EVALUATING THE POTENTIAL BENEFITS OF PERMEABLE PAVING SURFACES TO IMPROVE STORMWATER RUNOFF QUALITY

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By

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ABSTRAK

Asfalt berliang (PA) ialah ciptaan yang memberi manfaat kepada jurutera dengan kehadiran ruang udara yang berhubung yang membolehkan air larian menyusup, lalu mengurangkan kadar larian. Pengurangan ini membantu meminimumkan pengurangan kesan banjir kilat. Penyelidikan ini melihat potensi asfalt berliang sebagai lapisan permukaan jalan. Penggredan B Jabatan Kerja Raya (JKR) telah dipertimbangkan dalam kajian ini. Walau bagaimanapun, beberapa perubahan penggredan berdasarkan PA 16 Belanda telah dijalankan dan sampel campuran asfalt telah disediakan untuk menilai prestasi. Perubahan dalam peratus yang melepasi daripada 7.5% kepada 15% pada saiz ayak 2.36 mm menunjukkan nilai kestabilan yang lebih tinggi berbanding dengan penggredan asal. Had atas dan bawah kandungan pengikat untuk julat penggredan PA yang diubah daripada 4.3 hingga 5.7%. Kestabilan, kehilangan lelasan, dan hasil ujian saliran pengikat disahkan mengikut spesifikasi. Namun, kajian lanjut diperlukan untuk perbaiki kandungan lompang udara yang dicatatkan kurang daripada 18% lompang udara (15.66%) Sebagai alternatif, kajian ini juga berjaya menginovasi pembuat bata berongga mudah alih, yang menggalakkan penyusupan air melalui bata. Mesin berkuasa manusia ini menggunakan mekanisme penekan hidraulik yang memerlukan kerja minimum tetapi output daya yang besar untuk menghasilkan bata. Kajian ini juga memperkenalkan simulator aliran air skala makmal. Asfalt berliang digunakan sebagai lapisan permukaan untuk mengkaji kecekapan beberapa bahan penapisan terhadap penyingkiran logam iaitu plumbum, zink, kuprum, kadmium dan kromium. Sistem penapisan terdiri daripada tiga bahan alternatif iaitu karbon teraktif, tanah gambut dan batu kapur. Setiap bahan telah diuji kecekapan untuk kurangkan kandungan logam dalam air sintetik selepas tertakluk kepada penapisan. Karbon teraktif telah terbukti sebagai bahan paling berkesan dalam menyingkirkan logam yang kemudiannya diikuti oleh batu kapur dan tanah gambut.

ABSTRACT

Porous asphalt (PA) is an invention that benefited engineers due to the presence of interconnected air voids that allow stormwater runoff to infiltrate through, hence reducing the runoff volume. This reduction helped minimizing lowering the effect of flash flood. This research looked into the potential of porous asphalt as the surface materials. The Public Work Department (PWD) Gradation B was considered in this study. However, some alteration of the gradation based on Dutch PA 16 was carried out and asphalt mixtures samples were prepared to assess the performance. Change in percent passing from 7.5% to 15% at 2.36 mm sieve size showed higher stability value as compared to the original gradation. The upper and lower limits of design binder content for the modified PA gradation range from 4.3 to 5.7%. The stability, abrasion loss, and binder drain down tests results confirmed to the specifications. However, further study is required to improve the air voids content which recorded less than 18% air voids (15.6%) Alternatively, this study also successfully innovates the portable hollow brick maker, which promotes water infiltration through the brick. This man-powered machine used hydraulic press mechanism which required minimum work but greater force output to produce the brick. This study also introduced a laboratory scale water flow simulator. The porous asphalt was used as the surface layer to study the efficiency of a few filtration materials on removing heavy metals which are lead, zinc, copper, cadmium and chromium. The filtration system composed of three alternatives materials which are powdered activated carbon, peat soil and limestone. Each material has been tested on their efficiency on removing heavy metals in the synthetic water after subjected to filtration. Powdered activated carbon has been proven to be the most effective material in removing heavy metals which then followed by limestone and peat soil.

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INTRODUCTION

1.1 Background of Study

In a highly populated area, permeable pavement is considered as one of the cost-effective stormwater management strategies. Permeable pavements are environmentally friendly alternatives to typical impermeable asphalt and concrete pavements. Traditional urban stormwater controls are primarily concerned with swiftly draining runoff to avoid floods. However, upgrades to drainage facilities are either prohibitively expensive or ineffective in reducing combined sewer overflows caused by excessive rainwater runoff (W. Liu et al., 2020). During rainstorm events, interconnected empty gaps in the pavement allow water to penetrate a subterranean storage zone. The collected water infiltrates into the subsoil in places underlain by very permeable soils. Water can exit the pavement using an underdrain system in places with limited permeability soils. Exfiltrate refers to water that flows through and exits the pavement (Abustan et al., 2012). Permeable pavements with reservoir structures made of concrete paving stones allow for decentralized, long-term stormwater management and source control in metropolitan environments. Runoff from low-traffic roadways and parking lots, in particular, can be penetrated to assist groundwater recharge and relieve hydraulic stress in sewage systems, receiving waterways, and wastewater treatment facilities. Infiltration can aid in the restoration of the urban water cycle by enhancing groundwater recharge and evapotranspiration (Dierkes et al., 2002).

Nowadays, there are different types of permeable pavement that exist depending on their characteristics and application such as permeable concrete, porous asphalt, permeable interlocking concrete pavers, concrete grid pavers, and plastic grid pavers. The characteristics that have been considered are total pore space, spatial arrangement of underlying permeable layers, and structural strength (Abustan et al., 2012). Infiltration is gradually becoming a viable alternative to traditional drainage systems in a variety of infrastructure types. For example, permeable pavement (PP) is frequently utilized to reduce stormwater runoff while also enhancing soil infiltration and water storage.

