PURIFICATION ABILITY OF POROUS ASPHALT PAVEMENT

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ABSTRACT

PAP has widely used in Europe, the U.S, and Japan. As an effective technology for urban storm water management, PAP not only decreases storm water volumes but also improves runoff water quality including heavy metals, suspended solids (SS) and nutrients. In addition, it help protects groundwater and urban environment. In this paper the current trends of investigating the purification ability of PAP are introduced. The characteristics, the pavement structures and materials are analyzed. The recent researches in field studies and laboratory experiments are highlighted. The present applications of and challenges to PAP are discussed. Further research needs are recommended. Grainstone, algal packstone, algal wackestone, and foraminifera wackestone are porous rock types, and echinoderm wackestone and mudstone are nonporous rock types. The types of pore structure in the study area can be divided into four types. Type I has midhigh porosity and medium-high permeability due to its large throat, while type II has a fine throat type with midhigh porosity and midpermeability.

Keywords: *Porous asphalt pavement (PAP), purification ability, suspended solids (SS), pavement structures.*

INTRODUCTION

The asphalt pavement has become the major type of road pavement due to fast road construction in last decades. According to reports, more than 90% of operated highways in China are asphalt pavements. And around 95% of roads in the UK are paved with asphalt mixtures. Traditionally, the design of asphalt pavement has focused on providing a strong, durable and safe driving condition for public traffic. Increasingly, however, climate change, urbanization and environmental deterioration brought some new problems (e.g. traffic noise, road water logging in rain, groundwater lowering and urban heat island effect) to urban development and city life. Meanwhile, road traffic is considered the main source of mostly pollutants (e.g. heavy metals, SS, chemical oxygen demand (COD)) in road runoff water [3, 4]. Usually, such contaminated runoff water flows fast over the impervious surfaces, and finally pours into the nature without any treatment. This results in an increase of pollution in surface water, soil, and groundwater. Besides the improvement of vehicles and urban environment, porous pavement appears to be a potential solution for urban storm water runoff management. And it is really a cost-effective means for decreasing storm water runoff quantity and increasing runoff water quality associated with urbanization in Europe, North America, Australia, and Japan. Therefore, many research institutions has devoted to study it, however, a few works were on its capability for water environmental benefits. With the increasing needs for environment-friendly highway, PAP is getting more and more attention in recent years. Therefore, this paper will summarize the recent important progress about the purification ability of PAP to runoff water.

In the research of Park and Tia, silica fume and fly ash were added into porous cement concrete which could provide attachment points for terrestrial and aquatic microbes, and it was found that porous concrete with smaller aggregate size and higher void content had better ability to remove TN and TP from test water; but with the extension of purification time, its water purification ability soon reached the limit. Therefore, as the porous cement concrete mainly depends on the purification mechanism of interception and filtration and absorption, it has certain effects on the purification of runoff but the result is not stable, and it cannot effectively remove various types of pollutants such as dissolved organic compounds.

LITERATURE REVIEW

Jianming Su (2022) Millions of tons of reclaimed asphalt pavement (RAP) and reclaimed aggregate or reclaimed inorganic binder stabilized aggregate (RAI) is produced every year in China. The cold recycled mixture (CRM) technology reduces fuel consumption, emissions, and cost and utilizes the high content of RAP. In this paper, six types of CRM with varying RAP/RAI composition and asphalt binders were investigated. The laboratory tests included strength indicators, high temperature stability, low temperature crack resistance, water stability, and dynamic modulus. A full-scale trial section was constructed after the laboratory tests. Except for low temperature failure strain without secondary compaction in the mixture design, test results illustrated that the performances of different CRMs met the specifications.

