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RESEARCH ARTICLE Open Access

Load-Deflection Relationship of Beams Incorporating Aggregates from Demolished Concrete Blocks

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Abstract: This work investigates the load-deflection behavior of sustainable reinforced concrete wide beams with aggregates that are recycled from demolished concrete blocks. These recycled concrete aggregates RCA have been used with percentages (0%, 25%, 50%, and 100%) of replacement with normal aggregates. Superplasticizer doses were applied to keep the workability constant. Compressive strengths were kept around 35 MPa for better comparison. Four wide beams of (300×60×700mm) dimension were cast with concrete having a minimum steel reinforcement ratio allowed by the ACI 318 code. Curves of wide beams relating load to deflections were constructed. The ductility of these beams was recorded. The response of RCA beams to increasing load is comparable to that of normal beams, however little softer but with comparable ductility. The findings of this work provide further support for using the RCA in structural concrete.

Keywords: *One Way Slab; Recycled Concrete Aggregate; Structural Behavior; Sustainability*

1. Introduction and previous work

Recycling waste materials is a principal sustainability measure in construction [1–3]. Recycling reduces construction waste by reusing it in new construction projects, becoming an environmentally friendly process. Recycled concrete aggregates RCA can be employed in the production of new concrete [4]. This approach saves natural resources and reduces the waste problem due to demolition. The employment of RCA in concrete would be an economical approach.

Etxeberria et al [5] conducted an experimental study on concrete structures incorporating recycled aggregates sourced from damp areas of previously used concrete elements. Concrete mixes were control concrete with 0% recycled content, and concrete mixes with 25%, 50%, and 100% recycled coarse aggregates. The ultimate failure loads across all beam types were nearly identical.

Gonzalez-Fonteboa and Martinez-Abella [6] investigated both the properties of the recycled aggregates and the structural performance of two concrete mixes: one conventional and the other containing 50% recycled coarse aggregates. For each mix, four reinforced concrete beams with varying levels of reinforcement were tested to failure. The results indicated that the type of concrete—whether conventional or containing recycled aggregates—had a negligible effect on overall deflection behavior and ultimate load capacity. However, beams made with recycled aggregate concrete showed signs of cracking a bit earlier than those made with natural materials.

Taha et al [7] presented an experimental investigation on the flexural behavior of RCA beams reinforced with polymer bars reinforced with basalt fibers. The study examined two main variables:

(1) the concrete mix design incorporating 0%, 25%, 50%, and 100% recycled concrete aggregates (RCA), and (2) the type of reinforcement. The results indicated that varying the RCA content had minimal impact on the flexural performance of the RC beams. However, the type of reinforcement had a pronounced effect: replacing steel with BFRP bars resulted in reduced deformational capacity, while maintainingcomparable ultimate load.

Wang [8] explored sustainable construction strategies, focusing on the reuse of steel beams and recycled concrete. Specifically, it investigates the application of recycled concrete in composite floor systems. Replacement ratios of recycled aggregate were set at 0%, 30%, 70%, and 100%. The results revealed that increasing recycled aggregate content—alongside a lower w/c ratio—can increase the shear resistance of bolted connectors by up to 40%.

Anike et al [9] introduced a non-traditional mix design approach that incorporates recycled coarse aggregate, recycled fine aggregate, and steel fibers to produce recycled aggregate concrete. Results indicated that a mix with 100% RA and 1% SF exhibited a 13% increase in load-bearing capacity compared to a similar mix without SF, and an 8% increase over the control mix with normal aggregates. Sryh and Forth [10] investigated the strength and deflection with time of reinforced recycled aggregate concrete beams. 20-mm max size coarse recycled aggregates were used in the mixes, derived from construction and demolition waste (CDW). The main parameter was the recycled aggregate (RA) replacement level, with specimens prepared using 0%, 50%, and 100% RA content. Experimental findings indicated that increasing the RA content led to a significant strength reduction and a marked increase in both deflections (short- and long-term) of RA beams when compared to their normal concrete counterparts.

This work utilizes aggregates that are recycled from demolished concrete blocks. It is expected that these aggregates will provide sustainable material in the production process of structural concrete. This work explores the flexural load – deflection behavior of such new concrete beams and compares their behavior with other concrete beams made of aggregates recycled from demolished structural concrete members (CDW) found in the literature.

