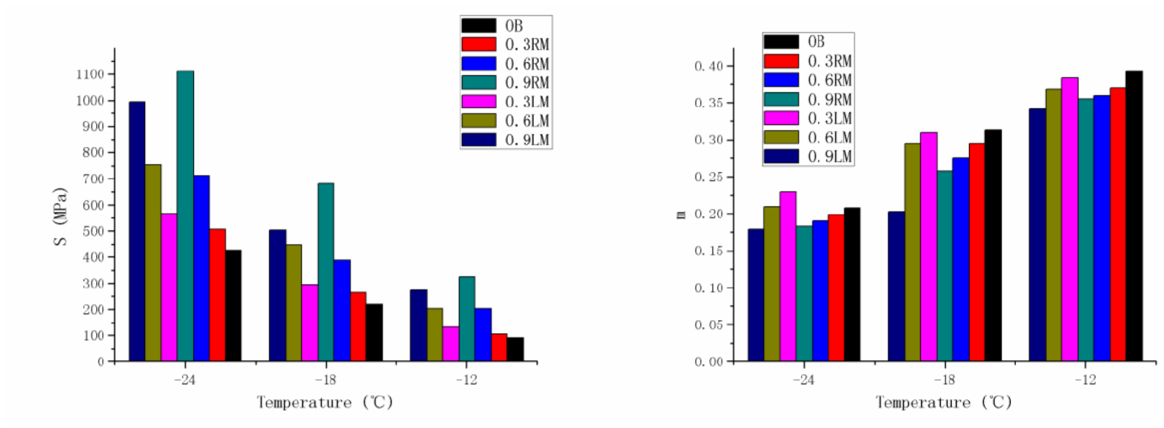


(a) (b)

FIGURE 3 MSCR test results of asphalt and asphalt mortar.

- From the perspective of viscosity, **the increase the filler-bitumen ratio** can lead to an increase to the viscosity, which will leads to **poor workability**
- Superpave high temperature binder criteria G*/sinδ and MSCR, exhibited that the **high temperature performance of the Red mud is better than that of the limestone filler.**

Results and discussion (Mortar)



(a)

(b)

FIGURE 4 BBR test results of asphalt and asphalt mortar.

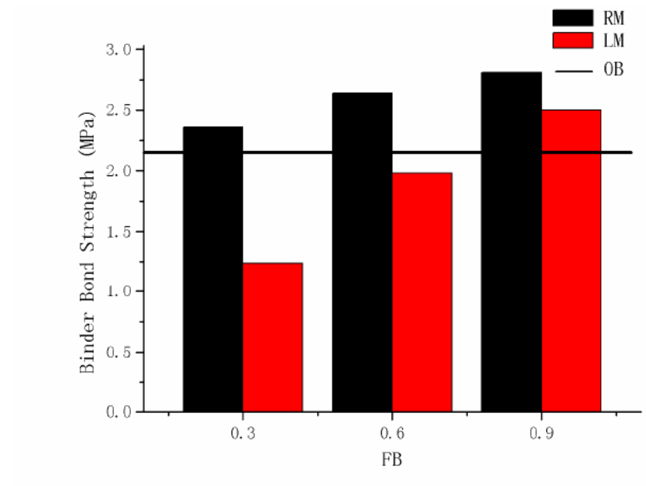


FIGURE 5 BBS test results of asphalt and asphalt mortar.

- With the increase of FB, both **LM (Motar with Limestone)** and **RM (Motar with Red mud)** will have a **larger S and smaller m**, which implies the **poor cracking resistance at low temperature**.
- However, when it comes to the low temperature performance comparison between RM and LM, **it is hard to draw a brief conclusion**.
- The bond strength improves with the increase of FB, **RM shows a better adhesion performance than that of LM**.

Results and discussion (Porous asphalt mixture)

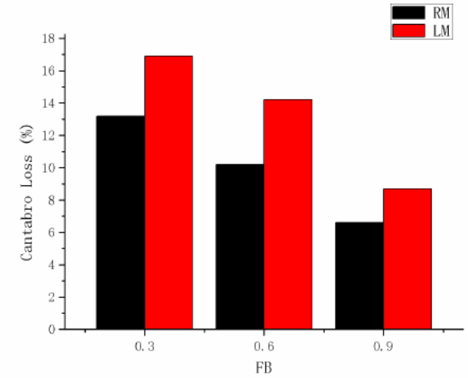


FIGURE 6 Standard Cantabro test results of PA mixture with different FB.

