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Effect of Water to Cement Ratio and Replacement Percentage of Recycled Concrete Aggregate on the Concrete Strength

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Abstract:

Fine Recycled Concrete Aggregate (FRCA) is one of the construction waste can be recycled. It can be the aggregate to replace the natural aggregate in concrete since we know the physical properties of materials are hard and strong. Demand for sand in the concrete production has been increased which become the problems in the concrete industry. This work deals with the effect of concrete incorporating with FRCA as partial replacement of sand. The percentage of natural sand replaced by the FRCA was 0%, 15%, 20%, 25%, 30%, 45% and 60%. Other than that, water cement ratio was manipulated variable started form 0.40, 0.45, 0.50, 0.55 and 0.60. In short, 20% replacement was the most suitable interaction of FRCA in the concrete occur that contribute to increasing in compressive strength. The porosity properties of FRCA been neutralized on that replacement percentage by the present of optimum filler effect generated form the very fine FRCA particle during the mixing process. Meanwhile, 0.50 water cement ratio was optimum condition for cement hydration process using FRCA as partial sand replacement.

Keywords: *Recycled concrete, partial sand replacement, compressive strength*

1. Introduction

Concrete had been a well known material in the construction industry. The main raw material consist in the production of concrete is aggregate with a proportion of 60%-80% from its total volume [1-2]. The increasing demand of natural aggregate especially in rapid growing nation like Malaysia due to the increasing of population and urbanization of rural area bring a negative effect to the environment ecosystem. This is because of the mining industry had being blinded by the profit that they receive and forget to consider the effect cause from their mining work to the environment [3]. Over the last decade, due to the depletion of natural aggregate. A lot of researchers tried to figure out the solution for this problem hence to promote the implementation of environmentally friendly construction and the needs for sustainability material and one of the solutions is by using the Recycled Concrete Aggregate (RCA). The use of concrete waste is an alternative for the replenishing quarry and river sand.

The crushing process of concrete waste from deconstructed and demolished provide a lots of Coarse Recycled Concrete Aggregate (CRCA) as well as Fine Recycled Concrete Aggregate (FRCA). Numerous studies had been used the CRCA as the coarse aggregate replacement and the properties of the CRCA had been thoroughly detailed as it is more easy to collect form the crushing process. However, researcher started to study the use of FRCA from the collected waste. An experiment conducted by Azmi et al. [4] which using 0%, 25%, 50%, 75% and 100% of FRCA replacement percentage show that the density of 2340 kg/m^3 and water absorption of 6.25%. The replacement also resulted that the decreasing of compressive strength by 15% and 30% at replacement of 25% and 100% respectively. Chen et al. [5] found that the density of the fine recycled aggregate concrete is 2165 kg/m^3 with the water absorption of 13.1%. The replacement percentage that took place in their study was 0%, 10%, 20%, 30%, 50%, and 100% of Fine Natural Aggregate (FNA) was replaced by FRCA. From the result gathered by both researchers, it can assume that the replacement of FNA by FRCA up to 30% does not jeopardize the mechanical properties of the fine recycled aggregate concrete.

Due to the few reductions of mechanical performance, the usage of FRCA in high performance concrete such as grade 50 concrete and above is widely not accepted yet. However, the incorporation of FRCA in the concrete do lowered the density of the concrete due to the present of the old cement paste which also result to the higher water absorption than the FNA [5]. Other researcher found that the present of old cement paste and old mortar is the main reason for the losses in recycled aggregate concrete leading to a recommendation to not incorporate them in the concrete mixing design just like the German specification because there is a fewer study on the use of FRCA [6-9]. This small fraction of study shows low mechanical and chemical properties such as greater amount of cement paste, porosity which lead to high water absorption and acid soluble sulphate content which limit the usage of FRCA in concrete production [10].

