A Review of Permeable Pavement in Indonesia: Performance and Application

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Abstract: This work aims to provide an overview of the development of permeable pavement in Indonesia based on the latest literatures regarding performance, infiltration, and application. Permeable pavements have become well-known as effective stormwater management for controlling rainwater runoff. Permeable pavement provides excellent benefits, especially in largely populated areas with a view catchment area so frequent flooding. This study was conducted by collecting the latest studies on a permeable pavement in Indonesia in recent years. From the literature collected, it was found that: first, the permeable pavement has excellent advantages. It can absorb water into the soil through its pores but has low strength. Second, in Indonesia, various studies have been carried out to increase the strength of permeable pavement by adding various additives but have not found optimum conditions. Third, in Indonesia, the permeable pavement has varying compressive strength but yet, it has a low compressive strength where can be implemented for parking, pedestrians, garden, and other uses. Several issues have been identified as challenges and needs for future research on permeable pavement systems: (a) Optimizing structural performances by modifying design; (b) developing a standard maintenance procedure to restore infiltration capacity, and (c) improving the bearing capacity of the structure to withstand higher vehicular loads.

1 INTRODUCTION

Indonesia is a developing country, especially in the socio-economic field in the last few decades. This can be seen in the infrastructure development plan in 2021. Indonesia plans to build 1,078.48 km roads, three large bridges, 2,189 flats, and two dams in 2021(Fadli, 2021). Massive infrastructure development has reduced water catchment areas, so developing an environmentally friendly sustainable development concept is necessary.

The concept of sustainable development has wide applications. In this study, the concept of watertight surface infrastructure development is used. Several researchers have reviewed impermeable surfaces and rainwater waste (Jayakaran et al., 2019; Kováč and Sičáková, 2018; Kováč and Sičáková, 2017). Larger amounts of rainwater end up falling on impermeable surfaces such as roads, buildings, sidewalks, and parking lots rather than seeping onto the ground. This creates an imbalance in the natural ecosystem and causes several problems such as flooding and erosion (Koohmishi and Azarhoosh, 2021). Typically, parking lots, driveways, sidewalks and roads etc are constructed with Portland cement concrete and asphalt. Concrete and asphalt are impermeable to water, helping to increase surface runoff which strains infrastructure and causes flooding in construction areas.

Permeable pavement is an alternative impervious pavement, allows stormwater to flow through the voids in the layer and then infiltrate the underlying original soil (Razzaghmanesh and Borst, 2018; Stormwater, 2019). Recent reviews stated that permeable pavement could provide many environmental benefits over conventional pavements, including reduced runoff and increased rainwater infiltration, improved groundwater quality, increased surface skid resistance, reduced hydroplaning and heat islands. This benefit can increase the resilience and traffic safety of the transportation system for road users or the community (Xie, Akin, and Shi, 2019;

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Jusli et al. 2014; Yu et al. 2021; Winston et al. 2016; Cheng et al. 2019; Kuruppu, Rahman, and Rahman, 2019; Li, Kayhanian, and Harvey, 2013; El-maaty, 2016). It also very useful to overcome urbanization in densely populated areas, where many buildings and roads are built where the catchment area are reduced, and eventually, become main cause of flooding during heavy rain. The system of permeable pavement infiltration shows in Figure 1. This type of pavement can be used for low-traffic roads, parking lots, gardens, and sidewalks.

The most commonly used permeable pavement surfaces are pervious concrete (PC), porous asphalt (PA), and permeable interlocking concrete pavers (PICP) (Alam et al. 2019; Selbig and Buer, 2018; Huang et al. 2016). The visual differences between the three types of permeable pavements can be seen in Figure 2. Razzaghmanesh and Beecham (2018) conducted a study by comparing the three types of permeable pavement and showed that porous concrete had the highest infiltration rate, followed by permeable interlocking concrete pavers and porous asphalt. The average infiltration rate was reduced in the second year after the installation.

In Indonesia, permeable pavements are used for parks, gardens, and sidewalks. Several studies have been conducted to increase the strength and durability of permeable pavement. (Pradoto et al., 2019), used

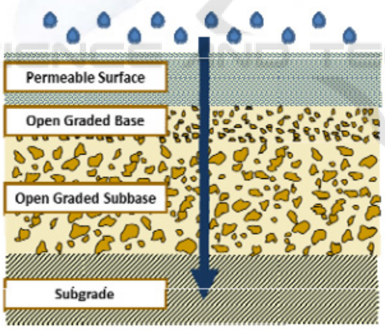

Figure 1: Permeable pavement system infiltration (Hein and Schaus, 2013).

fly ash as a filler in porous asphalt, volcanic ash (Rifa'i and Yasufuku, 2017), and coconut fiber (Maharana, Jena, and Panda, 2020).

