CHEMICAL ENGINEERING TRANSACTIONS
VOL. 46, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

ISBN 978-88-95608-37-2; **ISSN** 2283-9216
DOI: 10.3303/CET1546152

Experimental Research and Theoretical Analysis on Mechanical Behaviour of Recycled Aggregate Concrete Filled Square Steel Short Tube under Eccentric Compression Load

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To study the mechanical performance of recycled aggregate concrete filled square steel short tube under eccentric compression load, 15 specimens were designed and used in the monotonic loading test to obtain failure modes, failure loading, and curves on loading-deformation and loading-strain. Two factors were considered in the experiment which was recycled aggregate, replacement ratio and eccentricity in an effort to analyse consequence on mechanical property. The ultimate bearing capacity and bearing capacity formulas for axial compression and partial compression of RACFSST short column for different parameters is calculated by ABAQUS. The results show similarities between natural aggregate concrete filled square steel short tube and recycled aggregate concrete filled square steel short tube in the aspects of the bearing capacity, failure modes, deformation features and strain distribution in the section; bearing capacity of the aggregate concrete filled square steel short tube would slightly decrease as the rise of the recycled aggregate replacement ratio and would have a remarkable fall with the growth of eccentricity; the formula value of axial compression and bias short column is in good agreement with the test results.

1. Introduction

Since the 1980s, because of the rapid development of urbanization in our country, the construction industry consumed large amounts of natural sand and gravel aggregate, and produced a surprising number of waste concrete, thus resulting in two big problems: natural aggregate shortage and construction waste pile-up. The birth of the recycled concrete technology provides a good way to solve the above two problems. Recycled concrete is abandoned concrete block after crushing, cleaning, sorting, according to certain proportion, which partially or wholly replace natural aggregate configuration of concrete. Domestic and foreign scholars have studied on the mechanical properties and durability of recycled concrete, the results show that the mechanical properties and durability of recycled concrete is slightly lower than normal concrete, but can fully satisfy the project need, and get more extensive application in our country.

Concrete filled steel tube is featured with high bearing capacity and good seismic performance. Recycled concrete and concrete filled steel tube, forms the closed structure, not only improves the durability of recycled concrete, fire resistance, large shrinkage problems , but also, recycled concrete is in the three-way force state, which can significantly increase the compressive strength of recycled concrete. At home and abroad, the research of concrete filled steel tube has been mature and widely used, the research of recycled concrete filled steel tube mainly focuses on axial compression specimens, the research for the bending specimens is less, but most of members in practical process under both axial force and bending moment loads, and there is no absolutely axial compression member in practical process. Therefore, this article studied the stress of the steel tube recycled concrete under bending load performance. And on the basis of the experiment, ABAQUS finite element model is established, and analysed the influence factors of the bearing capacity of the concrete filled steel tubular short column. In the end the software simulation results is consistent with the experimental results.

Please cite this article as: Zhang J.H., 2015, Experimental research and theoretical analysis on mechanical behaviour of recycled aggregate concrete filled square steel short tube under eccentric compression load, Chemical Engineering Transactions, 46, 907-912
DOI:10.3303/CET1546152

2. Research and Analysis on Experiment

2.1 Overview of the Experiment

The experiment designed 15 square steel tube recycled concrete short columns, mainly considered two variable parameters -- replacement ratio and eccentricity which can influence the recycled concrete filled steel tube axial compression and bias short column of ultimate bearing capacity.

The source of the recycled aggregates is wasted C30 concrete block from Hebei construction group. Test tube is Q235 straight seam steel pipe, L = 300 mm, width of cross section B = 100 mm, the steel tube wall thickness t = 3 mm, Strain yield strength fy = 272.98 Mpa, the yield point is 2000με, fu = 370.21 Mpa, elastic modulus Ec = 206.9 Gpa, poison's ratio v = 0.305.

The test adopted the 5000KN long column load tester produced by Jinan, test results and the specimen detail parameters shown in table 1.

