Experimental Study of the Flexural Behavior of Concrete Beams with Recycled Brick Aggregate

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Abstract. Two specimen of concrete beam with recycled brick aggregate and a common reinforced concrete beam as contrast specimen were designed. The beams were simply supported, the width and height of the rectangle section of the beams was 150mm and 300mm, the span were 3m, reinforcement and loading method were the same. The replace ratio of mass of recycled clay brick aggregate to stone aggregate is 35%. MTS was used in the loading. Mechanical and flexural behavior of the beams was tested. Comparison and analysis were made on the stress of the reinforced bars and the deformation behavior of the beams. Results show that the bearing capacity of recycled aggregate concrete beam was lower than that of the reinforced concrete beam under the same condition, the recycled aggregate concrete beams own good ductility in flexural failure, but their bearing capacity and stiffness decreased slightly.

Introduction

The main part of construction waste was waste clay brick, by crushing and screening, waste clay brick can be recycled as aggregate, those recycled aggregate could partial or totally substitute for ordinary coarse aggregate in concrete. This method by clay brick recycled as aggregate in concrete was a new way of the reuse of construction waste. The existing research shows that the strength of concrete made by recycled clay brick aggregate is lower than that of ordinary concrete [1-3], therefore, the recycled aggregate concrete was mainly used in low structures, multi-story building structures or structures with low strength requirement.

Based on the chosen proportion of mixture, recycled aggregate concrete beam and ordinary concrete beams as compared test specimen were made. By test of the mechanical characteristics, deformation characteristics and failure patterns of the two types of beams, the structural behavior of the recycled aggregate concrete beam were studied.

Design of Test

Test Specimen. Three test beams were designed, the serial number of the test beam are RCB-1, RCB-2 and B-1, and RCB represent recycled aggregate concrete beam, C represent the ordinary concrete beam. The dimension and reinforcement of the beams was determined based on the practical application, code requirement and test condition. Beam was simply supported on the two ends (Fig. 1).

Material Properties. Comprehensive consideration the strength reduction of clay brick recycled aggregate concrete and the mixing amount of clay brick aggregate [4-6], based on testing, substitution ratio of 35% was chosen, which means 35%mass of ordinary aggregate were replaced by recycled aggregate. The other parameters of the mix proportion of concrete were the same, water-cement ratio are 0.4. Design strength of common concrete is C30. Mechanical properties of concrete materials and reinforced bars by test were shown in table 1 and table 2.

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Loading Plan. MTS hydraulic servo system was used in the test. Hydraulic jack was applied to exert the concentrated force, the concentrated force was transferred to the beam by the distribution beam symmetrically, and a 900mm length long pure flexural sector was formed in the middle of the beam. Fig. 2 is the detail of loading system and arrangement of test points.

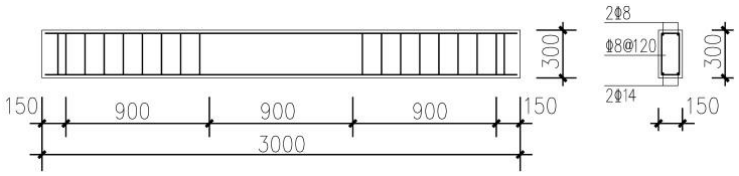


Fig. 1 Reinforcement of the test beam

Table 1 Mechanical paremeters of concrete

Strength of concrete	Substitution ratio	Cubic compression strength[N/mm^2]
RC30	35%	40.22
C30		56.31

Table 2 Mechanical paremeters of reinforced bars

Varieties of bars	Yield strength[N/mm^2]	Modulus of elasticity[N/mm^2]	Ultimate strength[N/mm^2]
14	461.34	2.01×10^5	584.79
8	357.85	1.99×10^5	536.78

Beam was test in accordance with the loading program of common static structures, including three stages such as pre-loading, loading and unloading. In the loading stage, loading value in each stage was calculated as 10% of failure load. In the loading process, after load stabilized, data were collected, and crack appearance and development were recorded. The interval between loading stage was 15min. Before crack and damage, the load level was increased. The load grade of the beam was 10 to 12, and the unloading stage of the test beam is 2.

