Effect of Water-Cement Ratio on Mechanical Properties of Rubberized Fly Ash Concrete

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Abstract. One of the efforts to reduce the dependency of concrete production on natural resources along with carbon reduction is by utilizing recoverable materials as concrete constituents such as crumb rubber from scrap tires and fly ash from industrial waste. This study aims to investigate the mechanical properties of rubberized fly ash concrete which utilized crumb rubber and fly ash as a replacement for a proportion of fine aggregate and cement, respectively. Crumb rubber was used to replace 5 and 10% fine aggregate while fly ash was used to replace 10% OPC by weight. Three different water-binder (w/b) ratio, 0.55, 0.50 and 0.45, were used. The concrete specimens were prepared and tested for their density, compressive strength, splitting tensile strength, and flexural strength. Result gathered from the experimental works show a reduction in properties of rubberized concrete when compared to conventional concrete. By using a lower w/b ratio, the reduction tends to decrease and rubberized concrete with 0.45 w/b ratio recorded comparable density and strength to that normal concrete. The use of a lower water-binder ratio in concrete mix improved the strength of rubberized fly ash concrete equivalent to the normal concrete, allowing for usage of green materials in real building construction.

1. Introduction

Concrete is known as the most commonly used building materials and played a significant role in the construction sector. Due to its advantages in terms of cost, availability and applicability, concrete has been chosen as the main materials in the construction of numerous buildings. Although there are many advantages offered by concrete, there are also adverse effects, especially to the environment. The production of concrete has led to continuous natural resource exploration and exploitation to fulfil the construction industry demand. Constant extraction and consumption of natural resources can cause various environmental damage and concrete production must be controlled to protect the environment. Cement production has also been identified as the major contributor to global carbon emission which leads to global climate change. With all the impacts of concrete production on the environment, any measures that can reduce the dependency of the concrete industry on raw materials can give a significant contribution to nature preservation [1].

New green materials are studied for their suitability and advantages over mechanical properties, construction costs optimisation and environmental pollution minimisation [2]. One of the approaches
is through material recovery in which the recyclable waste materials are processed as raw materials that are suitable to be used as a substitution to the raw materials in concrete. This effort will not only assuage the environmental issues that arise from the concrete industry but also reduce the solid and industrial waste disposal problem.

In recent years, the application of crumb rubber generated from scrap tires as a partial or full replacement for concrete constituents has been discussed by researchers. In general, the utilization of crumb rubber concrete has shown a decrease in the mechanical properties of concrete [3-6]. However, studies have shown that the strength reduction can be minimized or improved in several ways including surface treatment of crumb rubber and concrete mix modification. Immersion of rubber particles with sodium hydroxide (NaOH) solution is one of the surface pre-treatment approaches. Pre-treatment of rubber particles have shown improvement in compressive strength, flexural strength, and modulus of elasticity [7-8]. Supplementary cementitious materials such as fly ash, silica fume etc. are added to the concrete mix to enhance rubberized concrete properties. Previous studies have shown that the usage of fly ash in rubberized concrete would reduce the loss of strength caused by the application of crumb rubber in concrete [9-10].

The results from the previous studies have shown the possibility of using crumb rubber as concrete constituents along with the addition of supplementary materials as a green building material. Najmi, Mariyana, Shek and Nurizaty [11] have conducted a study determining the mechanical properties of rubberized concrete with various amounts of crumb rubber ranging from 0% to 20% and 0% to 30% fly ash replacing fine aggregate and cement, respectively. The results show lower mechanical properties of rubberized concrete compared to the control specimen. However, the addition of fly ash has shown improvement in strength reduction caused by the substitution of crumb rubber and concluded that 5% crumb rubber and 10% fly ash as the optimum substitution proportion. It has been suggested that adjustment and modification in the concrete mix are essential to improve the reduction in the mechanical properties of rubberized concrete. This purpose of this study is to investigate the impact of several different water-binder (w/b) ratio on the mechanical properties of rubberized fly ash concrete.

