# Mechanical Property and Durability Analysis of Crumb Rubber Modified Concrete

**Y B Jiao[1,2], H C Cai[2], M S Zhang[2,*], T Sha[2], Y Q Feng[2] and H Chen[2]**

[1]Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education, Beijing University of Technology, Beijing, China
[2]College of Transportation, Jilin University, Changchun, China

Corresponding author and e-mail: M S Zhang, zms@jlu.edu.cn

**Abstract.** With the increasing of waste rubber tires, their disposal leads to great threat to environment. Crumb rubber produced from waste tires can be used to modify the ordinary concrete, which can realize the utilization of waste resources. In this study, crumb rubber with particle size 2-4mm was used to replace the coarse aggregates of ordinary concrete. Corresponding mechanical and durability properties including compressive strength, splitting tensile strength, axial compressive strength, elastic modulus, freeze-thaw resistance and sulfate resistance performances were measured and analyzed. The results reveal that crumb rubber presents negative effect on mechanical properties and positive effect on durability performance of concrete.



## 1. Introduction

In recent years, waste utilization has got wide attentions for sustainable development. Reuse of waste materials can be conducive to not only environmental protection, but also reducing consumption of natural resources. Millions of used tires were generated because of the increasing number of vehicles. The number of end-of-life tires (ELTs) is about 200 million each year in China, which presents an increasing rate of over 10% [1, 2]. Disposal of these tires has become a serious social problem due to the difficulty to degrade.

Crumb rubber can be applied to modify concrete, which is an effective way for disposal of waste tires [3]. Si et al. [4] investigated the laboratory performances of self-consolidating concrete modified by rubber. The results revealed that mechanical properties were reduced because of the addition of crumb rubber. However, the durability performances were improved. Bisht and Ramana [5] evaluated the mechanical and durability properties of crumb rubber concrete. It has been observed that workability, compressive and flexural strength decrease with the increasing of crumb rubber.4% replacement of fine aggregates for crumb rubber can be used for non-structural elements. Xue et al. [6] demonstrated the compressive properties of rubber concrete at temperatures of -30 and 20°C. The results showed that the deformation ability of rubber concrete at -30°C was much better than ordinary one. Liu et al. [7] investigated the mechanical and durability performances of rubber concrete. The results revealed that crumb rubber presents negative effects on mechanical properties and positive effects on durability performance. 20% replacement of fine aggregate and 5% replacement of mixture present favorable performances.



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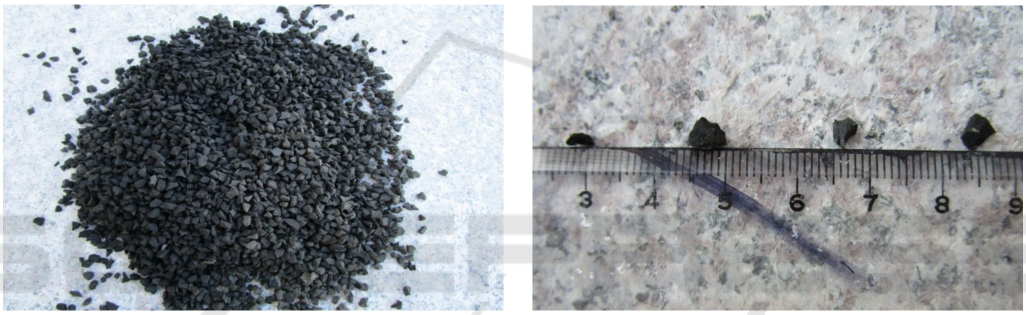
In this study, crumb rubber with particle size 2-4 mm was used to replace the coarse aggregates in ordinary concrete. Compressive strength, splitting tensile strength, axial compressive strength and elastic modulus were used to evaluate the effects of crumb rubber on mechanical performances of concrete. Freezing-thawing resistance and corrosion resistance were demonstrated to evaluate corresponding durability performances.

## 2. Materials and methods

### *2.1. Materials*

Cement used in this study was P. C. 32.5, which is composite Portland cement with compressive strength 32.5 MPa after 28d standard curing. Its physical properties were measured and listed in Table 1. Coarse aggregates were limestone, whose properties were listed in Table 2. Fine aggregate was river sand with finesse modulus of 3.0. The particle size of 2-4 mm for crumb rubber was used as replacement material, whose apparent density is 1200 kg/m$^3$. Crumb rubber was irregularly polygon, corresponding appearance was shown in Figure 1. Particle size distributions of fine aggregate and crumb rubber were shown in Figure 2.



