Modified Pervious Concrete Containing Recycled Asphalt Pavement and Waste Tire Rubber

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Abstract. Portland Cement Pervious Concrete (PCPC) can reduce the risk of flash flood by letting the storm runoff to sip through the voids available in the PCPC hence infiltrate into the soil. This unique ability of pervious concrete offers advantages to the environment, public agencies, and building owners by controlling rainwater on site and addressing storm water runoff issues. Thus, this study was conducted to substantiate the use of inorganic, cheap and reusable material namely Recycled or reclaimed asphalt pavement (RAP) and Fine Crumb Rubber (FCR) in pervious concrete. The primary objective of this study is to compare the compressive strength, density and the surface infiltration rate of pervious concrete containing waste tire rubber with pervious concrete that is made up by using natural aggregate without any enhancement. Standard pervious concrete will consist of natural coarse aggregates and cement. In this study, RAP will be replacing the natural coarse aggregates, the same size with the previous research. The modified pervious concrete will also be mixed with a certain percentage of FCR, replacing certain percentage of the coarse aggregate. The results of this study indicate that using recycled material could achieve similar performance as using natural aggregate, hence may reduce the construction cost.

1. Introduction

Pervious concrete is known to be a concrete mixture without any fine aggregate that has the ability to let fluid such as water, to flow through the concrete and infiltrate into the soil beneath. Portland Cement Pervious Concrete (PCPC) can reduce the risk of flash flood by letting the storm runoff to sip through the voids available in the PCPC hence infiltrate into the soil. This unique ability of pervious concrete offers advantages to the environment, public agencies, and building owners by controlling rainwater on site and addressing storm water runoff issues [3]. Based on [3], conventional pervious concrete has a flow rate of 3.4mm/s. With a rough calculation of 1m² area, it can infiltrate 204mm of water in 1 minute. Other than infiltrating water from the surface into the soil, PCPC also can be used for the noise barrier because of the voids available that can reduce the sound wave.

Research works done in enhancing the performances of pervious concrete using certain percentage of waste tire rubber by [2] and properties of porous concrete from waste crushed concrete (recycled
aggregate) by [1] has set the scope and objectives of this study. Using recycled material may contribute to the economical and environmental factors positively. With the increasing number of vehicles in Malaysia, the waste tire rubber has also increased and rubber is difficult to be degradable. It is better to recycle these waste tire rubber by shredding it into small size and turn into tire chips (TC) or making smaller size into the Fine Crumb Rubber (FCR), as small as 5mm to enhance the concrete and at the same time, reduce the cost of producing pervious concrete.

Recycled or reclaimed asphalt pavement (RAP) is another recycled material which is available due to the extensive pavement maintenance could be used as an additional mixture or replacement to natural aggregate other than the FCR. This is because RAP consists of aggregate with different size that has been mixed with asphalt emulsion, producing a layer of asphalt emulsion binder. It has been heated at high temperature to make a tight bond between aggregates to make a flexible pavement which may contribute to unchanging strength of aggregate.

In this study, inorganic, cheap and reusable material which is RAP and FCR is used to make a modified pervious concrete to compare the compressive strength, density and the surface infiltration rate with pervious concrete using natural aggregate. Considering the above factors, the primary objective of this study is to determine the compressive strength, density and surface infiltration rate for the modified pervious concrete that contain recycled asphalt pavement (RAP) and waste tire rubber. Besides, the percentage amount of rubber to replace the coarse aggregate that give the best performance of the sample is another concern of this study. The performance of modified pervious concrete will then compared to natural aggregate pervious concrete.

Therefore, the percentage of the FCR and also the material used for coarse aggregate between natural aggregate and RAP will be the dependent variables, which is the limitation of the study. The tests that will be conducted for this research are as follows (Table 1):

- Compressive strength – to determine the compressive strength of the pervious concrete.
- Density – to determine the mass of the concrete with a specific volume of the specimen.
- Surface infiltration test – to determine the surface infiltration rate / rate of water to flow through the sample

Table 1. Summary of the works that will be carried out in this study.

