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Fatigue Behavior of Multi-scale Recycled Aggregate Reinforced Concrete

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ABSTRACT

Aggregate obtained by breaking waste concrete is called recycled aggregate. Consistent with sustainable development, recycled concrete made from such aggregates could be a perfect solution to resource and environmental preservation. Its fatigue behavior is different from other concretes as a result of the different properties of the aggregate. Therefore, on the basis of experimental research, the fatigue behavior and multi-scale aspects of recycled concrete are described in this paper.

This study deals with investigations on the fatigue behavior of the axial and eccentric compression performance of recycled aggregate reinforcement concrete specimens, containing recycled aggregate proportions of 0%、50%、100%, with multi-scale (micro-structural and macro-structural) observations of the specimens. Based on the analysis of the experiment result, it was proven that it is feasible to apply recycled concrete in practical engineering.

KEYWORDS: *recycled reinforcement concrete, fatigue, multi-scale analysis, axial compression, eccentric compression*

1. INTRODUCTION

Reinforced concrete construction is now very common recently and extensively used in both industrial and commercial buildings. Every year, large amounts of waste residue are produced. Examples, in the “512 Wenchuan Earthquake” and the “420 Ya’an Earthquake” disaster areas, resulted in a mass of buildings collapsing and waste being produced instantaneously. How to deal with the waste residue properly? Consistent with sustainable development, recycled concrete, a new green material made from recycled concrete aggregate, could be a perfect solution in resource and environmental preservation. Its properties and applications can be very important.

At present, there are some publications on the mechanical behavior of recycled concrete [1-3], but there is little information on its fatigue behaviors. Therefore, on the basis of experimental research, the fatigue behavior and microstructure of recycled concrete were studied and reported in this paper. Investigations on the axial and eccentric compression performance of recycled aggregate concrete short-column specimens, containing recycled aggregate proportions of 0%、50%、100% were undertaken. The microscopic features were observed by Scanning Electron Microscopy (SEM). The results showed that the fatigue behavior of recycled aggregate concrete, eccentric short-column specimens with different replacements aggregate proportion is worse than on axial compression. Based on the analysis of the experiment results, it was proven that it is feasible to use recycled concrete in practice.

2. EXPERIMENTAL DETAILS

2.1. Materials

2.1.1. Ordinary Portland Cement

Ordinary #325 Portland Cement (OPC) was used as the cement material to produce the specimens. The OPC used was equivalent to GB175-2007 in China.

2.1.2. Natural Aggregate

The natural coarse aggregate and fine aggregate used were gravel and river sand. The diameter of the gravel was 5~31.5 mm, and the maximum size of the river sand was around 2.36 mm (Fig.1).

a) gravel b) river sand

Figure 1 Photographs of the coarse and fine natural

（a）15~31.5mm （b）5~15mm

Figure 3 Photographs of the coarse recycled aggregates

2.1.3. Recycled concrete aggregate aggregates

Fig. 2 Photographs of the recycling facility

The recycled concrete aggregate was obtained from the DuJiangYan, China area, one of the 512 earthquake disaster area. The recycling facility processes mainly concrete rubble sourced from demolition projects by crushing and sieving (Fig. 2). The crushed concrete rubble was processed to pass through a mechanical sieving system to produce coarse recycled aggregate (Figure. 3). The diameter of the aggregate was 5~31.5 mm, and was mainly divided into sizes 5~15mm and 15~31.5mm. In the experiment, the quality ratio of the 5~15mm to the 15~31.5mm aggregate was 3:2, and this ratio was used throughout the investigation.

2.2 Specimens

Table 1 Specimens' Proportions

Specimen number	Recycled aggregate proportion（%）	Proportions（kg/m^3）					
		Water	Cement	Sand	Gravel	Recycled aggregate	
						5~15 mm	15~31.5 mm
A	0	195	382	620	1203	0	0
B	50	195	382	620	602	362	241
C	100	195	382	620	0	722	482

The concrete specimens were short-column, 250×250×500mm in size, with concrete strength degree C20 [4]. The proportion of cement, sand and aggregate was 1：1.623：3.149, with a water/cement ratio of W/C=0.51. Based on the cube specimens with different recycled aggregate proportions, three series were designed in this study. These three series were separately named as A, B and C, each containing 0%, 50% and 100% of recycled aggregate respectively. Tab.1 shows the specimens' proportions. The specimens were preserved for 28 days under standard conditions and then tested. The Fig.4 showed the specimens' section dimension.

