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Flexural performance and evaluation method of steel fiber reinforced recycled coarse aggregate concrete

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HIGHLIGHTS

- This paper is focused on the flexural performance of steel fiber reinforced recycled coarse aggregate concrete (SFRCAC).
- The evaluation indexes of flexural performance from ASTM C1609 and Chinese Standard JG/T 427-2015 are investigated.
- A new set of evaluation indexes suitable for SFRCAC have been put forward.

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ABSTRACT

This paper presents the experimental results on the flexural performance of steel fiber reinforced recycled coarse aggregate concrete (SFRCAC). Test parameters include compressive strength (30 MPa, 45 MPa, 60 MPa), recycled coarse aggregate (RCA) replacement ratio (0, 30%, 50%, 100%), and steel fiber volume fraction (0, 0.5%, 1%, 1.5%, 2%). Evaluation method of flexural performance in ASTM C1609 and Chinese Standard JG/T 427-2015 was investigated with respect to the variance in test parameters. Test results showed that compressive strength has the similar influence on SFRCAC and normal concrete; with RCA replacement ratio increasing, the flexural performance of SFRCAC before crack is quite similar, flexural strength and flexural toughness increase slightly, deflection increases heavily; with the steel fiber volume fraction (V_f) increasing, the reinforcement effect is not obvious when $V_f < 0.5\%$, improved significantly when V_f increases from 0.5% to 1%, growth trend becomes flatter when V_f is above 1%. The evaluation methods of flexural performance in ASTM C1609 and JG/T 427-2015 are not suitable for SFRCAC due to its deflection is much higher than normal concrete. A new set of evaluation indexes have been put forward and test results have demonstrated that this evaluation method is concise and effective.

1. Introduction

Demolished concrete can be converted into valuable coarse aggregate by crushing into suitable sizes, rather than be discarded in landfill sites, this is an effective method for waste concrete cyclic utilization and environmental protection. Consequently, many researchers have investigated the properties of recycled coarse aggregate (RCA), the results have illustrated that RCA has higher porosity, higher crushing index and lower apparent density than natural coarse aggregate (NCA) [1–4]. Meanwhile, the inferior properties of old interfacial transition zone (ITZ) is another factor that leads to the inferior properties of RCA [5]. Therefore, the mechanical properties of recycled coarse aggregate concrete (RCAC) declines remarkably compared to that of natural coarse aggregate concrete (NCAC) with same mixture proportion [1,6–10].

The method to improve the performance of RCAC have been paid a lot of attention in recently years [11–15], in which adding steel fibers into RCAC is an effective method to recover the defect of RCA [16,17]. Previous studies have confirmed the reinforced effect of steel fibers on concrete [18,19], which inhibits crack formation and growth through the bridging of the fibers, and helps to prevent brittle fracture through increasing the tensile strength and toughness. Therefore, steel fiber reinforced coarse aggregate concrete (SFRCAC) will be a potential structure material because it meets the engineering requirement and has the value of environmental protection [20].

In order to promote the application of SFRCAC, it is necessary to know its mechanical properties, including compression, tensile, shear, flexural, crack control, and impact resistance. At present,

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there are some literatures dealing with the compression behavior [18,19,21], shear behavior [22–24], impact response [14] of SFRCAC. There are also some literatures talking about the flexural strength of RCAC [25–27], and steel fiber reinforced natural coarse aggregate (SFNCAC) [28,29], but few about the flexural strength of SFRCAC. However, the flexural performance especially the toughness of SFRCAC is the important index for structure design.

Based on a review of the existing literature, there is a lack of flexural testing method and the evaluation method about the flexural performance for SFRCAC specimens. The effect of factors like compressive strength, RCA replacement ratio and steel fiber content should be given prime importance while studying the flexural performance of SFRCAC. Consequently, the authors developed a testing plan to study flexural performance of SFRCAC, which takes into consideration the level of concrete compressive strength, RCA replacement ratio and steel fiber volume fraction. The experimental program, test results and analysis in this study are presented in the following discussion.

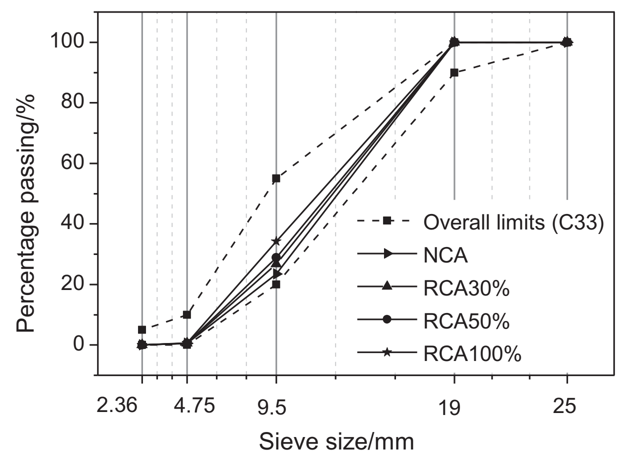

Fig. 1. Particle size distribution of coarse aggregates.

