A New Design of Recycled Concrete Aggregates as an Aerated Filter for Removal of Phosphorus

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Abstract. This paper assesses a new design of recycled concrete aggregates as an aerated filter for removal of phosphorus (P). Recycled concrete aggregates (RCA) obtained from crushed concrete waste. In this study, RCA is used as an Aerated Filter for removal of P. A commercial concrete was crushed, and the RCA were sieving according to different sieve size. The highest percentage passing sieve size is size 5 mm is 99.88%. The bulk density for RCA is 1680 kg/m³ while percentage of voids is 36%. Result for water absorption test of RCA is 1.27, the Aggregate Impact Value (AIV) test is 28.75 and the pH value for RCA is 9.30 which is alkaline. RCA with smallest size and lowest initial concentration of P which is 0mm to 5mm and 10mg/L respectively has the lowest uptake capacity which 0.996 mgL⁻¹/g but highest percentage of P removal which 99.60%. Besides cost saving, due to application of water material, the usage of RCA will ease the environmental problems that are currently perceived globally. RCA could also saves landfill space which helps reduce the needs for gravel mining and reduces pollution.

1. Introduction
Concrete is the most used construction material, with estimated annual production of 10 billion cubic meters. Since 60–80% of the concrete volume is taken by aggregates, the overall consumption of natural aggregates (sand and gravel) is very high, generating huge pressure on surrounding ecosystems. The environmental impact of aggregate extraction is particularly severe regarding sands, with distinct problems associated to different extraction or production technologies (Evangelista et al. 2015). Concrete is the most widely used construction material in the world due to its low cost, excellent durability, easy availability of its constituent materials, easy formability to any shape, etc.

In the following years, a large amount of experimental works have been carried out worldwide to investigate the recycling of waste concrete. Previous studies were mainly engaged in the processing of demolished concrete, mix-proportion design, mechanical properties, durability aspects and improvements. Recently, structural performances and economic aspects of using recycled concrete aggregates (RCA) are also analyzed. RCA are composite materials formed from cement, aggregates, water and eventually admixtures or partial cement replacement materials. The resulting properties are substantially different from those of natural aggregates and strongly dependent on processing and treatment.

Use of RCA fulfils the three green requirements that has been set out by the World Environmental Organization. Firstly, it can recycle and reduce natural resources and energy consumption. Secondly, it will not affect the environment and lastly, it can maintain sustainable development. Therefore, RCA is
green concrete. Although reuse of RCA reduces the consumption of limited resources and thereby saves costs, they have some limitation for example weak interfacial behavior between aggregate and cement paste high portion of cement mortar attached that lower its quality. To facilitate the use of RCA, it is vital to identify some ways to overcome these shortcoming.

Domestic wastewater treatment is also becoming more critical issue due to diminishing water resources and resulting water shortage. Aeration is one of the method which help in the removal of various contaminants present in domestic wastewater. The characteristics of wastewater having pH, Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Oil, phosphorus and nitrogen (about 6% of the BOD level) at a range of value which is harmful to human and environment was found to be the major polluting sources. The process of aeration was found to be an effective method in reducing these contaminants. A large amount of the waste then is directly discharged into the receiving water bodies, which bear the effect of ecological damage caused by its pollutants. The objective of this study is to determine physical and chemical characterization of recycled concrete aggregates as a aerated filter for phosphorus removal.

2. Experimental Study

2.1. Materials
This study is based on recycled concrete aggregate. Aggregates were crushed at a maximum size of 20 mm. The source of these RCA is a local concrete tested cube specimens (concrete grade, 25-30 MPa). In this study, Recycled Concrete Aggregates (RCA) was obtained from thrown waste cubes produced from the Material Laboratory in Universiti Tun Hussein Onn Malaysia (UTHM). Initially, the thrown waste cubes outside laboratory were selected. Then the waste cubes were crushed by using the crushing machines in order to produce the aggregates. Figure 1 shows crushing machine which is equipment for crushing the waste cube into recycled concrete aggregate while Figure 2 shows the RCA that has been crushed.
3. Results and Discussion

3.1. Physical Characteristics of RCA
There are four types of test on physical characterization which are sieve analysis test, bulk density test, water absorption test and aggregate impact value test.