This study is intended to evaluate the load–deflection behavior of reinforced concrete beams incorporating aggregates sourced from demolished concrete blocks, with emphasis on serviceability performance rather than strength alone. The findings aim to support the practical use of recycled concrete aggregates in structural members by providing experimental evidence relevant to deflection control, sustainability considerations, and potential alignment with existing design code assumptions.

2. Materials

2.1 Cement

An ordinary Portland cement manufactured by KAR-cement Company (Erbil, Iraq) was used. The chemical analysis of this cement was performed and found that all chemical compositions of cement were complying to ASTM C618 specifications. The physical properties of the cement were investigated. The surface area (Blane method) was 3000 m2/kg (minimum 2300), setting times: initial 60 min. (minimum 45 min.) and final 7 hrs. (maximum 10 hrs.), soundness is 10 (Le Chatelier), and consistency is 30%. These are within the limits of Iraqi specifications No. 5, 1984. The 3-day and 7-day compressive strengths of cement were 20 and 30 MPa, greater than the minimum allowed by Iraqi specifications (15 and 23 MPa), respectively. The specific gravity was 3.15.

2.2 Sand

The sand was taken from a local market in Erbil. Fig. 1 shows the sieve analysis of sand. The water absorption of sand was 3.4% having specific gravity of 2.67. The fine aggregate was normal fine sand passing through a 4.75 mm (No. 4) sieve and complies with Iraqi specifications.

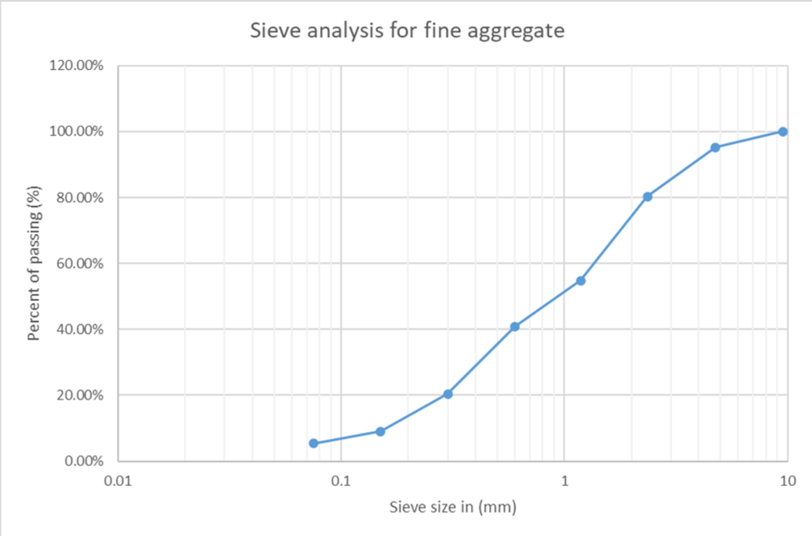

Figure 1: Sieve analysis of sand

2.3 Coarse Aggregates; normal and recycled

The recycled aggregates were all coarse aggregates taken from wasted concrete blocks taken from a site of a building under construction in Erbil. These recycled aggregates were crushed from concrete blocks, and those passing the 19.4 mm sieve were selected in this work. The normal coarse aggregates were taken from local markets.

The properties of normal and recycled aggregates that were used are listed in Table 1. The sieve analysis of recycled aggregates from demolished concrete blocks is shown in Fig 2.

Table 1: Properties of aggregates

Property	Normal Aggregates	Recycled Aggregates
Specific Gravity (SSD)	2.65	2.40
Water Absorption (%)	1.5	4.5
Bulk Density (kg/m³)	1600	1400
Moisture Content (%)	1.5	3.0
Shape	Angular or Rounded	Angular with Mortar Residue