Table 1: Parameters and test strength of specimens

Specimen number	r (%)	e(mm)	fc (MPa)	ξ	Nu(kN)
S—1—0	0	0	32.09	1.09	735
S—2—0	30	0	28.61	1.30	745
S—3—0	60	0	32.75	1.17	767
S—4—0	80	0	29.17	1.38	789
S—5—0	100	0	28.85	1.45	623
S—1—20	0	20	34.98	1.09	578
S—2—20	30	20	29.67	1.30	539
S—3—20	60	20	37.71	1.17	515
S—4—20	80	20	29.18	1.38	501
S—5—20	100	20	27.83	1.45	498
S—1—40	0	40	36.76	1.09	389
S—2—40	30	40	29.65	1.30	378
S—3—40	60	40	30.71	1.17	356
S—4—40	80	40	29.15	1.38	348
S—5—40	100	40	25.81	1.45	337

Note: 'r' represents the recycled concrete replace rate, 'e' represents the load eccentricity, 'fc' on behalf of the axis of the recycled concrete compressive strength; A - E represent the replace rate of 0%, 30%, 60% and 80%,100%;0, 20, 40, represent the eccentricity of 0, 20, 40.

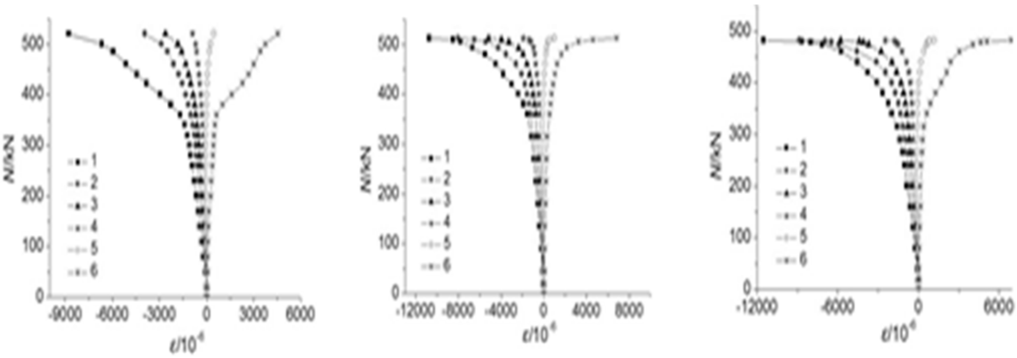
2.2 Damage process and form

For bias specimen, all specimens are presented in bending shape and no failure occurred, the biggest deflection occurred near the midspan of the specimen. At the beginning of the load, lateral deflection of the specimen is small, and the four surfaces are smooth and no wrinkle. To e = 20 mm and e = 40 mm specimens, when the load reached at about 85% and 95% of the limit load, the pressure side started to wrinkle, are within the specimen height 1/4 ~ 3/4, with the increasing of the load, the number of the wrinkle increased to 2 ~ 3, and by the pressure side gradually spread to the adjacent two sides of the pressure side, and the wrinkles are basically symmetrical distributed along the height. The side far away from the point of the force application keeps smooth, and presents a smooth curved surface in the late load, with further load. The S—1—20 specimens which was not set bracket, the top tensile side weld is torn. And for the rest of the specimen which set bracket, none of them occurred the phenomenon that the end crushed or the weld torn, which suggest that bracket significantly strengthened bending stiffness of the specimen.

The failure pattern of axial compression specimens is wrinkle occurring in cross section, the location of the wrinkle appeared for the first half the height of the specimens, this may be due to the aggregate sinking and the slurry floatation the process of the vibrating, which led to the upper strength is slightly lower than the lower. Then we connect the outstanding points of the fold, and the connection was found substantially horizontal 45° angle, diagonal-compression failure state. From early load to the ultimate load, the specimen did not appear obvious wrinkle; each face of the specimens began to appear relatively obvious wrinkle after reach the limit load. Increase with the axial deformation, the fold developed rapidly, the four corners of the cross section also gradually expanded, the cross section changed from square to approximate circle.