Some researcher had criticizing the restrictive of the standard and propose a further research regarding the usage of FRCA to the performance of the resulting concrete [11-12]. A study conducted by Katz [13] obtained satisfactory correlations between water absorption of recycled aggregates and concrete properties and come out with a conclusion that the performance of concrete decrease as the water absorption of the aggregate increases. The solution purpose by Khalid et al. [14] that using an alternative method which is by classing the recycled aggregate according on their saturated density, water absorption, abrasion resistance and drying shrinkage could overcome the current barriers and concerns. Most of the reason came not from the low density of the FRCA, but most of it are from the high water absorption of FRCA which is due to the porosity in its properties. The high water absorption rate could alter the water to cement ratio in the concrete mixing design.

Khoshkenari et al. [15] conducts a study which use two types of superplasticizer in which the replacement percentage of FNA take place by FRCA was 0%, 10%, 30%, 50% and 100%. Superplasticizer is an agent that to reduce the usage of water in the mixing while maintaining the workability and improve the mechanical and durability properties of recycled aggregate concrete. The result is remarkable and the concrete incorporating with FRCA and superplasticizer performance perform better than the reference concrete with no superplasticizer and the concrete with low performance superplasticizer. Khatib [16] found that the concrete incorporating with FRCA had low splitting tensile strength but stated that the compressive strength of the FRCA concrete could be improved by using the 0-2mm size of FRCA. As concluded by [10] that it is possible to use the FRCA in concrete production as a FNA replacement as long as the properties of FRCA are taken into account in the concrete mixing design.

When RCA is demolished by using crusher, it can produce aggregate which the particle of aggregate have variety of sizes and can be categorized by its size either coarse or fine aggregate. Other researchers interested using RCA as fine aggregates in construction materials [17-18]. They mentioned that fine aggregate would not contribute in the reduction of compressive strength and elastic modulus. Thus, there is a huge potential on substitution of RCA as a fine aggregates in construction materials. The previous study stated that the value of water absorption of concrete with RCA aggregates is higher compared to concrete with natural aggregate [19-20]. 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%. The water absorbability of RCA is higher, up to 24% compared with the NAC. As stated byLotfy [19] that the compressive strength of concrete containing all types of recycled fine aggregates are similar to conventional concrete. However, the strength starts decreasing when the volume of RCA replacement up to 25%. Therefore, the volume replacement is very significant to study to determine the optimum replacement of natural sand.

One of the possibilities is to utilize the FRCA as fine aggregate replacement. Therefore, this study aims to investigate the potential of FRCA as partial replacement fine material in terms of strength compared to control concrete. This study parameter was on percentages of replacement fine aggregates and water cement ratio used to find the relationship between both parameters. Therefore, the compression test was conducted to meet the objective of the study.

2.0 Materials and Methods

The cement used was ordinary Portland cement (OPC), which complies with MS 522: Part 1 (2007). The composition of OPC are shown in Table 2.1. The coarse aggregate particle size was 14 mm and the maximum size of fine aggregates was 5 mm.

Table 2.1 - Chemical composition of OPC

Chemical composition	Percentage (%)
Loss on ignition	4.40
Silica (SiO_2)	18.08
Iron Oxide (Fe_2O_3)	2.43
Alumina (Al_2O_3)	4.72
Calcium Oxide (CaO)	61.94
Magnesium Oxide (MgO)	2.54
Sulphur Trioxide (SO_3)	2.74
Alkali-Sodium Oxide (Na_2O)	0.18
Alkali-Potassium Oxide (K_2O)	0.99

The size of FRCA and FNA are been monitored to ensure that the materials are lies within the overall grading limit stated by BS 882: 1992. The size of sieve use from 10mm, 5mm, 2.36mm, 1.18mm 600µm, 300µm and 150µm and the result for grading curve are presented in Figure 2.1 and Figure 2.2 for FNA and FRCA respectively. From the result both of the FNA and FRCA lies within the limit stated by BS 882:1992 which means FRCA can be used as the FNA replacement.