1.1 Pervious Concrete (PC)

Pervious concrete is an open-graded structure with interconnected voids through which rain and stormwater are permitted to percolate into the aquifer (Maguesvari and Narasimha, 2013). According to [3] translucent concrete is a product of traditional materials used for the manufacture of concrete but without fine aggregate or the amount of fine aggregate added is very small to get high porosity in the range of 0.14 - 0.35. Pervious concrete is produced by adding aggregate into a cementious mix to maintain interconnected void space. As a result, it has a coarser appearance than standard concrete. Additives also can be combined to increase strength and improve binding, compared to conventional concrete due to its high porosity. Permeable concrete has a large cavity size, in contrast to conventional concrete which has small cavities. Pervious concrete has a large size of voids, different with conventional concrete, which has small voids. The porosity of the pervious concrete varies from 15% to 25% by volume (Dover, 2020; Paul et al. 2004; Chandrappa and Biligiri, 2016). The water permeability of pervious concrete typically ranges from 0.14 cm/s to 1.22 cm/s, and the compressive strengths generally fall under the range of 2.8 MPa to 28 MPa (ACI 552R-10 2010), compared to $1x9^{-10}$ mm/s for normal weight concrete. According to the American Concrete Institute and pervious concrete has a lower compressive strength of 5-10 MPa, the compressive strength is generally below the range of 2.8 MPa to 28 MPa compared to normal concrete because of its high porosity and tensile strength of between 1-3,8 MPa (ACI 552R-10 2010). Stability and durability of translucent concrete are affected due to lower compressive strength. Due to its relatively lower strength, the application of axle

(a) (b) (c)

Figure 2: Porous asphalt (a), pervious concrete (b), permeable interlocking concrete pavers (c) (Schultze-allen, 2018).

concrete is limited to low traffic. Additives can also be combined to increase strength and improve bonding. There have been many studies to improve the performance of porous concrete. Ramadhansyah et al., (2020) using Nano black rice husk ash, fly ash and superplasticizer. The same study was conducted by (Irlan, Rintawati, and Paikun, 2020; Mulyono and anisah, 2019; Mulyono and Anisah, 2019a) using fly ash, superplasticizer, and fiber. From their research found that additives can increase the strength of pervious concrete.

1.2 Porous Asphalt (PA)

Porous asphalt typically consists of conventional warm mix asphalt (WMA) or hot mix asphalt (HMA) with significantly reduced fines resulting in an open-graded mixture that allows water to pass through interconnected void space. The porous asphalt surface void space typically ranges from 10% to 25%. In comparison, voids for standard asphalt are typically 2% to 3%, and they are not interconnected (Dover, 2020). The properties of porous asphalt is shown in Table 1.

Table 1: Physical Properties of Porous Asphalt (Australian Asphalt Pavement Association 2004).

No	Planning criteria	Grade
1	Marshall Stability (kg)	Min. 500
2	Flow (mm)	2 - 6
3	Void in Mix (VIM) (%)	18 - 25
4	Marshall Quotient (kg/mm)	Max 400

1.3 Permeable Interlocking Concrete Pavers (PICP)

Permeable interlocking concrete pavement (PICP) comprises manufactured concrete units that reduce stormwater runoff volume, rate, and pollutants. The impervious units are designed with small permeable joints. The openings typically comprise 5% to 15% of the paver surface area, maintaining high permeability with small-sized aggregate fill. The joints allow stormwater to flow into a crushed stone aggregate bedding layer and base/subbase supporting the pavers while providing water storage, runoff quantity, and quality treatment. PICP is visually attractive, durable, easily repaired, requires low maintenance, and can withstand heavy vehicle loads (Dover, 2020). The physical properties of the paving block are shown in Table 2. Quality A used for road, quality B for parking, quality C for pedestrians, and quality D for garden and other uses.

Table 2: Physical Properties of Paving Block (SNI 03-0691 1996).