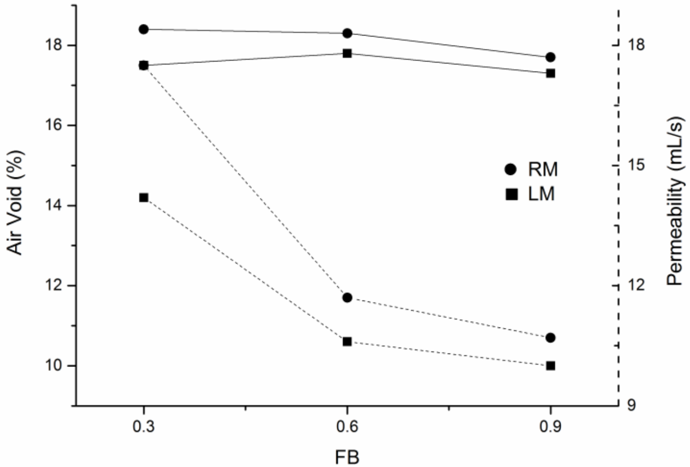


FIGURE 7 Air Void and Permeability test results of PA mixture with different FB.

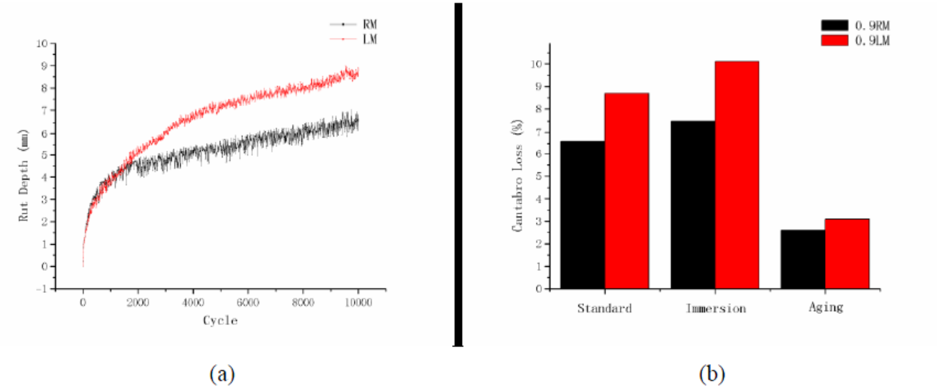


FIGURE 8 Hamburg Wheel Tracking test and three kinds of Cantabro test results of PA mixture with 0.9 FB.

