

A study on the performance of concrete containing recycled aggregates and ceramic as materials replacement

N B Azmi¹, F S Khalid¹, J M Irwan¹, N Anting¹ and P N Mazenan¹

¹ Jamilus Research Center, Faculty of Civil and Environment Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
Corresponding author: faisalsh@uthm.edu.my

Abstract. Natural fine aggregate materials are commonly used in development and commercial construction in Malaysia. In fact, concrete production was increased as linear with the growing Malaysia economy. However, an issue was production of concrete was to locate adequate sources of natural fine aggregates. There lot of studies have been conducted in order to replace the fine aggregate in which natural fine aggregate replace with the waste material in concrete preparation. Therefore, this study aims to utilize the Recycled Concrete Aggregate (RCA) and ceramic waste which has great potential to replace the natural aggregate in concrete mix with different type of method, admixture, and parameters. This research were focused on compressive strength and water absorption test to determine the optimum mix ratio of concrete mix. The concrete aggregate was chosen due to improvement capillary bonding mechanisms and ceramic presented similar strength compared to the conventional concrete using natural aggregate. Percent of replacement have been used in this study was at 25%, 35% and 45% of the RCA and 5%, 10% and 15% for ceramic, respectively. Furthermore, this research was conduct to find the optimum percentage of aggregate replacement, using water-cement ratio of 0.55 with concrete grade 25/30. The best percentage of replacement was the RCA35% C15% with the compressive strength of 34.72MPa and the water absorption was satisfied.

1. Introduction

Concrete is very familiar in civil engineering field since almost all the part of structure need to be concrete. This is because the properties of the concrete which have strong chemical bonding, high compressive strength and their durability can last for long life term very suitable to become part of structure. Many research have been done on concrete mixture which substitute the natural material with the waste material to counter environmental problems in construction engineering that increasing year by year due to the renovation and demolished of old building. The most popular study been done on the aggregate in average they study to improve the recycled waste material in building and replace it with natural source for cuts down cost of construction and achieve the development of sustainable construction method. To overcome this entire problem, research on recycling construction waste concrete and ceramic tile will be held to find the mechanical properties of the material as the substitution material in concrete replacing the natural aggregates.

This study aims to determine workability, compressive strength and water absorption of concrete containing RCA and ceramic wastes as fine aggregate and cement replacement materials, respectively. Based on the study of relationships between recycled concrete aggregates characteristics and recycled aggregates concretes properties, the open porosity is observed and that RCA are much porous than



natural ones and both methods provide quite similar values [1]. Moreover, it can be pointed out that fine recycled aggregates are characterized by a higher porosity than coarse ones. This can be explained mainly by the higher amount of old cement mortar in fine recycled aggregates [2,3]. Water absorption coefficient of RCA whatever the used method although a slight increase is observed for recycled sand between 24 and 48 h. It can be concluded, that compared with NA, RCA are characterized with higher values of WA due to the amount of attached old cement mortar.

Based the study on mechanical performance of concrete made with aggregates from construction and demolition waste recycling plants, the sharp shape of the aggregates make the bulk density lower compare to NA [4]. Moreover, the high substitution of RCA in concrete mix gives high value of water absorption and lower density compare to NA. By comparison with the NA, RCA have lower particles density and higher water absorption mixing water than the NA mixes. This results from the nature and porosity of the RCA. It demonstrates that there is a propensity of the RCA mixes to require more mixture. Water absorption coefficient of RCA has a slight increase is observed for recycled sand between 24 and 48h [1]. RCA has higher values of water absorption due to the amount of attached old cement mortar because The old cement paste always give an effect to the concrete in term of water absorption. Hence, RCA are much porous than natural ones. This can be explained mainly by the higher amount of old cement mortar in fine recycled aggregates.

The previous study stated that the value of water absorption of concrete with RCA aggregates is higher compared to concrete with natural aggregate [5]. The durability of RCA seems less durable compared to the NA. It is due to the ratio coarse aggregate replacement and the concrete age itself, make the RA less durable compared to the NA because it has high porosity value. The replacement of natural aggregate from 5 to 100% with the recycled aggregate reduce their compressive strength by 5 to 25%. However, the workability of concrete present that more water is need for RCA mixture to gain similar workability Due to the present of impurities and old cement paste attached on it enough water is needed in order to get the satisfied workability [5,6].