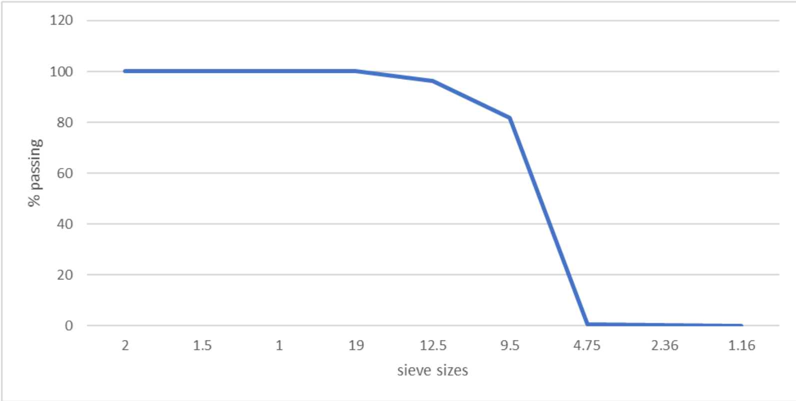

Figure 2: Sieve analysis of recycled coarse aggregates

2.4 Admixture

In RCA specimens, superplasticizer SP33, which is a high-range water-reducing admixture, was used during mixing to fulfill the desired flowability and keep the slump between 150 and 170 mm for all specimens.

2.5 Reinforcement

Strengths of steel bars of size 6 mm diameter were measured by tests and found to be 280 MPa for yield and 430 MPa for ultimate. The ultimate / yield ratio is 1.54, and elongation is 20%.

3. Methodology

Structural sustainable concrete beams were constructed incorporating RCA from demolished concrete block waste to be used as coarse aggregate, replacing the normal one. In this work, RCA replacement percentages for the concrete mixture used in the concrete beams were as 0%, 25%, 50%, and 100% replacement percentages. The density of concrete ranged from 2250 kg/m3 (100%RCA) to 2350 kg/m3 (0% RCA). Load deflection relationships were investigated for the sake of comparison when RCA is incorporated. Cracking behavior is also monitored and discussed.

3.1 RCA reinforced concrete wide beams

For flexural strength, 4 reinforced concrete wide beams were tested to failure under three-point bending at the construction laboratory at Tishk International University, TIU. The reinforced concrete beams were tested at age 60 days. Three RCA replacement levels (25%, 50%, and 100%) were investigated. The wide beam cross-section is 300×60 mm, with an effective depth of 270 mm. The tension reinforcement amount is 2 6-mm diameter bars, which comprises the minimum reinforcement based on ACI Code (ACI 318-19) [11]. Closed stirrups of 6 mm diameter spaced at 25 mm as shear reinforcement were provided along the length of the beam. Figs 3 and 4 show the wide beam testing set-up and the beams cross section sketch. The strength in compression a age of 28 days was measured using cubes of side 100 mm.

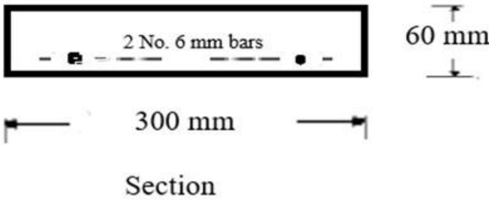

Figure 3: Experimental setup for the wide Beam test. Figure 4: Wide beam cross-section

4. Results

4.1 Compressive Strength

The results are shown in Table 2.

Table 2: Mix details and strength results

Code	Cement (kg/m^3)	Sand (kg/m^3)	Normal Aggregates (kg/m^3)	Recycled Aggregate RCA (kg/m^3)	RCA (%)	w/c ratio	Admixture SP33	Compressive Strength MPa (28 days)
B1	350	600	1200	0	0	0.40	--	35.2
B2	350	600	900	300	25	0.40	3 l / m3	33.1
B3	350	600	600	600	50	0.40	3 l / m3	36.3
B4	350	600	0	1200	100	0.40	3 l / m3	32.2

In trial mixes, the compressive strength of RCA concrete specimens generally resulted in lower values compared to control specimens as the RCA content is increased. Improvements occurred with the application of SP33.

After some trial tests, an SP at a dose of (3l/m3) was found suitable to result in similar slump values between 150 t0 170 mm, and to obtain similar target cube compressive strength of 35 MPa. Compared to control results without SP, the reductions ranged between 10% and 20% in compressive strength.

4.2 Flexural strength of RCA wide beams

Table 3 shows loads – deflections values of RCA wide beams tested to failure.