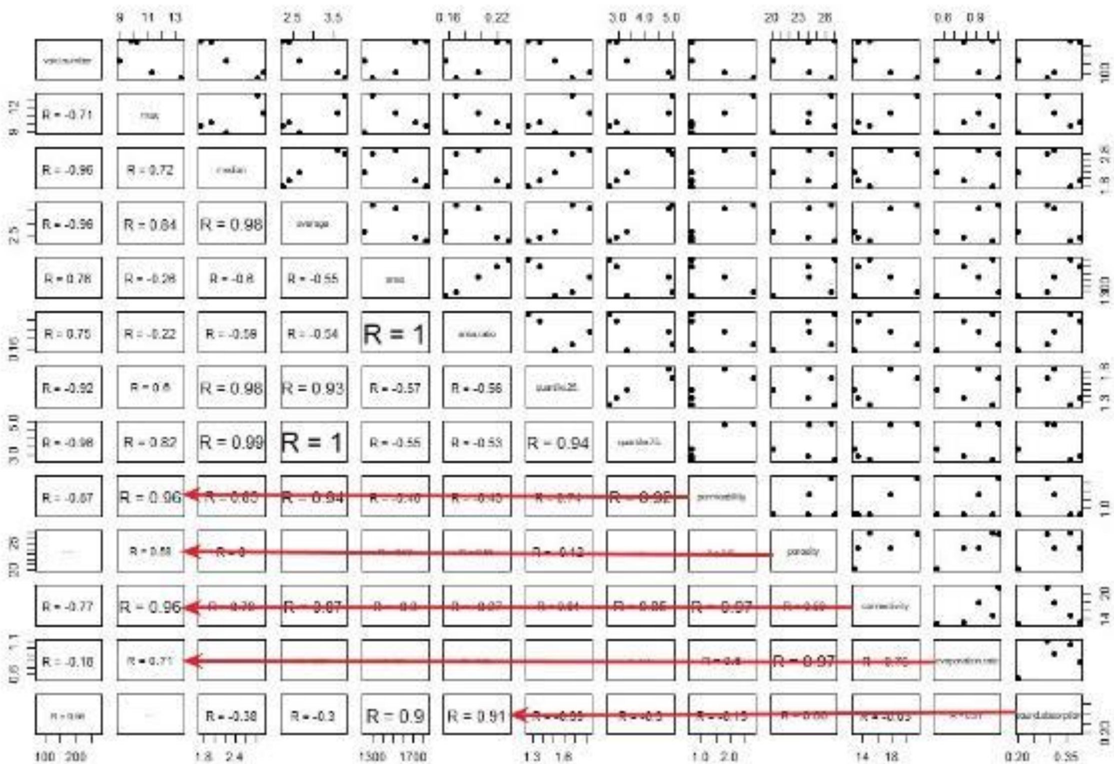
- With the increase of FB, the Cantabro Loss decreases gradually, **PA mixture with red mud as filler has better raveling resistance than that of limestone powder with the same FB** in this paper.
- **FB rarely affects the air void content** determined by volumetric method, **However, with the increase of FB, the permeability notably decreases.**
- When the **FB is 0.9**, **PA mixture with red mud shows a better rutting, moisture, raveling and aging resistance than that of PA mixture with lime powder.**

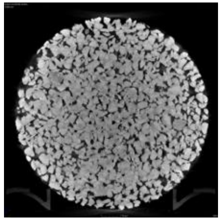
Hengji Zhang, **Hui Li***, et al. Performance enhancement of porous asphalt pavement using **red mud** as alternative filler[J]. Construction and Building Materials, 2018:707–713. https://doi.org/10.1016/j.conbuildmat.2017.11.105

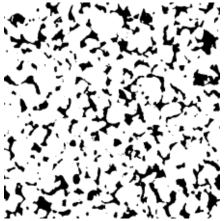
Effects of Pore Characteristics on The Performance of Porous Asphalt Pavement

