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The Determination of Optimum Ratio by using Recycled Concrete Aggregate and Crumb Rubber as Partial Sand Replacement Material in Sand Cement Brick Production

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ABSTRACT

During the last decades, it has been recognizing that a large volume of waste with growing concerned that wastes from construction and demolition (C&D) are increasing years by years. Most waste materials are left as a landfill material or illegally dumped. The environmental impact can be reduced by making more sustainable use of this waste by the recycling process. This study aims to establish the sustainable properties for sand cement bricks using Recycled Concrete Aggregate (RCA) and Crumb Rubber (CR) as partial sand aggregate replacement materials. The objectives of this study are to determine the optimum cement-sand ratio (1:5, 1:6, and 1:7) for sand cement brick through density, compressive strength, and water absorption tests. Then, investigate the mechanical properties and durability of sand cement bricks through shrinkage and carbonation and lastly identify the optimum percentages of RCA and CR as sand aggregate replacement in sand cement bricks. The brick specimens were prepared using 15%, 30%, 45%, and 60% of RCA and 1.5%, 3.0%, 4.5%, and 6.0% of CR by volume of sand with a water-cement ratio of 0.6. The size of the RCA used to measure less than 5 mm. Hence, the size of the sieved waste CR granules used is between 0.1 to 5 mm that made it physically similar to the size of fine aggregates. The overall results revealed that the best cement-sand ratio was 1:6. The density test indicates that the average density of sand cement bricks is lower than the control bricks. Besides, the percentage of water absorption for sand cement bricks was found to be satisfactory. In a nutshell, the optimal replacement of RCA and CR was R15C1.5 with a cement-sand ratio of 1:6 as it achieved the lowest values during the drying shrinkage and carbonation tests.

Keywords: Recycled Concrete Aggregate, Crumb Rubber, brick, strength, durability

1. INTRODUCTION

A brick is a building component used to build walls, sidewalks and other elements in masonry construction. A brick can be made from sand, lime and clay bearing soil. Brick is easy and cheap product to manufacture but now, the demand for bricks is high precisely in developing areas where manufactures find it tricky to locate sufficient sources due to scarcity of natural aggregate supply. Moreover, reuse and recycling of waste materials from C&D is one of the new concepts for brick manufacturing production. According to Ismail & Yaacob [1] the alternative of natural sand by RCA at the levels of 50% and 75% has excellent impacts on the strength of the bricks.

On the other hand, the quanitity of waste tires is gradually escalating, due to the optimial use of transport vehicles. By the year 2030, it is expected to reach 1200 million Rashad, [2]). Discarding of waste tires has become a worldwide issue. In many countries, burying the waste tires is a general disposal practice, which lessens the service life of the burial ground and

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imposes a very serious threat to ecology. Therefore, reusing waste tires in an effective way is an urgent and vital matter for saving energy and protecting the environment Liu et al. [3].

In this modern world, a lot of rubber based material is created because it is easy obtained and also easy to manufactured. One of the most common rubber based material that is used worldwide is rubber tires. This rubber tires are used to make vehicle move on roads. The used up old tire can be recycled and used as new recycled rubber. According to Kovler & Roussel [4], waste rubberized aggregates were used as sand in mortar production. This shows that rubber can be used as substitute for fine or coarse aggregates in the construction industries. The elements of CR concrete were heavily impacted by rubber content. According to Ghaly & Cahill [5], researched the compressive strength of concrete with different replacement ratios of crumb rubber by volume (5%, 10% and 15%). Compressive strength declined with the large inclusion of CR.

Besides, the government were able to find the answer to the problem concerning the discard in landfills of these waste materials and save the environment Hussein & Mansour,[6]. This improper treatment would decrease landfill capacity and contribute to environmental issues in the long term. It somehow gives negative impact to environment and human itself Hussein & Mansour,[6]. To overcome this problem, using RCA and CR in production of brick might lead to preserve the natural aggregate sources in landfill and save the environment from increase of demolition in construction waste. Through experimental method, this research is conducted to evaluate the mechanical and durability of brick containing RCA and CR as partial sand replacement materials.

Brick is a regular building material usually made of sand as aggregate, cement as binder and water which creates a sturdy stone-like mass material when it hardens. Sand and cement are the most general components used for construction. Cement and sand bricks are a type of bricks that are usually used in low- and medium-cost housing development and other commercial constructions in Malaysia because they are easy and cheap to make but currently, arise problems plague production of these materials especially in developing areas where manufacturers find it hard to find sufficient sources due to the inadequacy of natural aggregate stock. These comprises the exhaustion of natural resources in rivers and mining areas, including the shutting down of several of the mining sand quarries due to increasing environmental issues, forcing the state government to stop quarry licensing. Therefore, the price of sand has spiked, which influenced the price of cement and sand bricks.

Since the dumping of waste tires has become a global issue and has concerned administrators, researchers and environmentalists. Ibrahim et al. [7] mentions, Malaysia production of scrap tires is around 10 million pieces yearly and are currently discarded in an environmentally unfriendly way. It is considered as one of the significant environmental issues faced by cities worldwide because waste rubber is not easily decomposed even after a lengthy duration of landfill treatment. It somehow gives negative impact to environment and human itself. In order to effectively recycle waste tire rubber, one practicable method is to integrate it into cement-based material. Partial substitution of mineral aggregates in concrete with waste tire rubber could manage control environmental pollution and reserve sandstone resources Thomas & Gupta [8].