As experiment is finished, we cut the steel pipe using flame cutting, and found the concrete inside severe crushing wrinkle, which was closed to the outsourcing steel pipe. The obvious cracks can been see from bias specimen crushed zone. Overall, in the late loading, the core concrete shows the distinct plastic characteristics, and the deformation restrained by the steel tube.

Figure 1: Failure patterns of specimen



S-3-40 S-4-40 S-5-40

Figure 2: Load - strain curves of specimen's under eccentric compression

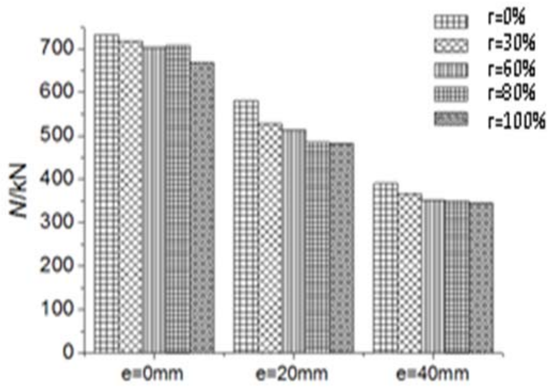


Figure 3: Longitudinal strain distribution of midspan section

2.3 Test results and analysis

By Figure 2, it could be found that the strain of the specimens have the same change trend, and in the late loading, the closer to the limit load, the faster the strain is growing. For axial compression specimens, the transverse and longitudinal strain of the specimens has increased with the increase of the replacement ratio, which is probably due to the low elastic modulus of the recycled concrete. For bias specimen, the longitudinal strain of the side close to the point of the force application is greater than the farther side, and the close side primarily yield. For e = 20 mm specimen, the compression face started to yield when the load reached at 69.92% ~ 80.98% of the ultimate load, to e = 40 mm specimen, , the compression face started to yield when the load reached at 63% ~ 72% of the ultimate load, which indicates larger eccentricity makes specimens earlier yield.

The Figure 3 shows that load - axial displacement curve of the specimens, the load-deflection curve are raising elastic, smooth and gentle decline three sections. Under the condition of the same eccentricity, along with the incensement of the replacement ratio, the bearing capacity of the specimens are slightly lower, the axial compression specimens, the substitution rate 30%, 60%, 80% and 100% of bearing capacity of the specimens than replace rate 0% was reduced by 1.89%, 3.94%, 3.35% and 2.01% respectively.
To e = 20 mm specimen, the substitution rate 30%, 60%, 80% and 100% of bearing capacity of the specimens than 0% was reduced by 10.49%, 12.43%, 18.25% and 10.09% respectively. To e = 40 mm specimen, the substitution rate was 30%, 60%, 80% and 100% of the bearing capacity of the specimens than 0% was reduced by 7.23%, 9.75%, 11.07% and 7.57% respectively. Together with the increment of the replacement ratio, the bearing capacity of the specimen decreases gradually, and the strain of the ultimate load increases gradually.

3. Finite element analysis

3.1 The finite element model

(1) This article uses the constitutive model of literature [2] of the material constitutive model of the steel, the core of the recycled concrete constitutive relation with the literature [3] and [4], and its modification such as type (1).

$$\begin{cases} y = Ax - Bx^2 & x \le 1 \\ y = \dfrac{x}{\beta(x-1)^{\eta} + x} & x > 1 \end{cases} \tag{1}$$

$$x = \frac{\varepsilon}{\varepsilon_o},\ y = \frac{\sigma}{\sigma_o} \tag{2}$$

$$\sigma_o = f_{ck}\left[1.194 + \left(\frac{13}{f_{ck}}\right)^{0.45}\left(-0.07485\xi^2 + 0.5789\xi\right)\right] \tag{3}$$

$$\varepsilon_o = \varepsilon_c + \left[1400 + 800\left(\frac{f_{ck}-20}{20}\right)\right]\xi^{0.2} \times (1 + r/\theta)(\mu\varepsilon) \tag{4}$$

