Experimental analysis of the toughness mechanism of rubber concrete

Y Xie¹, X R Su¹, H X Wang¹, D M Luo¹ and Y L Zhou²

¹Department of Civil Engineering, Foshan University, Foshan, China, 528000
²Department of Mechatronics Engineering, Foshan University, Foshan, China, 528000

Corresponding author and e-mail: D M Luo, dongmei_luo@126.com

Abstract. In this study, the Rubber Concrete (RC) specimen is manufactured by mixing the rubber particles with the size of 10 mesh, 40 mesh and 80 mesh instead of the refine aggregates with the volume fraction of 5% ~ 35% into the Plain Concrete (PC), and the complete stress-strain curves of RC are tested and compared to PC, and the results show that the mixing rubbers decrease the compressive strength, the flexural strength of the RC materials, but the RC has light weight and good toughness than ordinary concrete.

1. Introduction

It is expected to obtain the rubber concrete with high toughness and light weight by adding the rubber with different volume fractions into concrete. Most researchers studied the compressive strength, flexural strength, splitting tensile strength, elastic modulus of RC by different experimental methods, and the results show that the compressive strength and the flexural strength has declined with different speeds[1-2]. By filling the rubber particles with various content and sizes into the high-strength concrete (RHSC), Li et al. [3] found that the added rubber powder can decrease the strength and brittleness of high-strength concrete, but to increase energy absorption capacity and the ductility of high-strength concrete. Su et al. used rubber particles with various particle sizes in concrete instead of 20% of natural fine aggregate in volume [4]. The results showed that rubber aggregates with smaller or continuously graded size have relatively high strengths and low water permeabilities. Liu Feng[5] studied the relationship of the compressive strength and rubber particle size for low-strength RC under uniaxial compression condition, and some parameters for constitutive equations were obtained. By summarizing the static performance, dynamic performance and pretreatment method of RC, Yang[6] put forward to some existed problems in the study of RC. Thomas B S [7] rubber chloride ion permeability of concrete is studied, acid corrosion, electronic, etc., different rubber content for 0% to 20%, with 2.5% of the interval to replace natural sand producing rubber aggregate concrete, studies have shown that in the late of rubber concrete quality loss is obvious. The existed studies show that there is little study focus on the complete stress-strain curves for rubber concrete to discuss the toughness mechanism of RC.

In this paper, the rubber powder with different size and different volume fraction is added into ordinary concrete to investigate the influence of rubber particles on the compressive strength and flexural properties for rubber concrete, and the complete stress-strain curves are obtained from the
axial compression test, and the toughness mechanism is discussed for rubber concrete and ordinary concrete.

2. Experimental process
Brand sea snail P· O42.5R Cement and medium size sands with the density of 2600kg/m³ were used in the study. The aggregates are the natural stone with the density of 2800kg/m³. Rubber particles for 10 mesh, 40 mesh and 80 mesh with the density of 1100kg/m³ was produced by Zhejiang Enxiang Building Materials corporation (As shown in Figure 1).

![Figure 1. Rubber particles with different sizes.](image)

Based on the procedure for ordinary concrete mix design (JGJ55-2000), the mechanical properties of RC were studied by adding rubber particles with different size and volume fraction. The water cement ratio is 0.45, and the test match ratio is shown in Table 1.

| designation | water (kg) | cement (kg) | sand (kg) | rubber particles (kg) | replacement rate (%) | stone (kg) |
|-------------|------------|-------------|-----------|-----------------------|----------------------|------------|
| RC-0        | 185        | 411         | 678       | 0                     | 0                    | 1106       |
| RC-5-10     | 185        | 411         | 644.1     | 14.34                 | 5                    | 1106       |
| RC-15-10    | 185        | 411         | 576.3     | 43.03                 | 15                   | 1106       |
| RC-25-10    | 185        | 411         | 508.5     | 71.7                  | 25                   | 1106       |
| RC-35-10    | 185        | 411         | 440.7     | 100.38                | 35                   | 1106       |
| RC-5-40     | 185        | 411         | 644.1     | 14.34                 | 5                    | 1106       |
| RC-15-40    | 185        | 411         | 576.3     | 43.03                 | 15                   | 1106       |
| RC-25-40    | 185        | 411         | 508.5     | 71.7                  | 25                   | 1106       |
| RC-35-40    | 185        | 411         | 440.7     | 100.38                | 35                   | 1106       |
| RC-5-80     | 185        | 411         | 644.1     | 14.34                 | 5                    | 1106       |
| RC-15-80    | 185        | 411         | 576.3     | 43.03                 | 15                   | 1106       |
| RC-25-80    | 185        | 411         | 508.5     | 71.7                  | 25                   | 1106       |
| RC-35-80    | 185        | 411         | 440.7     | 100.38                | 35                   | 1106       |