2.3 Equipment

A 4890 fatigue experimental machine (EHF-UM/UV servo-fatigue experimental machine) made by Shimadzu in Japan (as Fig.5) was used, and a YAW-5000 compressive experimental machine was employed for compressive strength experiments, load capacity of 5000KN.

2.4 Testing

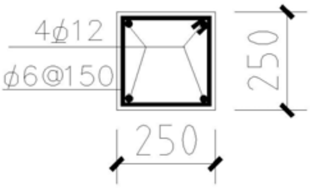


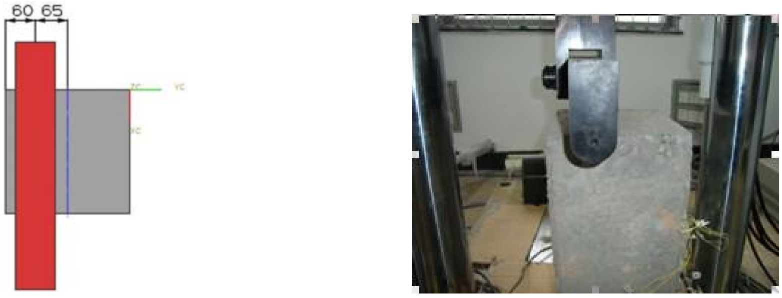
Figure 4 Section of specimen dimension

Figure 5 Shimadzu EHF-UM/UV servo-fatigue Experimental Machine

（A）Axial loading

（a）Top view of load position （b）Top view of loadactual position

（B）Eccentric Loading（e=65mm）



（a）Top view of load position （b）Top view of loadactual position

Figure.6 Load positions of tests

（a）Stereo schematic of the resistance strain gages testing points on the tendons （b）Actual resistance strain gages （c）Details of strain gages

Figure 7 The positions of the resistance strain gages

In the Shimadzu EHF-UM/UV servo-fatigue experimental machine, fatigue load is varied from 110kN~190KN at 5Hz frequency, and the static load was from 0 to 150KN, and then uninstalled, in steps of 30kN. The location of the load is axial or eccentric (e=65mm). The modeling and actual load positions are shown in Fig. 6.

In order to observe the displacement of the specimens during the experiments, resistance strain gages were used. In this experiment, paper based resistance strain gages, model D*120-5AA, were positioned along the lengthways tendon, and distributed on the contra-lateral longitudinal tendon. The specific data of the strain gages were resistance value 119.8 ± 0.1Ω; sensitivity coefficient 2.08 ± 0.1%; grid length and width 5×3mm. There were distributed at the bottom, middle, and at 1/4 and 3/4 position and one specimen had totally 8 testing points (as Fig. 7).

3. RESULTS AND DISCUSSION

3.1 Macroscopic changes

3.1.1 The axial fatigue load

After axial compression, the fatigue behaviour of each replacement proportion specimen was similar. At first, there was no obvious change in the squeezed static load, but when the fatigue load had reached about 3×10^5 cycle, cracks were generated at two places, one on the bottom of the specimen and another on the contact position with the test machine. At the bottom angle region of the specimen, there were vertical and horizontal small cracks, but not substantially expanded, and accompanied with the pastry and broken (as Fig.8 (a) - (c)); there were some longitudinal cracks on the contact surface of the test machine (as Fig. 8 (d)). After the first static loading and fatigue loading, small cracks appeared. However, during the following cycles of the static and