To overcome this problem, recycling was one of preferable option to reduce the amount of waste production from construction and rubber tire. Based on the hierarchy of solid waste management strategy, recycling was most desirable option to reduce waste from landfill besides reduce and reuse. This is because the environmentally more desirable and support the growing interest of the public in sustainable development. Therefore, to achieve this strategy and concept, this research has been used a recycle material from construction and rubber tire as a partial material of sand in sand cement brick production.

The incorporation of RCA and CR in sand cement brick is the better one because it also gives benefit to construction industry and cement sand brick industry. The creation of new material is not expected to offer an extra incoming profit for cement sand brick industry but also able to contribute towards improvement of Malaysian construction technology and environment without the pollution. One of the possibilities is to utilize the RCA and CR as fine aggregate replacement. Therefore, this paper showed the results of the mechanical and durability of brick containing RCA and CR as partial sand replacement materials.

2. METHODOLOGY

The cement used was a commercially available Portland cement (PC), which corresponds to MS 522: 2007. The ideal design mix of sand cement brick for partial sand replacement was 1.5%, 3.0%, 4.5% and 6.0% of CR and 15%, 30%, 45% and 60% of RCA. The brick moulded at length 215mm, width of 105mm and a depth of 65mm. CR was collected from Pasir Raja, Muar while RCA around Universiti Tun Hussein Onn Malaysia (UTHM). The crushing process was done by the crushing machine. Then the RCA produce by sieve process with a maximum size 5mm. Figure 1 shows RCA after sieved. The fine aggregates were dried naturally under the sun. The fine aggregates had a specific gravity of 2.86. The size of sieved waste CR granules with the maximum size of 5mm as shown in Figure 2.

Figure 1. Recycled concrete aggregate after sieved.

Figure 2. Crumb rubber.

In order to get the suitable sand cement ratio, three different ratios (1:5, 1:6 and 1:7) were conducted and follow by density, compressive and water absorption test. The best sand cement ratio was selected to continue in terms of durability properties of brick which is shrinkage and carbonation depth tests. Curing is a process that involves the maintenance of a suitable moisture content and temperature in samples for a suitable period of time immediately after placing and finishing so that desired properties of samples can be achieved. After pressing, the bricks were stacked on timber palettes and marked according to their percentage of aggregate composition. The volume replacement material was used to produce sand cement bricks were 15%, 30%, 45% and 60% of RCA and 1.5%, 3.0%, 4.5% and 6.0% of CR. The design mix for cement sand brick used accordance with BS EN 998-2 and the mixtures were designed according to the British Standard requirement [9].

3. RESULTS AND DISCUSSION

3.1 Density Test

Density of brick was calculated after a curing period of 7 and 28 days. The results for density against curing period for each percentage of RCA and CR in sand cement bricks at 7 and 28 days with cement-sand ratio 1:5, 1:6 and 1:7 were shown in Figure 3, Figure 4 and Figure 5.

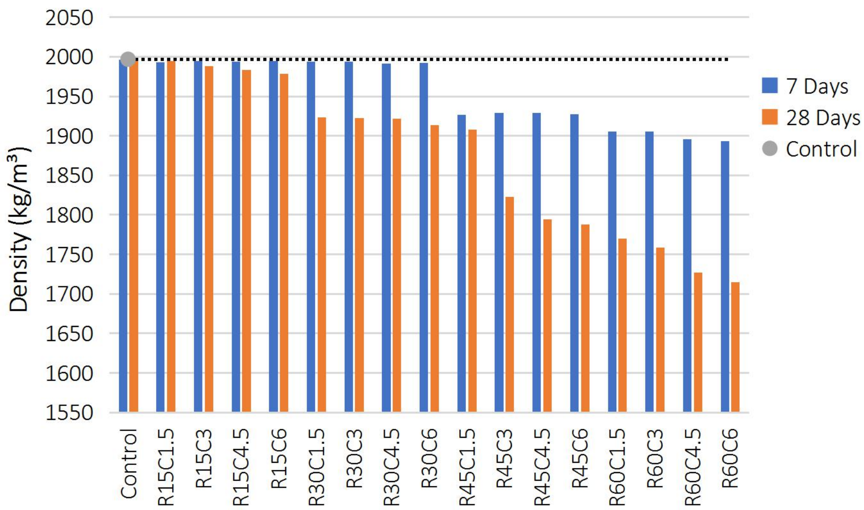

Figure 3. Density of sand cement brick for 7 and 28 days (cement sand ratio 1:5).