Quality	Compressive Strength (MPa)		Wear Resistance (mm/minute)		Maximum absorption (%)
	Average	Min	Average	Min	
A	40	35	0.09	0.10	3
B	20	17	0.13	0.15	6
C	15	12.5	0.16	0.18	8
D	10	8.5	0.22	0.25	10

Although Permeable pavement can provide environmental benefits, it has problems with the application which is related to durability and clogging. Some factors contributing to permeable pavement damage include sediments in stormwater from adjacent land or collapsed pores from vehicular traffic; (Kia, Wong, and Cheeseman, 2018; Kia, Wong, and Cheeseman, 2021). These problems are essential factors that affect in design, construction, and maintenance of Permeable pavements. In this case, this research aims to provide an overview of the development of permeable pavement in Indonesia, focusing on its performance, infiltration, and application.

2 METHODS

The research method uses a literature review from previous research studies that have been carried out in Indonesia. The structured literature review is a method in which critical research papers and studies directly related to the research question are collected and analyzed systematically. This study is designed to find future research on permeable pavements in Indonesia.

The literature is collected via keywords search on major databases including Google Scholar, Scopus, and, Web of Science journals. The keywords used include permeable pavement, paving porous, pervious concrete, asphalt porous, infiltration, and others presented in figure 3. Journals, proceedings, and books since 2011 were collected for review. Consideration of the suitability of the journal with the material used by the following criteria: relevance to the topic of review, quality, and impact on permeable pavement research in Indonesia. The final result of this work is to identify research gaps and provide recommendations for future research to enhance the performance of permeable pavement in Indonesia as a sustainable stormwater management practice.

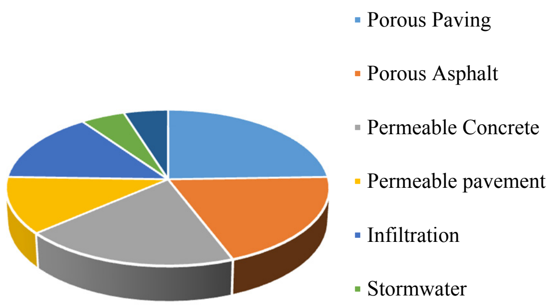

Figure 3: Categories studies on the permeable pavement.

3 RESULT AND DISCUSSION

3.1 Performance

For PC and PIPC, several studies in Indonesia, as shown in Figure 4, show that the compressive strength of the PC and PIPC varies, but in general, has low compressive strength (not more than 30 MPa)(Limantara et al. 2018; Rifqi, Amin, and Lesmana, 2018; Rifa'i and Yasufuku, 2017; Aman et al. 2016; Wijaya and Ekaputri, 2014; Saputra and Arie Wardhono, 2018; Mulyono et al. 2019; Ridwan et al. 2018; Chairuddin et al. 2016). In this research, efforts have been made to increase the compressive strength of permeable pavements by using additives. Materials such as fly ash, volcanic ash, coconut fiber, circle aggregate, natural aggregate, superplasticizer, recycle asphalt, and coal ash as shown in table 3. It is necessary to develop new permeable pavement in order to produce high-quality permeable pavement. Meanwhile, table 4 shows the good performance of porous asphalt in Indonesia where can be seen from the perspective of Stability, flow, marshal quotient, and porosity (Ramadhan and Reza, 2014; Tronge et al. 2017; Ayun, 2017; Rifqi et al. 2019; Arlia, Saleh, and Anggraini, 2018; Saleh, Anggraini, and Aquina, 2014). From the previous research, not all of them have been porosity tested. It is necessary to determine the percentage of void in mix of porous asphalt.

3.2 Porosity and Permeability

The compressive strength decrease as the porosity increase refers to Figure 5. It is caused by voids content in the structure of permeable pavement. When the void percentage increases, the strength of the hardened concrete tends to decreases. Permeability is a property of a porous material that allows the flow of seepage from a liquid (water or oil) to flow through the pore cavity. Based on previous study in Indonesia, the permeability of the permeable pavement varies