Based on earlier research, the production of ceramic waste is lower compared to the others waste on construction. However, the ceramic waste that have been recycled only 1% from the total of its production. Many study have been made to the ceramic waste in order to determine it properties such as the density, strength, water absorption and workability. However, this studies are carried out to determine the characteristic of ceramic waste [7]. As we know the ceramic is durable, hard and highly resistant to biological, chemical and also physical degradation forces. Besides that, it seems very suitable in term of lead to sustainable concrete design and greener environment. Moreover, previous study stated that the studies is about possible reuse ceramic sanitary wastes as the aggregate (both fine and coarse) in concrete [8]. The procedure of aggregate production (crushing, dividing particles into two groups – fine and coarse particles and establishing their proportion) and designing the concrete mix.

The result stated that increased by 45%, in comparison to strength recorded immediately after heating, as opposed to compressive strength of specimens based on granite aggregate that decreased by 40% and specimens made of concrete based on gravel which were completely damaged [8]. Compressive strength of concrete based on ceramic aggregate, tested 30 days after heating was 65% of compressive strength of unheated concrete. From the study on application of waste ceramic tiles aggregates in concrete, the ceramic properties which has high water absorption value [9]. Besides that, failures modes toward compressive loading test for concrete sample is similar with normal concrete failure. Water absorption for an average of six sample that been conducted, the result of water absorption of concrete with ceramic waste aggregates is lower compared to the natural aggregate concrete mix. In addition, the ceramic waste concrete mixture is more cohesive and workable [7].

Besides, the compressive strength for 10 percent of ceramic that been substitute indicates the increase about 3.5 percent [9]. After 30% of coarse waste ceramic were added, the compressive strength value decrease. However, he stated that to gain the good strength of concrete, the replacement of the ceramic waste as aggregates must not more than 30%. Moreover, water absorption of ceramic is higher that the gravel whereas, the porosity of the ceramic is also higher than the gravel [10].

However, the most important factor that influent the properties of the concrete with ceramic is the chemical properties of ceramic itself which is has greater water absorption value. Besides that, the dry ceramic has lower density compare to the NA concrete mix. Furthermore, the result of compressive strength obtained for compression strength, at 7, 28 and 90 days reference concrete. The case of recycled concrete with 25% substitution, there was an increase from 12% to 25% in compressive and splitting tensile strength compared to the reference concrete (RC).

As the conclusion, the replacement of RCA and waste ceramic has a great properties and performance in order to achieve the objective of this study which to determine workability, compressive strength and water absorption of concrete containing RCA and ceramic wastes as fine aggregate and cement replacement materials.

2. Methodology

To complete the objective of this study, a few step need to be followed to ensure the study on the RCA and ceramic waste as aggregate substitution material and cement substitution material in manufacturing concrete. In this study, several laboratory testing have been conducted to get the mechanical properties of these material and suitable design of concrete mix containing the RCA and ceramic waste. Mechanical testing that had been held was compression and water absorption. Data have been recorded from this test and analysed so the best result can be observed. In this study, only the good quality of materials had been used such as Ordinary Portland Cement (OPC), coarse aggregates, sand, water and substitution material, which is RCA and ceramic. The mixtures were designed according to the British mix design or the Department of Environment mix design revised in 1998. The absolute volume method was used to calculate the absolute volume of each component to occupy 1m^3 of concrete. The water cement ratio that have been used in the mix design was 0.55 used to all 90 cube specimens. Table 1 shows the mixtures proportion of concrete.

Table 1. Mixtures proportion for 1m^3 of concrete.