$$\varepsilon_c = 1300 + 14.93 f_{ck}\,(\mu\varepsilon) \tag{5}$$

$$A = 2.0 - K;\ B = 1.0 - K;\ K = 0.1\xi^{0.745} \tag{6}$$

$$\theta = 65.715r^2 - 109.43r + 48.989 \tag{7}$$

$$\eta = 1.6 + 1.5/x \tag{8}$$

$$\beta = \begin{cases} \dfrac{f_c^{\,0.1}}{1.35\sqrt{1+\xi}} & \xi \le 3.0 \\ \dfrac{f_c^{\,0.1}}{1.35\sqrt{1+\xi}\,(\xi-2)^2} & \xi > 3.0 \end{cases} \tag{9}$$

f_{ck} — Concrete standard compressive strength (MPa)
ξ —Constraints of features ($\alpha f_y/f_{ck}$), for steel tube the yield limit, α for component sectional steel ratio (As/Ac), the As and Ac respectively cross sectional area of the steel tube and its core concrete.
r-The replace ratio of the recycled concrete
(2) The unit type and mesh
Steel tube and core of recycled concrete with different cell types, respectively, of the shell elements and entity unit. The precision of the shell element S4R, based on specific requirements, shell element in finite element method when used in shell thickness direction Simpson integral (9 integral point); Choose C3D8R entity unit.
(3) The steel pipe with recycled concrete interface model

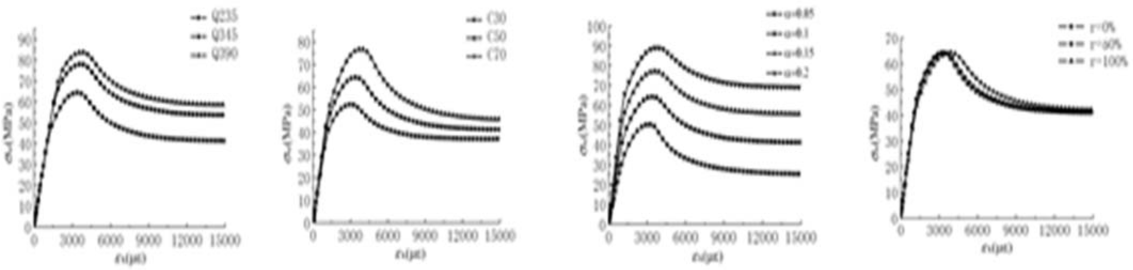
Steel tube and recycled concrete interface model by the method to contact and the bond-slip of tangential method to contact for hard contact, tangential bond-slip using coulomb friction model.

(4) Boundary conditions

Model uses the displacement axial loading, fixed in the lower end of the specimen, the upper set axial displacement.

3.2 Bearing capacity parameters analysis of axial compression short column

Using the finite element model, through the finite element software ABAQUS to calculate different steel (Q235, Q345, Q390) strength, strength of concrete (C30, C50, C70), containing steel ratio (α= 0.05, 0.1, 0.15, 0.2) and replacement ratio (r = 0%, 60%, 100%) of the axial compression bearing capacity of the recycled concrete filled steel tubular short column, and analysis of the recycled concrete filled square steel tubes axial compression bearing capacity of short column influencing factors. Short column section size, B = 100 mm, L=300 mm, with the intensity of steel Q235, C50 concrete strength, containing steel ratio of 0.1 (t = 2.33 mm), replacement ratio 60% of the basic invariant. Using ABAQUS finite element software for the specimens with different parameter as a variable stress - strain relationship (σ_{sc}-ε_L) curve, as shown in Figure 4.



(a) (b) (c) (d)

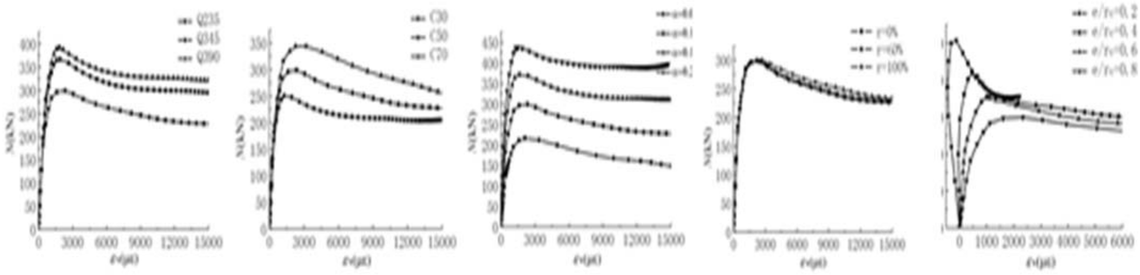
Figure 4: Short column axial compression stress-strain relationship curve (σ_{sc}-ε_L) under different parameters