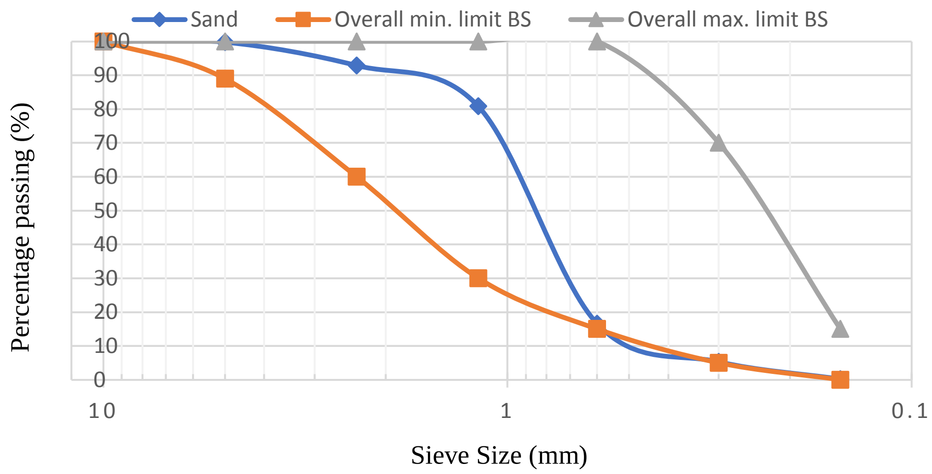

Figure 2.1 - Grading curve of fine natural aggregate

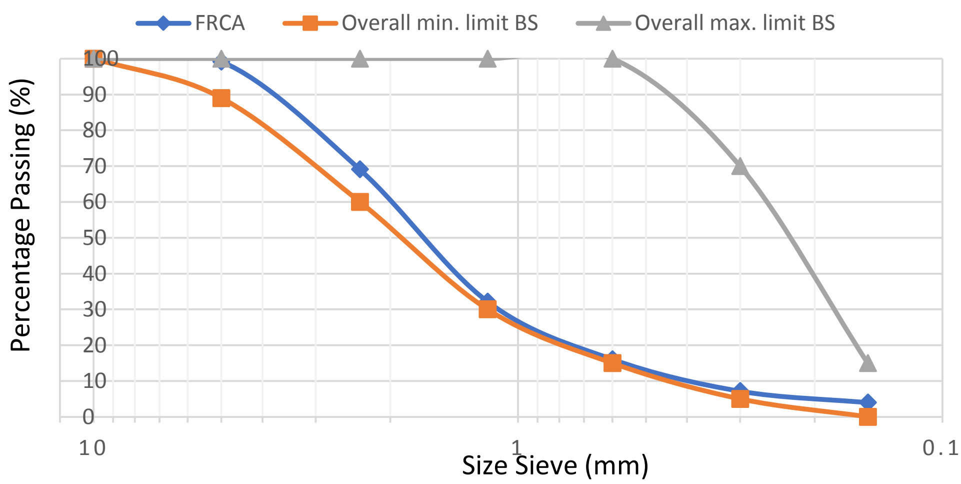

Figure 2.2 - Grading curve of fine recycled concrete aggregate

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There will be 5 batches of mixture with different of water cement ratio. The concrete is design for grade 30. The water to cement ratio for every batch are 0.40, 0.45, 0.50, 0.55, and 0.60. Every batch was mixed with 0%, 15%, 20%, 25%, 30%, 45%, and 60% of FRCA. The compressive strength of the concrete was tested at 28 days. A total of 105 specimens were prepared for the compressive strength test. All the concrete specimens were tested using three cubes for each batch of concrete mixture. The average of the three test results for each concrete batch was taken as the final result.

2.1 Mixing design

Table 2.2 to Table 2.6 shows the concrete mixing design for all batch from 0.4, 0.45, 0.50, 0.55 and 0.6 water cement ratio with the 15%, 20%, 25%, 30%, 45% and 60% fine natural aggregate replacement by FRCA. The replacement of FNA by FRCA is by volume which is the specific gravity of both aggregates will be used in the calculation. The specific gravity of FNA and FRCA are 2.64 and 2.51 respectively.