| Parameter               | Testing                  | No of Sample | Control sample | 0% FCR | 5% FCR | 15% FCR | Total no of Sample |
|-------------------------|--------------------------|--------------|----------------|--------|--------|---------|-------------------|
| Compressive Strength    | Compression Test         |              | Fresh aggregates = 9 [3 sample for 7, 14 and 28 days] |        |        |         | 36                |
|                         | (ASTM C109)              |              | RAP aggregates = 9 [3 sample for 7, 14 and 28 days] |        |        |         |                   |
|                         |                          |              | RAP aggregates = 9 [3 sample for 7, 14 and 28 days] |        |        |         |                   |
| Concrete Density        | Hardened Concrete Density|              | Fresh aggregates = 9 [3 sample for 7, 14 and 28 days] | RAP aggregates = 9 [3 sample for 7, 14 and 28 days] | 36    |
| Surface Infiltration Rate| Surface Infiltration Test|              | RAP aggregates = 9 [3 sample for 7, 14 and 28 days] |        |        |         |                   |

2. Methodology
Methodology adopted for this study includes the following steps that taken for the study are explained from sample preparation, mixing design of the pervious concrete, preparing the mould, molding and curing, and sample testing. This are the steps required to produce the pervious concrete sample and also to determine the objective.

2.1. Sample preparation
The preparation of samples for this study was done in reference to the work of [3] as shown in Table 2.
Table 2. Mix proportion according to [3].

|                                | Proportions, lb/yd³ | Proportions, kg/m³ |
|--------------------------------|---------------------|--------------------|
| Cementitious materials         | 450 to 700          | 270 to 415         |
| Aggregate                      | 2000 to 2500        | 1190 to 1480       |
| Water:cement ratio*** (by mass)| 0.27 to 0.34        |                    |
| Aggregate:cement ratio*** (by mass) | 4 to 4.5:1   |                    |
| Fine:coarse aggregate ratio**** (by mass) | 0 to 1:1 |                |

2.1.1. Natural aggregates. Natural aggregate required to be washed and dried to make sure the aggregate does not have any other materials other than natural aggregate and to make sure the aggregates is dried from any moisture. The natural aggregate is dried by leaving it in an open space where the water can evaporate naturally. If it was dried using furnace, it can give an effect to the strength of the aggregate itself. After it is dried for 1 day, the natural aggregate is sieved using sieve shaker, to obtain a single size aggregates that is between 16-10mm. Since it is used for pervious concrete, it is better to use natural aggregate that is smaller size than 20mm. Therefore; 16mm was picked as the maximum size and 10mm for the minimum size. The reason of choosing a smaller size than 20mm is because it will give a slight effect to the strength of the concrete by the increase of the contact area between the cement pastes with the aggregate, more economical mixture since will be using less cement to achieve a high strength and producing smoother surface of the concrete. Thus it will increase the binding between cement paste and the aggregates and produce higher compressive strength.

2.1.2. Recycled asphalt pavement. The recycled asphalt pavement (RAP) was bought from the storage place where the entire RAP was compiled that is located at Kampung Jalan Kebun, Shah Alam, Selangor. The place is prepared for any RAP to collect and it is sold if anyone wants to buy. The RAP was left in an open area where it is already dried. According to Mr. Apai, the owner of the RAP collecting center, the latest RAP brought to the place is from a road around Kota Kemuning, Shah Alam, Selangor. The pavement was scrapped after 4 years since it is being placed. Since the RAP was brought in a bulk, therefore it required to sieve because of the RAP was made up of coarse and fine aggregates. Therefore the RAP was sieved using a sieve shaker and kept in a safe and dry place.

2.1.3. Fine crumb rubber. There are a few factories that could process the waste tire rubber. The waste tire rubber was collected and it is shredded into small pieces. In this study, 20kg of waste tire rubber that has shredded into a small size of 5-8mm size called as Fine Crumb Rubber (FCR) was bought from Yong Fong Rubber Industries Sdn. Bhd that is located at Port Klang, Selangor. The FCR should not be less than 5mm to make sure there are sufficient voids that still available in the pervious concrete. If it is smaller, it will be act similar to fine aggregate where it will reduce the void thus affecting the main purpose of pervious concrete that is to make water flows through it. The FCR was placed in a closed container to prevent for any water to enter into it. If there is water, the FCR will be moist and soon reduce its ductility.

2.2. Mixing design of the pervious concrete

Based on the literature review, there is no specific method for designing the concrete mix of the pervious concrete. Therefore, according to the research by [2], stated the specific material proportion used.
research use a ratio of 0.27:1:3.57 (Water/cement: cement: Aggregate/cement) as shown in Table 2. In [3],
given material proportion range that may found to be suitable for designing pervious concrete.