3.1.1. Sieve Analysis
This test is used to determine the grading of RCA as an aggregates. Figure 3 shows equipment of sieving the RCA which is Sieving Machine.
Based on the tests that have been carried out, the highest percentage of the size of the RCA passing sieve size is size of 5 mm. Percentage passing sieve size of 5 mm is 99.88%. Grade curve for RCA specified entering the designated area. The conclusion proof that from the aspects of grading aggregate, RCA used beyond the specifications set by BS410: 1986 "Specification for test sieve".

3.1.2. **Bulk Density Test**

This test method is often used to determine bulk density values that are necessary for use for many methods. The bulk density also may be used for determining mass/volume relationships for conversions in purchase agreements. Table 1 show the bulk density for RCA.

| Sample                  | Bulk density (kg/m³) |
|-------------------------|----------------------|
| Recent Study, (2017)    | 1680                 |
| Faiz Uddin, (2016)      | 1247                 |
| Larbi *et al.* (2015)   | 1148                 |
| Evangelista *et al.* (2015) | 1004                |

Value of the bulk density of the aggregate depends upon the amount of effort used to fill the container as possible, size distribution, shape and specific gravity. More graded the aggregate, greater the bulk density. Angular and flaky shape of the material reduce the bulk density. The value for this bulk density of RCA was 1680 kg/m³.

Most study shows that the bulk density test for RCA is lower than this study. Several researchers have conducted study for determining Bulk Density of RCA and summarize in Table 1. It can be seen that the lower bulk density is 1004 kg/m³. It is significantly lower than those of RCA. This is because this RCA are mostly composed by mortar, and it presents a narrow size distribution. Different with Faiz Uddin (2016), the bulk density test for RCA is 1247 kg/m³. The RCA is generally sourced from crushed concrete structures, therefore, old mortars always adhered to the RCA. It is also known that in RCA the
old adhered mortars are more porous. Meanwhile Larbi et al (2015) determine that bulk density for RCA is 1338 kg/ m³. This is because the effect of the superplastizier on the density. Test clearly shows that compacted aggregate which has bigger bulk density provides better strength. Figure 5 shows the equipment for Bulk Density Test.

Figure 5: Equipment for Bulk Density

3.1.3. Water Absorption
This test helps to determine the water absorption of RCA as per IS: 2386 (Part III) – 1963.

| Researchers         | Percentage Water Absorption RCA (%) |
|---------------------|-------------------------------------|
| Recent study, (2017)| 1.27                                |
| Faiz Uddin, (2016)  | 4.9                                 |
| Dina Sadek, (2012)  | 0.83                                |
| Nikoo et al. (2016)| 0.59                                |
| Suraya et al. (2016)| 5.58                               |

According to Anchor (1998), the water absorption of aggregates should not exceed 3% of absorption. In this study, water absorption for RCA was 1.27. Hence the result shows it not exceed the maximum of 3% absorption. Water absorption gives an idea of strength of aggregates. Aggregates was composed of cement paste, which having more water absorption are more porous in nature and are generally considered suitable to be an aerated filter for removal of P. Ayaz et al. (2015) reported that larger the
porosity, larger the specific surface area where sorption of mechanism can take place. Therefore, the RCA in this water absorption can be said as higher strength because the results shows lowers than maximum absorption.

