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# Pervious concrete: the art of improving strength properties

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**Abstract.** Urban cities in Malaysia are highly vulnerable to flash floods due to improper drainage system and the impermeable road surface. The Pervious Concrete (PC) Pavement for urban water management indicates the implementation of this system shows promising results to reduce flash flood volume and among the mitigation that can be applied is by adopting the permeable pavement systems. This was based on a case study of Sponge City in China. Since the properties normally consist of coarse aggregate only/ or less fine aggregate to fill in the void structure. Regardless of the high advantage of these systems to reduce the flooding impact, this permeable pavement is known for its lower strength. Due to this fact, it is rare and impossible for this permeable pavement to be utilized at the main road and highway. Whereas, currently in Malaysia, the permeable concrete is only accustomed to light traffic loadings such as walkways and car park. This paper was discussing the way to improve the strength properties of PC pavements with a focus on sustainable development.

## 1. Introduction

In Malaysia, 9 % or 29,720 km<sup>2</sup> of the country is located in flood-prone regions with a total of 4.915 million people affected by floods [1-2]. Most of the states in Malaysia are prone to food risk due to (1) the natural physical topography and drainage, and (2) human geography of settlement and land use [3]. During 2014, Malaysia had recorded the worst flood events in its history, with Kelantan, Pahang and Terengganu were the states that were badly affected during the event. Moreover, it has been recorded that 21 fatalities and 237,037 people that been evacuated with the total loss for the whole country estimated by the government are over RM1 billion [4] This was due to the river bank overflow during the Monsoon seasons. The flood due to riverbank overflow usually took hours or even days to develop, giving residents ample time to prepare or evacuate. On the other hand, Malaysia is currently facing an increase in flash flood events due to deforestation and urban development. Urbanization has increased the impervious surface in the catchment and reduces the total water infiltration. Since the flash flood generates quickly, this has caused massive surface runoff. A larger runoff is discharged within a shorter interval, peak rate of water inevitably increases, giving rise to the danger of sudden



flooding of rivers [5] This flash flood causes a huge impact compared to monsoon flood by the number of people affected especially for an urban city like Kuala Lumpur [6].

Furthermore, the study shows that by 2030, the population growth will increase to 5 billion people worldwide and mostly took place around the Asian region. The population growth will increase the area of land cover by triple and it led to huge infrastructure development [7] This increases the risk of flooding due to the development of a low-lying area [8] The study by Yaakob et al., 2010 shows Malaysia has grown rapidly in the urban population increasing from 10.0 % in 1911 to 28.4 % in 1970 and 61.8% in 2000 [9] Between the urbanized infrastructures, the road network is the major element of fundamental facilities during the development in each country and plays a major role in economic growth. With the rapid increase of population number, climate change, and rapid urbanization causes the development of impervious surface took place near to the flood plain area and it increases the flooding risk.

In 2014, the world's largest developing country, China had established the concept of 'Sponge City'. This concept aims to tackle increased flood-risk due to rapid urbanization and create an overarching concept that includes key components of urban water resources management, urban planning, and sustainable development, including urban water body preservation, storm-water storage, and water quality improvement [10]. One of the important elements of this sponge city is permeable pavement technology. There are mainly three types of permeable pavement available in the market and have been applied in this Sponge City. There are 1) Permeable asphalt pavement, 2) Permeable concrete pavement, and 3) Permeable interlocking concrete pavers/ bricks. Among all these three, the Permeable Concrete (PC) pavement shows a high reduction in the total surface runoff and peak flow compare to the other two types of permeable pavement [11]. In this paper, we present a compilation of prominent findings of studies focused on mixture design, PC pavement material properties, and the potential for strength enhancement.

## 2. Pervious Concrete

Based on the definition given by American Concrete Institute (ACI, 2010) "pervious concrete" typically describes as a near zero-slump, open-graded material consisting of portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water. With the little or no fine aggregate, it will produce pores ranging in size from 0.08 to 0.32 in. (2 to 8 mm) that allowed the water partials to pass through easily. The increasing of pores size increases the void contains by 15 to 35%, with typical produce the compressive strengths of 2.8 to 28 MPa [12].