Replacement, %	Cement	Water	Water Cement Ratio	Coarse	Fine	FRCA
0	450	180	0.4	1313	438	0
15	450	180	0.4	1313	372	63
20	450	180	0.4	1313	351	83
25	450	180	0.4	1313	330	105
30	450	180	0.4	1313	306	126
45	450	180	0.4	1313	240	186
60	450	180	0.4	1313	174	251

Table 2.2 – Concrete mixing design for 0.4 w/c

Replacement, %	Cement	Water	Water Cement Ratio	Coarse	Fine	FRCA
0	400	180	0.45	1350	450	0
15	400	180	0.45	1350	383	65
20	400	180	0.45	1350	359	85
25	400	180	0.45	1350	338	108
30	400	180	0.45	1350	314	128
45	400	180	0.45	1350	248	193
60	400	180	0.45	1350	180	256

Table 2.3 – Concrete mixing design for 0.45 w/c

Replacement, %	Cement	Water	Water Cement Ratio	Coarse	Fine	FRCA
0	360	180	0.50	1380	460	0
15	360	180	0.50	1380	391	65
20	360	180	0.50	1380	370	88
25	360	180	0.50	1380	346	110
30	360	180	0.50	1380	322	131
45	360	180	0.50	1380	253	197
60	360	180	0.50	1380	185	261

Table 2.4 – Concrete mixing design for 0.5 w/c

Replacement, %	Cement	Water	Water Cement Ratio	Coarse	Fine	FRCA
0	327	180	0.55	1405	468	0
15	327	180	0.55	1405	396	68
20	327	180	0.55	1405	375	88
25	327	180	0.55	1405	351	110
30	327	180	0.55	1405	327	133
45	327	180	0.55	1405	256	200
60	327	180	0.55	1405	187	266

Table 2.5 – Concrete mixing design for 0.55 w/c

Replacement, %	Cement	Water	Water Cement Ratio	Coarse	Fine	FRCA
0	300	180	0.60	1425	475	0
15	300	180	0.60	1425	404	68
20	300	180	0.60	1425	380	90
25	300	180	0.60	1425	356	113
30	300	180	0.60	1425	333	136
45	300	180	0.60	1425	361	203
60	300	180	0.60	1425	190	271

Table 2.6 – Concrete mixing design for 0.6 w/c

3. Result and discussion

This section describes the results of the compressive strength due to the different percentage of FRCA and water cement ratio used. Test was performed after 28 days of curing. A detailed analysis was performed to study the effects of water cement ratio and percentage of FRCA replacement in the concrete matrix.

3.1 Effect of Replacement FRCA in Concrete Strength

Figure 3.1 shows all batches of specimen compressive strength test. The Y-axis of the Figure 3.1 represent the compressive strength (MPa) while the X-axis represent the replacement percentage of FRCA replacement. Overall result from this figure shows that the highest reading of compressive strength was on the 20% FNA replace by FRCA followed by 25% FRCA replacement. The reading seems to be at lowest when the replacement took place over than 30%. Most of the specimens does not perform better than the control sample on 45% and 60% FRCA replacement. This figure concludes that, the FRCA replacement does not jeopardize the strength of a concrete up to 30% and this also support by Diego et al. [9].

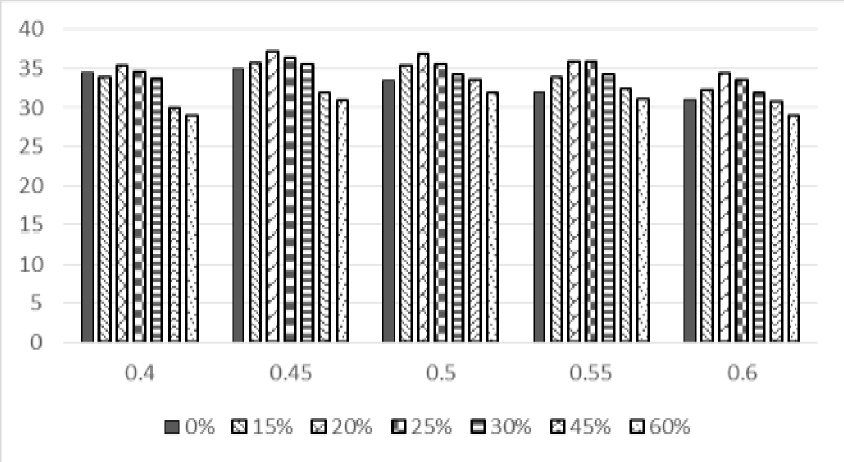

Figure 3.1 – Overall FRCA repalcement batches

The compressive strength for 0.4 water cement ratio is presented in Figure 3.1. The lowest reading of the compression test occurs when the replacement took place at 40% and 60% which is 30 and 29 MPa, respectively. The highest value recorded at 20% of FRCA replacement which is 0.9% increment in strength compared to the control concrete which is 34.5 MPa.

