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Review

Mechanical properties and stress–strain relationship in axial compression for concrete with added glazed hollow beads and construction waste

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HIGHLIGHTS

- Glazed hollow beads benefit the later compressive strength.
- One analytical expression is established to describe RATIC stress–strain curves.
- Natural concrete is more brittle than RATIC when RCA replacement is less than 70%.

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ABSTRACT

In this paper, experimental investigations are conducted on the mechanical properties and stress–strain curve (SSC) of recycled aggregate thermal insulation concrete (RATIC), in which a volume percentage of 130% glazed hollow bead particles were added, with different replacement percentages of recycled coarse aggregate (RCA). Concrete specimens were fabricated and tested with different RCA replacement percentages of 0%, 30%, 50%, 70% and 100%. A water to cement ratio of 0.5 was adopted. Concrete workability was in the slump range of 150–180 mm. All tests were carried out after 28 days of wet curing. In addition, the concrete mechanical properties, elastic modulus and stress–strain relationship were evaluated.

During the analysis, special attention was devoted to the failure behavior and the influences of the RCA replacement percentage on compressive strength, split tensile strength, flexural strength, elastic modulus, the peak and ultimate strains of the RATIC.

The results indicated that when 70% of the virgin aggregate was replaced with recycled coarse aggregate a C40 strength class structural concrete could be produced. In addition, a correlation between the elastic modulus and compressive strength of the RATIC was found. Finally, it was possible to determine differences in the stress–strain relationship for a conventional concrete and the RATC with various different replacement percentages.

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1. Introduction

Due to a supply shortage of natural aggregates in some parts of the world there is a need to develop recycled aggregate as an alternative source to the natural aggregate. The possible use of recycled aggregates derived from construction and demolition wastes has received increasing interest, due to its potential to be used in environmentally friendly concrete structures [1]. Many researchers have studied the use of recycled aggregate from building demolition in the production of concrete [1–11]. Some of them studied the mechanical behavior of concretes containing recycled coarse aggregate (RCA) [4–10], and the results showed how the strength loss caused by using RCA at an equal water to cement ratio (*W*/*C*) could be reduced if better concrete was used with the RCA.

In addition, the main focus of researchers has been to reduce the energy consumption and associated CO_2 emissions from the usage of heating and air conditioning in buildings by improving thermal insulation properties. Concrete with thermal insulation particles has been studied by some researchers [12–22]. These concretes that had glazed hollow beads (GHB) added were a new type of green concrete. The results showed that the concrete with suitable GHB added not only met the strength requirements for load-bearing, but also the thermal conductivity can be reduced to 0.4 W/(m K) for insulation. Researchers [17–22] also found that the failure modes of the mechanical properties, frost-resisting property, impermeability and seismic performance were similar to normal concrete, and the GHB thermal insulation concrete (TIC) had better ductility than traditional concrete.

A few researchers have considered the combination of RAC and thermal insulation concrete. This concrete is called recycled aggregate thermal insulation concrete (RATIC).

In this study, RATIC is composed of natural gravel, recycled gravel, cementitious materials, sand and GHB all mixed with water, which is the combined RAC and TIC. The mechanical properties and stress–strain curve (SSC) of the recycled aggregate thermal insulation concrete (RATIC), in which a volume percentage of 130% for the GHB particles were added, with different replacement percentages of the RCA, are investigated experimentally.

2. Materials and experiments

2.1. Materials

The cement (*C*) used in this study was ordinary Portland cement with a 28-day cylinder (40 mm × 40 mm × 160 mm) compressive strength of 42.5 MPa and a specific surface area of 340 $m^2\,kg^{-1}$ and fineness of 0.65. The chemical composition of the cement is presented in Table 1.

Ultra-fine slag (UFS) and hydrophilic nano-silica (NS) were used at the replacement percentages of 7% and 1%, respectively, for the cement to fill up the void space among the cement particles and the cracks that exist in the RCA as well as to improve the mechanical properties of the RATIC. The specific surface area of the UFS used was 860 $m^2\,kg^{-1}$. The chemical components of the UFS and NS are listed in Tables 2 and 3 respectively.

The coarse aggregates used were natural coarse aggregates (NCA) and RCA (5–10 mm accounting for 40% and 10–20 mm accounting for 60% in weight, respectively) obtained from waste concrete acquired from a recycled aggregate plant in Beijing, PR China. The strength class of the original concrete was not known, and would likely be different for each batch of waste concrete as each would come from a different source. The composition of the recycled aggregates was determined by visual inspection, and it was defined as 95.3% crushed concrete, 1.6% ceramic aggregates, 2.3% red brick and 0.8% other material. The thermal conductivity of recycled aggregate is 1.73 W/(m K) in this study. Table 4 presents the NCA's and RCA's physical properties.

River sand(S) and GHB particles were used as the fine aggregate in the concrete mixtures. The physical properties of the sand and the thermal insulation GHB particles are shown in Tables 4 and 5, respectively. Tap water was used as the mixing water.

2.2. Mix proportions

The water/cement ratio was kept constant at 0.5, in which the absorption of GHB and water content of the aggregates were included. Polycarboxylate high-efficiency water-reducer was used and the water reducing rate was 35–40%. The mixtures were divided into five groups, in which the RCA replacement percentage was altered at the levels of 0%, 30%, 50%, 70% and 100%. In the case of the RCA replacement percentage equal to 0%, the concrete is the thermal insulation GHB concrete, which served as the reference concrete. The mix proportions of the concrete mixes are shown in Table 6. The mix subsequence was as follows: firstly, referring to Table 6, mix GHB and recycled aggregate with 1/2 the mixing water for 30 s. Then add the water-reducer into the remaining water and mix together with the GHB, recycled aggregate, cementitious materials, sand, natural aggregate and remaining mixing water for 4 min.

2.3. Preparation and curing of specimens

According to GB/T 50081-2002 [23], 24 specimens were cast in steel forms for each concrete mixture, including nine cubic specimens with the dimensions of 100 mm for compression tests, three cubic specimens with the dimensions of 150 mm for splitting tensile tests, three specimens with the dimensions of 100 mm by 100 mm by 400 mm for flexural tensile tests, six specimens for evaluating the static modulus of elasticity in compression and three specimens for evaluating the stress–strain relationship with the same dimensions of 150 mm by 150 mm by 300 mm.

Concrete mechanical properties were tested according to GB/T50081-2002 [23]. Specimens were cured in a standard curing room at a temperature of 20 ± 2 °C and 95% humidity until the testing age was reached.

2.4. Testing

A YAW-5000 microcomputer controlled electro-hydraulic servo tester was used to perform the mechanical properties and stress–strain relationship experiments.

For each type of concrete, the compressive, splitting tensile and flexural tensile strength tests were measured at a curing time of 28 days. The loading rates for the strength tests were at 6 kN/s, in accordance with GB/T 50081-2002 [23].

To determine the dry density after 28-days, two test specimens (300 mm × 300 mm × 30 mm) were oven dried to a constant weight. A DRP-5W type thermal conductivity coefficient measurement instrument was used to measure the thermal conductivity coefficient [24].

Table 1
Chemical composition of cement.

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss of ignition
Content (%)	22.53	4.42	2.06	61.71	4.55	2.23	2.86

Table 2
Chemical components of UFS.

Chemical components	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Loss
%	33.9	37.6	15.7	0.9	10.6	0.3	0.1