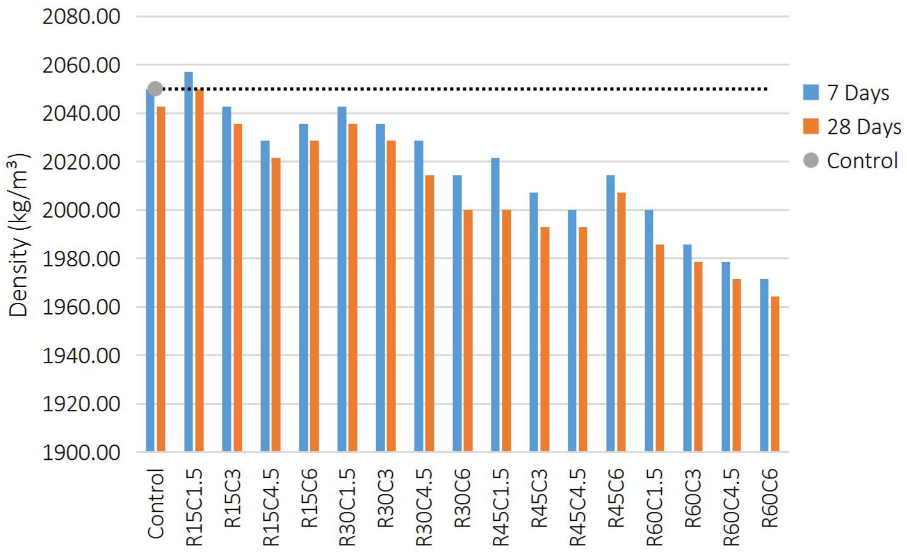

Figure 4. Density of sand cement brick for 7 and 28 days (cement sand ratio 1:6).

Figure 3 indicates decreasing in density with increment percentage of RCA and CR substitution. It shows that density at 28 days was lower than 7 days for all the brick samples. It shows that the densities obtained at 28 days was lower than the ones obtained at 7 days for all brick samples. This was due to the curing process that causes water from the samples to evaporate. This contributes to the decrease in brick density when the curing duration increases. Sample R30 shows a reduction in density compared to R15. This might be due to the volume mixture of RCA which contains a higher mortar percentage compared to fine aggregates. However, the incorporation of CR into bricks also contributed to the brick density. The increase in CR replacement can reduce the density of bricks due to the low specific gravity of CR. However, R45 presented a lower density value compared to R30 due to the different replacements of RCA and CR volume. The higher the percentage of RCA and CR replacement, the lower the density value due to the pore spaces present on the surface of sand cement bricks.

Figure 4 showed two samples, R15C1.5 and the control brick increasing densities at day 7 and day 28 with percentages of 0.34% and 0.35%, respectively. Normal bricks do not contain any fine aggregate replacement. Meanwhile, other brick samples contained RCA and CR. The RCA and CR content in R15C1.5 resulted in an increase in density because the volume of the mixtures increased and mixed sufficiently with the cement paste. The density of R15C1.5 increased even though RCA and CR have low densities compared to the control brick. It might due to the density of old mortar attached to the RCA which increase the volume of RCA density.

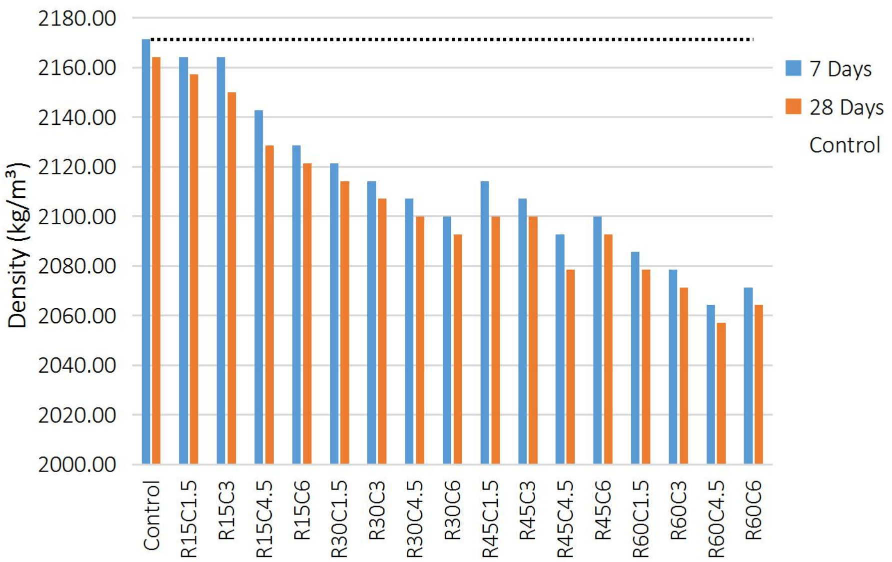

Figure 5. Density of sand cement brick for 7 and 28 days (cement sand ratio 1:7).

The lower specific gravity values of RCA and CR showed that they are lighter compared to natural fine aggregates would cause the density of bricks steadily decreased with the increasing content of RCA and CR. Addition these materials contributed to the reduction in mass of the brick samples. Additionally, the results also showed that the density of sand cement bricks was affected by the particle density of RCA. The lowest density for 28 days at percentage R60C4.5 with 2057.14kg/m3 with 4.95% compared to control brick. The overall result also points out that the average density of bricks with RCA and CR in them is lower than the control bricks.

Khalid et al. [10] also pointed the density significantly dropped as the RCA and PET content in the brick mixtures increases. Previous studies found that the decrease in density was the results of the insertion of RCA and CR. According to Bustamante et al. [11], the quantity of rubber crumbs in the mixtures leads to the depletion of densities of the manufactured composite bricks. In other words, the lower unit weight of RCA and CR causes the brick density to drop.

3.2 Compressive Strength

The compressive strength of bricks was tested at the age of 7 and 2 days. The compressive strength test was conducted on accordance with BS 6073 [12]. This study presents the influence of different mix design ratios and different curing periods on the use of RCA and CR as fine aggregate replacement material. The experimental results for compressive strength are tabulated in Figure 6, Figure 7 and Figure 8.