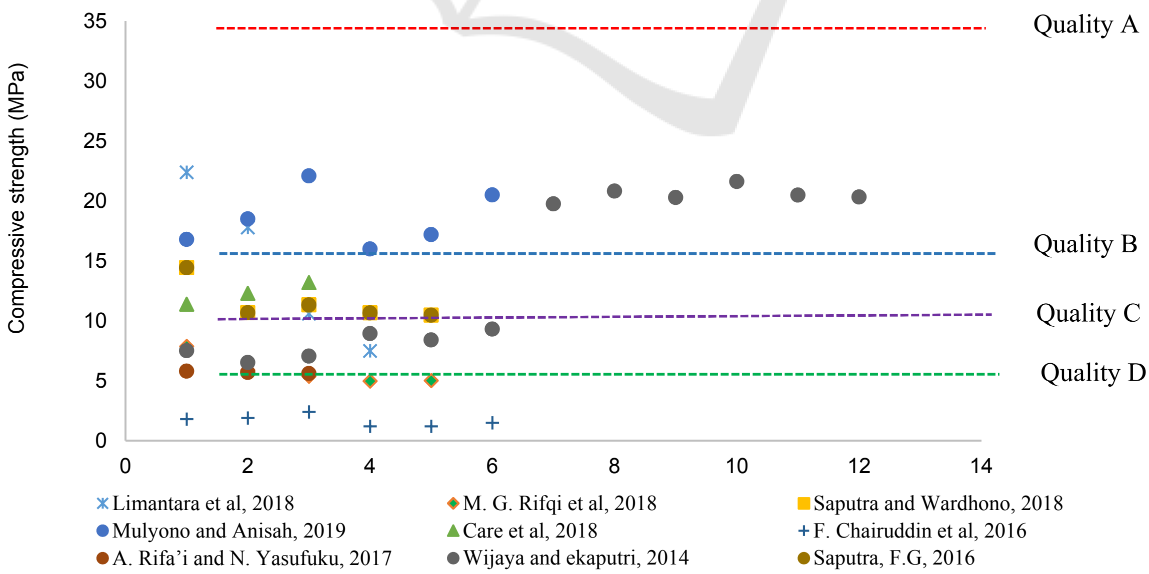

Figure 4: Performance of permeable pavement in Indonesia (Rifa'i and Yasufuku, 2017; Mulyono and Anisah, 2019; Rifqi, Amin, and Lesmana, 2018; Aman et al. 2016; Wijaya and Ekaputri, 2014; Saputra and Arie Wardhono, 2018; Ridwan et al. 2018; Chairuddin et al. 2016; Limantara et al. 2018).

greatly between 0.21 to 2.6 cm/s (Limantara et al. 2018; Saputra and Arie Wardhono, 2018; Rifa'i and Yasufuku, 2017; Ridwan et al. 2018). The permeability and porosity data are plotted in Figure 6. From Figure 6, it can be seen that the porosity is recorded between 15% until 35%. This porosity value is also in line accordance with the ACI standard with porosity between 15-35%.

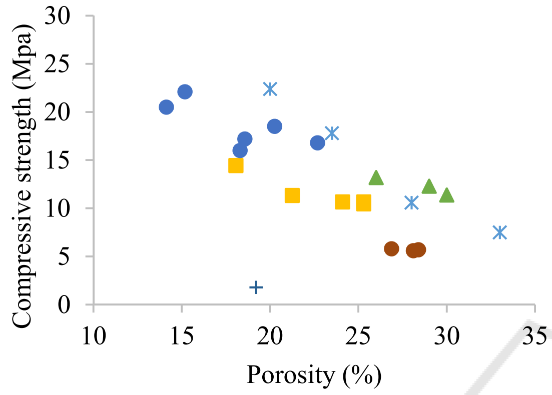

Figure 5: Correlation between compressive strength and porosity of some studies in Indonesia (Limantara et al. 2018; Rifqi, Amin, and Lesmana, 2018: Rifa'i and Yasufuku, 2017; Saputra and Arie Wardhono, 2018; Mulyono et al, 2019; Ridwan et al. 2018; Chairuddin et al. 2016).

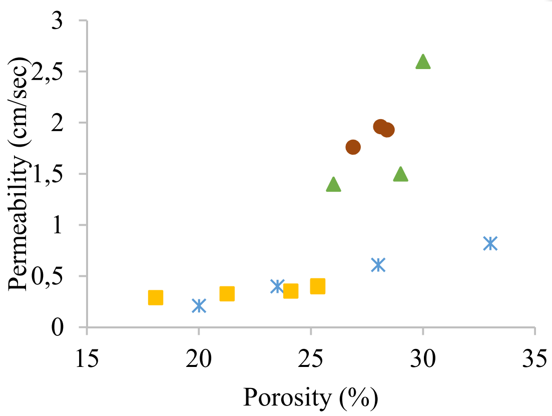

Figure 6: Correlation between porosity and permeability in some studies in Indonesia (Rifa'i and Yasufuku, 2017; Saputra and Arie Wardhono, 2018; Ridwan et al. 2018; Chairuddin et al. 2016; Limantara et al. 2018).

Table 3: Summary of selected studies on PC and PICP in Indonesia.