Note: The number meaning (take RC-15-10 as an example). 15 is the rubber incorporation, 10 is the rubber particle size.
3. Results and discussion

3.1 Destruction mode of concrete

![Figure 2. Surface destruction modes of PC and RC for axial test and cube test.](image)

The plain concrete is considered as typical brittle material, so the long and deep cracks to penetrate the specimen can be observed on Figure 2(a) and (c) for plain concrete with axial and cube test, but only some shallow cracks are found on the surface of the specimen for RC under the axial test as shown in Figure 2(b). For cube test, the cracks on the specimen of RC are similar to that in the PC specimen, but the cracks are much shallower compared to PC test, which show that the rubber particles are effective to stop crack extension for concrete material, and it is significant to improve the toughing mechanism by adding the rubber particles into concrete.

3.2 Uniaxial stress-strain constitutive relationship

Figure 3 shows the complete stress-strain relationship for PC and RC with different sizes under different ages. The results show that the stress-strain relationship for PC is typical brittle fracture, and the strain decreases very rapidly after the stress reached the peak value, and the destruction occurs without any early warning. However, the stress-strain curves with obvious strain-softening are observed for RC, and the greater of the rubber particle size, the higher of the peak stress, which show that the strength of RC is related to the rubber sizes. With the increase of dosage of rubber, the peak stress decreases, but the long strain softening zone can be observed. The results show that the compressive strength and elastic modulus decreases with the increase of rubber powder content. Comparing the left figures with the right figures in Figure 3, the higher stress is also observed for RC with a longer age.
3.3. Cube compressive strength and axial compressive strength

According to the GB/T 50081-2011 of "Test methods of mechanical properties for the ordinary concrete", the formula to calculate the cube/axial compressive strength is:

\[ f_c = \frac{F}{A} \]  

(1)

where \( f_c \) -Concrete cube/axial compressive strength (MPa); \( F \) -Breaking load (N); \( A \) -area of specimen (mm²).

The cube and axial compressive strength decreased with the increase of the rubber particles as shown in Figure 4 and Figure 5. Since the boundary effectiveness of cube specimen, the cube compressive strengths are different for PC with different ages, and the axial compressive test can avoid the boundary effectiveness, and the results are more reliable. The both compressive strengths increase with the increase of age, but they decrease with the increase of the size of rubber particles as shown in Figure 4 and Figure 5. The main reason for the decrease of compressive strength is that rubber particles increase the pore of concrete and decrease the concrete dense. The strength of rubber particle is lower than that of sand, and the bond performance of rubber granule and cement aggregate is poor, and the binding force is weak. Moreover, in the process of concrete vibration, rubber particles are easy to float on the surface, which result in the concentration of stress and reduce the concrete strength.

Figure 3. Stress strain relationship for PC and RC with particle size of 10 mesh.
Figure 4. Cube compressive strength for RC.

Figure 5. Axial compressive strength for RC.

Table 2. Ratio of flexural and compressive strength for RC.

| Particle size (mesh) | Rubber incorporation(%) | Flexural and compressive strength rate |
|----------------------|--------------------------|----------------------------------------|
| 0                    | 0                        | 0.148                                  |
| 10                   | 5                        | 0.152                                  |
|                      | 15                       | 0.15                                   |
|                      | 25                       | 0.184                                  |
|                      | 35                       | 0.194                                  |
| 40                   | 5                        | 0.152                                  |
|                      | 15                       | 0.162                                  |
|                      | 25                       | 0.208                                  |
|                      | 35                       | 0.23                                   |
| 80                   | 5                        | 0.163                                  |
|                      | 15                       | 0.167                                  |
|                      | 25                       | 0.333                                  |
|                      | 35                       | 0.394                                  |

The ratio of flexural to compressive strength is the physical quantity which reflects the toughness of the material, and the greater the pressure ratio, the better the ductility of RC. It can be seen from Table 2 that the addition of rubber particles improves the toughness of ordinary concrete to a certain extent.

4. Conclusions

The complete stress-strain curves for crumb rubber mortars are obtained from axial and cube compressive experiments, and the typical strain-soften is observed for rubber concrete. The peak stress of the rubber particles decreases with the increase of the rubber particle content, and the high stress can be obtained for the RC with greater rubber particles. The toughness mechanism is improved by adding the rubber particles into concrete.

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