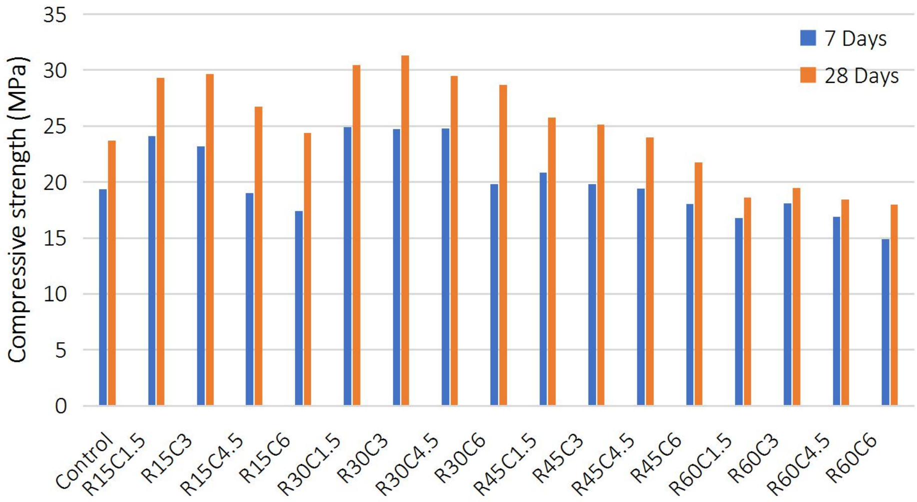

Figure 6. The average compressive strength of sand cement bricks (cement sand ratio 1:5).

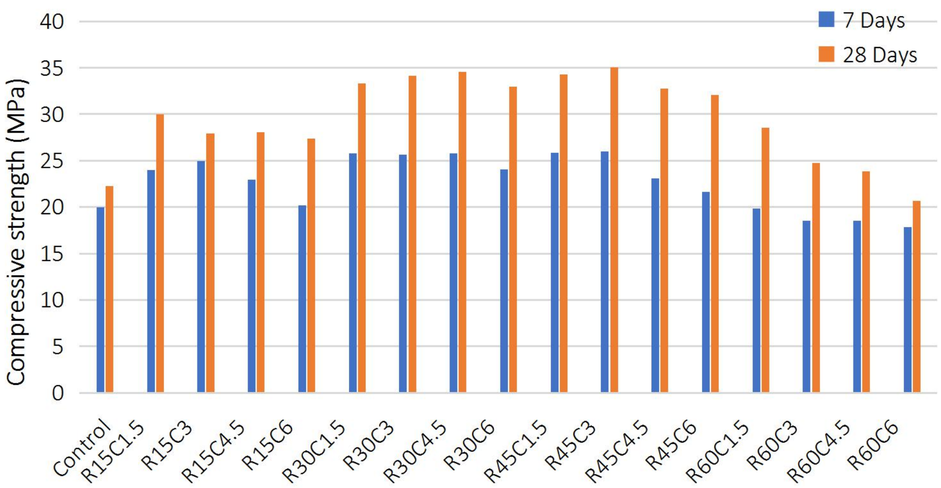

Figure 7. The average compressive strength of sand cement bricks (cement sand ratio 1:6).

From Figure 6, all the samples exceeded the minimum strength after a curing period of 7 and 28 days. BS 6073-1 [13] stated that the compressive strength of bricks should not be less than 7 N/mm^2. A few samples for both curing ages had lower strength values than the control brick. R30C1.5 exhibited the highest strength at 24.93 MPa, a value which was higher than the one obtained by the control brick. The compressive strength of R15C4.5 and R15C6 reduced due to the use of more than 1.5% CR. Nevertheless, R30 shows that the strength increased in line with the increase in RCA and CR percentages for R30C1.5. 30% of RCA had a higher effect on the value of compressive strength of a sample. However, the strength of sand cement bricks starts to decrease for R30C4.5 and R30C6 due to the increasing percentage of CR fillers in the brick composition. It was dependent on the fineness of CR particles that helped in the uniform bonding and better compaction between RCA and CR.

Figure 7 shows the results indicates that the maximum compressive strength at 28 days for R45C3 was 35.02 MPa. Nevertheless, the compressive strength values of RCA and CR mixtures were considered satisfactory since all samples exceeded the British Standard requirements, BS 6073-1 [13] which is more than 7 MPa. It is also seen that the compressive strength escalated with the inclusion 3.0% of CR for all percentages of RCA for both ages but the compressive strength was found to decrease when the percentages of RCA and CR increase. The samples R15C3, R30C3, R45C3 and R60C1.5 obtained the highest compressive strength than the control samples. The addition of 3.0% of CR for all brick samples caused a rise in compressive strength while mixture R60 the strength increased at 1.5% of CR. Hence, the reduction of strength decreased when 4.5%, and 6.0% of CR were added to the samples.