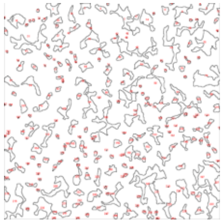
Correlation Analysis

Visualization of correlation by R studio: **environmental properties**

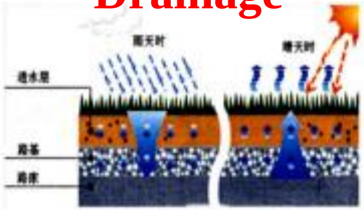




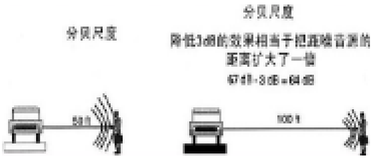




Drainage



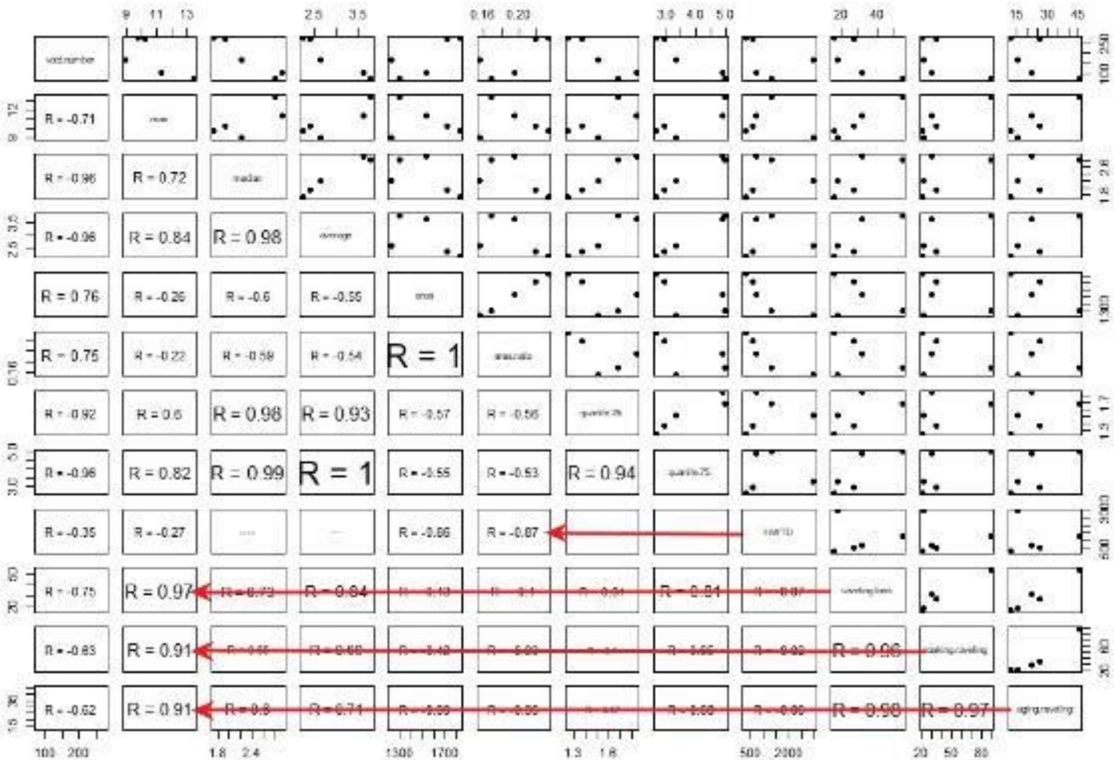
Cooling

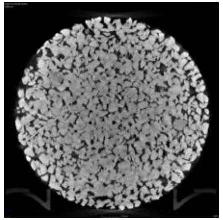


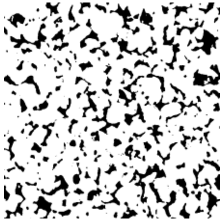
Noise reduction

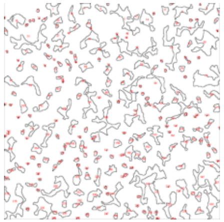
Correlation Analysis

Visualization of correlation by R studio: **mechanical properties**









Results and Discussion

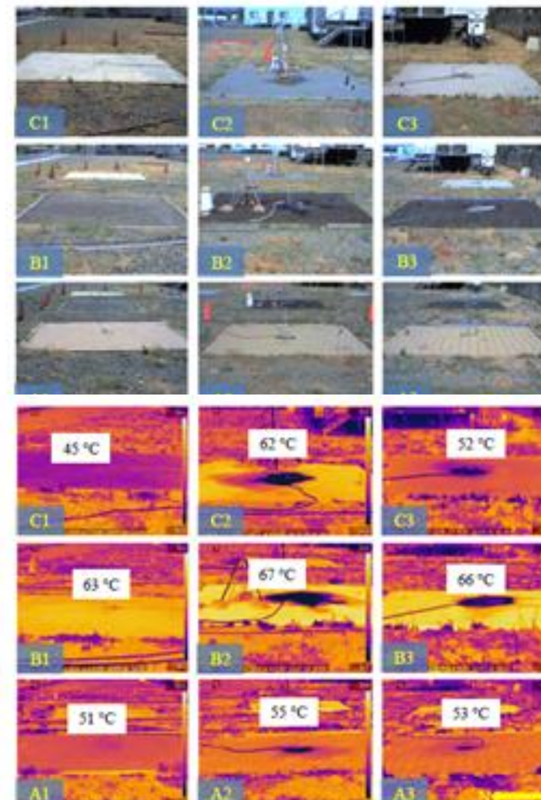
- As the **area ratio (porosity)** increases, the sound absorption coefficient of the mixtures increases. In other word, the bigger area ratio, the higher sound **absorption coefficient, the better noise reduction**.
- With the increase of **maximum equivalent diameter**, there is liner increasing trend of **evaporation rate and permeability**.
- With the increase of **area ratio**, there is **a risk on the resistance to moisture damage in high temperature**