Abdullah M. Al-Shamrani (2021) The systematic behavior of porous asphalt pavement (PAP) under normal traffic conditions has been studied in detail in the present work. In the first phase, an observation program measured the stability by Marshall Test for all the prepared design mix samples with normal bitumen (60/70). For the permeability test in the second phase of observation, a model is developed in the laboratory on the same falling head permeability test. The maximum permeability reaches 0.394 cm/sec for a fresh sample and 0.245 cm/sec after one year of environmental exposure. The maximum stability was 26.9 kN, and the average value obtained was 21 kN. The present work approach provides effectively reliable results in terms of stability and permeability of porous asphalt mix.

Shi Dong (2021) Cold recycled mixtures with asphalt emulsion (CRMEs) are environmentally friendly and cost-effective materials widely used in asphalt pavement maintenance and rehabilitation (M&R). However, CRMEs exhibit lower mechanical performance and durability than hot-mix asphalt. This study aims to evaluate the effects of different modification approaches on the mechanical properties and durability of CRMEs. To this end, four optimal additives, including the rejuvenation agent (RA), basalt fibres (BFs), styrene–butadiene rubber (SBR) latex, and Buton rock asphalt (BRA), were added to CRMEs during the mixing procedure. Comprehensive laboratory tests including immersion splitting and freeze–thaw splitting tests, high-temperature rutting tests, low-temperature semi-circle bending tests, and indirect tensile fatigue tests were conducted to evaluate the mechanical properties of the modified CRMEs.

Chen Zhang (2020) Emulsified asphalt mixture has the characteristics of convenient construction and durable performance, but its poor early strength and demulsification seriously restrict the popularization and application of this material. At present, the coal gangue produced by coal-fired power plants is generally discarded, resulting in serious environmental pollution. The combination of coal gangue and emulsified asphalt can explore an efficient utilization way for more and more coal gangue and also solve the curing problem of asphalt. The water stability of coal gangue emulsified asphalt mixture is evaluated by the immersion Marshall tests. Finally, the strength formation mechanism of coal gangue emulsified asphalt mixture is analyzed from the microscopic point of view.

Rosangela Motta (2020) The rehabilitation process of asphalt pavements using the technique of milling and filling can cause several environmental problems due to either the disposal of the milled asphalt mix or the exploration of natural resources. One alternative to mitigate these impacts is to reuse this milled material, known as reclaimed asphalt pavement (RAP), in the construction of new pavement layers. Within the several available techniques to reuse the RAP, cold recycling using an emulsified asphalt-recycling agent has shown great potential. The aim of this study is to evaluate the application of a cold recycled asphalt mix using 100% RAP with an emulsified asphalt-recycling agent as a new pavement base course.

Porous Pavement

Porous pavement is a paved surface with a higher than normal percentage of air voids to allow water to pass through it and infiltrate into the subsoil. This porous surface replaces traditional pavement, allowing parking lot, driveway, and roadway runoff to infiltrate directly into the soil and receive water quality treatment. All permeable paving systems consist of a durable, load-bearing, pervious surface overlying a stone bed that stores rainwater before it infiltrates into the underlying soil. Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and manufactured "grass pavers" made of concrete or plastic. Permeable paving may be used for walkways, patios, plazas, driveways; parking stalls, and overflow parking areas.

Preparation of Porous Asphalt

Care must be taken in batching and placing porous asphalt. Unless batched and installed properly, porous pavement may have reduced exfiltration ability. At Walden Pond State Reservation, several of the areas paved with porous asphalt did not meet the target exfiltration rate. Cores were taken and it was found that the batches had more sand and/or asphalt than was specified, and those sections had to be removed and repaved. It is critical to minimize the amount of asphalt binder. Using greater amounts of asphalt binder could lead to a greater likelihood of "binder" or asphalt drawdown and clogging of voids. Sun light heating can liquefy the asphalt. The liquefied asphalt then drains into the voids, clogging them. Such clogging is not remedied by power washing and vacuuming. The topcoat in such instances needs to be scarified and resurfaced. The University of New Hampshire has prepared detailed specifications for preparing and installing porous asphalt that are intended to prevent asphalt problems.