Table 2 shows result for water absorption test for RCA from different researchers. Most study shows that the percentage water absorption for RCA is lower than this study except in Faiz Uddin (2016). Several researchers have conducted study for determining percentage water absorption of RCA and summarize in table 2. This is because the RCA from geopolymer concrete. This increased absorption due to capillary rise is expected and is due to inferior properties of the RCA. Dina Sadek (2012) identified that percentage water absorption of RCA is 0.83. This may be attributed to the highly porous of RCA and may be due to the filler effect of the fine portion of the RCA. Other researchers Nikoo et al. (2016) found that the percentage water absorption is 0.59. This is because the RCA is from PVC concrete. This can be attributed to the lower relative humidity in the pores of the specimens which caused the hydration reaction of cement dose not progress satisfactory. Figure 6 shows equipment for Water Absorption Test. Suraya et al (2016) examined that water absorption for RCA was 5.58. This is due to high absorption characteristic of RA that developed the higher osmosis pressure. This higher osmosis pressure have a tendency to absorb more water from the surrounding of the samples (Cakur and Sofyanh 2015).

![Figure 6: Equipment Water Absorption Test](image)

### 3.1.4. Aggregate Impact Value (AIV) Test

This test is conducted to determining the aggregate impact value of aggregates as per IS: 2386 (Part IV) – 1963.

| Researchers      | AIV test (%) |
|------------------|--------------|
| Recent study, (2017) | 28.75        |
| Shahid et al. (2016) | 28.00        |
| John et al. (2017)  | 22.20        |
| Suraya et al. (2016) | 20.80        |
| Shahiron et al. (2016) | 12.70        |
The strength of aggregates is assessed by aggregates impact value. The aggregates impact value test provides a relative measure of resistance under a gradually applied compressive load. To achieve high quality strength, aggregate possessing low aggregate impact value should be preferred. Table 3 shows result for Aggregates Impact Value (AIV) test. In this study, the AIV test is 28.75. Based on IS: 2386 (Part IV) – 1963, it states that the aggregates impact value for wearing surface shall not exceed 45%.

Shahiron et al. (2017) shown that the AIV Test for RCA was 12.7 % which is the lowest percentage. This is because the recycled aggregates were treated first with 25% epoxy resin. Next, Shahid et al. (2017) shows that the value for AIV Test was 28% while John et al. (2017) state the value for AIV Test was 22.20 %. For John et al. (2017), the residual mortar content of the RCA particles was found using the hydrochloric acid dissolution method. Other researcher, Suraya et al. (2010) examined the AIV test for RCA was 20.80 %. This is due to the mortar attached to RA could most probably influence the amount of broken particles size smaller than 2.36 mm size after the blasting. All the results shows that AIV test not exceed 45% thus its proof that the RCA has achieve its strength. Figure 7 shows that the equipment used for AIV Test.

![Figure 7: The equipment for AIV](image)

3.2. Chemical Characteristics of RCA
There are three types of test in chemical characterization which is determine pH$_{pzc}$ and determine pH.

3.2.1. Determine Point Zero Charge (pH$_{pzc}$)

![Figure 8: Graph Point Zero Charge (pH$_{pzc}$)](image)
Point Zero Charge (pH\textsubscript{PZC}) is the pH value at which the sum of surface positive charges balances the sum of surface negative charges. In addition, the surface is positively charged at pH values below pH\textsubscript{PZC} and negatively charged at pH values above pH\textsubscript{PZC}. Figure 8 shows the point zero charge for RCA after shaken at 170 rpm for 24 hours. The reading point zero charge of RCA is 10.60. Its show that the pH value 9.30 lower than the point zero charge of RCA. Then, H\textsuperscript{+} contributes H\textsuperscript{+} is more than OH\textsuperscript{-}, therefore the surface absorption was negative charge. Figure 9 shows the equipment used in pH\textsubscript{PZC} test.

