Review of Recycles Concrete Aggregate and Polyethylene Terephthalate in the Manufacturing of Brick

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Abstract. Recycled Concrete Aggregate (RCA) and Polyethylene Terephthalate (PET) are one of the construction waste can be recycled. Both of them can be the aggregate to replace the natural aggregate in concrete since we know the physical properties of both materials are hard and strong. Demand for sand in the concrete production has increased which led to become problems in the industry. As a result, the price of the sand increased, which in turn affected the pricing of the cement and sand bricks. One of the ways to reduce this problem is to utilize the RCA and PET waste bottle in the production of construction materials such as brick. Replacing both wastes as sand aggregate in bricks is one of practices and imaginative solutions in order to minimize environmental impacts. In short, using 50% replacement of RCA as replacement of fine aggregate show the acceptable in strength of brick. Furthermore, the decision of using PET will make it worthwhile in increasing the workability of economical brick.

1. Introduction
Nowadays, there are various type of aggregate which has been produced that consist of materials, industrial waste, crushed glass, construction waste such as concrete, crushed brick and more [1]. Classification of aggregate is generally based on their geological origin, size, shape and unit weight [2]. Recycled aggregate consists of original aggregate and original mortar. Hence, it is using the aggregate refining method in production for the purpose of reduce the quality of using natural aggregate such as gravel or sand [2]. RCA obtained from crushed concrete that containing of 65-80 % of natural coarse aggregate and fine aggregate and 20-35 % of old cement [3]. According to ‘Sheikh Khalid et al. [4] study, when RCA is crushed from masonry, the content of the fine particles is much more than that form concrete. This leads to decrease in strength and workability of concrete containing recycled fine aggregate.

Recycled concrete aggregate produced by two stage which is start by crushing of demolished concrete, screening and removal of contaminants such as reinforcement, paper, wood, plastic and gypsum [5]. However, one of the problems exists when using the RCA for manufacturing of new concrete mixtures is the possibility of contaminants in original construction and demolition (CDW) debris passing into new concrete mixtures. The contaminants may be organic material, glass, lightweight bricks, chemical admixtures, clay and other metals [5]. The previous researcher found that 25% and 50% replacement of recycled aggregate in concrete brick and paving block showed the increase percentage of replacement was reduced compressive strength in production of samples [6].
Previous published paper explain which tells the cost of transportation of natural resources, energy and reduces the impact of waste material on industry environment [7]. However, the researcher claims that it would be inexpensive by using coarse and fine recycled aggregate as new construction materials [8].

2. RCA in Brick Production

The result of density sand cement brick shows that, the decreasing value of density at RCA 75% by 4.9% for 7 days and 5.4% for 28 days which are lower compared to control brick. However, 55% of recycled concrete aggregate is added showing that, the value of compressive strength decreases due to smaller porosity and is less permeable compared to control brick. High percentage of recycled concrete aggregate in sand cement brick was more permeable than the natural sand [9].

Bravo et al. [10] studied the durability performance of recycled concrete aggregate in brick. They used different mixes with 10%, 25%, 50% and 100% for volume of recycled concrete aggregate replacement of coarse natural aggregate (from five sources). Meanwhile, the same percentage had been used for volume of fine natural aggregate replaced by fine recycled aggregate. From this study, the water absorption was analysed that it can be concluded that the replacement of NA with RA caused an increase of the water absorption in samples. Dina M. & Mohamed M. [11] stated that concrete containing coarse crushed bricks had a relatively lower strength at early ages than normal aggregate concrete. Compressive strength, water absorption and unit weight of solid cement bricks containing crushed brick aggregates were determined and compared with the limits of the national and international standards for load bearing and non-load bearing units. The results obtained that specific gravity of brick aggregates had lower specific gravity compare to natural aggregates. However, the water absorption showed the higher value was 40% than natural aggregates due to porosity of the clay bricks.

