Construction and Building Materials 132 (2017) 529–542

Contents lists available at ScienceDirect

Construction and Building Materials

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

Cyclic torsion performance of recycled aggregate concrete beams with or without fly ash

Xiaohan Wang [a,b,*], Bingkang Liu [b], Cong Zhang [a]

[a] School of Environment and Civil Engineering, Jiangnan University, Wuxi 214000, China
[b] School of Civil Engineering, Hefei University of Technology, Hefei 230000, China

HIGHLIGHTS

- Research on seismic performance of RAC and MRAC members under combined flexure-shear-torsion cyclic loading is very limited.
- Seismic performance of RAC and MRAC beams subjected to combined cyclic torsion was presented.
- Cyclic torsion performance of RAC beam and MRAC beams were compared.

ARTICLE INFO

Article history:
Received 9 October 2016
Received in revised form 30 November 2016
Accepted 7 December 2016
Available online 19 December 2016

Keywords:
Recycled aggregate concrete
Seismic performance
Combined cyclic torsion
Hysteresis loop
Ductility

ABSTRACT

Although the material property and structural behavior of recycled aggregate concrete (RAC) and modified RAC (MRAC) have been widely investigated, the research on seismic performance of RAC and MRAC members under combined flexure-shear-torsion cyclic loading is still very limited. In this paper, the failure mode, hysteresis loop, strain of steel reinforcement, energy dissipation capacity, skeleton curve, deterioration, stiffness and ductility factor and torsional bearing capacity calculation of RAC and MRAC beams subjected to combined cyclic torsion were compared and investigated. The results indicate that the addition of fly ash didn't bring an obvious effect to the failure mode of test beams. Although the bearing capacity of MRAC beams is lower than that of RAC beams, the ductility factor and energy dissipation capacity of MRAC beams are larger than those of RAC beams. The addition of fly ash will weaken the hysteretic performance to some extent. The larger the torsion-shear ratio is, the more serious deterioration of stiffness is. The addition of fly ash does not bring apparent influence on the deterioration of stiffness. The variable angle space truss model was employed to calculate the torsional bearing capacity of RAC and MRAC beams subjected to combined cyclic torsion. The predictions agree well with the test results of the torsional beams.

1. Introduction

Building demolition will generate a huge amount of waste concrete. In order to relieve the pressure of environmental protection, it is urgent to process these waste concrete in a reasonable way. Using the recycled aggregate to produce the so-called Recycled Aggregate Concrete (RAC) is a feasible way [1–4], which can not only solve the problem of environmental protection, but also meet the demand of sustainable society.

Existing research of RAC mainly focuses on two points: properties of RAC materials and performances of RAC members. Compressive strength [5–7], tensile strength [8], elastic modulus [9], constitutive relationship [10–13], durability [14–17] of RAC materials and modified RAC materials [18–21] have been widely investigated. Flexural and shear performance of RAC beams [22–26], compressive performance of RAC column [27–30], seismic performance of RAC beam-column joint [31,32], RAC shear wall [33] and RAC frame structure [34] have also been reported in previous papers. However, research on the seismic performance of RAC members under combined flexure-shear-torsion cyclic loading is very limited. In order to provide experimental and theoretic basis for practical engineering application of RAC, experiments were carried out in this paper to better understand the seismic performance of RAC members under combined flexure-shear-torsion loading.

* Corresponding author at: School of Environment and Civil Engineering, Jiangnan University, Wuxi 214000, China.

E-mail address: wangxh412@163.com (X. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.022
0950-0618/

Nomenclature

RAC	recycled aggregate concrete	μ	the ductility factor
MRAC	modified recycled aggregate concrete	h_e	the equivalent viscous damping coefficient
LVDT	linear variable differential transformer	G_j	the stiffness of torsional beam at the *j* level of cyclic loading
P_y	the calculated yielding load	A_s	the section area of longitudinal reinforcement in up sidewall
P_u	the ultimate load	A_{sv1}	the single section area of stirrups
T	the torsional moment	f_y	the yield strength of longitudinal reinforcement
T_{cr}	the cracking torsional moment	f_{yv}	the yield strength of stirrup
T_y	the yielding torsional moment	f_c	the compression strength of concrete
T_u	the ultimate torsional moment	b	the width of section
T_f	the failure torsional moment	h	the height of section
V	the shear force	s	the stirrup spacing
T/V	ratio of torsion to shear	t	the wall thickness of box section
N	the axial force	e_{0x}	the eccentricity in the X direction
θ	the torsional curvature of section	e_{0y}	the eccentricity in the Y direction
θ_{cr}	the cracking torsional curvature of section	T_{exp}	the failure torsional moment in experiment
θ_y	the yielding torsional curvature of section	T_{pre}	the torsional moment calculated by Eq. (4)
θ_u	the ultimate torsional curvature of section		
θ_f	the failure torsional curvature of section		

2. Material and methods

2.1. Materials

Two types of RAC mixtures have been prepared, one of which with 15% fly ash (modified recycled aggregate concrete, MRAC) and the other one without fly ash (RAC). Basic introduction and chemical constituents of cement and fly ash are shown in Tables 1 and 2, respectively. Morphology and grading curve of recycled aggregate are shown in Figs. 1 and 2, respectively. Basic properties of recycled aggregate are given in Table 3. Due to the presence of micro-cracks and residual cement paste bonded to the outer layer of recycled concrete debris, the porosity of RCAs is significantly higher than that of natural ones. The aggregate used in our test were required from the Huangshan road waste concrete pavement slab in Hefei city of China. The original concrete quality was good and the recycled aggregate were well processed. For this reason, water absorption of the recycled aggregate used in this test is slightly lower than results from other reference [35].River sand (0–5 mm) and water are also used in this study. Mix design of concrete with or without fly ash is illustrated in Table 4. The 28d compressive strength of RAC and MRAC is 32.2 MPa and 30.2 MPa, respectively. Mechanical properties of steel reinforcement bars are shown in Table 5.

2.2. Design and construction of specimen

Two types of concrete beams have been manufactured, three RAC beams with the torsion-shear ratio (T/V) of 1.2 (rAC-1-1.2), 0.9 (rAC-2-0.9) and 0.6 (rAC-3-0.6) and three MRAC beams with the torsion-shear ratio of 1.2 (MRAC-1-1.2), 0.9 (MRAC-2-0.9) and 0.6 (MRAC-3-0.6), according to specifications in Eurocode 8. These six beams have the same dimension and reinforcement ratio, as illustrated in Fig. 3. In order to fix the beam, an enlarged head has been made in the fixed end of the tested beam, as shown in Fig. 3a.

Table 1
Properties of cement and fly ash used in this study.

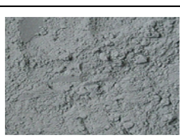
Materials	Specific surface (m^2/g)	Size	Origin
 Cement	0.35 Blaine Method	45 μm sieve residue 14.16%	Anhui Chaodong Cement Co. Ltd., China
 Fly ash	0.37 Blaine Method	45 μm sieve residue 23.72%	Anhui, Huainan Power Plant, China

Table 2
Chemical constituent of cement and fly ash (wt%).

Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	CO_2	MgO	K_2O	SO_3	Na_2O	P_2O_5	MnO
Cement	61.13	21.45	5.24	2.89	2.37	2.08	0.81	2.50	0.77	0.07	0.06
Fly ash	6.61	50.96	30.61	5.61	–	0.63	0.78	1.02	0.17	–	–