(a) (b)

**Figure 1.** Crumb rubber (a: appearance, b: particle size).

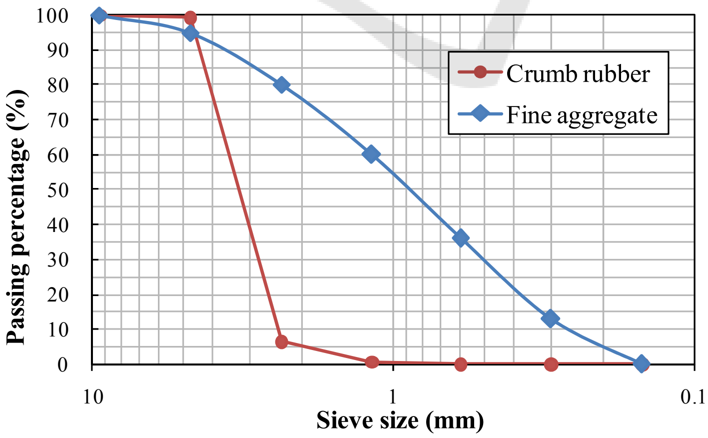



**Figure 2.** Particle size distribution of fine aggregate and crumb rubber [7].

**Table 1.** Physical properties of cement.

| Items | Measured values | Technical criterion [8] |
|---|---|---|
| Fluidity (mm) | 184 | ≥180 |
| Initial setting time (min) | 180 | ≥45 |
| Final setting time (min) | 260 | ≤600 |
| Flexural strength (28d, MPa) | 6.7 | ≥5.5 |
| Compressive strength (28d, MPa) | 35.9 | ≥32.5 |

**Table 2.** Physical properties of coarse aggregate.

| Items | Measured values | Technical criterion [8] |
|---|---|---|
| Clay content (%) | 0.4 | ≤1.0 |
| Elongated particle content (%) | 7 | ≤15 |
| Specific gravity ($g/cm^3$) | 2650 | ≥2600 |
| Crushing value (%) | 8 | ≤16 |

### *2.2. Mixture Proportion*

The mixture proportion for plain concrete (PC) was determined according to specification for mix proportion design of ordinary concrete (JGJ 55-2011) [9]. Crumb rubber concrete (CRC) was produced by replacing coarse aggregate in PC by crumb rubber. The replacement principle is to guarantee an equal volume between crumb rubber and coarse aggregate. The replacement levels varied from 5% to 20%. The mixture proportions used in this study were listed in Table 3.

**Table 3.** Mixture proportions for crumb rubber concrete

| Rubber content (%) | Mix | Weight per cubic meters (kg) | | | | |
|---|---|---|---|---|---|---|
| | | Water | Cement | Fine aggregate | Coarse aggregate | Crumb rubber |
| 0 | PC | 180 | 430 | 593 | 1197.0 | 0 |
| 5 | CRC-1 | 180 | 430 | 593 | 1135.8 | 26.6 |
| 10 | CRC-2 | 180 | 430 | 593 | 1074.6 | 53.2 |
| 15 | CRC-3 | 180 | 430 | 593 | 1016.1 | 79.8 |
| 20 | CRC-4 | 180 | 430 | 593 | 957.6 | 106.4 |

### *2.3. Characterization methods*

Concrete specimens were produced according to JTG E30-2005 [10]. Cube specimens (150mm×150mm×150mm) were used to evaluate the performances of compressive strength, splitting tensile strength and durability properties, while prism specimens (150mm×150mm×300mm) were produced for axial compressive strength and modulus of elasticity. Compressive strength, axial compressive strength, modulus of elasticity, splitting tensile strength for PC and CRC were measured after the specimens cured for 28 days according to GB/T 50081-2002 [11]. As for durability performance including freezing-thawing resistance and sulfate resistance, they were tested after the specimens cured for 60 days according to GB/T 50082-2009 [12]. Three specimens were used for each test and corresponding average value was treated as representative one.

Strength loss rate was used to evaluate the freezing-thawing resistance performance of CRC, which can be calculated by

$$\Delta f_c = \frac{f_{co} - f_{cn}}{f_{co}} \times 100 \quad (1)$$

where $\Delta f_c$ is strength loss ratio of concrete after freeze-thaw effects, $f_{co}$ and $f_{cn}$ are compressive strength before and after 25 times of freeze-thaw cycles.

