Analysis of Cube Compressive Strength on Concrete with Recycled Aggregate and Rubber Particles

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Abstract. This paper analyzed the cube compressive strength of concrete containing recycled aggregate as part of coarse aggregates and rubber particles as part of fine aggregate, simultaneously. The effect of content of both aggregates on concrete compressive strength was studied. 25 sets of samples were made with a constant water/cement ratio of 0.39. Cube compressive strength of different samples at age of 28 days were obtained in accordance with relevant standard. Influence of replacement ratio of recycled aggregate and rubber on strength was investigated basing on the analyses of testing data and microstructure inspections, respectively. Results indicate that both recycled aggregate and rubber particles weaken the compressive strength of concrete while rubber particles plays a more important role. Replacement of fine aggregate over 20 vol% by rubber particles should be used carefully.

1. Introduction
Two common wastes in construction and vehicle industry are concrete from demolished construction and scrap tires, respectively. For sustainability, recycled aggregate and rubber particles have been reused in concrete to alleviate the influence on our surroundings. So far, there are lots of reported researches on performance of rubber concrete [1-6] and recycled aggregate concrete [7-12]. In the area of rubber concrete, it is widely accepted that elasticity, damping capacity and impact resistance increase while strength decreases as an increasing amount of rubber in the sample. In the field of recycled aggregate concrete, the consensus is compressive strength of recycled aggregate concrete gradually decreases with the content of recycled concrete aggregate increases.

The investigations regarding the replacement ratio of sand by scrap tyre rubber and replacement ratio of crushed gravels by recycled concrete aggregate in separated concrete have been widely reported. However, study on substituting aggregates with rubber particles and recycled aggregate simultaneously is rarely seen in literature. Therefore, in this study, recycled aggregate and rubber particles were used at the same time, as well as pulverized fly ash and polypropylene fibre. One of the most basic and important property of concrete is compressive strength. The mix design is based on designing the dosage of each raw material in accordance with the target compressive strength [13]. Therefore, the objective of this paper is to study the influence of substitution ratio of rubber particles and recycled aggregate on cube compressive strength of concrete, and the aim is to support a more sustainable environment and society.
2. Experiment

2.1. Materials
Raw materials used were 32.5 MPa pulverised fly ash (PFA, 30 wt%) cement, tap water, crushed gravels, natural river sand, recycled concrete aggregate, scrap tire rubber particles and polypropylene fibre. Properties of each kind of aggregates are tabulated in table 1. Grading curves of aggregates and composition of recycled aggregate are shown in figure 1 and figure 2, respectively.

| Item                                      | Crushed gravels | Recycled aggregate | River sand | Tyre rubber |
|-------------------------------------------|-----------------|--------------------|------------|-------------|
| Aggregate crushing value                  | 20              | 23                 | N/A        | N/A         |
| Saturated surface-dried water absorption (%) | 1.26            | 7.09               | 1.37       | 8.46        |
| Saturated surface-dried density (kg/m³)  | 2581            | 2539               | 2512       | 973         |

Figure 1. Grading curves of aggregates in oven-dried state.

Figure 2. Composition of recycled aggregate in oven-dried state.

2.2. Mix design
Control concrete in this study was designed to reach 43 MPa compressive strength at the age of 28 days with 60-180 mm slump value. 25 sets of specimens, with each set containing 3 cube samples of 100 mm side length, were prepared. Water cement ratio of 0.39 was kept constant in all experiment programme. 0, 25%, 50%, 75% and 100% of coarse aggregate was replaced by recycled concrete
aggregate by weight while 0, 10%, 20%, 30% and 40% of fine aggregate was substituted by rubber particles by volume. Fibre content was 1.0 kg/m³. All mix proportions are listed in table 2.