Known for its capability to infiltrate water to the ground or store it for future uses, the PC does also have other advantages. In a study conducted by Elizondo-Martinez et al. [13], there are more advantages when PC is applied compared with other concrete. The installation of PC helped to mitigate the Urban Heat Island effects through the reflection of solar radiation because of their high reflection capacity (albedo). Besides is also helps to reduce the noise generated by the vehicles. This is due to the large volume of interconnected pores in PC. On top of that, the application of PC pavements will increase the road user safety during rainy days by increasing the skid resistance provided by their high air void content because of the rapid stormwater filtration capacity and pronounced macrotexture of their surface layer [13].

In current practices, PC pavements are mostly utilized for parking lots, drainage layers in exterior areas, residential street parking lanes, walkways/sidewalks, bike paths, and pavements with low traffic volume This is due to low compressive strength related to the air voids. Increasing porosity will decrease the compressive strength, due to the interconnected voids in the PC pavements itself [14]. Due to this limitation, researchers mostly focus on finding the optimal composition that would satisfy the compressive strength criteria. By the definition, the PC pavements consist of less or no fine aggregate compared to normal concrete. This indicates that the compressive strength of PC is highly influenced by the aggregate since it represents 70% to 80% of the total concrete volume, followed by the binder type, the water-cement ratio, and finally, by the additives within the concrete mixture [15] Apart from the highly void from the normal concrete, the compressive strength of PC is influenced by the interfacial layer between the aggregate and the cement paste. Therefore, increasing the strength of the paste and/or increasing the bond between the matrix (cement paste) and the filler (the aggregates)

are the keys to developing the strength of pervious concrete [16]. Having a higher strength of aggregates such as steel slag will improve overall PC strength. Other than that, several other methods and modifications can improve PC pavement strength. These methods include using polymeric materials, utilizing nanomaterial, applying different fibers, and increasing the fine aggregate percentage [17].

### 2.1. Mix Design

According to previous research, the most important parameters in pervious concrete are cement content, water-to-cement (w/c), and cement-to-aggregate (C/A) ratio [18]. To control this parameter, it is vital to study on mix design. The main objective of the mix design is to provide a guideline for the development of a concrete mixture to achieve targeted strength. Currently, most of the PC has been developed using ACI 522R-10 standards, while PCD (porous concrete design) have been derived from ACI 522R-10 and ACI 211.3R-02 standards. This PCD methodology tends to increase the mechanical capacity of mixtures (30% higher than those produced with ACI methodologies) while maintaining good values of permeability (rates close to 2 cm/s). But on the other hand, this method will increase the overall cost by 6% -16% compared to ACI methods due to increasing cement paste as the binder (Figure 1) [19]. Figure 1 shows the ACI 522R-10 and PCD methodologies dosages according to the s/c.