Table 3: Loads and corresponding deflections of RCA wide beams

No	Beam	RCA %	Cracking load P_{cr} (kN)	Flexural Load P_u (kN)	P_{cr} / P_u	1st Crack Deflection δ_{cr} (mm)	Maximum Deflection δ_u (mm)	δ_u / δ_{cr}
1	B-1	0	3.90	5.10	0.76	0.25	3.12	12.5
2	B-2	25						
3	B-3	50	3.40	4.40	0.77	0.28	3.68	13.1
4	B-4	100	3.10	4.20	0.74	0.30	3.78	12.6

The flexural strength is shown to be comparable between ordinary and sustainable RCA concrete beams, the latter being on the lower side. Although very fine cracks were observed at the initial stage of loading, especially for RCA beams earlier than the control beam, they were of marginal effect on elastic stiffness. Thus, the cracking load was effectively taken as the load at which linearity in behavior ends. The same finding of similarity among all beams is true for the ratio of cracking load to ultimate load, which range 0.74 to 0.77.

The results show higher deflection values at ultimate loads in the RCA beam than those of the control beam. However, the ductility index (Maximum deflection/first-crack deflection) is found to be approximately the same for all beams, ranging from 12.5 to 13.1.

4.3 Load – deflection behavior

Figure 5 shows the curves of loads and corresponding midspan deflections of 3 reinforced beams: one normal and two RCA wide beams, with RCA percentages (0%, 50%, and 100%). The specimen of 25% RCA was accidentally damaged before testing. It can be seen that in the early (before cracking) stage a linear relationship between loads and deflections. A comparable stiffness is found in the pre-cracking stage, with a greater value provided by the control one.

Although the flexural strengths are comparable in all beams with RCA from demolished concrete blocks, they showed higher deflections during the flexural test compared to the control beam, and the propagation of cracks was more pronounced in the RCA beams, especially at higher loads up to the failure stage. A bit more gradual failure may be seen in the recycled aggregates beams than in the control beams.

While beams with recycled aggregates exhibited slightly lower cracking loads (13 and 20% less) compared to the control specimens, the ultimate failure loads also exhibited slightly lower values by 14% and 18% for aggregate replacement percentages of 50 and 100%, respectively.

The ductility ratio (δu / δcr) is listed in Table 4 with similar values for all control and RCA beams. In general, the findings are in conformity with those of Exteberria et al [5], in which structural performance across the different concrete types exhibited only minor variations. Parameters such as load-bearing capacity, deflection response, and failure modes remained consistent in general, indicating that the incorporation of recycled aggregates had minimal effect on the beams' overall behavior under standard loading conditions.

Moreover, when comparing with the findings of Gonzalez [6], an identical observation recorded in this work is that beams made with recycled aggregate concrete showed signs of fine cracking a bit earlier than the control beam. However, it can be agreed that recycled aggregate concrete can still be reliably analyzed and designed using the tools and guidelines already available in international design codes.

The results of this study are generally consistent with those reported by Sryh and Forth [10], who observed that the overall load–deflection behavior of beams incorporating recycled concrete aggregates (RCA) was similar to that of control beams. In their study, short-term midspan deflections at design load increased by approximately 8% and 15% for 50% and 100% replacement levels, respectively, compared to corresponding increases of about 12% and 20% observed in the present work. Similarly, the cracking loads of RCA beams were reported to be about 15% and 30% lower than those of control beams for the same replacement levels [10], which compares well with the reductions of approximately 13% and 21% measured in this study. In terms of cracking behavior, RCA beams exhibited more closely spaced cracks than normal beams, consistent with previous observations [5,6,10]. The reduced crack spacing has been attributed to lower tensile strength and reduced tension stiffening of RCA concrete [10], which contributes to increased deflections.

The findings of this work suggest that recycled coarse aggregates from demolished concrete blocks can be effectively used as sustainable structural concrete, although they may have a slight reduction in strength compared to the other stronger types of RCA from CDW. The reduction in ultimate flexural strength recorded in this work using aggregates from demolished concrete blocks is 14% and 18% for RCA replacement ratios of 50% and 100%, respectively.