According to Scholz (2014), permeable pavement systems have been established not only as a sustainable drainage solution but also as a technique for pollution management in areas utilized as roadways or parking lots, where contaminated water may permeate into the underlying soil. Because of the range of pollutants prevalent in urban stormwater, typical urban drainage infrastructures, which are designed to collect stormwater in pipes and move it away from urban areas in the shortest amount of time, appear to be unsuited for the purpose. Thus, one viable solution for mitigating the negative consequences of urbanization is the deployment of Low Impact Development (LID), which provides a sustainable and creative stormwater management technique. LID systems are made up of a succession of temporal storage facilities that are designed to replicate the site's pre-developed hydrological processes by infiltrating, filtering, storing, evaporating, and detaining runoff near its source. PP is one of these solutions that offer a good solution to stormwater management concerns in both quantitative and qualitative aspects (Turco et al., 2020).

In this study, several methods have been adopted in the context to improve the water quality. Certain materials are selected to study their effectiveness on their ability to reduce the heavy metals content of the stormwater runoff. They will form as a filtration system that combined with the permeable pavement system. From this combination, the stormwater runoff will experience a thorough filtration process when it is infiltrating the voids available within the porous structure.

1.2 Problem Statement

Flash flood occurrence are frequently occurred due to rapid urbanization that affects natural hydrological processes by increasing surface runoff, decreasing runoff infiltration, decreasing groundwater recharge, and degrading water environment quality due to increased impervious areas. Road pavement and other impermeable surfaces linked with vehicle movement, such as driveways and parking lots, account for up to 70% of urban impermeable land, and are all sources of increased drainage load (Suripin et al., 2018). Most of the rainwater is discharged into the urban drainage system and eventually into the river. During the rainy season, river flows become quite high, resulting in frequent flooding.

Furthermore, porous asphalt gradation needed some improvement for better performance in countering stormwater runoff issue. This is because the road surface influences the traffic safety especially during rainy season. For instance, hydroplaning may be resulted on the fast-moving traffic due to poor drainage system. Thus, it will eliminate the contact between the tire and the road surface (Hamzah et al., 2010). Interlocking bricks should also be innovated to have better infiltration ability and can be produced efficiently with the aid of apparatus with appropriate mechanisms applied.

Heavy metals, being one of the most major elements of stormwater pollutants, may have detrimental environmental effects when concentrations exceed guideline limits. Metals in solution can exist as free ions, soluble salts, coupled ions with dissolved inorganic or organic ligands, or as particulate debris (Sdiri et al., 2012). Capturing heavy metals prevalent in urban runoff before it enters receiving waterways is thus an important factor in the design of urban drainage systems. Metal-contaminated media remediation is a time-consuming and costly procedure. Chemical precipitation, ion exchange, and phytoextraction are three of the more prevalent techniques for metal reduction that have all been found to successfully remove metal ions from aqueous solutions. Alternatives need to be utilized to the permeable pavement system to have better filtration to improve runoff quality in terms of heavy metals.

1.3 Objectives

The main objectives of this study are:

i. To study the gradation of porous asphalt for stormwater runoff qualit.

ii. To develop permeable concrete brick mould for small-to-midsize enterprise (SME) uses.

iii. To assess the quality of synthetic water simulating stormwater runoff on road surface subjected to the filtration process.

1.4 Scope of Works

A study on stormwater runoff improvement by applying permeable pavement. There are two types of permeable pavement being studied in this research which are permeable interlocking bricks and porous asphalt. For the interlocking bricks production, an improvise mould is designed by using AutoCAD software and fabrication process is required. Preparation for porous asphalt will be according to JKR/SPJ/2008-S4.

Enhanced permeable pavement with the application of suitable filtration media is tested using rainfall simulator. The synthetic water is composed of five heavy metals solutions which are chromium, copper, zinc, cadmium and lead that is dissolved in tap water. The amount of each heavy metals' solution is controlled. Chemical properties of water are tested before and after mixing to determine the presence of heavy metals before dissolving and after dissolved.

1.5 Significance of Study

The significance of this study is it aligns with two Sustainable Development Goal (SDG). The first one is SDG 9 which in the scope of industry, innovation and infrastructure. Porous asphalt and permeable concrete bricks modification in this study can be considered as an innovation of infrastructure that can be implemented in the industry. Plus, the materials proposed in this study to improve water quality can overcome the issue for heavy metals remediation that are costly and time-consuming.

Then, the second is SDG 11 which focus on sustainable cities and communities. The permeable pavement involved in this study are among the Sustainable Drainage System (SuDS) because the infiltration ability they have can be an alternative method to replace the conventional drainage system.

1.6 Dissertation Outline

The dissertation for this project comprises of 5 chapters which are Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion. Chapter 1 of this dissertation provide a glance on the background of study, problem statements, objectives, scope of work and the dissertation outline for overall chapter.

Besides, Chapter 2 related to the research regarding the existing permeable pavement technology and the characteristics of porous asphalt need to be focused on such as air voids and gradation. The review of existing interlocking bricks application also discussed in this chapter.

Furthermore, Chapter 3 described about the methodology and procedures that will be conducted for this study. All samples preparation modifications are specified in order to avoid erroneous information during laboratory sessions. Each phase is covered in full, along with supplementary information on data gathering, analysis, and presentation.