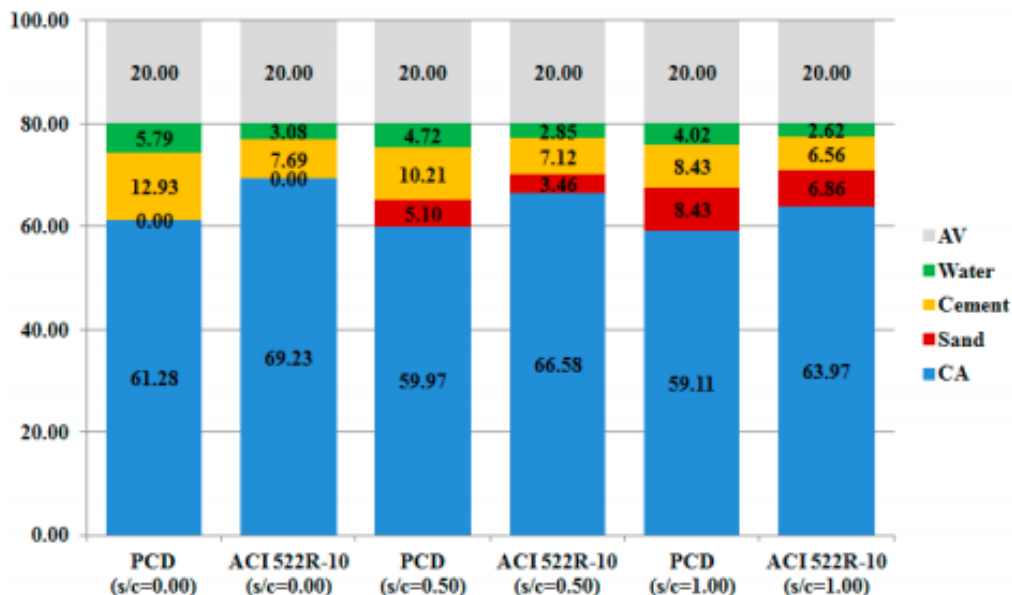


Figure 1. shows the ACI 522R-10 and PCD methodologies dosages according to the s/c [19].

## 3. Materials Preparation

With the growing concern over global warming and significant ecological changes, people start to practice sustainable development in their everyday life. With sustainable development, it helps to protect the natural resource and reuse the waste generated by local industries. Even though the PC pavement is known as one of the sustainable concretes, it still consumes a huge amount of energy, natural sources, and emits a large amount of CO<sub>2</sub>, mainly due to the production of cement [20]. Researchers had found several methods/modifications that have proven to reduce the natural resource while increasing the PC strength and the details show in the next subchapter.

### 3.1. Aggregates

In PC pavement, it consists of 60% - 70% volume of coarse aggregates and it plays a major role in the compressive strength development. The study shows that, by using single coarse-sized aggregates, it exhibited a much higher permeable coefficient but had lower compressive strength compared with the PC developed using two coarse-sized aggregates [21]. Also, the combination of fine aggregate in PC

pavements will increase the mechanical strength of the PC pavement since it helps to fill the void in the concrete. On the contrary, it will reduce the permeability of the PC. By replacing the natural aggregates (NA) with industrial waste will help to increase the PC strength. There is various industrial wastes that has been applied as the replacement NA in the PC pavements. In the current study, three major types on industrial waste have been widely used such as steel slag (SS), waste glass (WG), and recycle concrete aggregate (RCA).

One of the materials that can be used as the aggregate's replacement is steel slag. Study shows that steel slag does help to increase compressive strength, splitting tensile strength and flexural strength of the PC. This is due to the hydration process of cement developed in the PC using steel slag is better than the hydration process when incorporating PC with NA [17, 22]. In addition, a study by Meng et al. [23] had incorporated Waste Glass (WG) in the PC pavements to replace the NA. The results show that the strength decreased by 31.7% when the NA is replaced by WG aggregate. This is because the surface of WG is smoother compared to NA that led to weaker bonding strength between the cement matrix and WG aggregate [23].

The majority of the previous studies have concluded that the application of concrete incorporating a high percentage of RCA should be limited to non-structural elements or pavements due to weak mechanical strength since RCA normally consists of crushed bricks, glass, and ceramic waste. Study shows that replacing 100% of NA in the mix with RCA, it will increase the permeability by 25% but reduce the compressive strength by 60% compared to the NA [24]. However, the study conducted by Togholi et al.,2020 shows that the PC pavement can achieve high compressive strength by using specific amounts of pozzolanic additives and fibers while maximizing the use of RCA [25].

### 3.2. High strength binder

One of the sustainable development goals is to reduce the carbon footprint. Among all the material available in PC pavement, cements production, and hydration process in cement do increase CO<sub>2</sub> emission to the atmosphere. By replacing the supplementary cementitious materials (SCMs), it helps on the optimization of usage of industrial by-products. Some of the widely use of common SCMs are Fly Ash, Silica fume, and Metakaolin. Table 1 shows the advantages and disadvantages of all the SCMs respectively.