Table 2. Mix proportions and test results.

| Notation  | Recycled aggregate content (wt%) | Rubber content (vol%) | Water (kg/m³) | Cement with PFA (kg/m³) | Gravels (kg/m³) | Recycled aggregate (kg/m³) | Sand (kg/m³) | Rubber (kg/m³) | Fibre (kg/m³) | 28dCCS (MPa) |
|-----------|---------------------------------|----------------------|---------------|------------------------|----------------|---------------------------|--------------|---------------|---------------|--------------|
| RA0R0     | 0                               | 0                    | 230           | 589                    | 996            | 0                         | 572          | 0             | 1.0           | 50.9         |
| RA25R0    | 25                              | 0                    | 230           | 589                    | 747            | 249                       | 572          | 0             | 1.0           | 50.1         |
| RA50R0    | 50                              | 0                    | 230           | 589                    | 498            | 498                       | 572          | 0             | 1.0           | 49.1         |
| RA75R0    | 75                              | 0                    | 230           | 589                    | 249            | 747                       | 572          | 0             | 1.0           | 47.8         |
| RA100R0   | 100                             | 0                    | 230           | 589                    | 0              | 996                       | 572          | 0             | 1.0           | 46.2         |
| RA0R10    | 0                               | 10                   | 230           | 589                    | 996            | 0                         | 515          | 22.2          | 1.0           | 49.3         |
| RA25R10   | 25                              | 10                   | 230           | 589                    | 747            | 249                       | 515          | 22.2          | 1.0           | 48.6         |
| RA50R10   | 50                              | 10                   | 230           | 589                    | 498            | 498                       | 515          | 22.2          | 1.0           | 47.5         |
| RA75R10   | 75                              | 10                   | 230           | 589                    | 249            | 747                       | 515          | 22.2          | 1.0           | 46.5         |
| RA100R10  | 100                             | 10                   | 230           | 589                    | 0              | 996                       | 515          | 22.2          | 1.0           | 44.8         |
| RA0R20    | 0                               | 20                   | 230           | 589                    | 996            | 0                         | 458          | 44.3          | 1.0           | 46.8         |
| RA25R20   | 25                              | 20                   | 230           | 589                    | 747            | 249                       | 458          | 44.3          | 1.0           | 46.0         |
| RA50R20   | 50                              | 20                   | 230           | 589                    | 498            | 498                       | 458          | 44.3          | 1.0           | 45.4         |
| RA75R20   | 75                              | 20                   | 230           | 589                    | 249            | 747                       | 458          | 44.3          | 1.0           | 44.1         |
| RA100R20  | 100                             | 20                   | 230           | 589                    | 0              | 996                       | 458          | 44.3          | 1.0           | 42.5         |
| RA0R30    | 0                               | 30                   | 230           | 589                    | 996            | 0                         | 400          | 66.5          | 1.0           | 42.6         |
| RA25R30   | 25                              | 30                   | 230           | 589                    | 747            | 249                       | 400          | 66.5          | 1.0           | 41.6         |
| RA50R30   | 50                              | 30                   | 230           | 589                    | 498            | 498                       | 400          | 66.5          | 1.0           | 40.9         |
| RA75R30   | 75                              | 30                   | 230           | 589                    | 249            | 747                       | 400          | 66.5          | 1.0           | 39.8         |
| RA100R30  | 100                             | 30                   | 230           | 589                    | 0              | 996                       | 400          | 66.5          | 1.0           | 38.3         |
| RA0R40    | 0                               | 40                   | 230           | 589                    | 996            | 0                         | 343          | 88.6          | 1.0           | 36.1         |
| RA25R40   | 25                              | 40                   | 230           | 589                    | 747            | 249                       | 343          | 88.6          | 1.0           | 35.4         |
| RA50R40   | 50                              | 40                   | 230           | 589                    | 498            | 498                       | 343          | 88.6          | 1.0           | 34.8         |
| RA75R40   | 75                              | 40                   | 230           | 589                    | 249            | 747                       | 343          | 88.6          | 1.0           | 33.9         |
| RA100R40  | 100                             | 40                   | 230           | 589                    | 0              | 996                       | 343          | 88.6          | 1.0           | 32.8         |

Note: Gravels, recycled aggregate, sand and rubber are in surface-dried condition.

2.3. Preparation and testing of concrete specimens

Procedures of preparation of concrete specimens are mixing, sampling and curing. Cube compressive strength at the age 28 days (28dCCS) were tested according to BS EN 12390-3 [14]. Calculated mean value of the duplicates was recorded as the final result.