Lastly, Chapter 4 related to the result obtained from the test conducted and discussed in detail. The discussion is offered in the form of a table, graph, and explanation of whether or not the desired outcome was accomplished. Achieved results must satisfy the research outcomes, demonstrating the study's effectiveness.

Chapter 5 concludes the overall achievement that fulfilled based on the objectives of this research. Suggestions and improvements are included as reference for those who are likely interested to conduct further study on this topic.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this Chapter 2, previous research conducted by other researchers that are correlated to this thesis issue will be more emphasized. Several studies on the application of permeable interlocking bricks and porous asphalt on mitigating stormwater runoff issues and improving runoff quality by each material will be specified in this chapter.

2.2 Permeable Interlocking Concrete Pavement

Previous research has shown that permeable interlocking concrete pavement (PICP) is one of the most effective forms of permeable pavement for urban units (e.g., parking lots and pathways) owing to decreases in runoff volume, peak flow, and the accompanying strain on drainage systems (Fu et al., 2020). The fundamental reason for the current increase in PICP in water-sensitive urban design (WSUD) and sustainable drainage system (SuDS) is their hydraulic qualities. Because of their high permeabilities and hydraulic conductivities, they encourage water penetration through the pavement rather than directing it to surface drainage systems (van Vuuren et al., 2022). Notably, the total volume and duration of rainfall have a considerable impact on the effectiveness of permeable brick pavement (Fu et al., 2020).

Stormwater is manageable with the application of this type of permeable pavement. They can hold between 5000 and 10,000 mm/h of rainwater and naturally discharge it at a much slower pace, depending on the design (Fu et al., 2020). Previous research has shown that PICP is one of the most effective forms of permeable pavements for urban units (e.g., parking lots and pathways) owing to decreases in runoff volume, peak flow, and the accompanying strain on drainage systems. According to one study, implementing permeable pavements and other source-control methods at small urban catchment sizes can lower peak flows and runoff volume by 14–45 % and 9–23 %, respectively (Fu et al., 2020). PICP surfaces are typically two-part layers made up of interlocking, dry-cast concrete units (bricks or blocks) with sand or fine gravel-sized material deposited in the joints between them. This substance, also known as jointing sand, is made out of sand or gravel that is devoid of particles smaller than 0.425 mm in size, which are referred to as "fines." The bricks of PICP are not porous, but rather structured in such a way that their geometry allows them to firmly interlock while yet leaving specified distances between them. Several examples of PICP can be illustrated in Figure 2.1. These gaps, together with the jointing material, create channels for water penetration into the pavement (van Vuuren et al., 2022).

Figure 2.1: PICP Test Cells (Cell A and Cell F laid with Aquaflow® pavers, Cell B, C, D, E, G, H laid with Permealock® pavers, and Cell I and Cell J laid with ‘traditional’ exposed pavers) (B. K. Liu and Armitage, 2020)

2.3 Porous Asphalt

Porous Asphalt (PA) was first created in the United Kingdom for use on airport runways to reduce hydroplaning and sliding caused by fast moving aircraft on wet runway pavements (Mohd Hasan et al., 2013). Porous asphalt is defined as a bituminous bonded mix with carefully selected grading and high-quality aggregates to produce an asphalt mix with 20% air spaces. The existence of continuous air spaces in the wearing course allows water to flow laterally through the mix, preventing ponding water (Hamzah et al., 2010) . PA was presented in the late 1960s as an environmentally sound approach to improve soil percolation, minimize floods, raise the water table, recharge aquifers, and reduce stormwater sewer loads (Hamzah et al., 2013). A study on the link between air voids and gradation was conducted, and it was concluded that adequate mixture air voids were vitally important in maintaining the drainage capacity of PA pavement, which in turn dictated the determination of aggregate gradation of asphalt mixes. The aggregate gradation and binder concentration of PA mixes played critical roles in extending their durability and hydraulic efficiency. It has been proposed that aggregates with bigger maximum diameter sizes formed mixes with higher coefficients of permeability (Mohd Hasan et al., 2013). To allow appropriate drainage within the porous asphalt layer, a minimum thickness of 50 mm is required. Only static steel wheel tandem rollers shall be used to compress porous asphalt. Vibratory rollers are prohibited because they produce excessive compaction and the risk of aggregate crushing. Pneumatic tyre rollers are prohibited because they knead and seal the surface, reducing the drainability of porous asphalt. They also cause aggregates that adhere to their tyres to be stripped. Three-wheel rollers are also prohibited because they create roller markings that are difficult to erase.

Based on the laboratory results from the adjusted gradation mixes, the accepted gradation should meet the following stormwater management standards. Firstly, minimum air voids of 16% to 22% (or more) are allowed to ensure the mix's permeability. When calculating the PA air voids, the volume by dimension must be established. Then, adequate binder content is essential for the mix's longevity. Lastly, In general, a maximum drain-down of 0.3 percent is authorised to determine the optimal quantity of binder acceptable for mixing, transporting, and laying (Hamzah et al., 2013). To increase the strength and durability of porous asphalt, additives have been frequently employed. Because hydrated lime improves moisture stability, it can be utilised in porous asphalt compositions in wet locations.

