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# The damping property of recycled aggregate concrete

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## HIGHLIGHTS

- Damping property of RAC is investigated on three-point dynamic bending test.
- Damping ratio of RAC increases with an increase of RCA contents.
- Old and new ITZs are key phase mediums affecting the damping property of RAC.

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## ABSTRACT

Damping property is one of the intrinsic dynamic characteristics of a material. Currently, open studies on the damping property of recycled aggregate concrete (RAC) are very limited. This paper investigates the effect of replacement percentage and size of recycled coarse aggregate (RCA) on the damping property of RAC. Three-point dynamic bending test of beams and free vibration damping test were respectively conducted to study the loss tangent of RAC in elastic stage and the damping ratio of a RAC cantilever beam in inelastic stage. The results show that either an increase in replacement ratio or a decrease in RCA size leads to an increase in the loss tangent and damping ratio. Compared with natural aggregate concrete (NAC), the improvement in damping property of RAC may be induced by a number of factors such as the sliding among the old and new interfacial transition zones (ITZs), the propagation of micro-cracks, the friction within micro-cracks and macro-cracks, the compression and expansion of air in voids existed in old mortar. It is concluded that the replacement percentage and the RCA size have a significant influence on the damping property of RAC.



## 1. Introduction

Concrete is a kind of composite material mixing water with cement and aggregate. Admixtures are generally used to improve the mechanical properties of concrete. For aggregate in concrete, it plays a key role and occupies the largest volume of about 60–75% of the total concrete volume [1]. Concrete is critically important for the economy and society development due to its huge volume utilization. It consumes approximately 20 billion tons of raw materials (coarse aggregate) each year and will be doubled in the next two or three decades [2]. As a result, a large amount of natural resources, i.e. 50% of raw material, 40% of total energy, are being consumed by the concrete industry, and what make it worse, it produces 50% of total waste [3]. These have put a great pressure on the sustainable development of environment, energy and economy. Thus, for minimizing the environmental impact, energy consumption and $CO_2$ emissions, the reutilization of solid waste generated by concrete industry is an effective way to weaken these pressures.

In recent years, the rapid development of modernization and industrialization has generated large amounts of debris from construction and demolition (C&D) wastes. Major volume of these wastes comes from demolition of ageing constructions which are no longer able to fulfill their original service purposes after or even before the end of their service lives (e.g. lack of durability, load variation, inadequate bearing capacity). These C&D wastes account for 30–40% of the municipal solid waste [4]. Consequently, disposing of such debris has become one of very important issues in most countries and the recycling of C&D wastes can help conserve natural resources, reduce energy consumption, preserve environment and achieve sustainable development. The recycled coarse aggregates (RCAs) can be produced from the demolition of concrete structures and other construction debris such as waste concrete,

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rejected precast concrete members, broken masonry, concrete from ready mix concrete plant and discarded laboratory specimens [5]. The use of RCAs in structural concrete has thus generated extensive interest in civil engineering.

However, recycled aggregate usually has a lot of mortar on the surface and internal micro-cracks [6,7]. The shape and amounts of micro-cracks existed in recycled aggregate deteriorate the properties of recycled aggregate concrete (RAC), such as the Young's modulus, compressive and tensile strength [8–10]. Due to the intrinsic porosity of RCA, the durability of RAC is worse than that of natural aggregate concrete (NAC) [11–13]. Because of internal curing action of the RCA particles, the bond strengths of deformed steel bars are higher for RAC with 100% RCA compared to the NAC [14,15]. The creep and drying shrinkage of RAC increase significantly due to the lower modulus of elasticity of RCA [16–18]. The fatigue life of RAC is lower than that of NAC for the same stress level under cyclic bend loading and the dynamic compressive strength decreases with the increase of RCA replacement percentage at high strain rates [19,20]. The nature and initial moisture condition (oven dry, partially saturated, fully saturated) of RCA determines the micro structural characteristics of the aggregate-cement paste interface and the mechanical properties of the ITZ [21,22]. Currently, a large number of studies have been carried out to evaluate the mechanical properties, durability and volume stability of RAC and most test results have shown that the nature and properties of RCA have a notable influence, often reported as negative, on the performance of RAC [23]. Nonetheless, open studies on the damping property and damping mechanism of RAC are still very limited.