2.3. Molding and curing
There are several ways to molding the sample. However, in this study works done by [2] were followed.
Pour 3 layers of concrete paste into the mould. For each layer, tamp the concrete paste using the 1.8mm
diameter tapping rod, for 25 times. After that, the vibrators is turned on and make the sample vibrate for at
least 5 seconds to make sure the aggregate was well connected. Continue the same steps for the other 2
layers.
After it was done, the sample is placed at a place where it is covered from rain or direct sun to prevent for
any rapid hydrates or dehydrates process. If it is rapid hydrated, the samples will have more water and
causes the samples to take more time to dry, However if it is rapid dehydrated, it is possible to see a
visible cracks or hairline cracks on the sample after the sample is hardened., Therefore, place the samples
in a covered place and also place a piece of wet, clean cloth on top of the samples to make sure there are
no rapid dehydration since Malaysia’s average temperature is quite high.
The samples are left in the mould for 24 hours. Demould carefully to prevent any cracks on the samples.
The samples were inspected to make sure the concrete paste was well dry, enough for curing. If it was dry,
place the samples into a curing tank filled with water. Leave the samples in the curing tank according to
the aging time required that is 7, 14 and 28 days.

2.4. Sample testing
In this study, 3 tests conducted namely compressive, density and surface infiltration test. The compressive
test is to determine the strength of the concrete to resist the load applied. Meanwhile, for density test, it is
to determine the category of the concrete’s weight that is either lightweight or heavyweight concrete.
Lastly the surface infiltration rate is to determine the surface infiltration rate of the sample.

2.4.1 Compression test. Compressive strengths of the concrete samples were determined according to BS:
Part 116: 1983 (Method for determination of compressive strength of concrete cubes). Compression
Machine Test was used to obtain the maximum loads and compressive strength. The loading to the
concrete samples, were applied continuously at nominal rate within the range 0.2 N/mm²s to 0.4 N/mm²s
until no greater load can be sustained. By using the compressive Machine Test, the maximum load is
obtained and is recorded. The average of the concrete cube samples was calculated and recorded. By
determining the compression strength of the specimen, the maximum strength of the concrete mix to resist
the load is obtained. Thus it requires in designing either structural or non-structural component to make
sure it is suitable to be used.

2.4.2. Density test. To determine the concrete’s density, simply by placing the hardened concrete on a scale
balance. By calculation using equation.1, measure the density by calculating the weight of the concrete
divide with the volume of the concrete. The weight will be obtained in Kilogram (Kg)

\[
\text{Density} \left( \frac{kg}{m^3} \right) = \frac{\text{Mass (kg)}}{\text{Volume (m}^3\text{)}}
\]  

(1)

Density also plays a big role in determining the load applied cause of its self-weight. It is a better mixture
if it has higher compressive strength and at the same time have a low density. Therefore the pervious
concrete requires determining it’s self-weight to make sure it is adequate with the compression strength.

2.4.3. Surface infiltration test. This test is to determine the surface infiltration rate or rate of water to go
through the voids of the sample. This is the main function of the pervious concrete to determine how fast
water can go through it. The result may be considered good if the infiltration gets faster.
The test should be done according to ASTM C1871 – Surface Infiltration Rate. However since the material is insufficient to make a flat slab sample, approaching to do the test by modifying the equipment, using a similar concept as ASTM C1871. Using plastic container, the sample that already wrap with a plastic wrap is insert into the container (Figure 1). Time is taken for the water is drain out through the sample. The test only taken the vertical infiltration rate.

![Figure 1. The modified equipment to test the surface infiltration rate.](image)

2.5. Composition of material
The sample size used is 100mm x 100mm x 100mm and produced 9 samples for each mixture to check the average maximum load and stress, density and surface infiltration rate for each mixture. The previous research, with similar proportion of material (Table 3) used for the control sample, the researcher obtain a strength of 23.44 MPa of compressive strength after 28 days of curing in the water. The amount of material used for the control sample (M1) is using the same proportion by [2]. For M2, the coarse aggregate will be using the RAP instead of natural aggregate. For M3 and M4, 5% and 15% of the coarse aggregate will be replaced by the FCR.