Mix design		Cement (kg/m^3)		Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)		Water (kg/m^3)	Super-plasticizer (kg/m^3)
		N.C	Ceramic		NA	RCA		
Normal	345	0	805	980	0	189.75	41.4	Normal
RCA 25%	Ceramic 5%	327.75	17.25	805	735	245	189.75	41.4
	Ceramic 10%	310.5	34.5	805	735	245	189.75	41.4
	Ceramic 15%	293.25	51.75	805	735	245	189.75	41.4
RCA 35%	Ceramic 5%	327.75	17.25	805	637	343	189.75	41.4
	Ceramic 10%	310.5	34.5	805	637	343	189.75	41.4
	Ceramic 15%	293.25	51.75	805	637	343	189.75	41.4
RCA 45%	Ceramic 5%	327.75	17.25	805	539	441	189.75	41.4
	Ceramic 10%	310.5	34.5	805	539	441	189.75	41.4
	Ceramic 15%	293.25	51.75	805	539	441	189.75	41.4

Slump test have been conducted to the concrete mixture according to BS EN 12350 - 2:2009. The mould for slump test was fill with concrete mix in three layers, each approximately one-third of the height of the mould when compacted. Each layer was compacted with 25 strokes of the tamping rod. After the concrete was poured, the concrete was been harden for 24 hours. After it was hardened, the concrete will be soaked in water for a certain period of time which is 28 days and this activity is called curing. All result of slump test, compressive strength and water absorption were recorded and analyse

to determine the pattern of concrete performance as the percentage of aggregate replacement increased.

3. Results and discussion

This section discusses the properties of fresh state of concrete such as slump, compressive strength and water absorption of the concrete containing RCA and ceramic wastes as fine aggregate and cement replacement materials. The test was carried out to determine the strength and absorption of the cube sample.

3.1. Slump test

Slump test have been conducted to the concrete mixture according to BS EN 12350 - 2:2009. The concrete mixture has been through the slump test before the mixture was put into cube mold for curing. The result for slump test was record as shown in table 2 and the data was summarized in figure 1.

Table 2. Slump test data.

Types of mix		Slump test result
Normal		75mm
RCA 25%	C5%	71mm
	C10%	70mm
	C15%	70mm
RCA 35%	C5%	68mm
	C10%	63mm
	C15%	58mm
RCA 45%	C5%	57mm
	C10%	54mm
	C15%	53mm

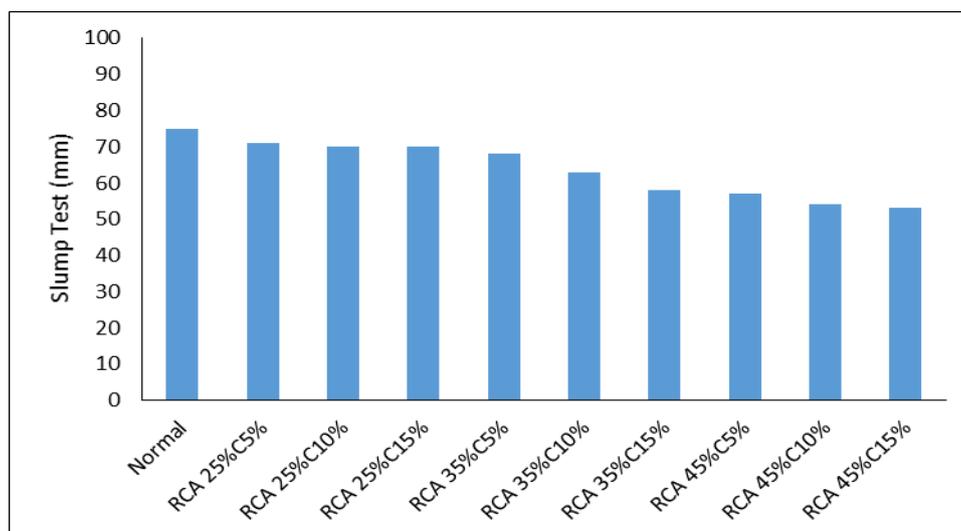


Figure 1. Slump test data (mm) of difference type of mixture.

By referring the figure 1, we can see that the slump for the normal concrete is 75 mm. It in the medium range of workability of concrete, meanwhile the concrete containing RCA and ceramic waste slump value is variant in mm but still have the workability. The pattern of the slump is decrease when the number of the RCA increase, the slump reading will be lower compared to the concrete mix which contain less RCA. Moreover, it can be concluded that the slump test result was decreasing as increasing the percentage replacement of both RCA and ceramic. This result was parallel to the study by Irwan *et al.* [2] where the value of slump test were increased as the percentages of RCA increased was obtained in their study.