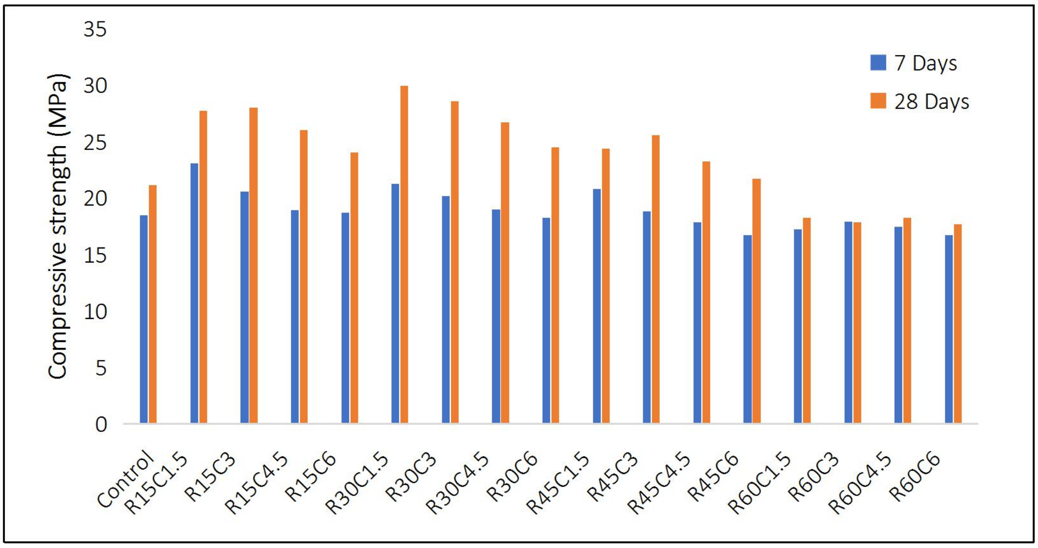

Figure 8. The average compressive strength of sand cement bricks (cement sand ratio 1:7).

Figure 8 shows that the highest compressive strength was acquired by R30C1.5. The compressive strength was 29.96 MPa with a gain of 41.52% as opposed to the control brick. The reduction in compressive strength started from R30C3 until R30C6. The reason for this reduction is due to the increasing amount of RCA and CR in the samples which leads to increasing porosity in the sample bricks. However, the weak bonding between cement pastes with RCA and CR may contribute to the reduction in compressive strength. It was dependent on the fineness of CR particles which facilitated uniform bonding and better compaction between RCA and CR. This means the compressive strength of brick samples containing CR decreases with increasing CR content. This result obtained from this study is similar to the results obtained by and Yaacob [1], where the compressive strength of the brick samples increased with the addition Ismail of 50% of RCA. However, if more than 50% of RCA is included, the compressive strength starts to declines. The result for this study can be confirmed by findings from studies done by Dina & Mohamed [14] and Bustamante et al. [11], where they agreed that excessive RCA and CR content negatively affects the compressive strength of bricks. Moreover, the results reveal that only certain amount of CR increases the strength with an addition of RCA of 15%, 30%, 45% and 60%. The trend of this study having the same pattern with the studied conducted by Irwan [15] and Noorwirdawati 16], that stated the good bonding between aggregate and binder as an increase in synthetic plastic content may result a decreasing in strength of materials.

The outcome of the study shows that the inclusion of RCA and CR with different mix design ratios can successfully strengthens the compressive strength of bricks. On the other hand, it can be concluded that the strength of the bricks increases as the percentage level of the RCA and CR content increases up to 50% while the strength of bricks starts to decrease when the percentage of replacement of RCA and CR is more than 45%.

3.3 Water Absorption

The water absorption of bricks was tested because it has been decided that suction is an important property of bond strength in bricks. The water absorption test was carried out after 28 days of air curing. The comparison between water absorption percentages and CR percentages (1.5%, 3.0%, 4.5% and 6.0%) for 15%, 30%, 45% and 60% of RCA was presented. The relationship between water absorption percentages and CR percentages is portrayed in Figures 9, 10, 11 and 12.

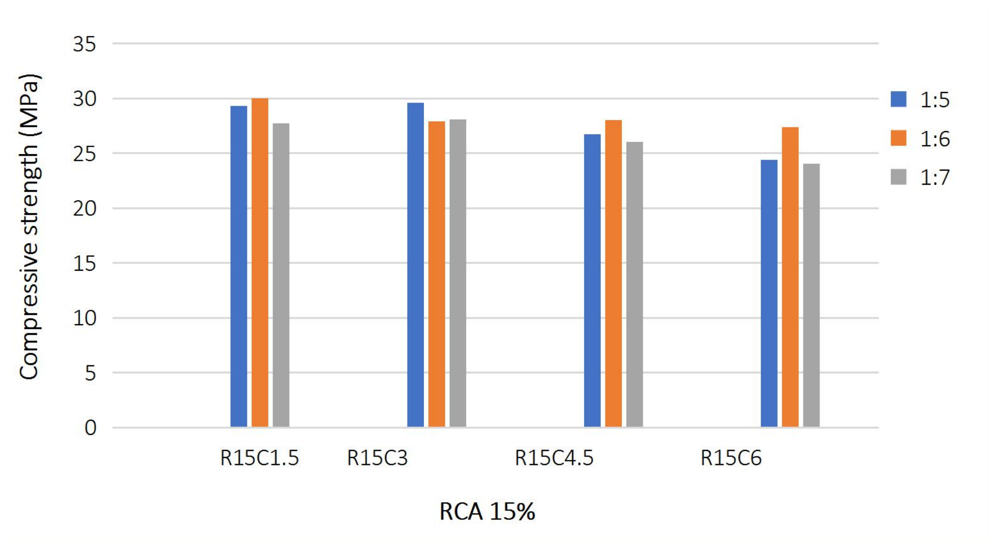

Figure 9. The relationship between water absorption percentage and replacement of CR percentages (R15C1.5, R15C3, R15C4.5 and R15C6) at RCA 15%.