| Mix design          | M1 - Control Sample | M2 – PC containing RAP with 0% rubber | M3 – PC containing RAP with 5% rubber | M4 – PC containing RAP with 15% rubber |
|---------------------|---------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Ratio (Water/Cement: Cement: Aggregate/Cement) | 0.27 : 1 : 4         |                                       |                                       |                                       |
| Cement (kg/m³)      | 400                 |                                       |                                       |                                       |
| Water (kg/m³)       | 121.5               |                                       |                                       |                                       |
| Natural Coarse Aggregate (kg/m³) | 1600 | -                                     | -                                     | -                                     |
| Recycled Asphalt Pavement (RAP) (kg/m³) | -                 | 1600                                  | 1520                                  | 1360                                  |

Table 3. Material composition for this study.
### 3. Result

Table 4 shows the results obtained in this study for compression and density. Based on the analysis that has been done, there are several discussion that can be done is that the physical appearance, amount of waste tire rubber effect the density of the sample, compression strength effected by the material and surface infiltration rate.

#### 3.1. Physical appearance

There are many differences in aspect of physical appearance between each sample’s mix, M1, M2, M3 and M4. For M1 shown in Figure 3, it is clearly seen that the surface is very rough even using a small size aggregate. This kind of roughness is not suitable to be used as side walk material or even the parking space. This is because of the uncomfortable surface of the pervious concrete. It is quite similar to M2 since both only using coarse aggregate, without any material that is smaller than the coarse aggregate. However when using RAP in mixture M2, the RAP that obtained for the study might slightly weak. Thus the RAP’s outer surface is easily cracked. Therefore during the mixing, the surface might be taken off and the debris fills the gaps that available. Therefore, it is seen to be a little smooth surface of sample M2 compare to M1 as shown in Figure 3.

**Table 4. Test results for density and compression**

| Test | Permeability Test (cm/s) | Density Test (kg/m³) | Compression Test (MPa) |
|------|--------------------------|----------------------|------------------------|
|      | 28 days | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days |
| Samples | Average | Average | Average | Average | Average | Average | Average |
| M1 - Control Sample | 0.615 | 1915 | 1893.333 | 1870 | 2.651 | 5.637 | 7.871 |
| M2 - RAP & 0% FCR | 0.493 | 1706.667 | 1691.667 | 1786.667 | 1.310 | 2.651 | 3.195 |
| M3 - RAP w/ 5% FCR | 0.522 | 1680 | 1703.333 | 1695 | 2.466 | 4.284 | 7.181 |
| M4 - RAP w/ 15% FCR | 0.735 | 1503.333 | 1508.333 | 1566.667 | 1.007 | 1.956 | 2.778 |
Meanwhile for M3 in Figure 2, the surface of the concrete is slightly smoother after replacing 5% of the coarse aggregate with the FCR. This surface is more comfortable for parking space and sidewalk. Furthermore, for M4, it has the smoothest surface among the 4 mixture sample as seen in Figure 3, since the coarse aggregate used that is the RAP is reduced to 15% and being replaced with FCR. In term of physical condition, M4 mixture sample is much more suitable to be used since it has less roughness. After the samples were compressed to do the compression strength test, it also found that the FCR used for the sample, hold the sample and prevent from crumble. For a normal concrete sample, after the compression test, the sample will crumble into pieces. However with the presence of FCR, even it is well cracked, but the FCR still hold the pieces.

3.2. Amount of waste tire rubber effect the density of the sample

When using the FCR to replace the coarse aggregate, theoretically it will be lighter since rubber is lighter compare with natural aggregate. Thus it is proven in Table 4 and Figure 3. This study indicates that not necessarily that a heavy material will have better strength compare with the lighter material. All mixture sample is in the suitable range of density as stated in [3] except for sample for mix M4. The sample is too light since it’s containing 15% of FCR that replacing the weight of the course aggregate.

3.3. Compression strength effected by the material

According to the previous study by [2], the control sample that is only using natural aggregate as the coarse aggregate, cement and water, the compression strength obtain after 28 days is 23.44 MPa. Based on
this study, the control sample that is M1, only obtaining 7.871 MPa after 28 days of curing as shown in Table 4 and Figure 4.

Figure 5. Compression strength vs. fcr percentages.  
Figure 6. Surface infiltration rate.