Figure 3.1 also shows the compressive strength result for 0.45 water to cement ratio. The pattern is the same except a bit increase in strength. The compression strength recorded for the control concrete was 35 MPa which is 6.29% lower than the FRCA replacement at 20%. The replacement that take place more than 40% shown the lowest compressive strength of all. For 0.5 water to cement ratio, the compressive strength result is shown in Figure 3.1. The highest compressive strength still on 20% FRCA replacement which is 9.52% higher than the control concrete. On the replacement of 40%, the result of compressive strength recorded the same as the control concrete that is 33.6 MPa and as the replacement increases to 60%, the concrete strength begins to decrease.

For the batch that use high water to cement ratio which is 0.55 and 0.6, the trend on both batches is quite similar. For overall batch, these two batch recorded the lowest compressive strength. However, the highest compressive strength for both still recorded at a replacement of 20% FRCA which is 35.9 and 34.5 MPa for 0.55 and 0.6 water to cement ratio respectively. The strength of the control concrete was 32 Mpa and 31 Mpa for 0.55 and 0.6 which is 12.19% and 11.29% respectively lower. Figure 3.1 shows that with the increasing percentage of FRCA replacement more that 30%, the compressive strength become lower.

The highest and optimum replacement of FRCA is at 20%. This phenomenon happen was due to the process of mixing the concrete together that generate a very fine broken particle from the FRCA that act as a filler effect which can counteracts the higher porosity of the recycled aggregate. In fact, 20% replacement of FRCA also is where the most effective percentage of replacement for the filler effect to make a positive effect which can contribute to the improvement of the mechanical properties of the concrete. Other than that, the usage of a high quality of RCA especially direct from the concrete mixing plant have a high tendency to create a stronger bond between the matrix and the aggregate [21].

Decreasing in compressive strength was due to the excessive mortar fraction in the FRCA. The mortar fraction is the effecting factor that increase the water to cement ratio in the mixes which can decrease the load transfer characteristic in the concrete. Other than that, the reduction in compressive strength was also due to poor “balling effect” of high content FRCA. This effect reduces the bonding between cement pastes with FRCA. Therefore, the cube become more voided within the particles and affected the concrete strength [3]. 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.

3.2 Effect of Water Cement Ratio in Concrete Strength

Figure 3.2 shows the relationship between a constant FRCA replacement and variety of water to cement ratio. The details result of compressive strength against water cement ration age for each sample were illustrate in Figure 3.2.