（a）horizontal crack and pastry at bottom （b）vertical crack at bottom

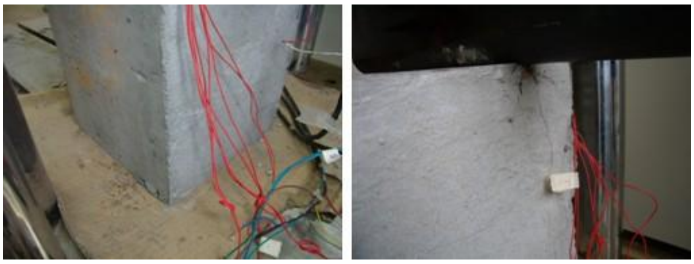
（c）horizontal crack and spalling at bottom （d）vertical crack at contact surface

（e）vertical crack at bottom
（60w cycles）

（f）expansion of vertical crack at the
contact surface（60w cycles）

Figure 8 The position and extension of the cracks after axial fatigue loading fatigue loading, the development of the cracks were very small (as Fig. 8 (E), (f)). After, containing with the fatigue experiments, there were no fractures even up to approximately 10^7 cycles.

3.1.2 The eccentric fatigue load



（a） horizontal crack and spalling at bottom （b） vertical crack at contract surface

（c） extension of the vertical crack （d） fracture of specimen

Figure 9 The position and extension of the cracks under eccentric fatigue loading

（a） （b）

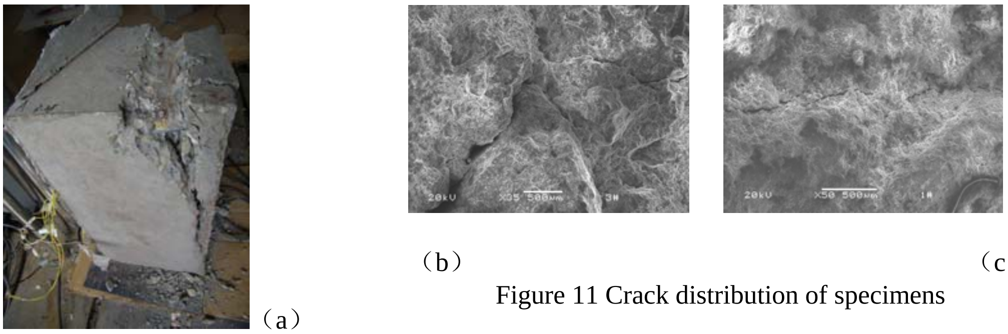
Figure 10 Fracture of the section

When eccentric (e=65mm) compression experiments was carried out, the fatigue behaviour of each replacement proportion specimen was also similar.

For the first static load, a few fine cracks appeared on the specimen, and the crack growth was very slow as the force was applied. After the first fatigue loads, the fine cracks gradually increased, extented, and accumulated especially those that could be seen in the vertical crack, at the contact surface of the machine. Generally, specimen failure due to these vertical cracks occurred at lower cycles, and was accompanied with a loud noise. The damage of the specimen was sudden, without warning (as Fig. 9)!

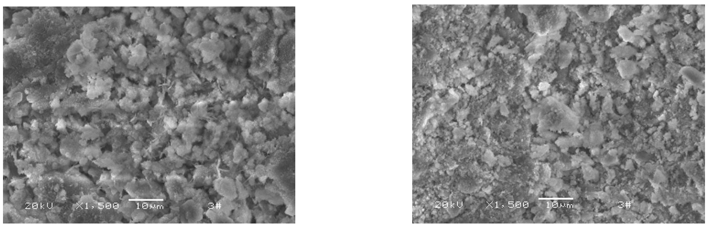
Moreover, the clear fractured zone was indicated on the RAC specimens. Fig. 10 showes that there were different interface roughness regions on the fracture surface. The fatigue source zone was in the cracks generated by the contact surface; in which, the two face parts of these cracks rubbed and deformed repeatedly together, thus making smooth regions on the fracture surface. These areas are called the expansion area. The fracture area was the roughest of the damage areas, caused by gradually expanding the cracks due to the alternating load.