2. Experimental program

2.1. Materials and mixture proportion

Normal Portland cement (P.O 42.5, according to Chinese Standard [30]) was used in the study. Coarse aggregate included NCA and RCA, in which NCA was crushed limestone, RCA was crushed waste ready-mix concrete sourced from a concrete testing station. The waste concrete was crushed through a jaw crusher, and then sieved. The detailed properties of NCA and RCA are shown in Table 1. NCA and RCA were the continuous gradation with the maximum size of 20 mm. The particle size distributions of the coarse aggregates are shown in Fig. 1, the particle size distribution of NCA is very similar with that of RCA except the percentage passing 9.5 mm sieve of 24% for NCA and 35% for RCA, but they all are within the upper and lower limit bounds of ASTMC33/C33M-13 [31]. Compared to NCA, RCA had lower specific gravity, higher water absorption, higher porosity and higher crushing index. The fine aggregate was river sand with a fineness modulus of 2.67 and apparent density of 2556 kg/m^3. Super plasticizer with 25% water-reducing ratio was used as water-reducing admixture to obtain target slump of 50 mm for all specimens, its optimum dosage was 1% of cement (by weight). All aggregates were used in the air-dry condition. The steel fiber was hooked at both ends, and had tensile strength of 1000 MPa, mean diameter (d_f) of 0.6 mm, mean length (l_f) of 30.5 mm, and aspect ratio (l_f/d_f) of 54.6.

RCA replacement ratio (r_g) was defined as the mass ratio of RCA to overall coarse aggregate, where r_g was taken as 0%, 30%, 50%, 100%. Steel fiber volume fraction (V_f) was taken as 0%, 0.5%, 1%, 1.5%, 2%. The target compressive strength (f_{cu}) was taken as C30, C45, C60. A new method was used to design the mixture proportion [32]. The mixture proportion details of SFRCAC are listed in Table 2.

2.2. Specimen preparation

SFRCAC was mixed through a shaft mixer. First, all aggregates and steel fibers were put together and mixed for 2 min to ensure the steel fibers were uniformly dispersed. Then, the cement was added and mixed for another minute. Finally, water and water reducing agent were added together and mixed for another 2 min. No segregation or bleeding of concrete or balling of steel fiber was observed in any of the mixtures.

The slump of fresh concrete was tested right after the mixing process. For each group, six 150 mm × 150 mm × 150 mm cubic specimens were cast for the tests of compressive strength and splitting tensile strength, six 150 mm × 150 mm × 300 mm prism specimens were cast for Young's modulus, and three 100 mm × 100 mm × 400 mm prism specimens were cast for flexural test. All specimens were cast using steel moulds and put on a vibration table to vibrate for 30 s to ensure compaction, then demoulded after 24 h and cured in a moisture room at approximately 95% relative humidity (RH) and (20 ± 3)°C temperature. The tests were performed after 28-day age.

2.3. Test procedures

The tests for cubic compressive strength (f_{cu}), splitting tensile strength (f_{st}), prismatic compressive strength (f_c) and Young's modulus (E_c) were carried on a servo-hydraulic closed-loop testing machine with capacity of 3000 kN, according to the test method in Chinese Standard GB/T 50081-2002 [33]. $E_c$is the secant modulus calculated at stress from 0.5 MPa to 00.4f_c. Test results are listed in Table 3.

Three prism specimens were tested for flexural performance according to ASTM C1609 (Using Beam With Third-Point Loading) [34] and Chinese Standard JG/T 427-2015 [35], respectively. The flexural tests were carried on a MTS810 testing machine with capacity of 500 kN by displacement control at a rate of 0.1 mm/min. The specimen geometry and flexural test setup are shown in Fig. 2. In order to measure the deflection excluding the support settlement, a steel frame with two LVDTs was installed at the middle height of specimen. The specimens were normally rotated an angle of 90° from the casting position to eliminate the eccentricity effect from the roughness of the surface. The whole testing process stopped when the deflection reached 2 mm (1/150 of the span length of test specimens).

Table 1
Physical property of the RCA and NCA.

Aggregate type	Apparent density (kg/m^3)	Bulk density (kg/m^3)	Water absorption (wt%)	Crush index (%)	Porosity (%)
NCA	2814	1630	1.40	8.80	44.3
RCA	2640	1412	4.85	17.7	50.3