3.2. Compressive strength test

The compressive strength of the concrete cube was tested at 14 and 28 days. The average of three test results for each batch has been taken. The details results of compressive strength against age for each samples were illustrate in figure 2.

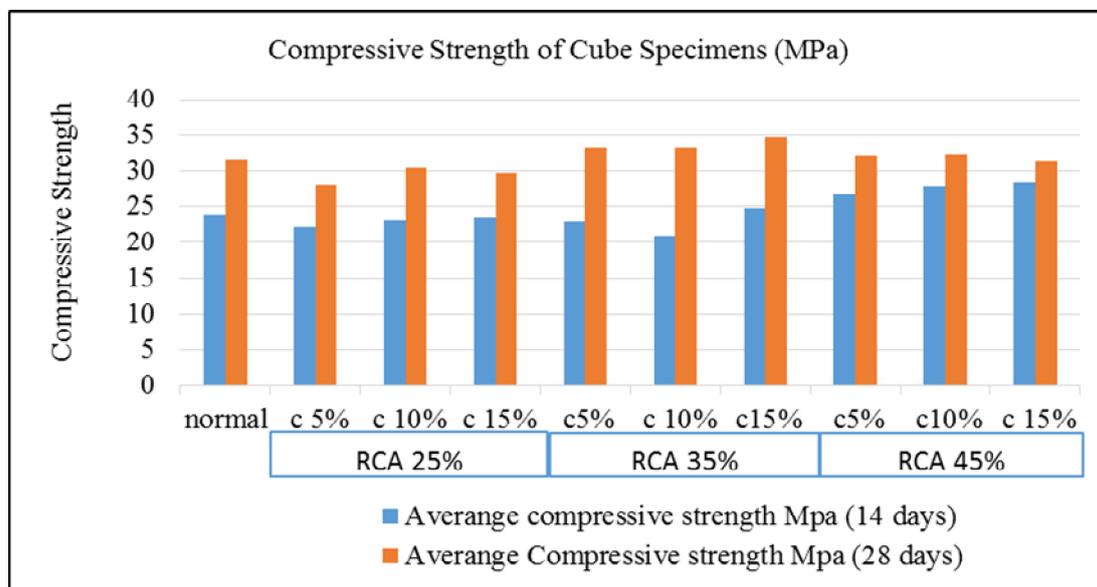


Figure 2. The average compressive strength of cube samples with RCA and ceramic versus ages.

By referring to figure 2, the result show that the maximum compressive strength at age 28 days for samples RCA35% C15% with the value 34.72 MPa. However, these sample show the lowest compressive strength compared to others mix and also control mix. Nevertheless, majority of the compressive strength values of RCA and Ceramic mixtures were found to be satisfactory since all samples almost exceed the target strength of 25MPa. It can also be observed that the compressive strength increased with the addition of RCA and ceramic up from RCA25%C10% to RCA45%C15% for both 14 days age and it was found that the compressive strength increased as the percentage of RCA and ceramic increase. The addition of RCA and ceramic at 28 days increase from RCA 25%C10% to RCA 35%C15%. The reduction in compressive strength might be due to poor bonding between cement pastes with RCA and Ceramic, therefore, the cube become more voided within the particles and affected the concrete strength [11,13]

This result is parallel to Yehia, as their experimental results obtained that with the addition up to 30% RCA the compressive strength increases [6]. However, the addition of RCA more than 50%, the strength starts to decrease [11]. The previous study demonstrated that the compressive strength between samples of concrete between 50%RCA replacement shown better results compared to larger

percentages RCA replacement. This is because the RCA was more porous than the natural aggregates. In addition the old cement paste bond to its particles effected the concrete strength [12, 14].

The overall findings reveal that the addition of RCA and Ceramic were recommended that the replacement from 35%RCA to 45%RCA with 5% up to 15% ceramic content shows better results. Since the value of ceramic replacement was too small, the materials only gives minor effect to the concrete strength. So the addition RCA plays important role to the concrete strength. At this level of replacement, the mixtures providing good interlocking structure. But after 50%RCA of replacement, the compressive strength of the sample start decrease. Therefore too much of RCA replacement was not recommended.