Characteristics of PA

The purpose of PAP is to improve skid resistance, minimize hydroplaning, reduce splash and spray, improve visibility and lower frictional noise levels between the tire and the road surface by special purpose mixes under high-speed driving conditions.

Advantages: The first important advantage of PAP is improving the conditions of driving by decreasing the frictional noise and the traffic noise, reducing the traffic accidents, and both flows and volumes of road runoff remarkably during rainfall events.

Another important advantage of PAP is helping to protect water environment. It not only recharges groundwater, but also helps maintain urban water circulation. More importantly, it has the ability to improve runoff water quality by significantly decreasing SS, heavy metals, mineral oils, nutrients, and other soluble and anthropogenic pollutants.

In addition, PAP is good for urban development by reducing land use for traditional storm water management and decreasing impervious areas which are directly related to urban flooding and temperature increases. As a result, PAP can mitigate the urban heat island effect in summer.

Disadvantages: Low strength is the first disadvantage of PAP. It is the result of low contact area among aggregates due to big air void ratio and high concentration of large diameter aggregate. Short service life is the second disadvantage, compared to the traditional dense asphalt pavement due to clogging, stripping, and poor durability. It is prone to clogging usually within three years after installation, and has to be removed entirely and subsequently replaced if totally clogging. In addition, PAP is not desirable to deal with fuel pollution on/in road surface.

Narrow scope of application is another disadvantage. Because of special asphalt concrete, its application would be limited by traffic volumes, axle loads, and driving speeds. The loss of aggregate particles should be the main problem of porous asphalt concrete. If this problem can be solved, the service level of PAP will be greatly improved.

Porous Asphalt has other Applications

Porous asphalt surface mixes are also used by highway engineers but instead of putting it over a stone recharge bed, they use it as a thin surface layer on conventional highway pavements. Rainwater sinks directly into the surface and then hits the impermeable asphalt layer below forcing the water to drain off to the sides. Even in a driving rainstorm, splash and spray from trucks disappear. Visibility for drivers is so much better than crashes and fatalities can be greatly reduced. Although they are thin, these porous asphalt surfacings also improve water quality.

METHODOLOGY

Both artificial rainfall experiments and field monitoring are used in field studies to investigate the long term impact of PAP on runoff water quality and monitoring the relationships between rainfall and the runoff on road surface in the natural conditions. In field studies, the monitoring equipments (e.g. runoff water samplers, collection pipes and rain gauges) must be installed at each pavement section during its construction, resulting in unequal sampling/monitoring periods at each experiment. Both influent and effluent samples are collected on schedule. Water samples are transported to the laboratory for chemical analysis following the standardized methods. And the first volumes of effluent are required to collect for analyzing the initial effects. Herein, samples must be stored in refrigerators or on ice before chemical analysis. The procedure used to collect the samples complied with the Brazilian guide for water sample collection. The main recommendations are: (i) the collection bottle should be opened only at the time of use, for the time required to fill it, and be closed immediately after collection; (ii) the samples must be wrapped in a thermal box and sent to the laboratory in the shortest time possible; and (iii) the maximum time elapsing between the collection and the test must be 24 h. Furthermore, all boxes were sealed to prevent the infiltration of water through the lateral edges.

RESULT

Uniformity evaluation of test water

As shown in Table 1, the pollutants concentration of S1 and E1 are similar, indicating that the runoff water in the water storage container was uniform under the agitation of electric mixer.

Table 1 Pollutants concentration of S1 and E1

Test index	S1	E1
pH Value	7.17	7.16
Turbidity, NTU	9750	10600
SS, mg·L^{-1}	785	796
COD, mg· L^{-1}	532	501
BOD, mg· L^{-1}	218	228
NH_4-N, mg·L^{-1}	0.929	0.948
TN, mg·L^{-1}	10.3	11.6
TP, mg·L^{-1}	0.39	0.408
PP,mg·L^{-1}	0.87	0.77
AVO, mg· L^{-1}	6.69	6.08
Cu, mg·L^{-1}	0.06	0.05
Cd, mg·L^{-1}	0.00219	0.00192
Cr^{6+}, mg· L^{-1}	0.036	0.036
Cl^-, mg· L^{-1}	37.7	36.2

Filtration effect of PAP on pavement runoff

Pollutant concentrations in the pavement runoff samples before and after the PAP filtration are listed in Table 2 against different sampling time between 10min to 70min.