Ecological Function of Permeable pavement

Cooling Function

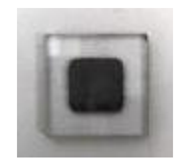
中度反射降温路面

适度**反射降温**
+
蒸发降温

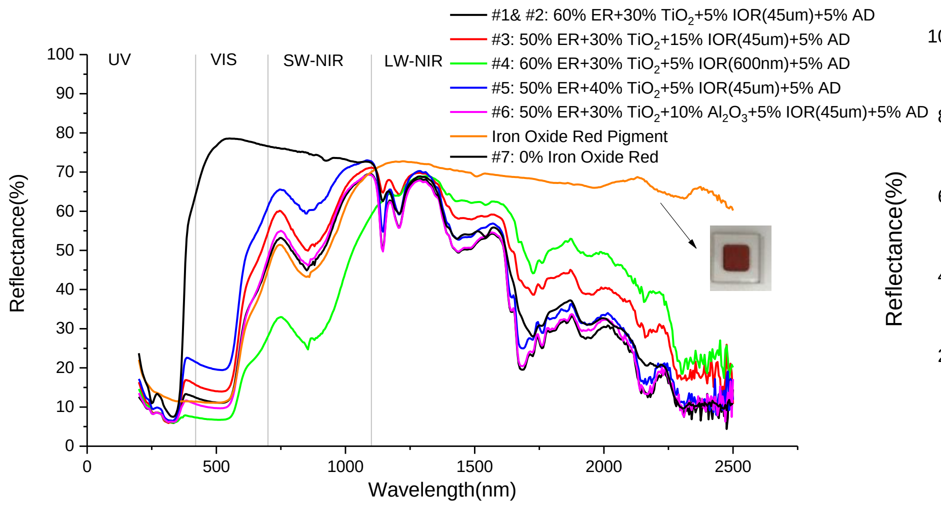


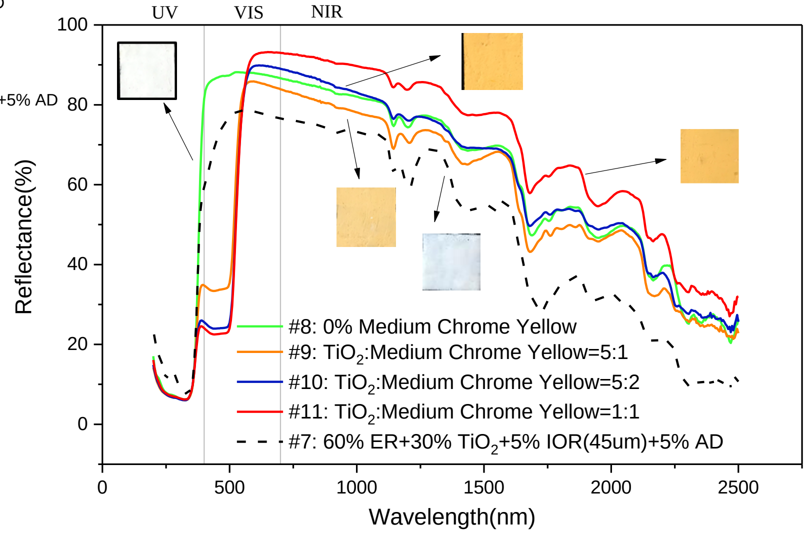
Li H., J. Harvey, P. Li and F. Li (2015). Pavement Treatment Practices and Dynamic Albedo Change of Urban Pavement Network in California (TRB 15-0079, Practice-Ready Paper). Transportation Research Board 94th Annual Meeting Compendium of Papers, Washington, D.C., Jan. 11-15, 2015.

Functional Pigment

Type	Color	Sample
二氧化钛Titanium Dioxide	白色	
二氧化硅Silicon Dioxide		
氧化铝 Aluminium Oxide		
氧化镍Nickel Oxide	黑色	
四氧化三铁 Ferriferrous Oxide		
三氧化二铁及其水合物 Ferric Oxide	蓝色	
	绿色	
	黄色	
	红色	
	灰色	