Test Parameters. The main parameters in the test are deflection of the beam, strain of concrete and longitudinal reinforced bars under each level of load, appearance and development of the cracks were also observed.

Force applied on the test beam was measured by pressure sensor, deformation of the test beam was measured by displacement sensor, strain of steel and concrete were measured by resistance strain gauge.

For the convenience of cracks observation, surface of the test beam has burnished and painted white coating before experiment, grid lines were draw in the beam surfaces with ink fountain before test.

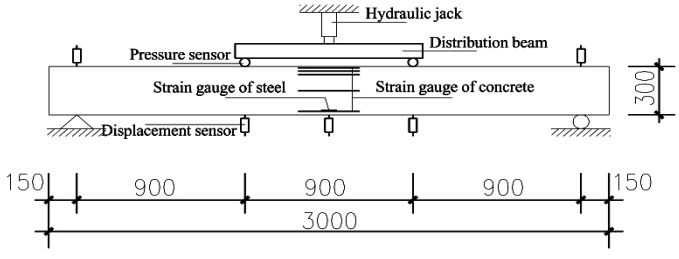


Fig. 2 Details of loading and test position

Analysis of Test Result

Relationship of Load with Deflection. Load-deflection curves of B-1 and RCB are shown in Fig.3 and Fig. 4 respectively. The whole process of RCB can be divided into three stages, which are non-crack stage, crack stage and damage stage. At beginning of load, strains were small, and the deflection was linear grow with the load of the beam. With the increase of load, deflection increased

speedy. When near to the yield load, deflection increases quickly, and a turn point was appeared in the load-deflection curve, the deflection and strain in the middle section were increased suddenly. Then, with the increase of load, more and more cracks in the middle span of the test beam were appeared, deflection was further increased, load-deflection curve was become nonlinear obviously. After yield of reinforced bar, load-deflection curve of the beam was became horizontal approximately. Deflection of the test beam was increased rapidly, cracks at the pure bending area were becoming wider rapidly, but the change of load value was very small. Finally, the test beam was destroyed because of the too large crack width and yield of tensile steels.

From Fig.3 and Fig.4, it can be seen that the deformation behavior of recycled clay brick aggregate concrete beams was similar to that of ordinary concrete beams. The difference is the crack load and damage load of the recycled aggregate concrete beams are lower than that of ordinary concrete beams due to the incorporation of recycled aggregate of clay brick. The crack load of the recycled aggregate concrete beams is 40% lower than that of ordinary concrete beams and the yield load and ultimate load are lower than that of ordinary concrete beams by 13%.

Load-strain Relationship of Steel and Concrete. The relationship curve of load with strain of the longitudinal tension bar of B-1 and RCB was shown in Fig.5. Strain of the longitudinal tensile bar was linearly proportional to the load. Before the concrete cracking, main pulling stress was supported by concrete, and the strain of longitudinal steel bar was small. After concrete crack, the concrete gradually withdraw from work, the bar starts to take on the main pulling force. With the load continues to increase, new cracks continues to produce and grow, and the strain of the bar was increasing continuously. When the longitudinal reinforcement was yield, the strain of the steel increases rapidly, but the load change was very small.