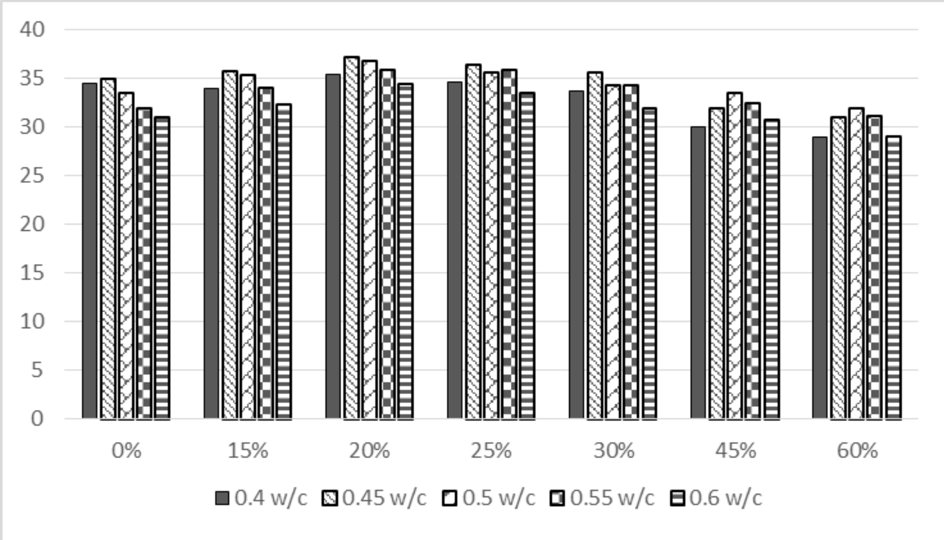

Figure 3.2 All batches W/C

Starting with 0% replacement in Figure 3.2, the best concrete mixing design for the control concrete was at 0.45 water to cement ratio that is 35 Mpa followed by 0.4 then 0.5 which were 34.5 and 33.6 respectively. The least strength in compression was the concrete mix with 0.6 water to cement ratio recorded only 30 Mpa. The difference in compressive strength had been noticed when introducing the FRCA in replacing the FNA use in the control specimens just as shown in Figure 3.2. Therefore, the analysis will be detailed in percentage of FRCA replacement with different batches of water cement ratio used.

Concrete with 15% of FRCA replacement shows that the highest strength recorded for concrete with water cement ratio at 0.45 which obtains is 35.8 MPa as shown in Figure 3.3. Then it is followed by concrete with 0.50 water cement ratio followed by both 0.4 and 0.55 water to cement ratio. The lowest concrete strength recorded was 32.3 MPa with 0.6 water cement ratio.

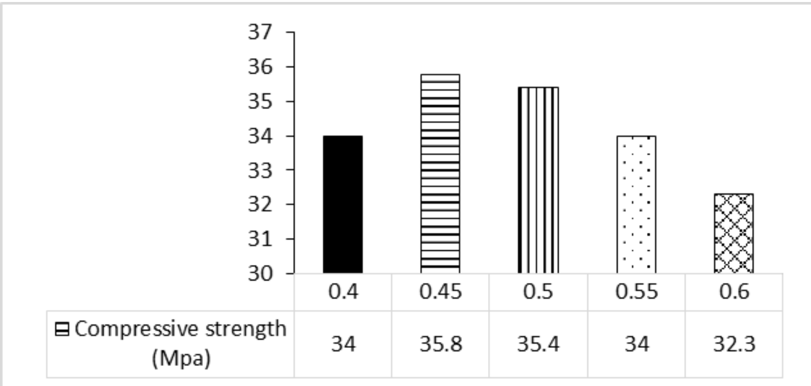

Figure 3.3 – Compressive strength of 15% FRCA replacement

Figure 3.4 shows concrete with 20% FRCA replacement with highest strength at 0.45 water cement ratio followed by 0.5 water cement ratio with strength of 37.2 and 36.8 MPa respectively. The third highest was concrete with 0.55 water cement ratio while the lowest strength is 34.5 MPa for concrete with 0.6 water cement ratio. On the 25% FRCA replacement shows in Figure 3.5, concrete with 0.55 water to cement ratio is more acceptable than 0.5 even though the difference is very narrow between them. The concrete strength also seems to be decrease a little for all water to cement ratio when comparing to 20% FRCA replacement batch.