3.3. Water absorption test

Water absorption was carried out to determine the percentage of water absorption of the cube sample. The detailed of these result were illustrated in figure 3.

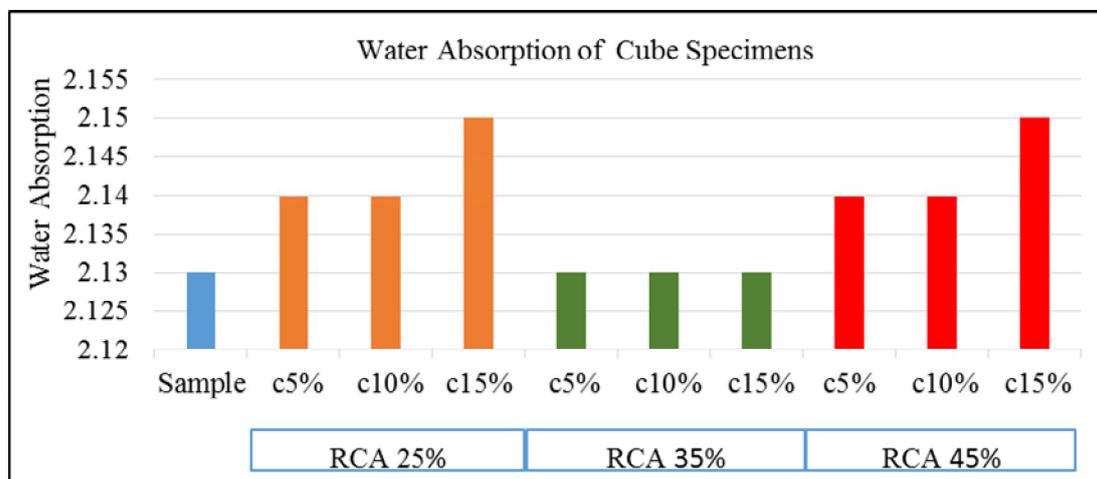


Figure 3. Average of water absorption on cube sample on 28 days.

Figure 3 above illustrated the pattern of average water absorption based on experiment that has been conducted. By refer the chart, it can be observe that the water absorption on 28days were gradually increase at RCA25%C5% to RCA25%C15% as the percentage of the RCA increase. However, it is start decrease at RCA35%c5% as the percentage of RCA increase. The value of water absorption at RCA 45%C5% to RCA45%C15% start increase as the percentage of RCA and ceramic increase. From the previous study [7], it obtained that the water absorption result for concrete aggregate with Ceramic aggregate was higher compared to conventional ones. Besides that, based on previous study of RCA incorporating with concrete [6], it got the result for water absorption of concrete with RCA aggregates was higher compared to conventional ones. Referring the figure 3, the replacement of 25% RCA and 45%RCA with 5%C, 10%C and 15%C recorded the highest percentage of water absorption among the samples. It has been proved by previous study for both RCA and ceramic incorporating with concrete stated that these two material had high result in water absorption compared to the conventional concrete. The presence of old cement paste makes the concrete become more effective in absorb the water had been mentioned in their study [15]. It can be concluded that the water absorption of concrete will increase as the increase the replacement of these material.

4. Conclusion

Based on the study that have been done, the conclusion by observing the compressive strength of cube specimens at 28 days, it can be concluded as the increase of RCA and ceramic replacement will increased the compressive strength of specimens. RCA35%C15% shows the highest value of

compressive strength at 28 days with 34.72 MPa. It was also observed whenever the replacements of RCA and ceramic reach the optimum content, the compressive strength of the specimens decreased. The water absorption of cube specimens at 28 days, it can be concluded that the increase of RCA and ceramic content will increase the value of water absorption of specimen. This is parallel to previous study stated, regarding the study on ceramic obtained the result for water absorption value increased as the percentage of ceramic content increase [9].

However, variety of replacements have been done with RCA and ceramic. Then the specimens through several test to determine the best performance of replacements. Compressive strength and water absorption of the specimens were evaluated and based on the test the best mixture of cube specimens were obtained. Based on the compression and water absorption test result, it can be concluded that the best percentages of replacement was RCA35%C15% with the value for both compressive strength and water absorption were 34.72 MPa and 2.13% respectively.