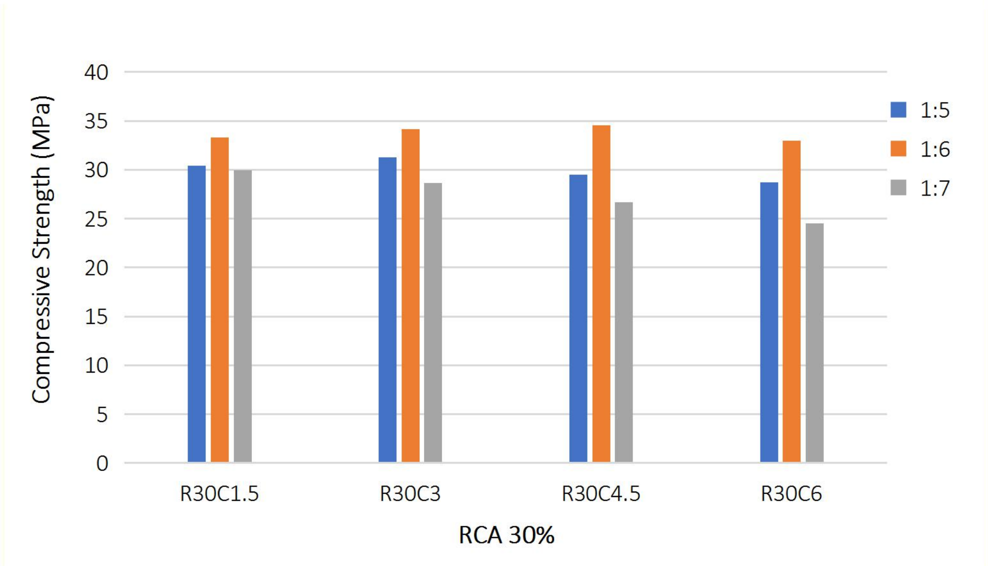

Figure 10. The relationship between water absorption percentage and replacement of CR percentages (R30C1.5, R30C3, R30C4.5 and R30C6) at RCA 30%.

Figure 9 shows the data obtained from different CR percentages with 15% of RCA with a cement-sand ratio of 1:5. The water absorption percentages obtained were 4.38%, 4.47%, 4.39% and 4.48% for R15C1.5, R15C3, R15C4.5 and R15C6 respectively. The linked factor is the fact that R15 with a cement-sand ratio of 1:5 had a decrease in water absorption because the level of free water in the mix and the voids were lower. Therefore, the cohesion between particles rises meanwhile the absorption rate by capillary suction drops. Bricks samples containing all percentages of CR with cement-sand ratios of 1:6 showed similar trends in terms of water absorption. The highest percentage of water absorption stated that the sand cement brick with a cement sand ratio 1:7. The result obtained were 4.77%, 4.86%, 4.79% and 4.87% for R15C1.5, R15C3, R15C4.5 and R15C6 respectively.

The water absorption percentages increased as the cement sand ratio and percentage of CR increase as shown in Figure 10. The cement-sand ratio of 1:5 achieved the lowest water absorption value compared to cement-sand ratios of 1:6 and 1:7 for all different CR percentages. R30C4.5 shows the lowest water absorption value compared to R30 with a cement-sand ratio of 1:5. The reduction in the percentage of water absorption was due to less water migrating outwards into the capillary pores in the hardened cement paste due to lower brick porosity. However, the water absorption of bricks also depends on the amount of mortar adhering to RCA particles. It can be summarised that the water absorbed by these samples was less compared to other R30 samples with a cement-sand ratio of 1:5. However, water absorption decreased as RCA and CR content increases for cement-sand ratios of 1:6 and 1:7 except at R30C6 showed the increases of the water absorption.

Figure 11 shows the water absorption results of brick samples containing 45% of RCA with different CR percentages and cement-sand ratios. This data also evaluated the similar pattern between RCA 25% in Figure 4.28. The value of water absorption increases when the value of cement-sand ratios and CR percentage increase. The lowest value was obtained by the cement-sand ratio of 1:5. Water absorption percentages of 5.01%, 5.00%, 5.11% and 4.98% were obtained by R45C1.5, R45C3, R45C4.5 and R45C6.

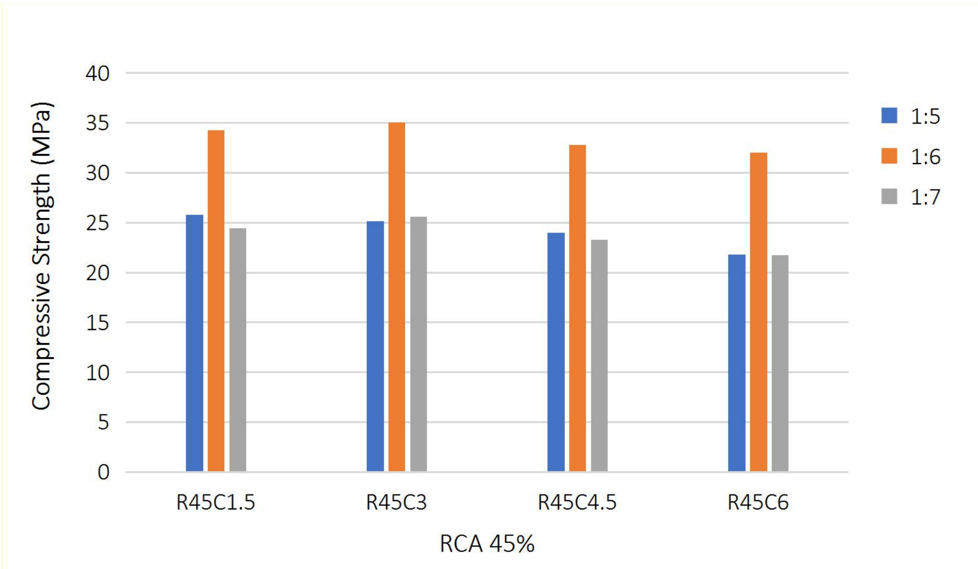

Figure 11. The relationship between water absorption percentage and replacement of CR percentages (R45C1.5, R45C3, R45C4.5 and R45C6) at RCA 45%.