Based on Ismail and Yaacob [12], this study aims the possibility of recycled fine aggregate produced from waste as a substitution for natural aggregate in brick. The percentage of recycled aggregate used were 0%, 25%, 50%, 75% and 100%. The replacement of recycled fine aggregates at level 50% and 75% showed a good value on compressive strength in replacement of natural sand. Hence, in flexural strength test, the result of 50% replacement recycled aggregate showed slight decrease which due to porously of recycled aggregate in brick. However, water absorption and shrinkage results of the brick shows a good result. Poon et al. [13] studies aims to using RCA in sand cement bricks. A total series of mixtures was remove repared according to the replacement of RCA in natural aggregate of 0%, 25%, 50%, 75% and 100%. The test that involved in their studies is compressive strength, drying shrinkage and transverse strength test. The results obtained, the compressive strength for brick shows that the percentages of 50% have a greater value rather than the control brick. However, the result shows a reduction when the percentage of RCA is 75% and 100%. Transverse strength test presents that all percentage of RCA shows a high value compare to control and its pattern similar with drying shrinkage test. They indicated that the although percentage of 25% and 50% of RCA shows an impact on compressive strength, transverse strength of the specimen increased as percentage of RCA increased. Table 1 shows the overall summary of previous study on RCA.

Table 1. Summary of previous work on RCA.

| Author          | Percentage of replacement | Description                                                                 |
|-----------------|--------------------------|-----------------------------------------------------------------------------|
| Sheikh Khalid, F et al., 2017[9] | 55%, 65%, and 75%         | • Replacement by weight of recycled concrete aggregate were 55%, 65%, and 75% |
|                 |                          | • Compressive strength, water absorption and density test                   |
|                 |                          | • The density of sand bricks containing recycled fine aggregate decreases when the percentages of recycled fine aggregate increases. |
|                 |                          | • The value of compressive strength decreases but it shows less permeable compared to control brick when 55% of RCA is added |
Bravo et al., 2015 [10] 10%, 25%, 50% and 100% • The replacement of 10%, 25%, 50% and 100% of the overall volume of coarse and fine natural aggregate was replaced
• The water absorption can be concluded that the replacement of NA with RA caused an increase of the water absorption in samples.

Dina et al., 2012 [11] 0%, and 25% • The substitution ratios of natural aggregates with RCA were 0% and 25% by volume.
• Four series of mixtures with cement content 100, 150, 200 and 300 kg/m³ were prepared
• The water absorption increased and the unit weight of solid cement bricks decreased
• Bricks that containing crushed aggregates present the decreasing value of compressive strength due to increasing the size and content of crushed bricks.

Ismail, 2010[12] 25%, 50%, 75%, and 100% • The design proportion was used 90% sand, 5% cement and 5% laterite soil of the cement and sand bricks
• The replacement were 25%, 50%, 75%, and 100% by weight of natural sand aggregates.
• The higher replacement of recycled fine aggregate, the lower the density of cement and sand bricks
• 50% and 75% replacement showed a good value on compressive strength in replacement of natural sand.
• Water absorption and shrinkage results of the brick shows a good result.

Poon et al., 2002 [13] 25%, 50%, and 100% • Natural aggregate was replaced at level from 25% to 100% by weight.
• Compressive strength showed a little effect at level 25% and 50% when coarse and fine natural aggregates was replaced to the bricks and blocks sample.
• The increase levels of replacement reduced the compressive strength of samples.

3. PET Waste in Brick Production
PET stands for Polyethylene Terephthalate is usual plastics which is used as a raw material for making products like blown bottle which is used to produce soft drinks, food containers and other consumer goods. [14]. These non-biodegradable waste materials along with population growth have caused a global environmental crisis all around the world. In order to protect the environment, the new technologies to recycle and convert waste materials have to be developed. This leads to waste materials into reusable materials that important to sustainable development of society. The present application of recycled PET waste in the construction industry includes its use as resin for polymer concrete [15] and as fiber for reinforced concrete [16]. PET waste can be substitute as aggregate to reduce the waste in order to bring the economical way in construction industry. Moreover, the using PET waste in concrete has a few advantages such as reduce the usage of natural resources, decrease the waste consumption and protect the environment economizing energy and pollution [10,17].
Vadivel et al. [18], used the volume of PET of 0%, 5%, 10%, 15%, 20% and 25% as sand replacement and the compressive strength, flexural strength and split tensile strength test. The compressive strength of PET gradually increases until volume of 15% but it starts to decrease in 20% and 25%.
replacement of 15% PET shows high value compare to the normal concrete. Split tensile strength of PET performed very well compared to conventional concrete. The volume of 25% PET shows high split tensile strength which is 24.87% than conventional. The flexural strength of PET shows a good result rather than the normal concrete where the 25% replacement of PET provides the higher value. Silva et al. [19] study the effect of curing conditions on the durability of concrete mixes with selected plastic waste aggregates. Tests for chloride penetration, carbonation, water absorption and compressive strength were carried out to determine the durability of each sample. Low bonding strength between PET and aggregates make the reduction of strength concrete due to the PA’s impermeable nature. The coarser the particle size of the PA lead to reduction in the level of packing concrete and the aggregate leading to poorer bonding of concrete when water absorbed by the PA.