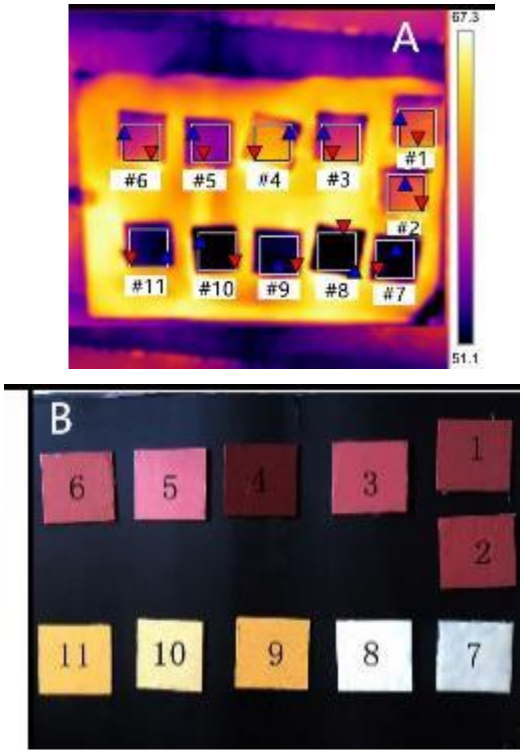
Optimal formulation based on optical properties

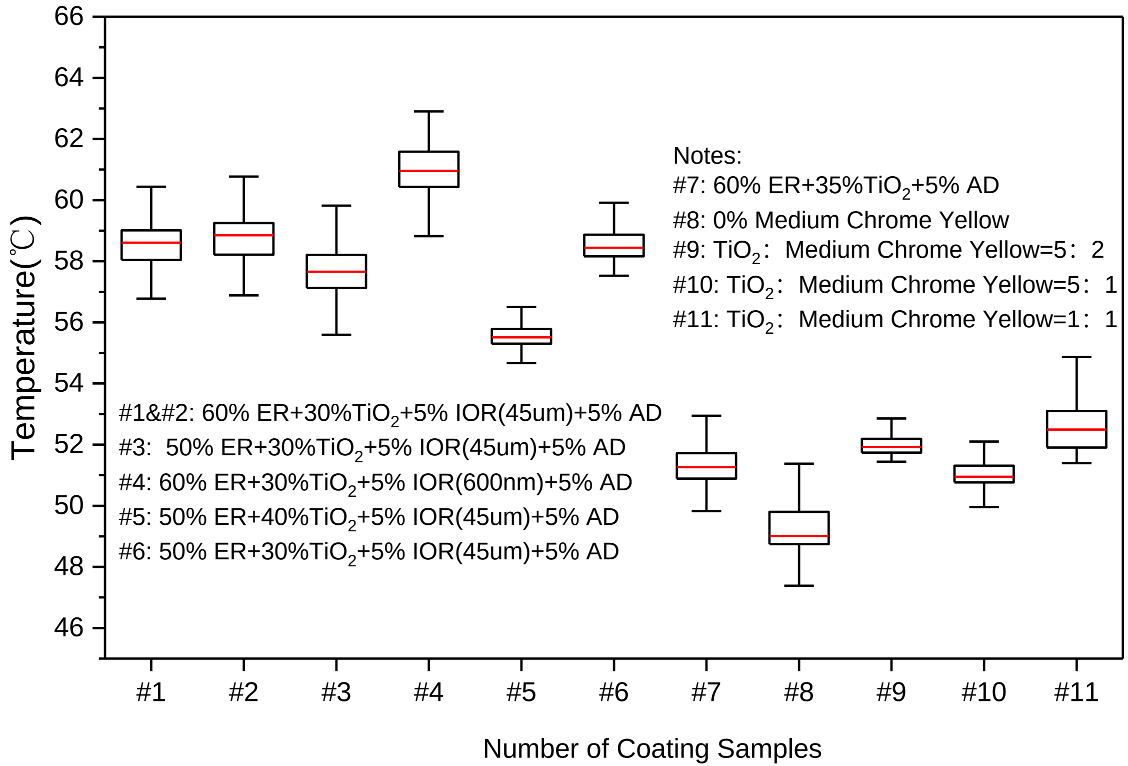




- Optimal formulation based on optical properties (% by mass)
- Silicone-acrylic emulsion 50%, functional pigment filler 40%, anhydrous ethanol 5%
- The additive (aqueous defoamer, polyurethane leveling agent, polycarboxylate sodium salt dispersant) has a mass percentage of 5%
- **Near-infrared reflectance reaches 86.2%**