As for sulfate resistance performance, specimens were firstly immersed into sulfate solution and then dried at temperature 80°C. Anti-corrosion coefficient of specimens after 15 cycles sulfate soaking and drying was calculated by

$$K_f = \frac{f_{cn}}{f_{co}} \times 100 \quad (2)$$

where $K_f$ is anti-corrosion coefficient of concrete after sulfate soaking and drying, $f_{co}$ and $f_{cn}$ are compressive strength before and after 15 times of sulfate attack.

## 3. Results and discussions

### *3.1. Mechanical properties*

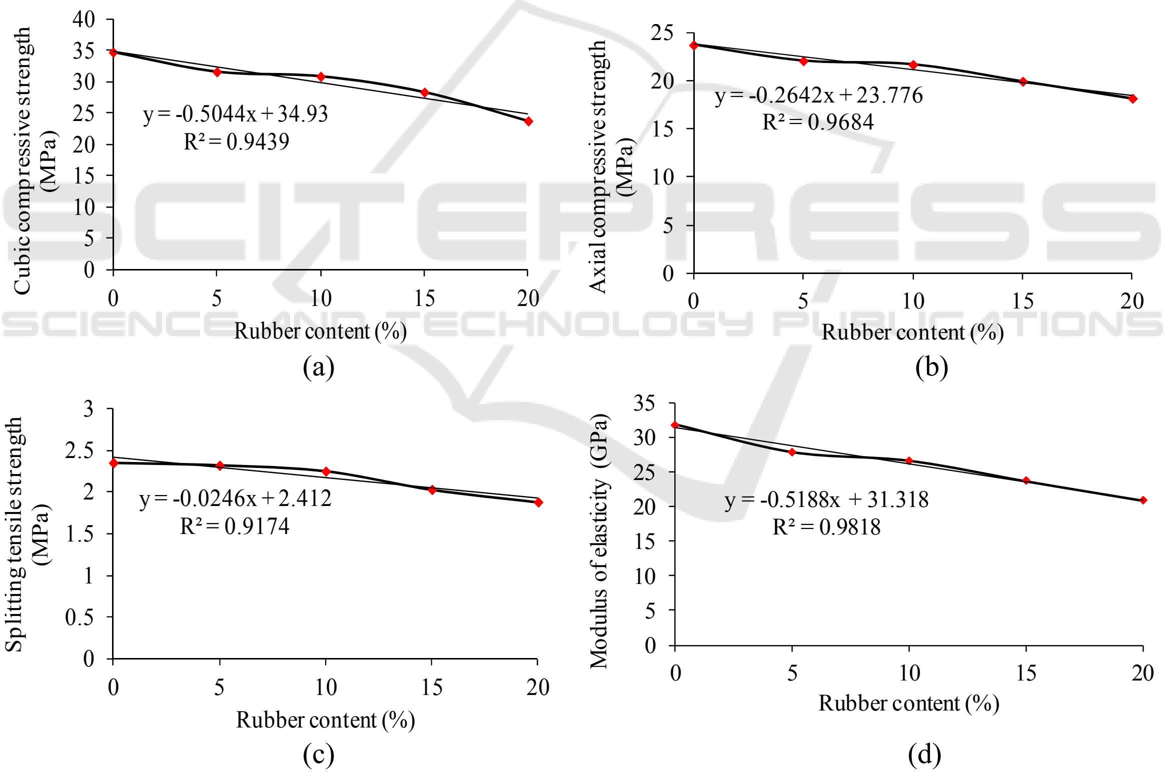



**Figure 3.** Relationships between mechanical properties and rubber content (a: cubic compressive strength, b: axial compressive strength, c: splitting tensile strength, d: modulus of elasticity).

The relationships between cubic compressive strength, axial compressive strength, splitting tensile strength, modulus of elasticity and crumb rubber content were shown in Figure 3, respectively. As can be seen from the results, mechanical properties of rubber concrete decrease with the increasing of rubber content, which have favourable linear relationships. It revealed that replacement of coarse aggregate for crumb rubber presents negative effects on mechanical properties of concrete. Moreover, the downtrends are relatively slow for mechanical properties of concrete, when the rubber content is less than 10%. The reasons lie in that rubber particles is elastic material, whose compressive strength is weaker than coarse aggregate. Moreover, adhesive ability between aggregate and cement mortar is better than that between crumb rubber and cement mortar. Therefore, replacement of coarse aggregate by crumb rubber lead to the reduction of concrete.