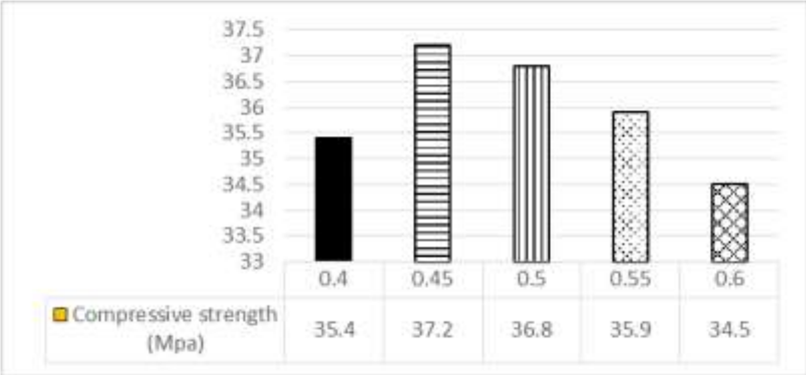

Figure 3.4 – Compressive strength for 20% FRCA replacement

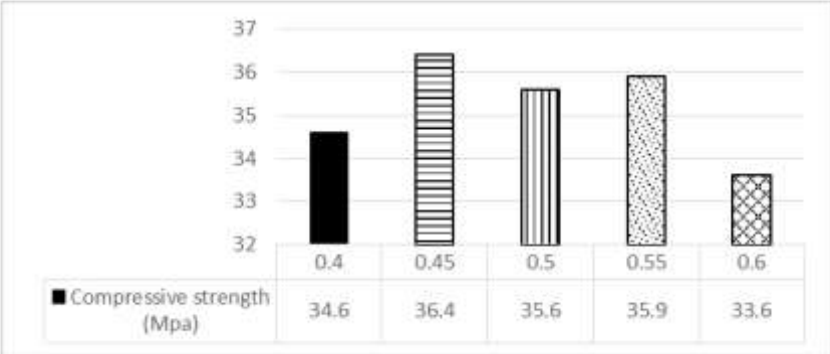

Figure 3.5 – Compressive strength for 25% FRCA replacement

Compressive strength for 30% FRCA replacement as shown in Figure 3.6 shows the same trend but the performance of concrete with 0.55 are getting lower and the same strength recorded as the 0.5 water to cement ratio concrete mix. Concrete with 0.45 water cement ratio was the highest strength recorded which 35.6 MPa. Meanwhile, concrete with 0.60 water cement ratio was the lowest strength recorded which 32.0 MPa.

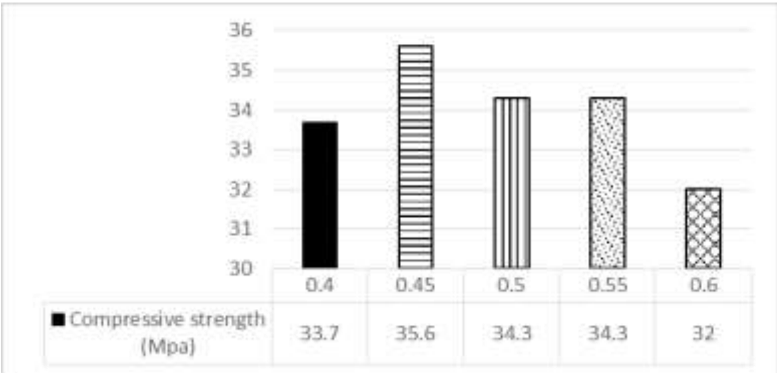

Figure 3.6 – Compressive strength for 30% FRCA replacement

Concrete containing 45% and 60% of FRCA replacement as shown in Figure 3.7 and Figure 3.8 respectively were started to show different trend of concrete strength behavior. Figure 3.7 and Figure 3.8 show that the concrete with 0.45 water cement ratio is begin to loss compressive strength compared to the others percentages of FRCA. Record shows that the highest strength for both 45% and 60% FRCA with 0.50 water cement ratio were 33.6 and 31.9 MPa respectively. Meanwhile, concrete with 0.4 and 0.6 water cement ratio indicates the lowest strength. As can be seen throughout all the mixing batch, the compressive strength of concrete with 0.5 water cement ratio concrete mix was significance and consistence. It also shows that concrete strength with 0.5 water cement ratio is higher compared to the control concrete except at concrete containing 60% of FRCA replacement.