![Equipment in pH\textsubscript{PZC} test](image)

3.2.2. *Determine pH*

The pH value of the filter media that is RCA was determined by the principle of extraction with boiling water. The pH of the extracts was determined and accepted as the pH value of filter media. From the boiling water extraction principle, the pH value of RCA is 9.30 which is alkaline. Regarding Izzati *et al.* 2016, RCA contains high concentration of SiO\textsubscript{2} which is 57.20%, while 11.60% of CaO, 3.99% of Al2O3 and 2.13% of Fe2O3. This shows that RCA also could be one of the potential substrates for removal of P in wastewater treatment process. Besides, RCA also gives high alkalinity content. Thus, based on the determination of pH that has been conducted, its demonstration that RCA was alkaline. The influence removal of P related to pH level and Ca content of filter material. As a calcium ions can form stable and insoluble products with phosphate, calcium-based materials are considered to be one of the potential sorbent of phosphorus removal. The most of materials with high pH also have higher Ca content which is (>15%) (Xiangling *et al.* 2016). Najwa Nasir (2016) also get pH value for steel slag as an alkali which is 10.19. Although steel slag is the product of different processes and different chemical compositions, but they share similar characteristics such as high calcium content and alkalinity, which makes them good for phosphorus removal (Zuo *et al.* 2015).
3.2.3. X-ray Fluorescent (XRF) Analysis of RCA
In this project, XRF Analysis was conducted in order to identify chemical composition in RCA. Based on the XRF analysis conducted for RCA, it showed that, RCA also contains high concentration of SiO$_2$ which is 57.20%, while 11.60% of CaO, 3.99% of Al$_2$O$_3$ and 2.13% of Fe$_2$O$_3$. This shows that RCA also could be one of the potential substrates for P-removal in wastewater treatment process. This is because all these chemical compositions were easily react with P (Izzati et al 2016). Table 4 shows the chemical composition of RCA based on the XRF analysis.

| Formula | Concentration |
|---------|---------------|
| SiO$_2$ | 57.20%        |
| CaO    | 11.60%        |
| Al$_2$O$_3$ | 3.99%    |
| Fe$_2$O$_3$ | 2.13%    |
| C      | 1.00%         |
| K$_2$O | 0.98%         |
| SO$_3$ | 0.60%         |
| Na$_2$O| 0.48%         |
| MgO   | 0.46%         |
| TiO$_2$ | 0.23%     |
| Cr$_2$O$_3$ | 0.18%    |

3.2.4. Scanning Electron Microscopy (SEM) Analysis of RCA
SEM images of the surfaces of the RCA samples are shown in Figure 11. The surface of the RCA sample is covered by loosely bonded cement mortar and considerably amount of porous fine particles which were created by a crushing process. The SEM analysis has demonstrated that recycled concrete aggregate provide less porous, more dense and connected microstructure.
3.2.5. Batch experiment process
In this project, the laboratory work has been conducted for 8 weeks. 96 samples of wastewater have been treated by using RCA. Each of the samples was treated for 24 hours. RCA that was used in this experiment were categorized into two different sizes which are 0mm to 5mm and 10mm to 20mm. Besides, the initial concentration of P in synthetic wastewater were fixed into six which are 10mg/L, 20mg/L, 30mg/L, 40mg/L, 50mg/L while 0mg/L as standard solution (control). The dosage of RCA are fixed which is 10g.

3.2.6. Uptake Capacity of Phosphorus & Percentage of Phosphorus Removal
For this project, uptake capacity, \( q \) of Phosphorus (P) is the amount of P absorbed by a unit gram of RCA. Observation and calculation on uptake capacity of P is to show the ability of RCA as filter media in removing P from wastewater. Equation 3.0 shows the formula used in calculating the uptake capacity and equation 3.1 shows the formula used to calculate the percentage of P removal. Table 5 shows the uptake capacity of P and percentage of P removal for 0mm to 5mm and 10mm to 20mm.

\[
\frac{\text{initial concentration} (C_0) - \text{final concentration} (C_e)}{\text{weight of RCA}} = \text{uptake capacity} (q) \quad \text{(Equation 3.0)}
\]

\[
\frac{\text{influent–effluent}}{\text{influent}} \times 100 = \% \text{ of P removal} \quad \text{(Equation 3.1)}
\]

Table 5 shows the uptake capacity of P and percentage of P removal for 0mm to 5mm and 10mm to 20mm.
Table 5: The uptake capacity of P and percentage of P removal for 0mm to 5mm and 10mm to 20mm.