2. Experimental Details

2.1. Materials

Ordinary Portland cement (OPC) CEM I was used as the main binder. River sand of size 4.75 mm and crushed aggregate of size 10 mm was used as fine and coarse aggregate, respectively. Supplied tap water was used for all concrete mix. Crumb rubber (Figure 1a) used as fine aggregates replacement was obtained from a local tire recycling plant having a size of 1 mm to 3 mm. Sodium hydroxide (NaOH) solution was used to treat the crumb rubber before rinsed using tap water. The treated crumb rubber was then dried in room condition for 24 hours. Class F fly ash used in the concrete mix (Figure 1b) was obtained from Tanjung Bin Energy Power Plant.

![Figure 1. Waste product used in the concrete mix as concrete constituent replacement: a) crumb rubber, b) fly ash.](image-url)
2.2. Concrete mix proportions
The concrete was designed for strength 30 N/mm$^2$ with target mean strength of 43 N/mm$^2$ based on the method described in “Design of Normal Concrete Mixes” [12]. Seven types of concrete were prepared and the concrete mix proportion is shown in Table 1. A control mix of normal concrete (NC) was made with a water-binder ratio of 0.55 for comparison to the rubberized fly ash concrete (RuPC). RuPC mixes were prepared by replacing 5% and 10% fine aggregate with crumb rubber while 10% of the cement was replaced with fly ash, namely 5Ru10PC and 10Ru10PC, respectively. In a previous study by Najmi, Mariyana, Shek and Nurizaty [11], using the constant w/b ratio, which is 0.55 for control specimen and RuPC showed a decrease in strength of RuPC compared to the control specimen. Thus, modification in w/b ratio in RuPC mix was carried out so that the strength could be improved to achieve comparable strength to that of normal concrete. Three different water-binder (w/b) ratios, 0.55, 0.50 and 0.45, were used. Superplasticizer was used in RuPC mixes to achieve workability of 60-180 mm slump.

Table 1. Mix proportion of concrete.

| Specimens      | w/b ratio | Cement (kg/m$^3$) | Fine Aggregate (kg/m$^3$) | Coarse Aggregate (kg/m$^3$) | Crumb Rubber (kg/m$^3$) | Fly Ash (kg/m$^3$) | Water (kg/m$^3$) |
|----------------|-----------|-------------------|---------------------------|-----------------------------|-------------------------|-------------------|------------------|
| NC             | 0.55      | 425               | 1065                      | 610                         | 0                       | 0                 | 235              |
| 5Ru10PC        | 0.55      | 383               | 1012                      | 610                         | 53                      | 42.5              | 235              |
| 10Ru10PC       | 0.50      | 383               | 959                       | 610                         | 107                     | 42.5              | 235              |
| 5Ru10PC        | 0.50      | 423               | 969                       | 610                         | 51                      | 47                | 235              |
| 10Ru10PC       | 0.45      | 423               | 918                       | 610                         | 102                     | 47                | 235              |
| 5Ru10PC        | 0.45      | 468               | 917                       | 615                         | 48                      | 52                | 235              |
| 10Ru10PC       | 0.45      | 468               | 869                       | 615                         | 96.5                    | 52                | 235              |

Note: NC: Normal concrete; 5Ru10PC: Concrete with 5% crumb rubber and 10% fly ash; 10Ru10PC: Concrete with 10% crumb rubber and 10% fly ash.

2.3. Casting and testing of concrete specimens
Concrete specimens comprising cube (100 mm), cylinder (100 mm diameter and 200 mm height) and prism (100 x 100 x 500 mm) were cast to determine the mechanical properties of the hardened concrete. The concrete specimens were cast in steel moulds and demoulded after 24 hours. The specimens were then cured in a water tank of ambient temperature 25 ± 2 °C until testing time. A total of 105 concrete specimens comprising 63 cubes, 21 cylinders and 21 prisms were prepared for the tests. The density of concrete was determined in compliance with BS EN 12390-7. The compressive strength test, splitting tensile test and flexural strength test of hardened concrete were according to BS EN 12390-3, BS EN 12390-6 and BS EN 12390-5, respectively.

