Performance of Concrete Containing Fine Recycled Concrete Aggregate (FRCA) and Fine Crumb Rubber (FCR) As Partial Sand Replacement

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Abstract. Natural fine aggregate materials are frequently used in development and commercial construction in Malaysia. In fact, concrete production was increased as linear with the growing Malaysia economy. However, an issue of concrete production 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 will promote usage of fine recycled concrete aggregate (FRCA) and fine crumb rubber (FCR) as suitable materials to be used in the construction industry as partial sand replacement materials. It helps to protect the natural environment from the disposal of wastes and also reduce construction cost by using industrial waste. Until today, none of researchers have done studies for the effect of combination of FRCA and FCR as partial sand replacement materials towards the strength properties of concrete. Therefore, this research will study the strength properties of concrete containing combination of FRCA and FCR as partial sand replacement materials. The design replacement of FRCA which is 0\%, 15\%, 30\%, 45\% and 60\% and CR of 0\%, 1.5\%, 3\%, 4.5\% and 6\% will be evaluate. Other than that, 0.5 water cement ratio will be used in this research. This study involved is workability, density, compressive strength, tensile strength and water absorption tests.

1. Introduction

Concrete is the most generally used construction material due to its suitability for all types of civil engineering construction such as building, bridges, dam and etc. Nowadays, the increasing in number of population leads to the needs of urbanization due to demand of houses and other major construction which requires extremely usage of natural resources. It is the most economical construction material compared to other type of materials used in construction. The raw materials used in concrete are spreading into the world makes the prices cheaper while the performances and the properties of the
concrete that confers it a large scale of application [1]. However, increasing the demand of concrete causing the use of natural resources become increasing. The demand for construction materials has grown exceedingly as many countries are facing a huge number of development nowadays which leads to the increasing in the amount of construction and demolition waste [2]. Concrete that use natural fine aggregate were substitute with recycled fine aggregate and crumb rubber was helps the natural resources from depletion and also get benefit from waste production before thrown away. Besides that, rubber tire also produced a lot of waste material that need to be disposal.

Several researchers reported that the increase of the RFA content in concrete mixture up to 50% can increase the compressive strength of the concrete [3]. It was also reported that the slump of recycled concrete aggregate, due to higher water absorption, angularity and rough texture of construction and demolition waste, was lower than conventional one [4]. Density of concrete incorporating with crumb rubber as partial fine aggregate replacement will decrease as the percentage of crumb rubber increase [5, 6]. Density for w/c ratios of 0.35, 0.45, and 0.55 reduce when the percentage of rubber ash in concrete increase. [7]. Concrete with crumb rubber decrease gradually on workability when crumb rubber percentages increase [8].

As the percentage of CR increased, compressive strength of concrete decreases [5]. This is because physical properties of CR which entrapping air into its surfaces and during the mixing process water were repelled [9]. CR (4.75mm) used at a changeable percentage up to 40% with a step size of 10% as a replacement of fine aggregates also show that compressive strength decreased when percentage of CR increased [10]. In tensile strength test the strength of crumb rubber concrete showed a decrease in strength in comparison to the strength of normal concrete [11]. The fine crumb rubber concrete had lower tensile strength in comparison to control mix at 7 days and 28 days except for 5% of crumb rubber replacement at 7 days age [13]. Studied on the performance of concrete mix incorporating 5%, 7.5%, and 10% of discarded crumb rubber as fine aggregate showed that the water absorption increased when percentages of rubber as aggregates increase [14].

Recently, vast study has been done by engineers and material researchers in finding the solution on recycling the waste generated from construction activity as an alternative of resources to be used in concrete in order to environmental conservation and efficient usage of natural resources. For construction of new a building, there is significant amount of construction waste generated such as concrete, timber, reinforcement bars, finishing waste from tiling. Therefore, utilization of recycled concrete aggregate and crumb rubber waste as replacement in concrete production may help reducing the amount concrete and crumb rubber waste at disposal site. Since cement and aggregate contain almost 70% of concrete volume, the usage of concrete waste and crumb rubber waste as recycled fine aggregate can reduce environmental impact [2].