3.2 Microscopic changes



（a）（b）（c）

Figure 11 Crack distribution of specimens



a）internal of grout b）stone surface in fracture interface

Figure12 Microscopic characteristics of the concrete specimens

The microscopic characteristics viz. the CH and pore distributions of the concrete specimens were observed by Scanning Electron Microscopy (SEM). It can be seen from Fig. 11 that shows the B series specimen in eccentric (e=65mm) compression experiments that some fine-cracks grow and gradually expand and become a main crack. Finally, the fracture is along this main crack. From the all eccentric experiments, it can be concluded that the fracture mostly occurs on the surface of the stone and in the interior grouting (as Fig.12).

3.3 Correlation between Fatigue Compressive Strength, Location of Load

3.3.1 The axial fatigue load

Fig. 13 shows the strain and static load on the same testing point 1 during the same cycle. From the figure can be seen that there are obvious differences in the A, B, C three series of specimen in regard to strain changes in the load. The relative strain or deformation of the B series compared to A and C was smaller. It also showed that series B has a better performance.

3.3.2 The eccentric fatigue load

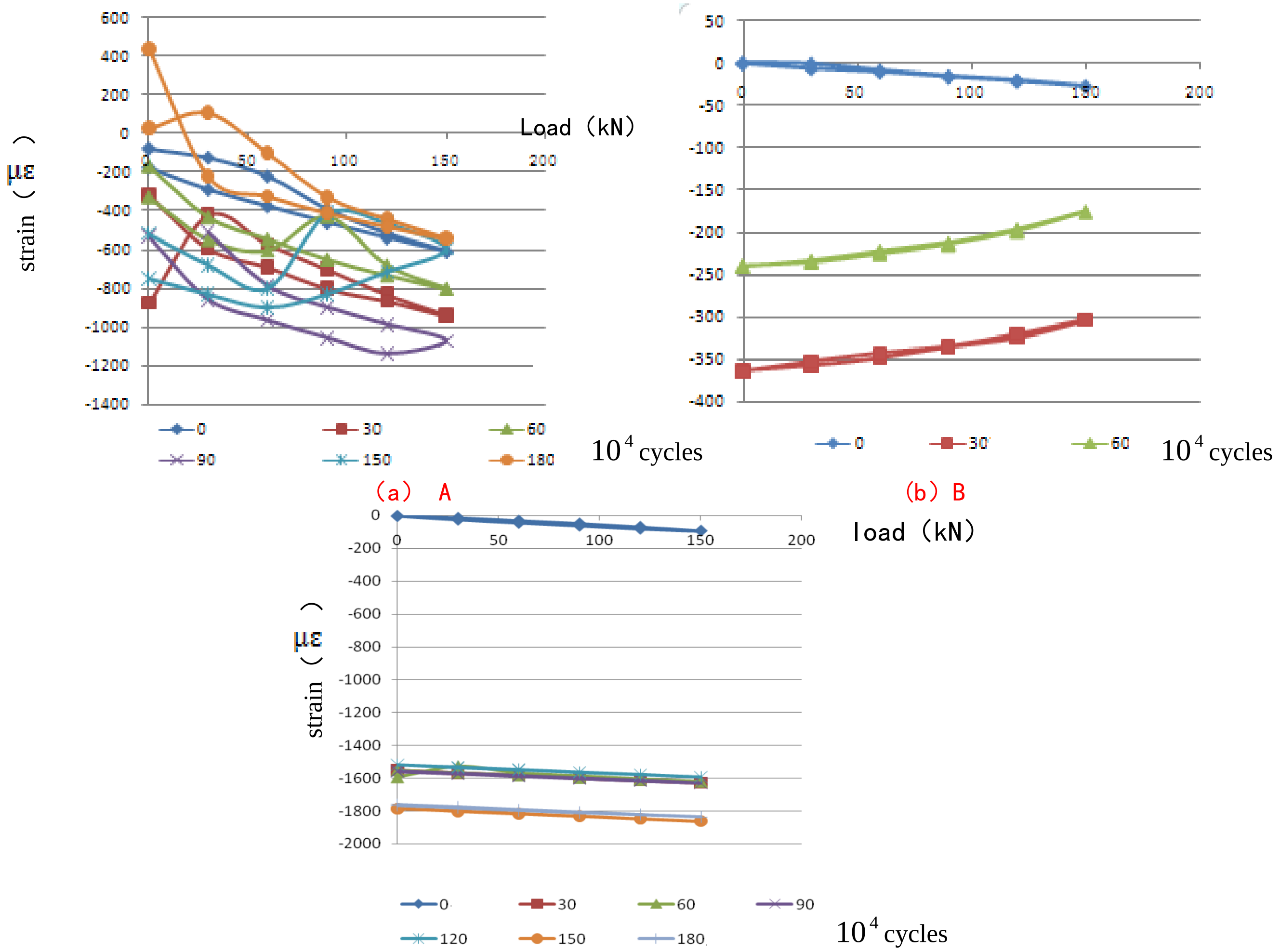
From the experiments, sudden fatigue failure could easily happen in the eccentric fatigue test. A large number of fractures occurred in low-cycles. Fig. 14 shows the change of the strain relationship between various specimens under low cycle damage, for the same testing point "6". It was found that the relative maximum strain was for the series C RAC, then the second was A RAC, and series B RAC was minimum. So, the series B RAC has a relatively better performance.

