Resources, Conservation and Recycling 53 (2009) 107–112

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Review

Recycling and reuse of waste concrete in China Part II. Structural behaviour of recycled aggregate concrete and engineering applications

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ARTICLE INFO

Article history:
Received 1 May 2008
Received in revised form 20 October 2008
Accepted 5 November 2008
Available online 31 December 2008

Keywords:
Recycled aggregate concrete (RAC)
Structural behaviour
Design approach
Practical engineering applications

ABSTRACT

This paper presents an extensive overview of the achievements in the study on the mechanical behaviour of elements and structures made of recycled aggregate concrete (RAC) in China. Experimental findings on the flexural and shear properties of RAC beams, the compressive behaviour of RAC columns, the seismic performance of RAC column-beam joints and frame structures are summarized and discussed. The related design recommendations given in the first Chinese code on RAC—Technical Code for Application of Recycled Aggregate Concrete (DG/TJ07-008), are also briefly introduced. The design formulas are evaluated using the test data available. Furthermore, some successful practical applications of RAC in the pavements and building structures are also presented.

Contents

1. Introduction

A review of the interesting findings on the material behaviour of recycled aggregate concrete (RAC) in China has been given in a preceding paper (Li, 2008). It can be seen from the test results that the mechanical and durability performance of RAC are generally lower than that of normal or conventional concrete. However, none of the studies revealed that RAC is insufficient for practical use in Civil Engineering. However, to make RAC as an accepted structural material, the mechanical and durability behaviour of structural elements made of RAC must be also carefully evaluated. In the recent years, related researches have been intensively carried out in China. This part presents an overview and discussion on the test results for the behaviour of RAC beams, columns, column-beam joints and frames. The design recommendations in the first (current) Chinese code for RAC (SCSS, 2007) are also introduced and evaluated. Furthermore some successful applications of RAC in the pavements and structures are also included. The information presented in this paper is very helpful to make RAC as a widely accepted structural material.

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doi:10.1016/j.resconrec.2008.11.005

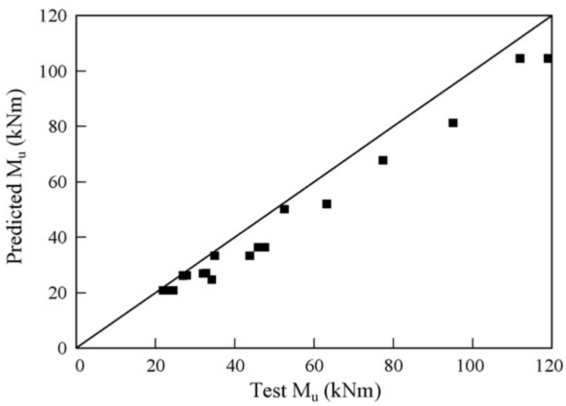

Fig. 1. Comparison of the test and predicted results for ultimate moment of RAC beams.

2. Structural response of RAC elements

2.1. Flexural properties of RAC beams

The influence of recycled concrete aggregate (RCA) content on the behaviour of reinforced concrete beams under flexure was investigated by Lan (2005), Song (2006) and Lin (2007), respectively. In all of the above-mentioned tests, the RACs were designated to have similar compressive strength as the reference concrete (i.e., concrete with natural aggregates). The test results indicate that the beams show very similar pattern of cracks and shape of failure, irrespective of the RCA content. The traditional assumption "plane sections remain plane" in the classic flexure theory, that is, sections perpendicular to the axis of bending which are plane before bending remain plane after bending, is verified to be also suitable for reinforced beams with various RCA contents. That means the procedure developed for normal concrete beams could be also suitable for the analysis of RAC beams subjected to flexure.

In addition, Song (2006) and Huang (2005) evaluated the effect of the reinforcement ratio on the bearing capacity and deformation characteristics of RAC beams.