2.3.1 Gradation of Porous Asphalt

The gradation of the aggregate was a significant variable that influenced the performance of the combination. However, the aggregate gradation used also depends on the purpose of the pavement layer. For example, under wet conditions, a PA mixture is employed to assist surface water drainage (Mohd Hasan et al., 2013). The aggregate gradation and binder concentration of PA mixes played critical roles in extending their durability and hydraulic efficiency (Suresha et al., 2010). It has been proposed that aggregates with bigger maximum diameter sizes resulted in mixes with higher permeability coefficients (Cooley et al., 2002). A study on the link between air voids and gradation was conducted, and it was concluded that adequate mixture air voids were vitally important in maintaining the drainage capacity of PA pavement, which regulated the determination of aggregate gradation of the asphalt mixes (Mohd Hasan et al., 2013). Few research has been conducted to investigate the influence of porous asphalt concrete with nominal maximum aggregate size and aggregate gradation on pore properties from a microstructural standpoint. In general, coarse aggregates (more than 2.36 mm) are used to construct the skeletal structure of porous asphalt concrete, and asphalt mastic, which includes asphalt binder, mineral fillers, and fine particles, fills the pores generated by coarse aggregates. In this scenario, aggregate sizes and gradations are crucial for developing a combination that meets traffic loads and particular runoff requirements (Huang et al., 2020).

A study conducted by Huang et al., (2020) found that sieves of 2.36 mm and 4.75 mm are commonly regarded as crucial sieves because they have a significant impact on the air void volume in the mixture. Five kinds of commonly used porous asphalt concrete gradations are tested in the study which are PAC-5, PAC-10, PAC-13(1), PAC-13(2), and PAC-13(3) (Table 2.1). By referring to sieve size 2.36 mm and 4.75 mm, PAC-13(3) has the highest percentage passing. In Figure 2.2, PAC-5, PAC-10, and PAC-13(1) specimens with the same target air void content were compared, it was discovered that these three types of PAC specimens showed identical distribution characteristics along the specimen height direction. The mean proportion of linked pores to total pores grew significantly as the desired air void content increased for PAC-13(1), PAC-13(2), and PAC-13(3). From the study, in can be said that branching nodes in porous asphalt concrete appear to have a more uniform geographical distribution when the nominal maximum aggregate size or goal air void content is less. However, as the nominal maximum aggregate size or target air void content increases, so does the percentage of cross-linked nodes to total nodes. This research suggests that porous asphalt concrete with bigger nominal maximum aggregate sizes or goal air void content has a higher interconnectivity (Huang et al., 2020).

Table 2.1: Gradations of Porous Asphalt Concrete (PAC) with Different Maximum Aggregate Sizes and Air Void Contents (Huang et al., 2020)

Sieve Size (mm)	**Percentage Passing (%)**				
	PAC-5	**PAC-10**	**PAC-13(1)**	**PAC-13(2)**	**PAC-13(3)**
16	-	-	100	100	100
13.2	-	100	87	87	87
9.5	100	84.7	63.7	63.7	63.7
4.75	90	22.8	22	22	28.3
2.36	21.1	15.6	16.5	19.3	22.1
1.18	20	12.6	14	14	14
0.6	15.5	9.4	9.2	10.2	10.2
0.3	11.9	6.5	6.3	7.2	7.2
0.15	9.1	5.1	4.5	5.2	5.2
0.075	7	4.6	4	4.7	4.7
Asphalt binder (%)	6.3	5.7	5.67	5.8	5.9
Target air void content (%)	20	20	20	18	16

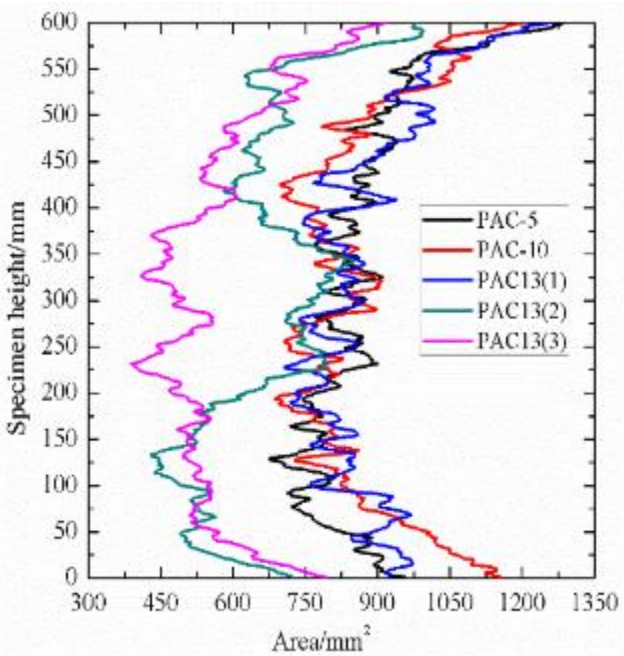

Figure 2.2: Area of Pores Along the Specimen Height Direction (Huang et al., 2020)

According to Suresha et al., (2010), aggregate gradations have a considerable impact on the voids in coarse aggregates and permeability of the compacted mix, whereas binder concentration has a large impact on the bulk specific gravity (G_{mb}), air voids (V_a), and unaged abrasion loss. There are several agencies providing the gradation that has been used for the study and industry purpose. In Figure 2.3, six gradations have been provided which include the Australian Asphaly Pavement Association (AAPA), Transit New Zealand (TNZ), American Society for Testing and Materials (ASTM), Southern African Bitumen Association (Sabita), Japan Highway Public Corporation (JHPC), and Federal Aviation Administration (FAA) (Suresha et al., 2010).