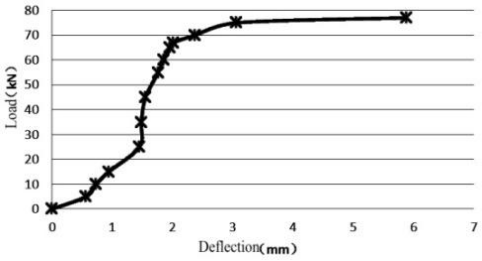


Fig.3 Curve of load-deflection of B-1

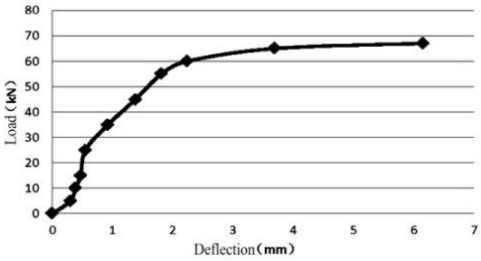


Fig.4 Curve of load-deflection of RCB

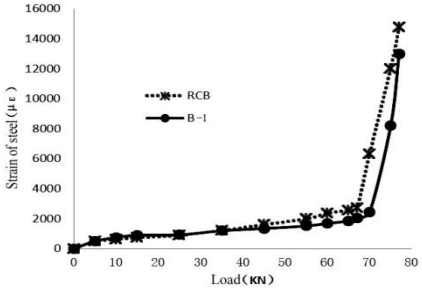


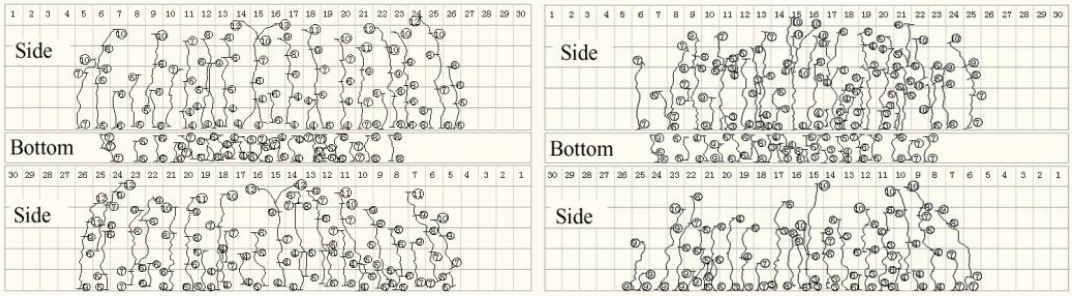
Fig.5 Curve of strain-load of reinforced bars

After the steel bar yield, compared with ordinary concrete beams, stress increase of longitudinal reinforcement were more obvious in the recycled aggregate concrete beams.

The average strain of concrete in the cross section was approximately linear under different levels of loading. This shows that the recycled clay brick aggregate concrete beams and ordinary concrete beams in accordance with the same assumption of plane cross section.

Crack. Fig.6 shows the distribution of cracks in the test beam. Cracks are less, narrow and shorter at the beginning of loading. In the middle of the loading, the cracks begin to grow and continue to develop, cracks in the pure bending section were distributed densely, many cracks are approximately parallel to the vertical extension, but the crack width increase was not very obvious. At the end of the loading,

cracks continued to extend and widen. The experimental results show that the crack of the recycled aggregate concrete beam and the ordinary concrete beam are similar in different loading stages.



a) B-1 b) RCB

Fig.6 Spread of cracks of the beams

Conclusions

By comparative test and analysis of two recycled clay brick concrete beams and a common concrete beam, the following main conclusions were obtained.

(1) The flexural behavior of recycled aggregate concrete beams and ordinary concrete beams are basically the same. In the whole process from beginning to destruction of the beam, the behavior of recycled clay brick aggregate concrete beams can be partitioned to four stages: elastic, crack, yield and failure, when reach to the ultimate state, there are large deflection growth and crack development in the beams, all beams are damaged plastic.

(2) Under the same conditions, crack load of recycled aggregate concrete beams is 40% lower than that of ordinary concrete beam, yield load and ultimate load are 13% lower than those of ordinary concrete beams, and deflection was 15% larger than that of ordinary concrete beams.

(3) In the course of loading, the average strain in the section of the recycled aggregate concrete beam was accord with the assumption of plane section.

(4) It is feasible to use the recycled clay brick aggregate concrete beam as a structural material.

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