3.3.3 Fatigue life

As mentioned before, the axial fatigue compressive strength of three series A, B and C were relatively good, so there were no fractures even for approximately 10^7 cycles.

However, for the eccentric fatigue, it can be seen that there were fractures at low cycles. Cracks, basically in the force contact, were generated for A and B specimens, and there was fracture for the C specimen. However, when fatigue load was added, the fracture occurred in the relatively low cycles for A and B specimens. For example, A was about 91cycles and B was around 528cycles.

The correlation between Fatigue Compressive Strength and Location of Load was analyzed experimentally. For the A, B and C specimens, the fatigue behaviour of each replacement proportion specimen was similar. The axial fatigue behaviour of the short-column specimen was better than the eccentric case.



（a） A

（b） B

（c） C

Figure 13 Relation between the strain and the static load at same testing point 1 with axial fatigue load

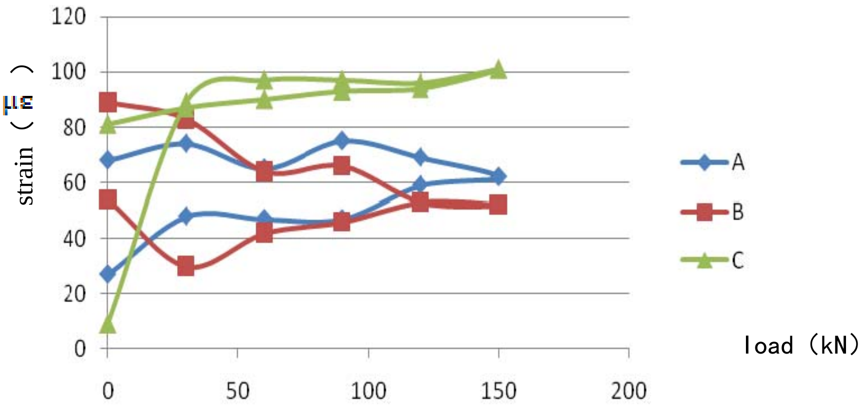


Figure 14 Relation of the strain and the static load at same testing point 6 for eccentric fatigue

4 CONCLUSIONS

The variation of recycled aggregate concrete fatigue behaviour with different aggregate proportions was investigated experimentally.

The findings can be summarized as follows: (1) the axial fatigue or static load for all replacement short-column specimens was better than the eccentric case in the same conditions. (2) for the axial condition, the fatigue cycle is extraordinarily higher than the eccentric case. (3) for the same load location and style, the B specimen is better than the others. So the fatigue-protection of recycled aggregate concrete with 50% replacement of recycled aggregate is better than others, even natural aggregate concrete.

In conclusion, this study on the fatigue behaviour of recycled aggregate concrete provides many insights into practical real-time situations.

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