| Size of RCA (mm) | Co / Influent (mg/L) | Ce / Effluent (mg/L) | Uptake Capacity (q) | Percentage of P removal (%) |
|-----------------|----------------------|----------------------|---------------------|-----------------------------|
| 0mm to 5mm      | 0                    | 0                    | 0                   | 0                           |
|                  | 10                   | 0.045                | 0.996               | 99.60                       |
|                  | 20                   | 4.610                | 1.539               | 76.95                       |
|                  | 30                   | 7.526                | 2.247               | 74.91                       |
| 10mm to 20mm    | 0                    | 0                    | 0                   | 0                           |
|                  | 10                   | 0.555                | 0.945               | 94.45                       |
|                  | 20                   | 7.452                | 0.627               | 62.74                       |
|                  | 30                   | 14.15                | 0.528               | 52.83                       |

Figure 12 shows the result for uptake capacity of Phosphorus (P) and percentage of P removal for RCA size 0mm to 5mm with three different initial concentration of P which is 0mg/L, 10mg/L, 20mg/L and 40mg/L. For 10mg/L, the uptake capacity of P is 0.996 and the percentage of P removal is 99.60% while the uptake capacity for 20mg/L is 1.539 and the percentage of P removal is 76.95%. The last initial concentration of 30mg/L shows the uptake capacity is 2.247 and the percentage of P removal is 74.91%. Based on the result, it shows that the uptake capacity of P increasing as the initial concentration increasing. However, the percentage of P removal decreasing as the initial concentration increasing.

Figure 12: Initial concentration of Phosphorus (P) Vs Uptake capacity and Percentage of P removal for RCA size 0mm to 5mm
Figure 13 shows the result for uptake capacity of Phosphorus (P) and percentage of P removal for RCA size 10mm to 20mm with three different initial concentration of P which is 0mg/L, 10 mg/L, 20 mg/L and 40 mg/L. For 10 mg/L, the uptake capacity of P is 0.945 and the percentage of P removal is 94.45% while the uptake capacity for 20mg/L is 0.627 and the percentage of P removal is 62.74%. The last initial concentration of 30mg/L shows the uptake capacity is 0.528 and the percentage of P removal is 52.83%. Generally it can be seen that the uptake capacity of P increasing as the initial concentration increasing but the percentage of P removal decreasing as the initial concentration increasing. From the two graph for different size of RCA which is 0mm to 5mm and 10mm to 20mm, it is obvious shown that RCA which smallest size and lower concentration have the highest uptake capacity and percentage of P removal. This results, shows the similarities finding with Akratos and Tsihrintzis (2007) found greater removal efficiency of P removal for fine gravel is 89%, followed by medium gravel with cattail 67% and cobbles (57%). Percentage of P removal efficiency was predominantly affected by porous media size and initial concentration.

![Figure 13: Initial concentration of Phosphorus (P) Vs Uptake capacity and Percentage of P removal for RCA size 10mm to 20mm](image)

### 4. Conclusion

Based on the experimental result and data analysis, number of conclusions could be made.

1. Based on physical and chemical characteristic of RCA, it shows that RCA could be a new types of filter for removal of phosphorus.
2. RCA with smallest size and lowest initial concentration of P which is 0mm to 5mm and 10mg/L respectively has the lowest uptake capacity which 0.996 mgL⁻¹/g.
3. RCA with smallest size and lowest initial concentration of P which is 0mm to 5mm and 10mg/L respectively has the highest percentage of P removal which 99.60%.
References

[1] Adnan, S.H., Hamdan, R., Yassin, N.I.M., 2016. Removal of phosphorus from synthetic wastewater using recycled concrete aggregates as filter media. 2nd International Conference on Science, Technology and Social Science 2016.

[2] Adnan, S.H., Loon, L.Y., Rahman, I.A., Saman, H.M., Soejoso, M.W., 2010. Compressive Strength of Recycled Concrete with Various Percentage of Recycled Aggregate.