3. Results and discussion

3.1. Density
The density of rubberized fly ash concrete measured at 28 days for all mixes is shown in Figure 2. Concrete containing crumb rubber resulted in lower density when higher crumb rubber content was used in the concrete mix. The control specimen showed the highest value of density which is 2293 kg/m$^3$ followed by concrete with 5% and 10% replacing fine aggregate. The decrement of rubberized concrete density is up to 2% for 5Ru10PC while up to 6.8% density reduction for 10Ru10PC. The lower density is mainly caused by the lower specific gravity of crumb rubber in comparison to that of natural fine aggregate. Also, rough surfaces of crumb rubber tend to entrap air, increasing the air content and reduce the density of concrete [13-14]. Regarding the w/b ratio, the density of rubberized concrete increase when a lower w/b ratio was used while maintaining the workability of concrete. The 5Ru10PC with w/b ratio of 0.45 shows a comparable density to the control specimen, which is 2292...
kg/m³ with only a 0.1% reduction. The almost similar density may result from workmanship at which the specimens may be over compacted when compacted using the vibrating table that was manually controlled. However, according to the trend of concrete density, the density of 5Ru10PC with 0.45 w/b ratio was still lied in between the density of 5Ru10PC using 0.50 w/b ratio and NC.

![Figure 2](image)

**Figure 2.** Density of NC and RuPC with different water-binder (w/b) ratio.

### 3.2. Compressive strength

When crumb rubber is introduced in the concrete mix, the compressive strength is known to be reduced. This was confirmed based on the results obtained from the compressive test as shown in Figure 3 and Table 2. The control specimen, NC present compressive strength of 34.8 N/mm² which was between the design strength and target mean strength of the concrete mix based on the method used. At the same w/b ratio, rubberized concrete recorded a lower compressive strength compared to the control specimen where the concrete strength reduced with higher rubber content. Increasing rubber content from 0% to 10% resulted in a decrease in compressive strength from 34.8 N/mm² to 17.5 N/mm², which is equivalent to 50% reduction at 28 days. The elastic nature of crumb rubber compared to the harder natural fine aggregate reduced the load-carrying capacity of the concrete [15]. The lower bonding between crumb rubber and cement matrix create the development of cracks around crumb rubber when subjected to loading [16].

When a different w/b ratio is applied to the concrete mixes, compressive strength rubberized concrete tends to increase when the w/b ratio decrease. The compressive strength of 5Ru10PC increased from 29.6 N/mm² to 36.5 N/mm² (23.5% increment) and 17.5 N/mm² to 20.7 N/mm² (18.1% increment) for 10Ru10PC when w/b ratio was reduced from 0.55 to 0.45. Only 5Ru10PC with 0.45 w/b ratio recorded higher compressive strength compared to the control specimen with 5% increment while the remaining concrete mixes show lower strength.
Figure 3. Development of concrete compressive strength.

Table 2. Properties of normal and rubberized concrete.

| Specimen   | w/b ratio | Density (kg/m³) | Compressive strength (N/mm²) | Splitting tensile strength (N/mm²) | Flexural strength (N/mm²) |
|------------|-----------|-----------------|------------------------------|-----------------------------------|--------------------------|
|            |           | 28-day | 7-day | 14-day | 28-day | 28-day | 28-day |
| NC         | 0.55      | 2293   | 27.6  | 30.8   | 34.8   | 3.2    | 4.9    |
| 5Ru10PC    | 0.55      | 2248   | 24.5  | 25.8   | 29.6   | 2.5    | 4.8    |
| 10Ru10PC   | 0.55      | 2138   | 13.5  | 16.7   | 17.5   | 1.9    | 3.6    |
| 5Ru10PC    | 0.50      | 2252   | 26.4  | 27.6   | 32.1   | 2.9    | 5.0    |
| 10Ru10PC   | 0.50      | 2150   | 16.2  | 17.3   | 19.3   | 2.1    | 4.2    |
| 5Ru10PC    | 0.45      | 2292   | 32.6  | 33.9   | 36.5   | 3.3    | 5.3    |
| 10Ru10PC   | 0.45      | 2162   | 17.0  | 19.5   | 20.7   | 2.4    | 4.3    |

Note: NC: Normal concrete; 5Ru10PC: Concrete (RuPC) with 5% crumb rubber and 10% fly ash; 10Ru10PC: Concrete with 10% crumb Rubber and 10% fly ash.