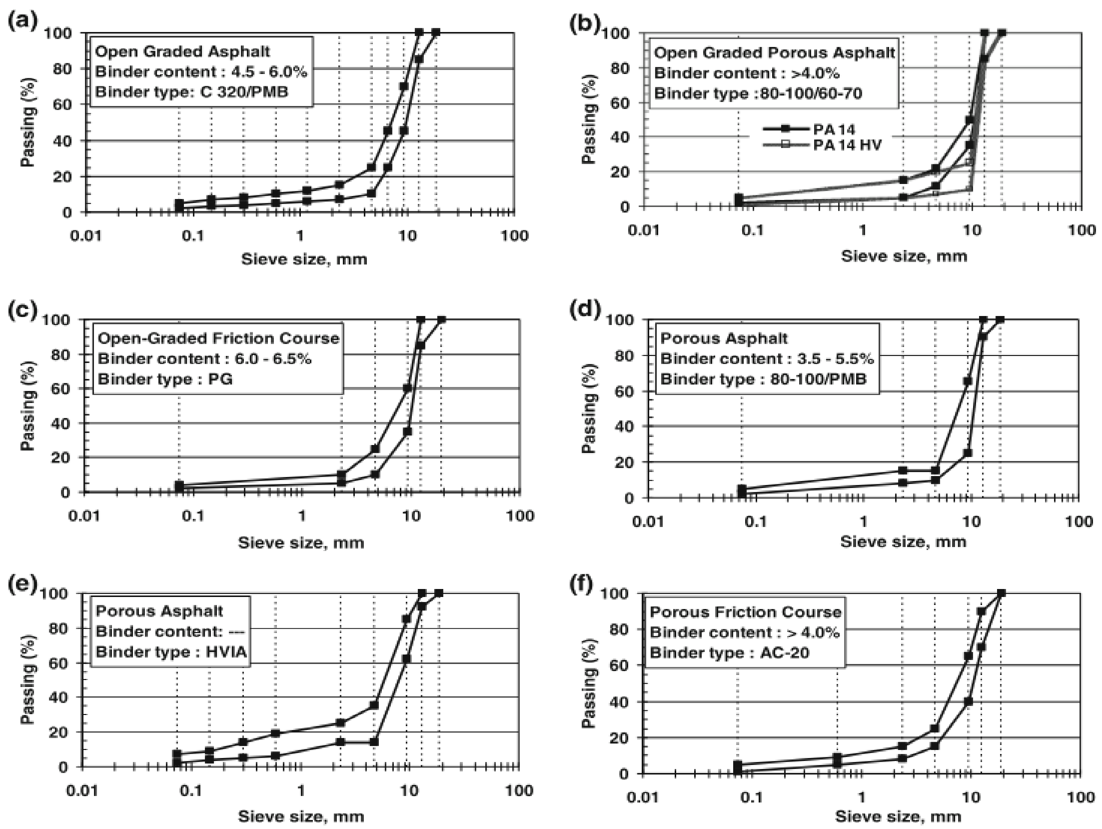

Figure 2.3: Gradation Band, Terminology, Binder Content, and Binder Type Specified for Porous Friction Course (PFC) Mixes by **a)** AAPA, **b)** TNZ, **c)** ASTM, **d)** Sabita, **e)** JHPC, **f)** FAA (Suresha et al., 2010).

Gradation can influence certain parameters such as clogging resistance, permeability, and air void contents. In a study performed by Ranieri et al., (2010), 10 gradations which are three gradations from Italian Motorway Agency (ANAS)(curves identified as "AA", "AB" and "AC"), three from Autostrade per l'Italia (curves identified as "AU_DR", "AU_MD" and "AU_MT"), one gradation from Italian Society of the Bitumen and Roads (SITEB) (curves identified as curve "STB"), and one gradation of the road agency for Bari County (identified as curve "IV") and two gradations identified as "M12" and "M14" (Figure 2.4) have been tested for the mentioned parameters to investigate the trend for each of them. The gradations were divided in three main groups according to the maximum aggregate size (D_{max}). Group 1 composed of AA, AB, AU_DR and M14 (D_{max} 100% passing to the 20 mm sieve), Group 2 composed of AC, IV, STB, AU_MT and M12 (D_{max} 100% passing to the 15 mm sieve), and Group 3 composed of AU_MD D_{max} 100% passing to the 10 mm sieve). Vertical and horizontal hydraulic conductivity increase linearly as the total void content and porosity increase. However, the clogging resistance of each gradation will decrease after one year due to dust contamination.

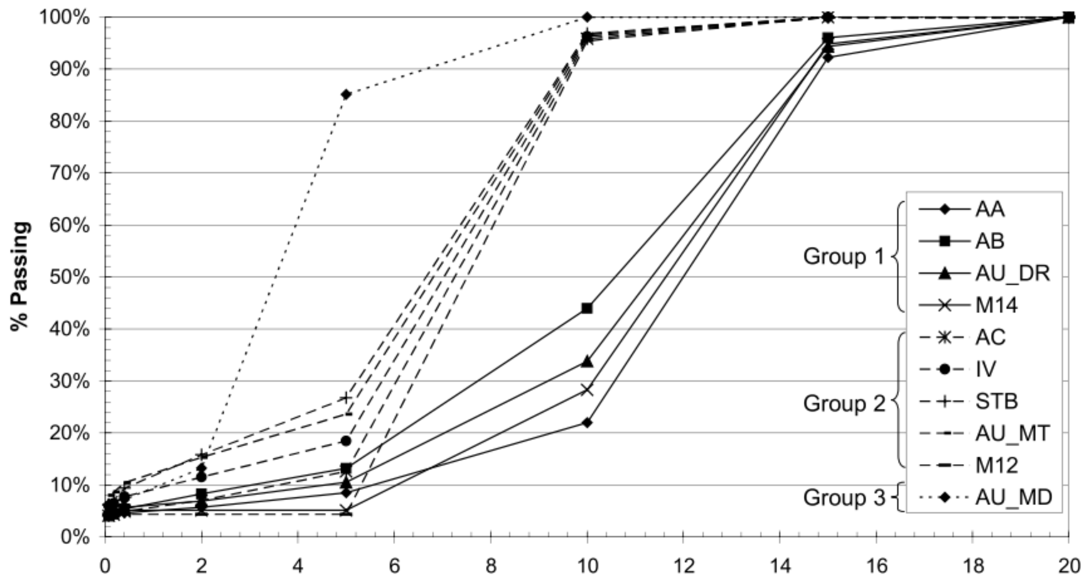

Figure 2.4: Aggregate Gradation Curves of the Porous Asphalt Tested (Ranieri et al., 2010)