2. Materials and experimental procedure
The recycled concrete aggregate and crumb rubber will be used as fine aggregate replacement. The percentages of both replacement materials for recycled fine aggregate is 15%, 30%, 45% and 60% and crumb rubber is 1.5%, 3%, 4.5% and 6%. The testing conducted to determine concrete strength is compressive strength test. The concrete will be tested for 7, 28, 56 and 90 days curing period.

2.1 Materials
The types of cement used is Ordinary Portland Cement (OPC) as comply in MS EN 197-1: 2014. The size of coarse aggregate use in the study is ranging from 5mm to 14 mm. It is obtained from sieve analysis which passing 14 mm sieve and retained at 5mm sieve. The size of sand use in the study is the sand passing 5mm sieve. After the sieving process are complete, the sand will be left dry naturally under sun to eliminate the water content in the sand. FRCA is one of the replacement materials will be used in concrete mixture as natural fine aggregate replacement. The maximum size of FRCA use in the mixture is passing 5mm sieve. FCR are recycled waste rubber that comes from automotive tires at recycling factory tires at Jalan Bukit Pasir, Muar. The crushed FCR will be separate according to their
size. The size of the sieve waste FCR granules with the maximum size of 5mm which physically similar to the sizes of sizes of the fine aggregate.

2.2 Mixture proportions
The concrete mixtures will be designed by according to the Department of Environment mix design in 1998 or the British mix design. The concrete construct to achieve 30 N/mm² at ages of 28 days and the slump range from 60 mm to 180 mm. The replacement volume of FRCA and FCR will be calculate by volume replacement due to the FRCA and FCR have lower specific gravity and it has a huge difference as compare to the sand. The absolute volume method will be applied in calculating the volume of each constituent materials to occupy 1m³ of concrete mixture. The design mixture proportion of 1m³ of concrete are as shown in Table 1 will be constructed according to the DOE with 0.5 of water-cement ratio

| Sample       | Cement (kg/m³) | Sand (kg/m³) | Fine Recycled Concrete Aggregates (kg/m³) | Fine Crumb Rubber (kg/m³) | Coarse Aggregate (kg/m³) | Water (kg/m³) |
|--------------|----------------|--------------|------------------------------------------|---------------------------|--------------------------|---------------|
| Control mix  | 390            | 568          | -                                        | -                         | 1207                     | 195           |
| FRCA 15%     | 390            | 474.28       | 85.2                                     | 8.52                      | 1207                     | 195           |
| FCR 1.5%     | 390            | 465.76       | 85.2                                     | 17.04                     | 1207                     | 195           |
| FCR 3%       | 390            | 457.24       | 85.2                                     | 25.56                     | 1207                     | 195           |
| FCR 6%       | 390            | 448.72       | 85.2                                     | 34.08                     | 1207                     | 195           |
| FRCA 30%     | 390            | 389.08       | 170.4                                    | 8.52                      | 1207                     | 195           |
| FCR 1.5%     | 390            | 380.56       | 170.4                                    | 17.04                     | 1207                     | 195           |
| FCR 3%       | 390            | 372.04       | 170.4                                    | 25.56                     | 1207                     | 195           |
| FCR 6%       | 390            | 363.52       | 170.4                                    | 34.08                     | 1207                     | 195           |
| FRCA 45%     | 390            | 303.88       | 255.6                                    | 8.52                      | 1207                     | 195           |
| FCR 1.5%     | 390            | 295.36       | 255.6                                    | 17.04                     | 1207                     | 195           |
| FCR 3%       | 390            | 286.84       | 255.6                                    | 25.56                     | 1207                     | 195           |
| FCR 6%       | 390            | 278.32       | 255.6                                    | 34.08                     | 1207                     | 195           |
| FRCA 60%     | 390            | 218.68       | 340.8                                    | 8.52                      | 1207                     | 195           |
| FCR 1.5%     | 390            | 210.16       | 340.8                                    | 17.04                     | 1207                     | 195           |
| FCR 3%       | 390            | 201.64       | 340.8                                    | 25.56                     | 1207                     | 195           |
| FCR 6%       | 390            | 193.12       | 340.8                                    | 34.08                     | 1207                     | 195           |