Ge et al. [20] study the effects of aggregate gradation, sand-to-Polyethylene Terephthalate (PET) ratio and curing conditions on physical and mechanical properties of recycled PET mortar. Results show that sand-to-PET ratio increased, the density and water absorption of the recycled PET mortar also increased. Similar observations conducted by Ghernouti et al. [21], where the results showed that the use of plastics bag wastes (PBW) containing 10 and 20% of waste enabled to reduce by 18-23% the compressive strength of mortars, which remains close to the reference mortar (without PBW waste). The author used (10, 20, 30 and 40 %) of PBW as sand replacement aggregate.

Shahidan et al. [22] focus this study on physical and mechanical behavior of recycled PET fiber reinforced mortar. This study claims that, PET bottle was adding about 0%, 0.5%, 1.0% and 1.5%, in dry mix mortar remarkably better to improve strength of concrete. The best replacement of 1.0% PET fiber is the best maximum volume in production of sample. Some previous studies conducted by Akcaozoglu et al. [23] used 0.45 water binder ratio and 0.50% PET in the mixtures. This study aimed the physical and mechanical properties of mortars containing PET as replacement of aggregates. The test concluded such as the compressive strength, water absorption and carbonation tests. The mixtures were prepared by using only waste PET granules and half of the mortar mixture sand the rest mortar mixtures were prepared with sand and waste PET granules together. The results showed that the mixtures containing sand and PET were higher in compressive strength compared to the mixtures containing PET without sand.

Choi et al. [24] studied the performance of properties of waste PET lightweight aggregates (WPLA) in mortar and concrete. In this study, the author used 0%, 25%, 50%, 75% and 100% volume of WPLA and the test involved was density, compressive strength and water absorption tests were conducted. The mortar and concrete mixtures were used with water cement ratio 0.6. The compressive strength with 0% WPLA 100% showed the value 44.9 Mpa at strength 28 days. However, the compressive strength at 28 days reduced as the percentage of WPLA replacement was increased. The replacement of 100% WPLA showed the compressive strength at 28 days slightly reduce 42% of mortar samples. Other researchers studied the behavior of concretes reinforced with PET bottles waste fibers. It was concluded that adding small quantity of PET bottle fibers have a noticeable effect on post-cracking behavior of concretes. Additionally, PET fibers enhance the toughness and improve the concrete plasticity [25-26]. Moreover, it can be concluded that the increase percentage of WPLA, the more the compressive strength of the mortar decrease. Summary of previous work on waste PET are shown in Table 2.

**Table 2. Summary of previous work on waste PET.**

| Author          | Max. size of PET (mm) | W/c ratio (%) | Volume of PET (%) | Test Involved                                      | Description                                                                 |
|-----------------|-----------------------|---------------|-------------------|---------------------------------------------------|-----------------------------------------------------------------------------|
| Vadivel et al., 2016 [18] | <5                    | 0, 5, 10, 15, 20, 25 | 0, 5, 10, 15, 20 and 25 | compressive strength, split tensile strength and flexural strength test. | The higher replacement of PET decreases the strength of concrete compare to normal concrete. |
Silva et al., 2015 [19]  
0.52 to 0.61 0, 7.5 and 15  
Compressive strength, water absorption by immersion

Ge et al., 2012 [20]  
0.5 10, 20, 30 and 40  
Compressive Strength

Shahidann et al., 2018 [22]  
0.45 0, 0.5, 1.0, 1.5 and 2  
Measured the compressive and splitting tensile strength of concrete

Akcaozoglu et al., 2010 [23]  
0.45 0.50  
Compressive strength, water absorption and carbonation

Choi et al., 2009 [24]  
0.15 0.6 0, 25, 50, 75 and 100  
Density, compressive strength and water absorption

4. Conclusion
From the researchers’ discussion above, it is clearly shown that Recycled Concrete Aggregate (RCA) and Polyethylene Terephthalate (PET) are suitable to use in the construction industry and more economic in the making of brick. RCA and PET are found to be suitable as a partial replacement of fine aggregate in brick production. Most of the researchers suggested up to 50% replacement of RCA as a fine aggregate replacement in the brick production. Replacement more than 50% leads to the decreases in the strength of brick. For PET waste, the increasing replacement percentage of PET will decrease the mechanical properties of brick respectively.

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