Ref	Research Location (year)	Type of permeable pavement	Addition materials	Content (%)	Compressive strength (MPa)	Porousity (%)	Permeability (cm/sec)
(Limantara et al. 2018)	Kediri	PC	Coconut fiber		17.10	23.00	0.50
(Rifqi, Amin, and Lesmana, 2018)	Banyuwangi	PIPC	Circle river aggregate		7.84	16.93	0.26
(Rifa'i and Yasufuku, 2017)	Prambanan	PIPC	Bantak and volcanic ash		6.05	28.40	1.93
(Aman et al. 2016)	Riau	PIPC	Fly ash		18.84	-	-
(Wijaya and Ekaputri, 2014)	Mojokerto	PIPC	Coal ash		20.80	5.27	-
(Saputra and Arie Wardhono, 2018)	Surabaya	PIPC	Fly ash	10,00	14.44	25.30	0,41
(Mulyono and Anisah, 2019)	Jakarta	PC	Fly ash, superplasticizer	15,00 0.20	15 – 22	20 – 22	1.7 - 2.1
(Ridwan et al. 2018)	Bandung	PC	Fly ash HRWR VMA	0.60 – 0.70 2-2.4	6.2 – 15.2	25 - 32	1.4 – 2.6
(Chairuddin et al. 2016)	Makasar	PA	Buton natural asphalt	4,00	2.40	19.20	-

Table 4: Summary of selected studies on PA in Indonesia.

Ref	Location (year)	Type of permeable pavement	Addition materials	Content (%)	Stability (kg)	Flow (%)	M.Quotient (kg/mm)	Porousity (%)	Permeability (cm/sec)
(Ramadhan and Reza, 2014)	Malang	PA	Gilsonite	8.00	805.196	3.78	219.22	-	-
(Tronge et al. 2017)	Makasar	PA	Wetfik	0.33	854.14	3.00	287.90	17.26	0.28
(Ayun, 2017)	Surabaya	PA	Sulfur	10.00	563	2.70	203,70	-	0,517
(Rifqi, Amin, and Lesmana, 2018)	Banyuwangi	PA	Local material	5.00	1123,61	4.68	241.82	-	0.367
(Arlia, Saleh, and Anggraini, 2018)	Aceh	PA	Gondorukem	8.00	554.81	0.28	143.02	-	-
(Saleh, Anggraini, and Aquina, 2014)	Aceh	PA	Styrofoam	9.00	495.92	3.07	169.05		0.144
Standard					**Min. 500**	**2 -6**	**Max. 400**	**15 - 25**	**-**

3.3 Application

The applications of permeable pavement can be used for low-volume pavements; residential roads and walkways; sidewalks and pathways; parking lots; tennis courts; slope stabilization; floors for fish hatcheries, floors for zoos or children parks, etc. Based on previous research, which is summarized in Figure 4, it can be seen that permeable pavement in Indonesia is classified into quality B, C, and D refer to the (SNI 03-0691, 1996). These pavements can be used for parking, pedestrians, garden, and other uses. The current design specifications and several studies have been carried out to investigate and find solutions and innovations to improve permeable pavement performance. These efforts can be seen in table 1, but they still have not produced a strength of more than 35 MPa (Quality A) so that it can be used for roads.

4 THE POTENCY OF FUTURE RESEARCH

This paper has identified several pavement permeable problems in Indonesia. Repairs are required for use on road pavements, especially repairs in terms of mix design, manufacture, and maintenance. Several studies have been carried out to investigate the properties of the permeable pavement, but no ideal proportion has been found. Permeable pavement in Indonesia has a low compressive strength, it is necessary to develop an appropriate innovation to optimize the performance of porous pavement. Innovation can be done from the mix design, shape, method of manufacture, and maintenance.

In summary, several challenges and needs for future research on permeable pavement systems were identified mainly on: (a) optimizing structural performance by modifying the design; (b) The right treatment system so that the permeable pavement can function properly and last a long time.

5 CONCLUSIONS

This review has identified several unresolved performance, infiltration, and application issues that require further investigation to optimize permeable pavement application as sustainable urban drainage systems in Indonesia. The compressive strength of the permeable pavement in Indonesia is still minimal which is, less than 30 MPa and cannot be applied for road. Porosity and permeability are following the requirements of SNI 03-0691-1996. The permeability obtained from the existing reference is between 0-25 cm/sec, while the porosity is between 15 - 35%. This review also highlights the need to develop new permeable pavement with high compressive strength that can effectively reduce stormwater runoff.

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