((a) The effects of the strength of steel (b) the effects of concrete strength (c) the effects of steel ratio(d)the effects of the replacement ratio)

From Figure 4 (a), (b), (c), the axial compression bearing capacity of the square steel tube recycled concrete short column influenced by the strength of the recycled concrete and the steel, and the steel ratio, and along with the incensement of the parameters, the bearing capacity increases. As Figure 2 (d), under the same recycled concrete strength, the different replacement ratio almost has no effect on the bearing capacity. However, the different replacement has a great influence on the strength of the recycled concrete. Therefore, the influence on the steel tube recycled concrete bearing capacity of the replacement ratio regards as the influence of the bearing capacity of the recycle concrete.

3.3 Bearing capacity parameters analysis of bias compression short column

Using the finite element model, through the finite element software ABAQUS to calculate different steel (Q235, Q345, Q390) strength, strength of concrete (C30, C50, C70), containing steel ratio (α= 0.05, 0.1, 0.15, 0.2) and replacement ratio (r = 0%, 60%, 100%) ,and eccentricity ratio (e/rc = 0.2, 0.4, 0.6, 0.4) of the bias compression bearing capacity of the recycled concrete filled steel tubular short column, short column section size, B = 100 mm, L=300 mm, with the intensity of steel Q235, C50 concrete strength, containing steel ratio of 0.1(t = 2.33 mm), replacement ratio 50%, eccentricity e=0.8(40mm) of the basic invariant. Using ABAQUS finite element software for the specimens with different parameter as a variable load –longitudinal strain of the midspan (the tension side) (*N-εv*) curve, shown as Figure 5. According to Figure 5 (a)(b)(c),the bearing capacity of the recycled aggregate concrete filled square steel bias compression short column is influenced significantly by the following factors, steel strength, concrete strength and steel ration. With the increase of the three parameters, the limit bearing capacities are growing. In the Figure 5 (d), replacement rate plays a minor role in limit bearing capacity. In Figure (e), limit bearing capacity reduce as eccentricity is growing.



(a) (b) (c) (d) (e)

Figure 5: The bias compression load - strain relationship of different parameters

((a) The effects of the strength of steel (b) The effects of concrete strength (c) The effects of steel ratio (d) The effects of the replacement ratio (e) The effects of the eccentricity ratio)

4. Conclusion

(1)The mechanical form of the recycle correct steel pipe is in accordance with the ordinary one, through elastic stage, elastic-plastic segment and failure stage. The load bearing capacity of the recycled concrete filled steel tube falling slowly after the failure stage, deformation increases more rapidly, and the surface appears obvious wrinkle, the ductility is better.
(2)With the increase of the eccentricity, the bearing capacity of the steel tube recycled concrete appears linear decrease trend, compared with the e = 0 mm specimen, the bearing capacity of the e = 20 mm and e = 40 mm was reduced by 27.78% and 28.79% respectively.
(3)Along with the increase of the replacement ratio, the strain and deformation of the recycled concrete filled steel tube increase. Bias specimen can accord with flat section assumption before the 80% limit load, with the increase of the load, the neutral axis of the cross section gradually closes to the force point.
(4) Refer to the related literature, the core recycled concrete is obtained by modified constitutive relation to establish reasonable finite element model of the recycled concrete filled square steel tubes, and accord well with those of finite element calculation value and experimental value.

Acknowledgments

The author was endowed by the Natural Science Foundation of Shaanxi Province (2014JM7297) and Industry University Research Project in Yulin city (2015CXY-21).

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