[3] Akratos, C.S., Tsihirintzis, V.A., 2007. Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. Ecol. Eng. 29, 173–191.

[4] Annual Book of ASTM Standard, Standard test for pH of Point Zero Charge, ASTM D 3838-05, Philadelphia PA, United State of America, 2011.

[5] ASTM (1995). D1293-95: Standard test methods for pH of water. ASTM International, West Conshohocken, Pennsylvania.

[6] ASTM C1723-16. Standard Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy.

[7] ASTM Designation C 114-1. Standard Test Method of X-ray Fluorescent (XRF) Analysis.

[8] ASTM Designation C136-01. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

[9] ASTM Designation: C 29/C 29M-03 (2003). Standard Method of Test for Bulk Density (Unit Weight) and Voids in Aggregate.

[10] Dina, S. Physico-mechanical properties of solid cement bricks containing recycled aggregates. Journal of Advanced Research.

[11] Evangelista, L., Guedes, M., Brito, J., Ferro, A.C., Pereira, M.F., 2015. Physical, chemical and mineralogical properties of fine recycled aggregates made from concrete waste. Construction and Building Materials 86 (2015) 178–188.

[12] Evangelista, L., Guedes, M., Ferro, A.C., 2015. Physical, chemical and mineralogical properties of fine recycled aggregates made from concrete waste. Construction and Building Materials 86 (2015) 178–188.

[13] Faiz, U. 2016. Mechanical and durability properties of fly ash geopolymer concrete containing recycled coarse aggregates. International Journal of Sustainable Built Environment.

[14] IS: 2386 (Part III) – 1963. Water Absorption Test.

[15] IS: 2386 (Part IV) – 1963. Aggregate Impact Value Test.

[16] John, R.P., Gaurav, G., Singh, B., 2017. Splice strength of deformed steel bars embedded in recycled aggregate concrete. Structures 10 (2017) 130–138.

[17] Larbi, B., Abdelaziz, M., Miloud, B., 2015. Study of the physico-mechanical properties of a recycled concrete incorporating admixtures by the means of NDT methods. 7th Scientific-Technical Conference Material Problems in Civil Engineering.

[18] Nasir, N.N., 2016. Effect Of pH and Density Metal Oxide on Removal of Phosphorus Using The Filter System Vertical Steel Slag.

[19] Nikoo, H., Yassin, S., Jalal, S., 2016. Properties of recycled PVC aggregate concrete under different curing conditions. Construction and Building Materials 126 (2016) 943–950.

[20] O. Cakir, O.O.Sofyanh, Influence of Silica Fume On Mechanical and Physical Properties of Recycled Aggregate Concrete, Housing and Building National Research Center, 11, 157-166, (2015)

[21] Shahid, K., Ammar, A.S., Imran, M.K., 2016. Recycled Construction Debris as Concrete Aggregate for Sustainable Construction Materials. International Conference on Sustainable Design, Engineering and Construction.

[22] Shahiron, S., Kumanan, K., Azmi, M.A., Zuki, S.S., Alie, N., 2017. Utilizing Construction and Demolition (C&D) Waste as Recycled Aggregates (RA) in Concrete. 2016 Global Congress on Manufacturing and Management.

[23] Xiangling, Z., Lu, G., Hualing, H., Yinghe, J., Meng, L., Yujie, L., 2016. Removal of phosphorus
by the core-shell bio-ceramic/Zn-layered double hydroxides (LDHs) composites for municipal wastewater treatment in constructed rapid infiltration system. Water research, 280-291.

[24] Xu, D., Wang, L., Li, H., Li, Y., Howard, A., Guan, Y., … Xu, H. (2015). The forms and bioavailability of phosphorus in integrated vertical flow constructed wetland with earthworms and different substrates.

[25] Zuo, M., Renman, G., Gustafsson, J. P., & Renman, A. (2015). Phosphorus removal performance and speciation in virgin and modified argon oxygen decarburisation slag designed for wastewater treatment.