3. Results and discussion

Test results of cube compressive strength are listed in table 2. Association of 28dCCS and recycled aggregate and rubber replacement ratio was analysed using linear models and correlation tests. As shown in figure 3, the negative correlation of 28dCCS and the both factors can be clearly observed. Furthermore, rubber substituting ratio and 28dCCS is highly correlated, whereas the correlation of recycled aggregate replacement ratio and 28dCCS is not statistically significant. It means that rubber substituting ratio has a dominant effect, i.e. substituting ratio of rubber is of more significant influence than recycled aggregate on compressive strength.
For a more obvious comparison, results were plotted in a column figure in figure 4. As expected, all the samples behaved a decreasing trend of compressive strength with increasing content of either rubber particles or recycled aggregate. When rubber substituting ratio was less than 20 vol%, 28dCCS of the samples were all greater than 43 MPa regardless of substituting ratio of recycled aggregate, except RA100R20. On the contrary, specimens of over 20% rubber substituting ratio failed to achieve 43 MPa which was designed. 28dCCS of RA100R40 was 32.8 MPa, which is 35% weaker compared to control samples of 50.9 MPa. Therefore, rubber particles for substituting more than 20 vol% of fine aggregate should be paid careful attention to, particularly for structural application.

The above statements were supported by analysis of crushed samples and micro inspection. Interfaces of recycled aggregate-matrix and rubber-matrix were scanned. From figure 5(a), a noticeable cracking which was highlighted in Zone I can be clearly seen. Besides, a distinct discontinuity in Zone II can be found from its three-dimensional (3D) image as shown in figure 5(b). These observations at the boundaries of rubber-matrix indicated a poor adhesion between them, resulting in an increase of weak phase and poor interfacial transition zone (ITZ) [15]. Additionally, rubber particles acts as voids in concrete because of its lower stiffness comparing with other ingredients. Therefore, stress concentration often gives rise around interface when compression is exerted, leading to degradation of strength of concrete. In contrast, from micrograph of figure 6(a), a well-developed adhesive joint area annotated by Zone III can be clearly seen between matrix and recycled concrete aggregate. The 3D image shown in figure 6(b) suggests that the ITZ between matrix
and recycled aggregate was smooth comparing to the counterpart shown in figure 5(b). The moderate reduction of cube compressive strength induced by recycled concrete aggregate is attributed to its higher aggregate crushing value comparing with crushed gravels. As seen in figure 6(a), the micrograph of matrix-recycled aggregate, a crack was initialised within the recycled concrete aggregate rather than along the boundary, indicating a relatively stronger adhesion in the ITZ. The mechanism regarding adhesive strength demonstrated above proves that substituting fine aggregate by rubber particles is of more significant influence on 28dCCS than substituting coarse aggregate by recycled concrete aggregate.

![Micrograph of interface of rubber-matrix.](image)

![3D image of rubber-matrix interface.](image)

**Figure 5.** Interfaces of rubber-matrix, (a) micrograph (b) 3D image.

![Micrograph of interface of recycled aggregate-matrix.](image)

![3D image of interface of recycled aggregate-matrix.](image)

**Figure 6.** Interfaces of recycled aggregate-matrix, (a) micrograph (b) 3D image.

### 4. Conclusions

Analysis of cube compressive strength of concrete containing recycled concrete aggregate and waste tire rubber particles as replacement of crushed gravels and natural river sand respectively with different substituting ratio were conducted. According to the results of cube compressive strength test basing on relevant standard, the following conclusions can be drawn from the experimental study:

- Cube compressive strength of concrete is influenced by content of both rubber and recycled aggregate. The strength decreases gradually as the increase of rubber particles and recycled concrete aggregate replacement ratio.
• Various replacement ratio has different influence on reduction level regarding the cube compressive strength. Basing on the analyses of experimental testing results and failure mechanism study of the samples, a conclusion can be drawn that rubber particles have a more significant influence on strength reduction than recycled aggregate.

• Concrete achieves designed strength although coarse aggregate was completely replaced by recycled aggregate by weight. However, rubber substituting ratio more than 20 vol% of fine aggregate results in the compressive strength lower than the target strength. Therefore, rubber particles substituting more than 20 vol% of fine aggregate should be adopted with care, especially for structural application.

5. References
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