Table 2: Pollutants concentration of pavement runoff before and after infiltrated in PAP with different sampling time

Test index	S1	S2	S3	S4	S5	S6
pH Value	7.17	7.18	7.13	7.14	7.17	7.18
Turbidity, NTU	785	110	107	96	91	77
SS, mg· L^{-1}	9750	2500	2000	1900	1500	1250
COD, mg· L^{-1}	532	258	240	235	226	226
BOD, mg· L^{-1}	218	111	106	95.7	93.4	92.8
NH4-N, mg· L^{-1}	0.929	0.96	0.638	0.611	0.608	0.602
TN,	10.	10	10.6	10.7	10.9	10.6

$mg \cdot L^{-1}$	3					
TP, $mg \cdot L^{-1}$	0.39	0.371	0.326	0.307	0.297	0.271
PP, $mg \cdot L^{-1}$	0.87	ND 0.04[a]	ND 0.04	ND 0.04	ND 0.04	ND 0.04
AVO, $mg \cdot L^{-1}$	6.69	3.86	3.78	3.13	2.46	2.32
Cr^{6+}, $mg \cdot L^{-1}$	0.036	0.035	0.033	0.029	0.021	0.02
Cl^{-}, $mg \cdot L^{-1}$	37.7	38.2	37.4	36.2	36.2	35.2
Cu, $mg \cdot L^{-1}$	0.06	ND 0.05	ND 0.05	ND 0.05	ND 0.05	ND 0.05
Zn, $mg \cdot L^{-1}$	0.46	ND 0.05	ND 0.05	ND 0.05	ND 0.05	ND 0.05
Pb, $mg \cdot L^{-1}$	0.0427	ND 0.001	ND 0.001	ND 0.001	ND 0.001	ND 0.001
Cd, $mg \cdot L^{-1}$	0.00219	0.00100	0.00092	0.00065	0.00056	0.00038

a: ND represents Not Detected. The number after ND is the limit value that can be detected.

pH value

From Table 2, the water specimen shows no significant changes in the pH values before and after 231 infiltrating through PAP.

Suspended solid (SS)

SS concentration of pavement runoff before and after infiltrated in PAP with different sampling time. It was found that the SS concentration of pavement runoff decreased sharply by 86.0% after initial infiltrate in PAP, and continued to decrease but very slightly over sampling time. The total reduction was 90.1% with the sampling time at 70min. This is due to the fact that SS in pavement runoff mainly refers to the particle with grain size larger than 0.45μm. In the process of infiltrate, these particles were easy to be intercepted and adsorbed by PAP materials.

CONCLUSION

This study assessed porous asphalt pavement structures in order to evaluate their capability to reduce pollutants concentrations. As for phosphorus and aluminium, their concentrations exceeded the established limits; phosphorus concentration also exceeded the limit in the control. As for the analyses regarding storm water, there was no significant difference between the results for both models. The concentration of phosphorus, iron, aluminium, zinc, nitrite, chromium, and copper increased in comparison to the control. The pH value increased after storm water was filtered through the layers of the models. The concentrations only exceeded the limits for phosphorus and aluminium. Both models were capable of filtering and reducing the ammonia concentration. No odours in the rainwater and storm water were detected in comparison to the control. Also, no fecal coliforms were detected either in the rainwater or storm water tests. Additionally, for the implementation of porous asphalt pavements, it is important to avoid their proximity to potential sources of pollutants such as sewers, polluted rivers, and landfills.

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