Ratios between splitting tensile strength and cubic compressive strength (λ) were also calculated, which were shown in Figure 4. The results revealed that λ of PC increases after the addition of crumb rubber. Replacement of coarse aggregate for crumb rubber can improve the brittleness of concrete.

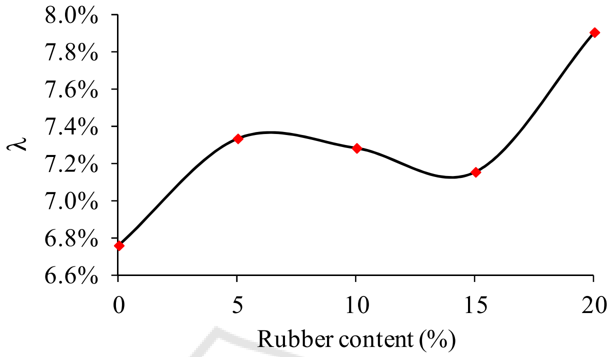



**Figure 4.** Relationships between λ and rubber content.

### *3.2. Durability performance*

Strength loss rates of PC and CRC after 25 times of freeze-thaw cycle were calculated. Meanwhile, anti-corrosion coefficients for PC and CRC after 15 times of sulfate attack were also obtained. The results were shown in Figure 5. The results revealed that compressive strength loss rate of concrete decreases with the increasing of rubber content, and anti-corrosion coefficient increases with the increasing of rubber content. Replacement of coarse aggregate for crumb rubber can improve the freezing-thawing resistance and corrosion resistance abilities. Freeze-thaw resistance improves by 34.5% when the rubber content is 5%.

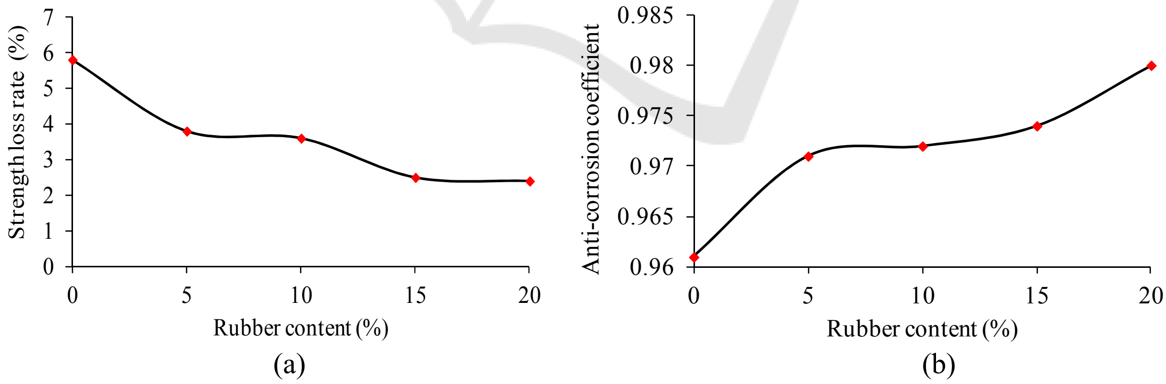



**Figure 5.** Relationships between durability performances and rubber content (a: strength loss rate, b: anti-corrosion coefficient).

## 4. Conclusions

In this study, crumb rubber with particle size 2-4mm was used to replace the course aggregate and realize the modification of concrete. Mechanical and durability performances of crumb rubber modified concrete were demonstrated. Following conclusions can be obtained:

(1) Addition of crumb rubber into concrete to replace the course aggregates presents negative effects on cubic compressive strength, axial compressive strength, splitting tensile strength and modulus of elasticity.

(2) Ratios between splitting tensile strength and cubic compressive strength show rising trend with the increasing of rubber content. Replacement of coarse aggregate for crumb rubber can improve the brittleness of concrete.

(3) Compressive strength loss rate of concrete decreases with the increasing of rubber content, and anti-corrosion coefficient increases with the increasing of rubber content. Replacement of coarse aggregate for crumb rubber can improve the freezing-thawing resistance and corrosion resistance abilities of concrete.

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