Based on the related results, the important findings on the flexural behaviour of RAC beams can be summarized as the following:

- The RCA content has nearly no influence on the bearing capacity of the beams, while the immediate deflections of beams tend to increase as the RCA increases. For beams with 100% RCA, an increase of the deflections by 10–24% was found. However, the difference in the deflections is much smaller than the difference in the modulus of elasticity of the RACs and normal concretes.
- The stiffness of the RAC beams is somewhat lower compared to normal concrete beams, especially for a large RCA content.
- The RCA content has only a slight influence on the maximum crack width. This difference can be generally omitted.
- In the range of under-reinforced, the bearing capacity of the RAC beams increases with the increase of the longitudinal reinforcement.

In the current Chinese technical code for RAC (SCSS, 2007), the following formula is used to calculate the flexural bearing capacity of RAC beams,

$$M_u = 0.95 f_c b \left(h_0 - \frac{f_y A_s}{2 \times 0.95 f_c b} \right) \tag{1}$$

where M_u is the ultimate moment (kNm), b, h_0 are the width and the effective height of the section (mm), f_y, A_s are the yield strength (MPa) and the area (mm^2) of the longitudinal reinforcement.

Fig. 1 presents a comparison of the test data (Lan, 2005; Huang, 2005; Song, 2006; Lin, 2007) and the predicted results from the above equation. It can be seen that Eq. (1) leads to relative safe results.

2.2. Shear behaviour of RAC beams

It is well known that the concrete aggregate has a remarkable influence on the shear behaviour of reinforced beams. For instance, the responses of lightweight aggregate concrete beams under shear are significantly different from that of normal concrete beams. For recycled concrete aggregate, it might be regarded as an aggregate between natural and lightweight aggregate. Thus, the research work on the behaviour of RAC beams subjected to shear is of great significance.

In China, Lan (2005) carried out the first experimental work on the shear performance of RAC beams. In his test, the beams were prepared with stirrups and three RCA contents, i.e., 0, 50 and 100% were used to evaluate the influence of the RCA content. All the concretes were designated to have a similar compressive strength of 30 MPa.

Later Zhang (2006), Zhang et al. (2006) investigated the influence of both the RCA content and the shear span ratio on the shear response of reinforced concrete beams without stirrups.

The following conclusions can be drawn from the above test results:

- The RCA content has a significant influence on the shear capacity of the beams. The test results from Lan (2005) indicated that a reduction of 10 and 17% for beams made of concrete with 50 and 100% RCA, compared to the control beam. Similarly, a decrease

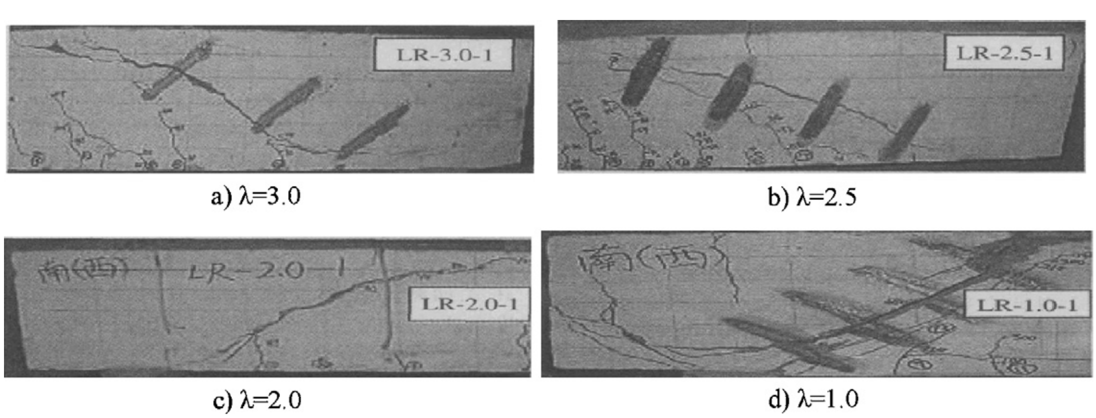

Fig. 2. Failure of RAC beams under shear with different shear span ratios (Zhang, 2006). (a) λ = 3.0, (b) λ = 2.5, (c) λ = 2.0 and (d) λ = 1.0.