2.4 Heavy Metals

Heavy metals are commonly trapped in porous pavement top layers. The term "heavy metals" refers to a group of metals and metalloids that have an atomic density greater than 4000 kg/m^3, or 5 times that of water (Wijeyawardana et al., 2022). High quantities of cadmium, zinc, lead, and copper were discovered in one field examination of debris that blocked permeable pavements. These concentrations looked to be proportional to the amount of traffic. Heavy metal concentrations were higher in clogging materials with finer particle dispersion (Abustan et al., 2012). They are primarily a result of vehicle exhaust, industrial soot, fossil fuel combustion, sandstorm dust, and corrosion of various metal facilities, and heavy metals copper, zinc, and lead are common constituents in highway runoff, usually in relatively high concentrations. Heavy metals, unlike organic contaminants, are difficult to decompose in the environment and easily accumulate in the human body through the food chain and other means.

Excessive intake of heavy metals in the human body can irritate mucous membranes, resulting in hepatic and renal damage, capillary damage, and central nervous system disorders (Wang et al., 2015). Several studies on various pavement systems found that infiltrating water contained much lower amounts of copper and zinc than direct surface runoff from an impermeable asphalt region. Based on a field study which has been conducted on a parking lot of a supermarket in Stadthlon, Germany, application of porous concrete able to reduce heavy metals concentrations such as lead, cadmium, copper and zinc (Dierkes et al., 2002). Tire wear, motor oils, grease, fuel, metal plantings, asphalt paving, fertilizers, and building exposure to rain are all primary sources of heavy metals. A high concentration of heavy metals in urban stormwater is recognized as a global problem that can surpass the threshold levels specified in guidelines for recreational and portable purposes (Wijeyawardana et al., 2022). Cu, Pb, and Zn have been discovered in all documented cases, making them the most frequent heavy metals found in urban runoff.

2.5 Enhanced Filtration System

A study conducted by Dierkes et al., 2002, four distinct subbase materials were tested: limestone, basalt, sandstone, and gravel (Figure 2.5). The investigations were conducted concurrently with the pavement investigations. Four different materials were explored in the rigs. The rigs were filled with synthetic rainwater with mean concentrations of 180 µg/l Pb, 470 µg/l Cu, 660 µg/l Zn and 30 µg/l Cd and a pH of 4.9 by using simulation of rainfall or sprinkler. The results of each metals concentration after subjected to filtration are tabulated in Table 2.2.

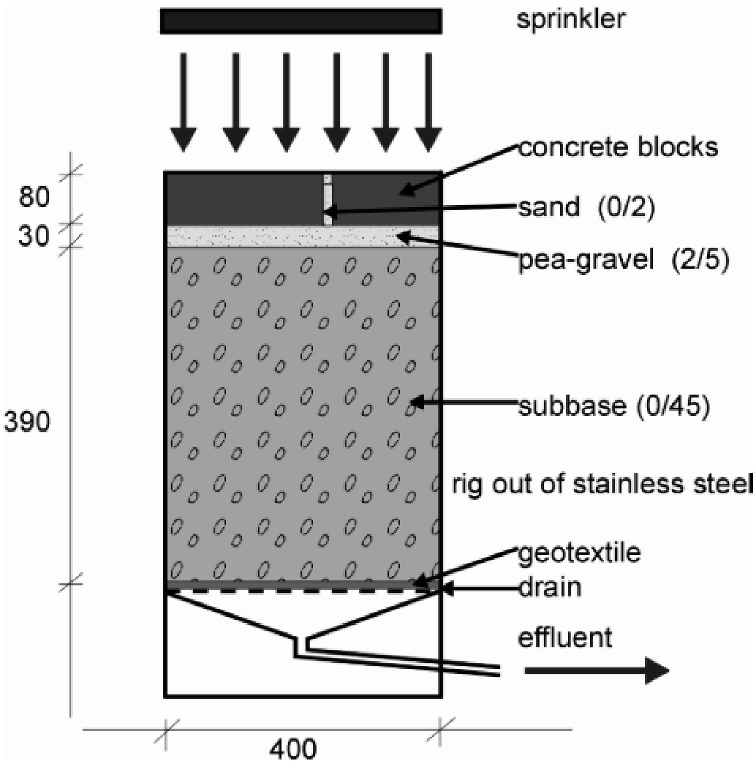

Figure 2.5: Test Rig Filled with a Porous Pavement with Reservoir Structure Complying to German Regulations (Dierkes et al., 2002)

Table 2.2: Concentrations of Metals in the Synthetic Runoff and in the Effluent of the Test Rigs, Percentage of Metals Retained in the Columns after Infiltration of the Loads of About 50 Years and Permissible Limits for Seepage After the German Regulations (Dierkes et al., 2002)