Cooling performance

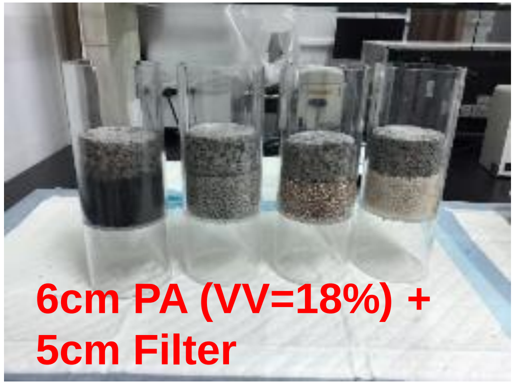


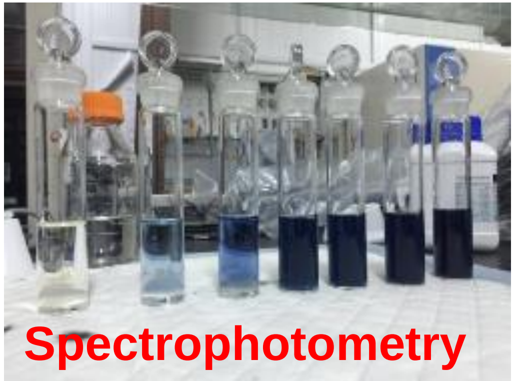


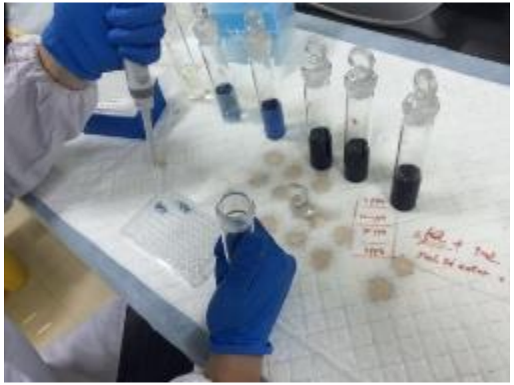
- **At noon time in summer, the temperature of the road surface can be reduced by up to 13 °C.**

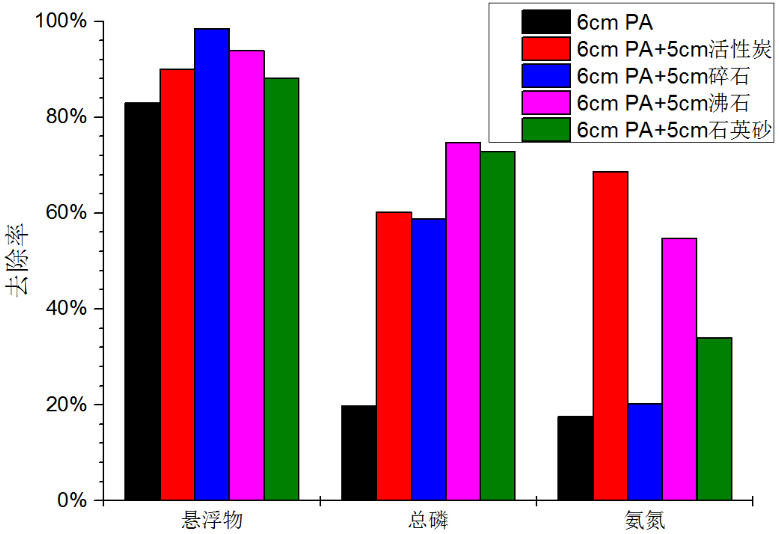
Ning Xie, **Hui Li***, Ahmed Abdelhady, John Harvey, Laboratorial investigation on optical and thermal properties of cool pavement nano-coatings for urban heat island mitigation,Building and Environment, 2019, 147(1), : 231-240.

Water Purification Performance of Porous Asphalt (PA)









- The removal rate of PA for **suspended solids** is over **80%**
- **PA has a low removal rate of ammonia nitrogen and total phosphorus in surface runoff, both less than 20%**
- PA+ **Zeolite** or PA+ **Activated Carbon** can stably **improve the water purification performance of PA**
- The PA+ Gravel can significantly improve the removal rate of total phosphorus, but the removal effect of ammonia nitrogen is not obvious

Thanks!

Q&A!

THANKS!

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