Nevertheless, the sample’s compression strength for 28 days was in the range 3 to 28 MPa as stated in [3]. Even M3 obtain only get 7.481 MPa, but with that strength, it still can resist the load from a vehicle that park on pervious concrete surface parking lot. Furthermore, the difference between mixture M1, that using natural aggregate and M2, that using RAP for the coarse aggregate. It shows that M2 is weaker compare to M1. The reason of this to be happen is probably the RAP that used for this study was weak than it is expected. Therefore, to choose the right RAP to be used in the mixture, the condition of the RAP such as the period of time of exposure to the moving load on it, any water retained on the surface, type of moving vehicle that moves on it, may need to be considered. Even though it was coated with bitumen, it is unnecessarily to remaining its strength even after years of moving load applied on it. The RAP is originated from the stretch of road that sometimes heavy vehicles moves on it but there are no water usually retained on the surface. However it might be a little crack that makes the coarse aggregate of the RAP to be exposed to water and weaken the inner part of it, before it is bought to the collection center.

Moreover, the sample mixture for M3 was almost similar to the control sample and higher compression strength compare with M4. The possible reason behind of the result is 5% FCR is sufficient enough to make the concrete matrix to well bond between FCR and RAP and obtain a high strength. Meanwhile for M4, even it is far lighter, but the amount of FCR (Figure 5) is too many, at the same time make the harden concrete to be easily cracked during the compression test. Plus, as a rubber, when it is compressed, it will stretch. Therefore it cracked the bond of concrete between the FCR itself with the coarse aggregate. It might be stronger if the amount of cement used is more than 400 kg/m³ or using superplastisizer. Results indicate that pervious concrete can be used as a non-structural material; it is more suitable for parking space or sidewalks. Further study requires producing more high compressive strength pervious concrete.

3.4. Surface infiltration rate

The surface infiltration rate varies for each sample (Figure 6). The surface infiltration rate is depending on the voids available in the pervious concrete mix. According to the result from Table 4, it shows that M4 has the highest surface infiltration rate among the entire mixture sample. This happens is probably because
of the FCR that mixed in the previous concrete, producing much more voids with a larger surface area. Therefore, it is easier for water to flow through the pervious concrete sample. M2 sample has the lowest surface infiltration rate because of the broken outer surface of the RAP that turn into debris that fills between the coarse aggregate.

4. Conclusion
As a conclusion, sample mixture M3, that using recycled material that is RAP and FCR, has almost similar characteristics as sample mixture M1 that using new material that is natural aggregate. This shows that using recycled material could achieve the similar performance as using new material. At the same time, this could reduce the cost of material to be used for the pervious concrete, yet having the almost similar performance with the control sample.

Other than that, using RAP to replace natural aggregate as the coarse aggregate could be implemented in making pervious concrete. However the RAP needs to be in a good performance and condition. This also shows that there are significant differences when using RAP and natural aggregate as the coarse aggregate in the pervious concrete.

From this study, also shows that the amount of FCR required to get the best performance is 5%. Sample mixture that using 5% of FCR that is M3, obtaining almost similar compression strength and surface infiltration rate with control sample, M1 and lesser density compare to M1. Even the compression strength obtain from this study is very low, however it is still in the range that provided by [3]. Therefore, the objective of this study is achieved. However there are more studies on the usage of waste tire rubber and waste aggregate such as FCR and RAP, which is a recycled material, in making pervious concrete. Instead of this materials being decomposed, it can be used for the benefits of the society.

5. Recommendation
Based on the result acquired through this study, the following are recommended for future studies as to substantiate the modified pervious concrete containing RAP and FCR

i. Increase the amount of cement slightly higher from 450 kg/m3. According to [3], stated that aggregate cement ratio is in the range of 4-4.5. However the study’s aggregate cement ratio is 3.55.

ii. Determine the RAP’s strength that used for the experiment.

iii. Use percentage of FCR to be used between 5% and 15%. Since this study has the limitation of amount of FCR to be used, the future study should use various percentage of the rubber to determine the amount of FCR that give the best performance to the pervious concrete.

iv. Use the right equipment to determine the surface infiltration rate that is ASTM C1871. By producing the flat slab size, the result of the test would be more precise.

6. Reference
[1]. Bhutta, M. A. R., Hasanah, N., Farhayu, N., Hussin, M. W., Md Tahir, M., & Mirza, J. (2013). Properties of Porous Concrete from Waste Crushed Concrete (Recycled Aggregate). Construction and Building Materials, 1243–1248.

[2]. Gesoğlu, M., Güneyisi, E., Khoshnaw, G., & İpek, S. (2014). Investigating properties of pervious concretes containing waste tire rubbers. Construction and Building Materials. http://doi.org/10.1016/j.conbuildmat.2014.04.046

[3]. Tennis, P. D., Leming, M. L., & Akers, D. J. (2004). Pervious Concrete Pavements EB202.02. Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland, USA.

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