2.3 Testing method
Test consist of 204 cube specimens and 51 cylinders specimens. Cube specimens with size 100mm x 100mm were prepared for the workability test, density test and compression strength test. Cylinders specimens with a diameter of 100 mm and a height of 150 mm were prepared for the splitting tensile
strength test. The moulds were filled to the top with compaction, then screen the top surface of the moulds to ensure it is even.

After the concrete cubes being left for 24 hours and become hardened, the moulds ready to be removed and curing process can be done. Curing process is the process of soaking the concrete in water for a certain period. The water cement ratio was used in the mix design is 0.5. After that, slump test was test and the value were taken. In order to get the density of the concrete the sample was weight first. The sample was tested for compression test and splitting tensile test using ordinary compression machine. The result of the testing was analyzed and the compressive strength and the tensile strength were gained.

3. Result and Discussion

The characteristic of constituent materials was investigated by conducting material testing such as workability and performance of concrete containing FRCA and FCR as partial replacement to fine aggregates. To accomplish the objectives, a few tests have been conducted at the UTHM Structure and Material Laboratory such as slump test, density test, compressive strength test, and tensile strength test.

3.1 Slump Test

The workability of concrete was measured by performing the slump test. The slump flow describes the drop of concrete from the slump cone to ensure that the consistency of fresh concrete meets the specifications. Figure 1 shows the workability of concrete resulting from the slump test.

![Figure 1: Slump value of concrete containing recycled fine concrete aggregate and fine crumb rubber as partial replacement](image)

From Figure 1, all mixes have a slump value ranging between 78.8 mm to 62 mm. It is clear that the workability of concrete decreased as the replacement percentage of RFCA increased. As the percentage of sand replaced with RFCA increased, the workability decreased to 62 mm with 1.5% FCR in concrete. Most of the concrete mixes fall within the true slump range since the concrete mix was designed for slump values ranging between 60 mm to 180 mm. The slump value of concrete also decreased significantly as the percentages of FCR were maintained while the percentages of FRCA
increased. Concrete with 4.5% of FCR replacement has the highest slump value between the other FCR replacement in concrete.

The fact that FRCA has a harsh surface texture and greater angularity, which increases the agitation among the particles resulting on decrease in the workability of concrete. Thus, cement pastes of fine aggregate will increase then produced more friction between the particles, thereby reducing slump in the concrete when the FRCA replacement ratio was increased. This result is in same understanding with the obtained in previous study [4].

3.2 Density Test

From the result in Figure 2, the density of concrete decreases with the increase in FRCA as partial sand replacement. The same situation happened when the percentage of FCR used in concrete increases. The highest density of 2321 kg/m$^3$ was recorded by control concrete. Meanwhile, the highest density of concrete containing both FRCA and FCR was recorded by R15C1.5. Its density was 2291 kg/m$^3$ which only differed by 0.3% from the density of the control concrete. On the other hand, R60C6 recorded the lowest density of 1900 kg/m$^3$ which differed 4.21% from the density of control concrete. This finding is in agreement with those obtained in previous study [5-6].

The decreased density of the sample may be due to the specific gravity of CBA and FCS which are lower than natural fine aggregate. The replacement of sand with FRCA and FCR resulted in the replacement of heavy particles with lighter particles since the specific gravity of FRCA and FCR are lower than natural fine aggregate. This increased the voids in the sample and led to a lower density value. The continuous decrease in the concrete with crumb rubber as partial replacement density was proclaim by several authors and was attributed to the lower relative density of rubber in comparison to natural aggregates [15]. Some researcher also reported that sand cement brick with partial replacement of FRCA have negative effect on the density [16].