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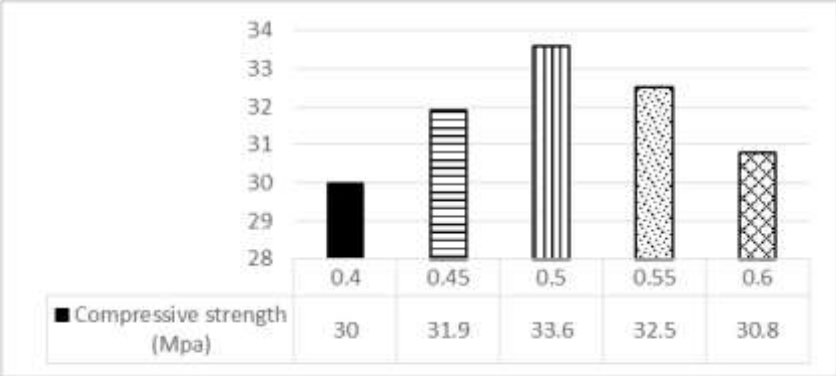

Figure 3.7 – Compressive strength for 45% FRCA replacement

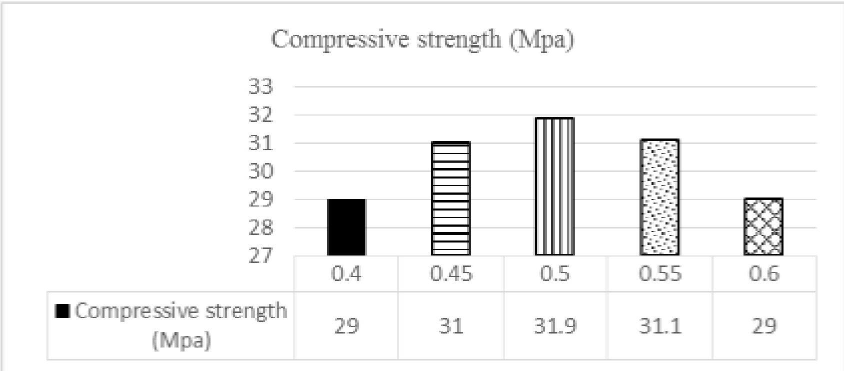

Figure 38 – Compressive strength for 60% FRCA replacement

The performance shows concrete with 0.5 water cement ratio incorporating with 15%, 20%, 25%, 30% and 45% of FRCA as optimum percentage replacement. Water is important for cement hydration and provide concrete its mechanical properties. Too much of water will increase concrete porosity and reduce its mechanical strength while too low of water the hydration of cement cannot take place perfectly and reduce its workability [22] This shows the reason that on 0.6 water cement ratio cannot achieve a strength to compete with the others. As for the low water to cement ratio on 0.4, due to the high water absorption of FRCA which resulted from its high porosity properties, the water is insufficient for the concrete to be hydrated which lead to low workability and low strength. The water absorption of FRCA materials significantly affected the decreased of concrete strength [2]. According to [23-24], the high water to cement ratio is not affecting the strength characteristic concrete, it was only affected by the quality of the RCA when the water to cement ratio is low. This phenomenon is due to the presence of the unhydrated cement in the RCA that affected the properties of the concrete [23] and of course when too excessive of water also bring down the performance of the concrete [24-25].

From the results, only concrete with 15%, 20%, 25% and 30% present significantly result with increased of water cement ratio. Thus, one would expect the decrease of water cement ratio and increase of FRCA replacement would tend to reduce the concrete strength [26]. As for the low water to cement ratio on 0.4, due to the high water absorption of FRCA which resulted from its high porosity properties, the water is insufficient for the concrete to be hydrated which lead to low workability and low strength.

4. Conclusion

It can be concluded that the replacement of FRCA does not jeopardize the strength of a concrete up to 30% replacement. Best replacement of FRCA will be on 20% which the most interaction of FRCA in the concrete occur that contribute to increasing in compressive strength. The porosity properties of FRCA been neutralized on that replacement percentage by the present of optimum filler effect generated from the very fine FRCA particle during the mixing process. Other than that, the water to cement ratio shows that the on 0.45 shows aggressive increase in strength, however the replacement took place on 40% and 60%, the compressive strength on that batch drop drastically. It also been observed that on

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0.45 water to cement ratio, the workability of a concrete is low. By that, the optimum water to cement ratio shows on 0.5. it shows a consistency of strength in every FRCA replacement which means on 0.5 ratio is the most suitable condition for cement hydration take place. There is high possibility to use the FRCA in the concrete mixing design as long as the properties if FRCA itself cannot be neglected.

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