**Table 1.** Advantages and Disadvantages of Application of Fly Ash, Silica Fume, and Metakaolin. [26-27]

Supplementary Materials (SCM)	Cementitious	Advantages	Disadvantages
Fly Ash (FA)		<ol style="list-style-type: none"> <li>1) Improve workability in fresh concrete by providing a lubricant effect.</li> <li>2) Help to achieve a low w/c ratio while maintaining the workability.</li> <li>3) Increase ultimate strength at a later stage compared to concrete without FA.</li> </ol>	<ol style="list-style-type: none"> <li>1) Excessive amount of FA will act as a retarder and increase the setting time.</li> <li>2) Low high early strength.</li> </ol>
Silica Fume (SF)		<ol style="list-style-type: none"> <li>1) Help to fill in void inside cement paste since its size is smaller than the cement size.</li> <li>2) Increase the concrete strength in early ages.</li> </ol>	<ol style="list-style-type: none"> <li>1) Require a superplasticizer to improve the workability.</li> <li>2) The price is higher than the original Portland Cement (OPC)</li> <li>3) Reduce the permeability of PC pavement.</li> </ol>
Metakaolin		<ol style="list-style-type: none"> <li>1) Possess the same pozzolanic reactive as SF but is cheaper.</li> <li>2) Accelerates the initial setting</li> </ol>	<ol style="list-style-type: none"> <li>1) Require a superplasticizer to improve the workability but compare to SF, Metakaolin does</li> </ol>

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time of concrete.	have better workability.
3) Helps in the development of the early-age strength of concrete.	2) Reduce the permeability of PC pavement

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Studies by Huang et al. [28], the combination of two types of SCMs in PC pavements with appropriate proportion do improve both permeability and compressive strength compared to PC pavement without mineral admixtures. In addition, the results show an increase in compressive strength when the level of silica fume increases while the compressive strength decreases with the increase of replacement level of fly ash. The highest compressive strength recorded with the mix SF is 6% and FA by 15% [25, 28].

### 3.3. Polymer

The polymer modifications to cement concrete were implemented through the addition of polymer latex, dispersible polymer powder, a water-soluble polymer, or liquid polymer into the cement mortar. Polymeric latexes are widely used to improve the physical and mechanical properties in normal concrete since both concrete and polymeric latexes do have the same water-based nature [29]. Studies have shown the presence of polymer in the mixture will enhance the workability, compressive strength, and flexural strength of PC pavements. While undergoing the hydration process, a membrane will form. This membrane will fill the voids and cracks within the Interfacial Transition Zone (ITZ) thus increase the compressive strength. In addition, the properties of the latex polymer will increase the tensile strength that is beneficial in PC pavements construction [16].

## 4. Discussions

From the review presented, the application of PC pavement has the potential in reducing flash floods in an urban area. Currently, the application of PC pavement is only limited to parking or pavements with low traffic volume. This was due to its lower strength compared to normal concrete pavement. Theoretically, the strength will decrease with the increasing volume of the void. As a result, there several successful modifications proved the increase of strength such as; 1) using high strength aggregates. 2) Incorporate fine aggregate in mixture and 3) Adapt ultra-high-strength cement paste. With the mix size of fine and coarse aggregate, it will help to reduce the void and increase the compaction in PC concrete. For normal concrete, the failure mode of compressive strength is due to the strength of the cement matrix with the aggregates (binder). While in ultra-strength the failure mode depends on the strength of aggregates. By increasing the high strength cement paste, it will increase the PC pavements performance. The ultra-high-performance paste was used to replace the conventional matrix to coat the aggregate surface and bonded them together to improve the strength of the pervious concrete [30].

### 4.1. Proposed solution

The potential solution is proposed based on the improvement in mechanical properties of the pavements to achieve high strength PC pavement. One of the major challenges is to develop high strength PC pavements without jeopardizing the permeability. Three types of solutions were proposed such as replacing the NA with steel slag, introduce fine aggregate, and apply pozzolanic materials as part of cement replacement. As for the pozzolanic material, Metakaolin is chosen since it gave the same results as SF but much lower in price.

## 5. Conclusions

It is very important to note that urban cities in Malaysia are highly vulnerable to flash floods due to improper drainage systems and among the mitigation that can be applied is by adopting the permeable pavement systems. Regardless of the high advantage of these systems to reduce the flooding impact, this permeable pavement is known for its lower strength. Due to this fact, it is rare and impossible for this permeable pavement to be utilized at the main road and highway. Whereas, currently in Malaysia, the permeable concrete is only accustomed to light traffic loadings such as walkways and car park.

Therefore, this study aims to design a PC pavement that can possess high strength for medium traffic load with minimum defects.

## 6. References

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