Damping property is one of the intrinsic dynamic characteristics of a material. It strongly affects a structure's dynamic response and damage evaluation. However, up to present a uniform understanding of damping that explains in detail its complex mechanism has not been obtained. Concrete is a highly complex and non-homogeneous material consisting of three phases such as coarse aggregate, cement matrix, and ITZ. Each individual constituent has a significant effect on the damping property. The influence of aggregate addition on the damping property of mortar matrix depends on the volume content of aggregate, the degree of hydration and the state of curing, and it is reported that adding coarse aggregate can reduce the damping of mortar [24]. The addition of sand degrades the vibration-reduction ability of cement paste by decreasing in both loss tangent and storage modulus due to the large sand particle size (compared to that of silica fume), and the greater degree of compositional homogeneity with a sand particle than that with cement paste [25]. Aggregates with large specific area impart greater interfacial damping than aggregates with smaller specific surface; also the rounded and smooth natural aggregates possess higher damping capacity than crushed rock aggregates because of a weaker bond strength; limestone aggregate in wet specimens exhibits lower damping than crushed gravel aggregate due to the physico-chemical bond between limestone aggregate and cement paste [24]. The weaker mix (higher aggregate/cement ratio and higher water/cement ratio) shows, on average, 15% higher damping than the control mix, and reasons being that the higher aggregate/cement ratio produces more sites for micro-cracking and the higher water/cement ratio gives lower bond strength [26]. The damping ratio of a concrete cantilever increases remarkably if the surface of natural coarse aggregate is covered with viscoelastic materials (e.g. asphalt), and larger total treated surface area of natural coarse aggregate yields higher damping ratio, the mechanism being that the weaker interface between the treated surface of natural coarse aggregate and cement mortar increases the interfacial viscous sliding during vibration [27]. Admixtures, such as silica fume and carbon fibers, can be employed to enhance the damping capacity of concrete materials [28–30]. The authors established a stress amplitude-dependent damping model for RAC and studied the effect of stress amplitude on the damping of RAC. The results show that the loss tangent of RAC increases with the stress amplitude and it can be further improved by adding modified admixtures [31]. So far, few studies have investigated the influence of aggregate, especially recycled coarse aggregate, on the damping of concrete.

This paper presents a study to investigate the influence of replacement ratio and RCA size on the damping properties of RAC, i.e. loss tangent and damping ratio. Three-point dynamic bending test and free vibration damping test were both carried out and the mechanism of how RCA affects the damping property of RAC was discussed. This study provides a deep understanding of the damping property of RAC, the results can be useful for design and dynamic response analysis of recycled concrete structures.

## 2. Materials and experiments

### 2.1. Materials

The cement used in all concrete mixes was ordinary Portland cement with a 28 days compressive strength of 42.5 MPa. The chemical composition of cement is shown in Table 1. The water used was ordinary tap water.

The natural fine aggregate (NFA) was river sand and natural coarse aggregate (NCA) was common crushed limestone. Recycled coarse aggregate (RCA) was obtained by crushing from demolished laboratory concrete samples, and the estimated compressive strength of these samples was 30–40 MPa. The maximum diameters of NFA and NCA are 5 mm and 20 mm, respectively. Three fractions of RCA, with different nominal sizes, were considered, i.e. 5–20 mm (RCA1), 5–10 mm (RCA2) and 10–20 mm (RCA3). Main properties of RCA and NCA are shown in Table 2. These characterizations were obtained according to the Chinese code "Standard for technical requirements and test method of sand and crushed stone for ordinary concrete (JGJ 52-2006)".

### 2.2. Mixture proportion and Specimen details

The mixture proportions are shown in Table 3. Seven proportion cases were considered. Take RCA1-50 as an example, RCA1 denotes the first fraction of RCA and 50 represents 50% (wt.) recycled aggregate replacement percentage. Whereas RCA2-100 stands for the second fraction of RCA with 100% (wt.) recycled aggregate replacement percentage. As shown in Table 3, water reducer was only used to achieve a target slump of 30 mm when the recycled aggregate replacement percentage was 100%.

For each proportion case, two reinforced concrete (RC) beams and three 100 mm cubic blocks were cast. These beams were prepared for damping tests and the cubic blocks were used to assess the 28 days compressive strength. Due to limited loading applied by the electromagnetic vibration exciter and the requirement that the three-point bending beam must work in elastic stage during the loss tangent test, the dimension of beam is 80 mm × 80 mm × 1000 mm. In order to test the loss tangent of RAC in elastic stage and damping ratio of RAC cantilever in inelastic stage for each beam, the reinforcing bars were laid in RAC beams to avoid brittle fractures, and the reinforcement details are shown in Fig. 1.

**Table 1**
Chemical composition of cement (mass%).

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $R_2O$ | Ig-loss |
|---|---|---|---|---|---|
| 18.73 | 5.88 | 3.37 | 61.89 | 0.54 | 3.03 |