3.3. Splitting tensile strength

The splitting tensile strength of the concrete behaved in the same trend as the compressive strength. The tensile strength of rubberized fly ash concrete tends to decrease when higher rubber content was used. 21.9% and 40.6% reduction was observed for 5Ru10PC and 10Ru10PC, respectively, when compared to the control specimen. The splitting tensile strength reduction is ascribed to the same reasons that affect the compressive strength [16-17]. The increase in porosity due to the addition of crumb rubber in the concrete mix and weak bonding between the concrete matrices which led to the initiation of crack was causing the drop in strength.

Decreasing the w/b ratio improved the splitting tensile strength of rubberized concrete as presented in Figure 4. The result shows a linear relation, in which the tensile strength is inversely proportional to the w/b ratio. The increment in tensile strength for 5Ru10PC and 10Ru10PC are 32% and 26.3%, respectively, when the w/b ratio was reduced from 0.55 to 0.45. Among all the rubberized concrete with different w/b ratio, 5Ru10PC with 0.45 w/b ratio achieved higher tensile strength in comparison to the control specimen while the value of tensile for the rest of rubberized is lower than the control specimen.
Figure 4. Splitting tensile strength of concrete specimens at 28 days.

3.4. Flexural strength
Figure 5 presents the results of flexural strength for normal concrete and rubberized concrete with different w/b ratio. When crumb rubber was added to the concrete mix, the flexural strength was tend to decrease and the reduction in strength performed in the same pattern as in compressive strength and tensile strength. The reduction in flexural strength of rubberized concrete is not as large as in compressive and tensile strength. RuPC with 5% crumb rubber showed 2% flexural strength reduction and 26.5% reduction for 10% crumb rubber replacement. Gupta, Chaudhary, and Sharma [18] mentioned that the flexural strength is inversely proportional with the amount of crumb rubber due to poor interlocking between rubber ash and concrete paste.

It is shown that increasing cement content can improve the flexural strength loss due to the addition of crumb rubber. When the w/b ratio decreased to 0.45, 10.4% and 19.4% increment in flexural strength are recorded for 5Ru10PC and 10Ru10PC, respectively. The flexural strength of 5Ru10PC at 0.55 w/b ratio is comparable to the control specimen and further reduction in the w/b ratio show a higher value of strength compared to normal concrete. On the other hand, the flexural strength of 10Ru10PC is lower than normal concrete for all w/b ratio.

Figure 5. Flexural strength of concrete specimens at 28 days.
4. Conclusions

This paper aims to determine the impact of different water-binder ratio on the properties of rubberized fly ash concrete with 5% and 10% crumb rubber and 10% fly ash replacing fine aggregate and cement, respectively. Based on the experimental findings, it is concluded that replacing fine aggregate with crumb rubber in concrete mixture resulted in a decrease of density and mechanical strength of concrete. The strength further decreases when higher crumb rubber content was used in the concrete mix. However, the reduction in mechanical properties of rubberized fly ash concrete can be improved through the usage of a lower water-binder ratio. 5% crumb rubber in fly ash concrete with 0.45 w/b ratio shows comparable properties in comparison to the control specimen with similar density and slightly higher compressive, tensile and flexural strength compared to normal concrete. 5% crumb rubber with 0.45 w/b ratio is identified as the optimum concrete mix for rubberized concrete with 10% fly ash, considering the strength properties obtained throughout this study. The improvement of rubberized fly ash concrete (RuPC) properties by modification of concrete mix to attain equivalent strength with that of normal concrete have shown the possibility of the material to be used as a construction material. Further study should be conducted to determine the applicability of rubberized fly ash concrete as building materials for structural application.

5. References

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