	Lead	Cadmium	Copper	Zinc
Synthetic runoff	180 µg/l	30 µg/l	470 µg/l	660 µg/l
Effluent (mean conc.)				
Gravel	< 4 µg/l	0.7 µg/l	18 µg/l	19 µg/l
Basalt	< 4 µg/l	0.7 µg/l	16 µg/l	18 µg/l
Limestone	< 4 µg/l	3.2 µg/l	29 µg/l	85 µg/l
Sandstone	< 4 µg/l	10.5 µg/l	51 µg/l	178 µg/l
retention				
Gravel	98%	98%	96%	97%
Basalt	98%	98%	96%	98%
Limestone	98%	88%	94%	88%
Sandstone	89%	74%	89%	72%
Limits for seepage	25 µg/l	5 µg/l	50 µg/l	500 µg/l

Most of the metals precipitate in the top 2 cm of porous concrete. However, the pH of the effluent demonstrates that the concrete's buffer capabilities are quite high, indicating that there is no threat of mobilization. After modelling 50 years of operation, increased quantities of metals were discovered in the subbase to a depth of 20 cm for cadmium and lead and 10 cm for copper and lead. Metal concentrations in wastewater only exceed the allowable limits for cadmium and copper when very coarse material for the subbase is utilized. During the testing, most constructions demonstrated no risk of potential groundwater pollution, implying that porous pavements composed of concrete blocks might be utilized without worry of metal breakthrough for at least 50 years (Dierkes et al., 2002).

Another study by Hamzah et al., (2013) about simulation of porous asphalt parking lot system which on laboratory scale has been conducted by using fabricated water flow system. A porous asphalt slab of 75 mm thickness and prepared according to the minimum compacted porous asphalt thickness proposed by the guideline (Jackson, 2007). Figure 2.6 illustrated on how the slab is placed into the water flow system to simulate the condition on the parking lot. The porous asphalt prepared with 4.65% binder content and having 20.6% air voids. Based on the interconnected air voids, the permeability of the porous asphalt allow water to flow in both vertical and horizontal.

Figure 2.6: Assembly of Porous Asphalt Slab Inside Water Flow Simulator's Body (Hamzah et al., 2013)

A research by Turco et al., (2020) shows that he metal concentrations (Cu and Zn) used in the porous pavement were based on rather high levels. The chemical amounts and sources employed to create synthetic stormwater were 5–15 mg/L of dissolved Cu using Cu (SO_4) and 6–15 mg/L of Zn using Zn ($(CH_3COO)_2$ $2H_2O$). According to the results, the removal rates of Cu and Zn from lab-scale pavements vary from 85 to 92% and 65 to 82 %, respectively. These varying outcomes may be influenced by a variety of factors, including the kind of material used in the construction of permeable pavement (porous asphalt, porous concrete, pervious block, etc.), the flow rates of the pollutants, the climatic condition, particle material, and so on (Turco et al., 2020).

For the treatment of stormwater, enhanced filtration employing organic medium was an effective alternative to chemical precipitation. Geotextiles can be utilized to provide a separation and reinforcing layer beneath new roads and parking lots, as well as as a filter in specific SuDS applications such as permeable pavements and infiltration trenches. Geotextiles can help improve organic matter removal (e.g., leaf litter and hydrocarbons) by trapping impurities on the surface voids and enabling microbial biodegradation to proceed (Scholz, 2013). The filtering effect of runoff by the reservoir structure included into the pavement system reduced pollutant concentrations by approximately 64% for suspended particles (typically associated with adsorbed metals) and 79% for lead. The majority of metallic micropollutants (lead, copper, cadmium, and zinc) collected on the pervious asphalt surface. A lower fraction of these contaminants also collects at the level of the geotextile layer that separates the structure from the underlying soil. Filtration via an adsorbent organic medium can remove up to 95% of the dissolved Cu and Zn (Scholz et al., 2012).

A study by Bali and Tlili, (2019) to study the effectiveness of infiltration-percolation method with the addition of adsorption from powdered activated carbon of heavy metals such as zinc, lead, copper and cadmium. Adsorption, membrane separation, coagulation-flocculation, precipitation, ion exchange, and filtration are all treatment procedures used to remove inorganic substances such as heavy metals contained in water. Adsorption is more successful than other approaches. Indeed, materials with a large specific surface area, such as activated carbon, have a high adsorption power. Powdered activated carbon (PAC) is often favored because it has a higher adsorption capacity and rate than granular activated carbon (Bali and Tlili, 2019). The adsorption capacity is affected by adsorbate concentration. The number of heavy metals adsorbed increased with the amount of PAC dissolved, eventually stabilizing at 45 g. This resulted in higher removal rates for Zn^{2+}, Pb^{2+}, Cu^{2+}, and Cd^{2+}, which were 63.25 %, 59.80 %, 60.93 %, and 73.56 % respectively.

A research on investigating the ability of peat soil in removing heavy metals has been conducted by Hou et al., (2020). Peat is an unavoidable by-product of swamp growth and one of the hallmarks of swamp topography. Peat is a pure natural organic substance that is rich in nitrogen, potassium, phosphorus, calcium, and other different components. According to research, modifying natural peat can boost its potential to absorb heavy metals. This study used Cr-contaminated soil as the treatment object to increase the remediation impact of peat on heavy metals polluted soil and to investigate the potential environmental dangers posed by peat. When peat was added to Cr-contaminated soil, the amount of acid-soluble Cr dropped as treatment time increased. This shows that peat can be an alternative medium to improve runoff quality.