![Figure 2: Density of the concrete](image-url)
3.3 Compressive Strength Test

From Figure 3, it clearly shown that the strength of concrete on 28 days starts to increase when replacement of waste also increases.

![Compressive strength pattern](image.png)

**Figure 3:** Compressive strength of concrete

There was a huge development in strength of concrete from 7 days to 28 days curing age. For 28 days curing age, 4 specimens had recorded higher strength than control specimen which were R15C3, R30C1.5, R30C3 and R30C4.5 with strength of 34.08 MPa, 37.13 MPa, 37.56 MPa and 34.48 MPa respectively. The highest strength was recorded by R30C3 with 46.74 MPa at 90 days curing age while the lowest compressive strength was recorded by R60C6 with 14.90 MPa at 7 days curing age. The strength of concrete increase with replacement of FRCA up to 30% with 3% of FCR. The compressive strength pattern shows an increasing in samples containing RFCA 30% for all curing age. The addition of 3% FCR with 30% of FRCA gives the highest strength compared to other samples. When the volume of FCR increase from 4.5% to 6% for FRCA 30% it will show the reduction of strength in concrete. In addition, increment strength with the highest percentage between 7 days to 90 days among other samples is 28.97%, 11.45%, 22.51% and 24.08% respectively for 30% of FRCA with a volume of FCR for 3%. This result has a different result compared to studied by Azmi et al. [18] that stated concrete with 25% of FRCA with addition of 2.0% of PET have the highest compressive strength.

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Moreover, the results explain that when amount of FCR increase the strength of the concrete decreased. The result also reveals that optimum percentage of FRCA replacement is at 30% at age 7 days, 28 days, 56 days and 90 days. This result having the same pattern with the result conducted by
Azmi et al. [12] that stated decrease in compressive strength is mainly because of the lack of adhesion between the rubber particles and the cement paste.

3.4 Tensile Strength Test
Figure 4 show the splitting tensile strength results of control concrete and concrete containing FRCA and FCR at a age of 28 days. It can be seen that the tensile strength of concrete increased with the use of FRCA as partial sand replacement. However, the strength of concrete increased when up to 30% of FRCA was used but further increase in FRCA percentage resulted in a decrease in tensile strength. When FRC was used, the strength decreased along with the presence of FRCA. The highest strength achieved was 3.16 MPa with 30% of FRCA and 3% of FCR which was higher than that of the control mix. Further replacement of FRCA and FCR decreased the tensile strength of concrete. The lowest tensile strength of 2.64 MPa was recorded by R60C6.

According to Selvakumar et al. [13], it shows that the strength of crumb rubber concrete decrease in strength in comparison to the normal concrete in splitting tensile strength test. This supported by Gideon et al. [11], studied that crumb rubber in concrete lowered the splitting tensile strength with an increase of crumb rubber use as a replacement. This is because crumb rubber as replacement to fine aggregates possess less bonding ability which has affected on strength of concrete. Some researcher also finds that using of rubber ash in concrete up to 3% increased the flextural strength of the concrete at ages 7 days and 28 days [17].

![Figure 4: Tensile strength test result at 28 days](image-url)
4. Conclusions

From the compression and tensile result, it can be concluded that 30% of FRCA and 1.5 FCR as partial replacement to fine aggregate is the most suitable proportion for both mechanical. Significant increase showed from these about 24.1% and 10.5% increases for compressive and tensile strength respectively, in comparison to the normal concrete. Concrete containing 30% of FRCA and 1.5% of FCR has the highest difference percentage of tensile strength with the differences about -7.7% in comparison to the normal concrete. Meantime, concrete containing 60% of FRCA and 6% of FCR replacement with the differences about -7.7% have the smallest difference percentage and the nearest value to the normal concrete. It can be concluded that concrete with suitable percentages of FRCA and FCR as partial replacement display a good result for both test that is compressive and tensile strength. Meanwhile, additional percentage exceed 30% of FRCA and 1.5% of FCR is found to be not relevant which can be seen from the decrease in performance.

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