Similar water absorption percentages were obtained by R60C1.5, R60C3, R60C4.5 and R60C6 as shown in Figure 12. The cement-sand ratio of 1:5 achieved the lowest water absorption value compared to cement-sand ratios of 1:6 and 1:7 for all different CR percentages while R60C6 shows the highest water absorption value compared to R60 with a cement-sand ratio of 1:5 and 1:6.

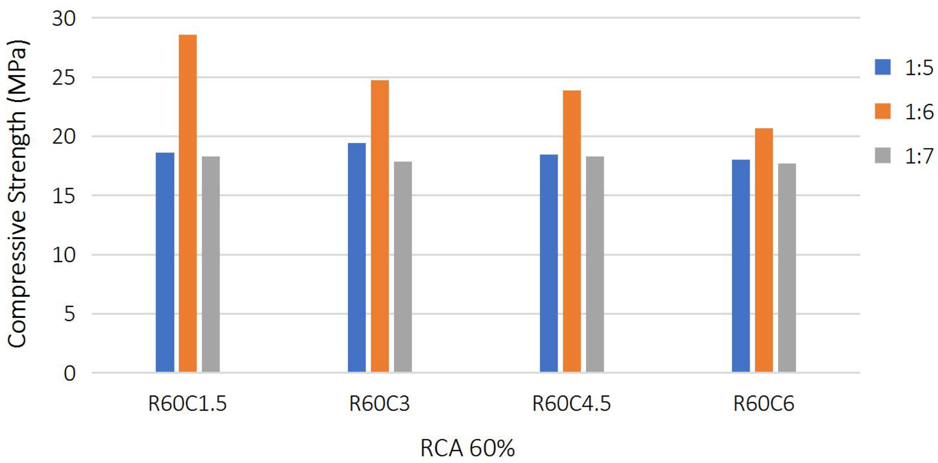

Figure 12. The relationship between water absorption percentage and replacement of CR percentages (R60C1.5, R60C3, R60C4.5 and R60C6) at RCA 60%.

R60 samples with cement-sand ratios of 1:5, 1:6 and 1:7 resulted in increased water absorbability. Remains of old mortar attached to recycled aggregates increase porosity and increased water absorption for R60 sand cement bricks. Bricks with 15%, 30% and 45% of RCA had a lower permeability because the aggregates are bonded tightly, thus decreasing the pore rate and increasing brick density. Nevertheless, the percentage of water absorption of sand cement bricks was found to be satisfactory since all samples fulfilled the British Standard requirements BS 3921 [17] namely, not more than 15% of water absorption.

On the other hand, to sum up the water absorption of sand cement bricks with recycled fine aggregates and CR impressively increased the water absorption of bricks. From the results, only bricks with 15% RCA, a 1:5 cement-sand ratio and CR content of 1.5%, 3%, 4.5% and 6% were less permeable compared to other bricks. Thus, it is expected that the density decreases meanwhile the water absorption increases along with the increase in RCA and CR content.

3.4 Carbonation

The carbonation depth was measured at three different times namely, 28, 56 and 90 days. Based on the average carbonation values, a significant increase was noted for all percentages of RCA and CR at 28, 56 and 90 days. The relationship between the carbonation depth of sand cement bricks versus age was plotted in Figure 13.

Based on the results presented in Figure 13 brick samples containing different RCA and CR percentages showed significant differences in the carbonation test at 28, 56 and 90 days. The carbonation depth increased as the exposure period increases the highest carbonation depth values were obtained at 90 days for all brick samples with different percentages of RCA and CR. R60C6 obtained a carbonation depth of 2.78 mm at 90 days. The difference between the data measured at 28, 56 and 90 days for each variable seems to become larger as the RCA and CR content increases.

The sand cement bricks containing R60 at 28, 56 and 90 days showed higher carbonation depths compared to bricks containing R15, R30 and R45. This behaviour may be linked to the decreased calcium hydroxide content in bricks due to the minimisation of cement content which dominates pore refinement, causing a delay in the hydration process Oliveira et. al [18].