Multiple studies have looked on the removal of harmful metals by natural limestones. Limestone may be an excellent natural geological material for the remediation of heavy metal-contaminated water (Sdiri et al., 2012). According to a study, more than 90% copper (Cu) with concentrations up to 50 mg/l could be removed from the solution with a limestone amount more than 20 ml (equal to 56 g), indicating the relevance of limestone medium in the removal process (A. Aziz et al., 2001). Limestone also can significantly remove more than 90% of most metals (Cd, Pb, Zn, Ni, Cu and Cr (III)) at a concentration of 2 mg/L (A. Aziz et al., 2008).

2.6 Water Quality and Surface Water

Urban runoff is also known to include a number of contaminants that contribute significantly to the degradation of water quality in streams, wetlands, and their associated ecosystems. It contains contaminants such as suspended solids, fine particles, heavy metals, nutrients, organic compounds (including herbicides and pesticides), and faecal indicator bacteria (FIB), which can degrade receiving water quality significantly. Concerns about water pollution in the United States are handled through the Clean Water Act (CWA) regulation, which was created in 1972, and later national pollutant discharge elimination (NPDES) permits, which were established in 1983. The CWA requires all states to develop rules to restrict urban stormwater discharge and decrease pollutant mass loading prior to release into recipient water bodies (Kayhanian et al., 2012).

A study by Mallin et al., (2009), there are different impact of water quality based on the degree of urbanization which are urban, suburban and rural areas. Nutrients (nitrogen and phosphorus) are significant contaminants in urban stormwater for rural. Similarly, in agricultural regions, rainfall-driven phosphorus runoff into streams is an issue that results from both particle phosphorus erosion and surface or subsurface movement of dissolved phosphorus. For urban and suburban, low dissolved oxygen, faecal bacterial pollution, periodic algal blooms, and turbidity pulses are all known issues in these waterways.

Additionally, water quality also depends on the rainfall intensity and the surface involved such as roof and road surfaces. Roof surfaces contribute sediment by atmospheric deposition of particles from the airshed onto these surfaces. The particles are deposited from a variety of sources, including industrial activity, automobile emissions, and windblown soils. Previous research in the Christchurch catchments and elsewhere in New Zealand has identified copper (Cu), zinc (Zn), and lead (Pb) as contaminants of concern in urban rivers. Zn is obtained from roadways as well as zinc-based roofing products. Galvanized roofing, which contributes zinc through dissolution and degradation, is often utilised for industrial and commercial structures. Zn is utilised as a vulcanizing agent in tyre rubber and brake linings, and hence contributes to their deterioration and wear. Cu is obtained by dissolving of copper roofing and cladding material, as well as corrosion of automobile brake linings. Pb levels in the environment have been found to be decreasing since the phase-out of leaded fuels, although it is still thought to be contributed to urban runoff from cumulative previous use of leaded fuels in soils, old paint, and present contributions from car tyre weights (Egodawatta et al., 2013).

A study by Kayhanian et al., (2009) that a higher dissolved chromium content was shown to be connected with concrete surface pavement materials, particularly leachate samples obtained within the first hour of the experiment. Ten different pavement specimens are tested in the study (Table 2.3). Dissolved chromium, particularly Cr (VI), is very poisonous and a proven carcinogen and mutagen in humans. Based on Table 2.4, in comparison to other metal elements, the leachate of concrete (but not asphalt) pavement materials included a higher quantity of Cr. The source of the chromium in the leachate of concrete pavement specimens was discovered to be the portland cement, not the aggregate.

Table 2.3: Pavement Specimens Mix Type and Binder Materials (Kayhanian et al., 2009)

Specimen	Mix Type	Binder
A	Rubberized asphalt concrete open (RAC-O) graded	Rubberized asphalt cement
B	Rubberized asphalt concrete gap (RAC-O) graded	Rubberized asphalt cement
C, D	Open graded asphalt concrete (OGAC)	2 Unmodified performance grade (PG) binder
E, F	Open graded asphalt concrete polymer modified (OGAC-PM)	2 Modified performance grade (PG) binders
G	Modified asphalt binder (MB-G)	MB4 binder
H	Conventional dense graded asphalt concrete (DGAC)	Unmodified performance grade (PG) binder
I	PCC-Dense	Portland cement
J	PCC-Permeable	Portland cement

Table 2.4: Dissolved and Particulate Cr concentration for Ten Pavement Specimens (Kayhanian et al., 2009)

Pavement Specimen	Cr concentration (μg/L)		
	Dissolved	Particulate	% Difference
A	0.10	6.39	98
B	0.09	0.54	83
C	0.24	0.68	65
D	0.18	0.39	54
E	0.32	0.39	18
F	0.20	0.31	35
G	0.18	0.32	44
H	0.17	0.28	29
I	26.30	33.10	21
J	15.30	133.90	89

2.7 Summary

Overall, permeable pavement is a technology that significantly contribute to the stormwater runoff issue. Especially for porous asphalt, it is environmentally friendly and have several benefits other than known for its infiltration ability such as noise reducing, higher skid resistance, good rut and cracking resistant and has good filtration which can filter out pollutants that may harm the water body. PICP can greatly assist in managing stormwater runoff due to the gaps and channels it has as a structure which allow water to easily infiltrate. Porous asphalt also plays a major role in handling runoff because of its porosity structure allow water to seep through however the performance of runoff infiltration may depends on the gradation to balance out the coarse and fine aggregates for it to have optimal stability and permeability. Heavy metals are likely to be present in the stormwater runoff as it produces by the transportation may contaminate the water body. Thus, an enhanced permeable pavement system must be proposed to alleviate the heavy metal contents to a minimum value that are likely less harm the environment such as applying activated carbon, peat soil, limestone and appropriate geotextile which are highlighted by the researchers of the materials effectiveness on reducing heavy metals content in the water system.