5. References

- [1] Omary S, Ghorbel E and Wardeh G 2016a Relationships between recycled concrete aggregates characteristics and recycled aggregates concretes properties, *Constr. Build. Mater.* **108** 163–174
- [2] Irwan J M, Asyraf R M, Othman N, Koh H B, Aeslina A K, Annas M M K and Faisal S K 2014 Deflection behaviour of irregular-shaped polyethylene terephthalate fibre reinforced concrete beam *Advanced Materials Research* vol 911 (Switzerland: Trans Tech Publications) pp 438–442
- [3] Khalid F S, Herman S H and Azmi N B 2017 Properties of Sugarcane Fiber on the Strength of the Normal and Lightweight Concrete *MATEC Web of Conf.* vol 103 (Paris: EDP Sciences) 01021
- [4] Bravo M, De Brito J, Pontes J and Evangelista L 2015 Mechanical performance of concrete made with aggregates from construction and demolition waste recycling plants, *J. Clean. Prod.* **99** 59–74
- [5] Khalid F S, Herman S H, Azmi N B and M I Juki 2017 Sand Cement Brick Containing Recycled Concrete Aggregate as Fine-Aggregate Replacement *MATEC Web of Conf.* vol 103 (Paris: EDP Sciences) 01016
- [6] Yehia S, Helal K, Abusharkh A, Zaher A and Istaitiyeh H 2015 Strength and Durability Evaluation of Recycled Aggregate Concrete, *Int. J. Concr. Struct. M.* **9**(2) 219–239
- [7] Senthamarai R, Manoharan P D and Gobinath D 2011 Concrete made from ceramic industry waste: Durability properties, *Constr. Build. Mater.* **25**(5) 2413–2419
- [8] Halicka A, Ogrodnik P and Zegardlo B 2013 Using ceramic sanitary ware waste as concrete aggregate, *Constr. Build. Mater.* **48** 295–305
- [9] Daniyal M and Ahmad S 2007 Application of Waste Ceramic Tile Aggregates in Concrete, *Int. J. of Innovative Research in Science, Engineering and Technology* **4**(12) 12808-12815
- [10] Medina C, Sánchez De Rojas M I and Frías M 2012 Reuse of sanitary wastes as coarse aggregate in eco-efficient concretes, *Cement and Concrete Composites* **34**(1) 48–54
- [11] Grdic Z J, Toplicic-Curcic G A, Despotovic I M and Ristic N S 2010 Properties of self-compacting concrete prepared with coarse recycled concrete aggregate, *Constr. Build. Mater.* **24**(7) 1129–1133
- [12] Khalid F S, Azmi N B, Sumandi K A S M, and Mazenan P N 2017 Mechanical properties of concrete containing recycled concrete aggregate (RCA) and ceramic waste as coarse aggregate replacement *AIP Conference Proc.* vol 1891 (United States: AIP Publishing) 02007
- [13] Irwan J M, Annas M M K, Aeslina A K, Othman N, Koh H B, Asyraf R M and Faisal S K 2014 Cracking propagation of reinforced concrete using polyethylene terephthalate (PET) bottles as fine aggregate, *Adv. Mat. Res.* **911** 474-478

- [14] Faisal S K, Irwan J M, Othman N, Wan Ibrahim M H 2017 Flexural toughness of ring-shaped waste bottle fiber concrete *MATEC Web of Conf.* vol 47 (Paris: EDP Sciences) 01002
- [15] Zamer M M, Irwan J M, Othman N, Faisal S K, Anneza L H, Teddy T and Alshalif A F 2017 Influence of Ureolytic Bacteria Toward Interlocking Compressed Earth Blocks (ICEB) in Improving Durability of ICEB *MATEC Web of Conf.* vol 103 (Paris: EDP Sciences) 01027

Acknowledgment

This work was financially supported by University Tun Hussein Onn Malaysia (UTHM) and Minister of Education Malaysia (KPM) through Dana Pembudayaan penyelidikan (RAGS) Vot. No. R-058.