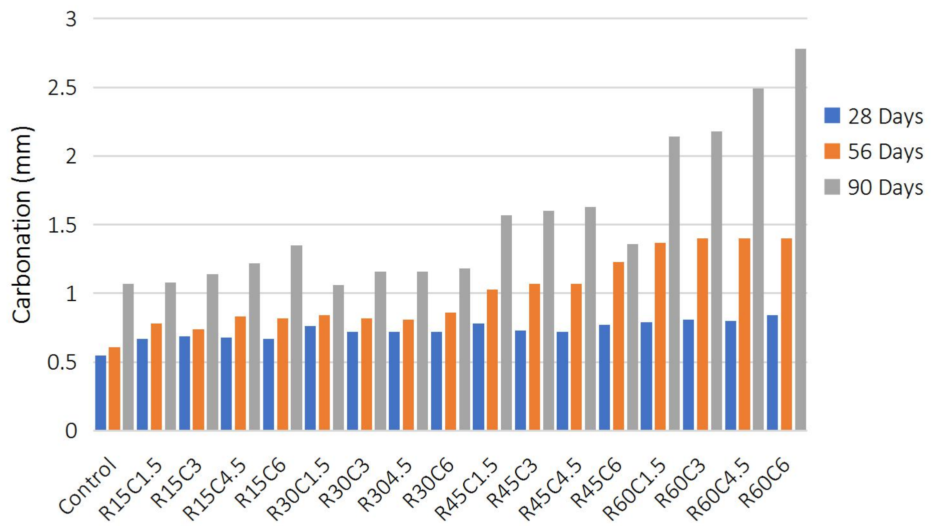

Figure 13. Carbonation depth of sand cement bricks with RCA and CR.

Moreover, the higher amount of filled pores could slow down carbonation in the brick samples Leemann et al. [19]. According to Li [20], if the RCA percentage increases, the carbonation depth increases too. The authors found that the carbonation depth of the composite brick was 62% higher than the reference concrete and concluded that the high porosity caused by the aggregates contributes to this outcome. Gomes and Brito [21] claimed that the carbonation depth for concrete with up to 50% of RCA content was 10% higher than that of normal concrete. The calcium carbonate resultant from carbonation processes partially reduces diffusivity and causes the carbonation coefficient to decrease as a function of time Limbachiya [22].

3.5 Shrinkage

The drying shrinkage of the sand cement bricks was determined using mixtures with a cement-sand ratio of 1:6 after the selection for density, compressive strength and water absorption tests were conducted. The initial length of the control brick at 28 days was 0.023 mm. After 56 days, the shrinkage value of the control bricks increased by 0.037 mm from the initial length. The results showed that the increase RCA and CR percentages in the samples increased the value of drying shrinkage. A graph depicting drying shrinkage versus percentages of the sample was plotted in Figure 14.

It can be seen that the bricks made with the highest percentage of RCA had higher drying shrinkage values. This is due to the higher percentage of water absorption in bricks containing 45% and 160% of RCA. The shrinkage for bricks containing 60% of RCA at 28 days showed the highest shrinkage compared to all the other bricks. Excess water in the specimens with higher RCA content leads to a higher percentage of shrinkage.

This is consistent with the results by Ismail and Yaacob [1] where the drying shrinkage value increases with the addition of 50% and 75% of RCA. However, the increase in CR percentage was insignificant to the drying shrinkage of the sample bricks. From these results, it can be concluded that the drying shrinkage of the bricks is still dependent on the amount of RCA used. The overall drying shrinkage results were lower by 0.06% compared to the requirements of the British Standard Institution as stated in BS 6073 [12].

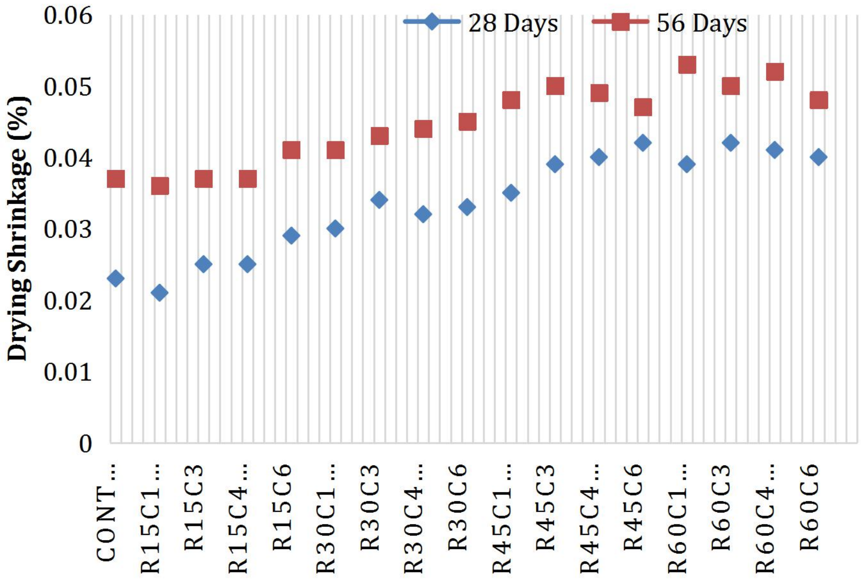

Figure 14. The drying shrinkage of sand cement brick.

4. CONCLUSION

The overall result for the selection optimum sand cement ratio by density, compressive strength and water absorption test, it can be concluded that the ideal sand cement ratio of 1:6. However, for the density value, the outcome displays that the average density of brick is second-rate in comparison to control brick. The sand cement ratio of 1:6 was the optimum value of compressive strength for all the sample bricks. Nevertheless, the ability of water absorption of sand cement brick was found to be satisfactory since all samples fulfilled the British Standard requirement which is not more than 15% absorption.

Shrinkage of brick depends on the amount of RCA. Brick with more than 30% of RCA has significantly more shrinkage compared to control brick. Shrinkage test was presented that R15C1.5 shows the lowest value of shrinkage compared to the other brick samples. The reason behind this is because of the sand cement brick R15C1.5 abilities to absorb water is lower and decrease the attached mortar and cement paste in the RCA in brick R15C1.5.

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