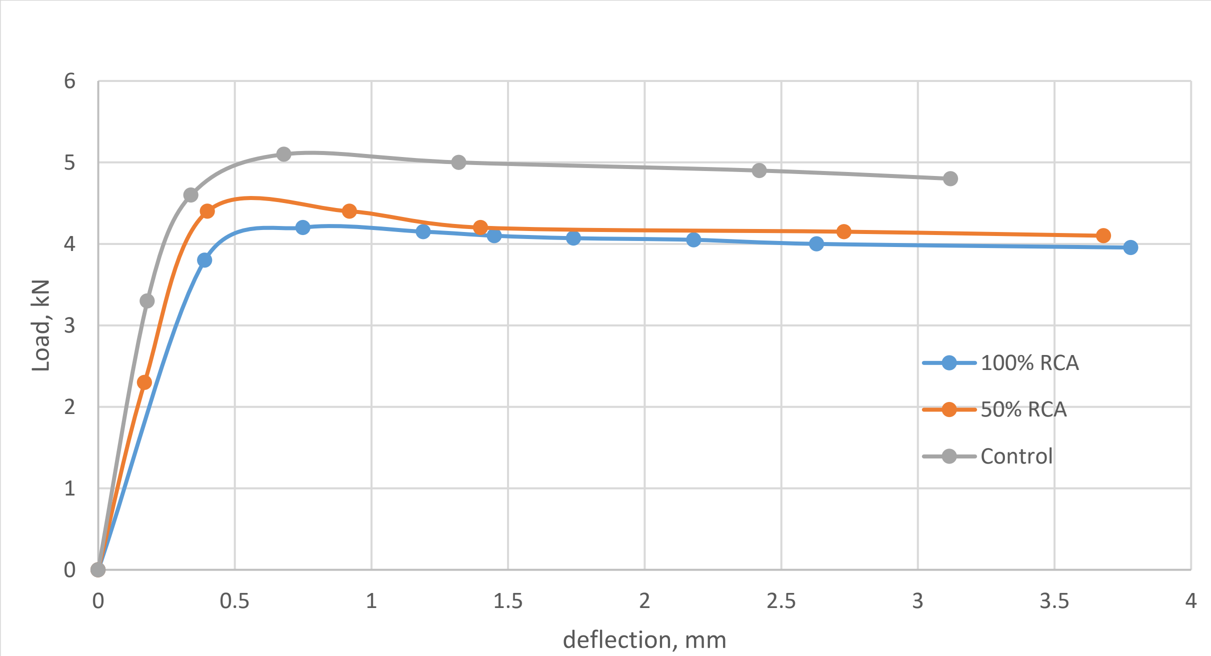

Figure 5: Load - deflection curves for all beams

5. Conclusion

Sustainable wide concrete beams using aggregates from demolished blocks were loaded until failure. The beams were reinforced with a minimum steel ratio per ACI Code 318-19 [11]. The work reached several conclusions.

Keeping the workability constant, a reduction of compressive strength is found with the RCA percentage of the concrete mixture. With the application of the SP33 dose, the specimens' strength average was about the target strength of 35 MPa.

The flexural strength of sustainable RCA concrete beams has been found to be comparable to that of the control beam. For the two replacement ratios (50 and 100%), the flexural loads measured for the recycled aggregate beams were about 86 and 82%, respectively, of those recorded in control beams.

First-crack midspan deflections for 50% and 100% replacement levels were, respectively, 13 and 21% more than normal beams.

From the obtained load-deflection curves, the failure loads were found to be comparable for RCA wide beams and the normal ones. However, this work claims this for lighter reinforced concrete beams. It needs to be confirmed for RCA beams with higher steel ratios.

Similar pre-cracking load deflection behavior is obtained for both control and RCA beams. Propagations of cracks were more pronounced in the RCA beams.

The ductility ratio ($\delta u / \delta cr$) is found to be similar for both control and RCA specimens.

In general, it is recommended to use sustainable structural concrete made of recycled aggregates from demolished concrete blocks in building construction. For durability concerns, further studies are required to decide its status regarding exterior exposure.

It should be noted that the experimental program was based on a limited number of beam specimens. Consequently, while the observed deflection trends with increasing recycled aggregate replacement are informative, the results should be interpreted with caution and verified through further studies involving a larger test database.

Conflict of interest

The author declares that he has no conflict of interest.

Use of the AI tool declaration

The author declares that no AI tools were used in any part of the preparation of this manuscript.

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