Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (1) January 2021

Flexural Behavior of Recycled Concrete and Repaired Reinforced Concrete Beams

Ashraf Adel Shawky[1] and Abdel-Rahman Hazem[2]
1- Associate Professor, Structural Dept., Faculty of Engineering- Cairo University
2- Structural Engineer, Student- Cairo University. Egypt

ملخص البحث:
في الأعوام الأخيرة ازدادت كمية مخلفات المنشات بشكل سريع وذلك حفاظا على الاستخدام الفعال للموارد و اصبحت اعادة تدوير مخلفات المبانى عملية هامة في المجال الصناعي بحيث انه يتم استخدام الركام الكبير الناتج من اعادة تدوير مخلفات المبانى فى صناعة الخرسانة الجديدة. في هذا البحث تم اختبار 7 كمرات لدراسة سلوك الانحناء للكمرات الخرسانية المسلحة المستمرة سابقة التحميل والمعالجة والمستخدم فيها خلطات خرسانية مصنوعة من الركام الكبير المعاد تدويره. المتغيرات الرئيسية فى هذا البحث هى نسبة الركام الكبير المعاد تدويره ونسبة التحميل المسبق للكمرات. اظهرت النتائج المعملية ان الخرسانة التى تحتوي على ركام طبيعى تعطى خصائص ميكانيكية اكبر من الخرسانة التى تحتوي على ركام معاد تدويره بنسبة 50% وان نسبة 100% من الركام المعاد تدويره أفضل من نسبة 50% خلال حالات التحميل المختلفة وذلك لوجود تجانس وقد تصل نسبة الزيادة في الحمل الاقصى الى 10% في حالة استبدال 50% من الركام الطبيعي بركام معاد تدويرة مع وجود تحميل مسبق بنسبة 60%.

Abstract :

Over the past few decades, the amount of facility waste has increased rapidly in order to maintain the effective use of resources. In the industrial field, the recycling of building waste has become an important process. So, recycled aggregate of building waste is being used in the manufacture of new concrete. In this research, seven beams were tested to study the flexural behavior of preloaded and repaired continuous reinforced concrete (RC) beams with concrete mixtures containing recycled coarse aggregate (RCA) . The main parameters are the ratio of RCA in the mixture of 50%, and 100%, also the ratio of preloading of 60%, 80%, and 100%.

Laboratory results showed that using concrete with natural aggregate gives more mechanical properties than the concrete with 50% recycled aggregate. It is better to use 100% recycled reinforced concrete than 50% through different loading cases to achieve homogenization. The enhancement in ultimate capacity was reached 10% for cases of 50% RCA replacement ratio and 60% preloading level.

Keywords: Flexural behavior; Recycled Concrete Aggregate; preloading; Continuous RC beam; repairing;

1. Introduction

Recycling of concrete has become an important process due to the increase rate of demolition to preserve the environment. This process includes the creation of old concrete resulting from the old construction works known as destruction wastes, then use an amount of RCA to decrease the use of natural resources. To build a new structure of recycled concrete, the concrete waste from an old building has been crushed thin cured to be utilized as RCA.

The physical properties of RCA have been discussed and compared with natural aggregate by many researchers [1-11]. Water absorption and total voids volume increased when the replacement ratio of RCA increased [1]. Also, water absorption decreased when maximum nominal size of aggregate increased [2]. To achieve specific compressive strength, RCA requires higher cement content and lower water per cement ratio compared to concrete with natural granite aggregate [2]. More than 50% replacement of RCA has a considerably higher shrinkage when compared with natural aggregate concrete [3].

For the mechanical properties, Padmini, A.K., Ramamurthy, K., and Mathews, M.S. [2] reported that the variance in strength between normal concrete and RCA concrete increases with the increase of concrete compressive strength. For RCA concrete, the flexural and tensile split strengths are lower than in normal concrete, and a higher reduction ratio in modulus of elasticity was observed when using smaller sized aggregates. Buraczewska, B.S., Hunek, D.B., and Szafraniec, M. [6] evaluated the performance of RCA in high performance concrete (HPC) compared with basalt natural aggregate. Increasing the ratio of replacement with RCA led to a reduction in flexural strength, and an increase by 45% in long term deflection.

Performance of fine recycled aggregated (FRA) replacement also has been evaluated [12-14]. Evangelista, L., and Brito, J.D. [12] evaluated the behavior of concrete with FRA. There was no significant effect on the compressive strength for replacement ratio up to 30%. Also the abrasion resistance increased with the replacement of FRA. While the tensile splitting strength and modulus of elasticity were reduced with the increase of FRA ratio.

The objective of this research is to experimentally evaluate the behavior of preloaded continuous RC beams subjected to flexure before and after repairing with injecting epoxy inside cracks. Ultimate load, the load-deflection, and the load-strain distribution for preloaded beams have been recorded. The two considered variables in this study were; levels of preloading of 60%, 80%, and 100%, also RCA replacement ratio of 0%, 50%, and 100%.

2. Experimental program

2.1. Materials

Three trial mixes were conducted with 0%, 50%, and 100% RCA as shown in Table 1. An additive BVF was used as a super plasticizer and high range water reducer to reach the required workability. Two sizes of coarse aggregate were used. The first size with nominal maximum size not less than 15 mm, and not larger than 25 mm, while the second size doesn't exceed 15 mm. The fine aggregate had sieve analysis with maximum aggregate size of 4.75 mm. According to the standard tensile test of steel bars, the yield strength of the longitudinal and stirrups reinforcement were 312, and 405 N/mm^2 respectively, also the ultimate strength of the longitudinal and stirrups reinforcement were 471, and 651 N/mm^2, respectively. kemapoxy 165 [15] was used as filling mortar to close the crack extension from the other sides to ensure sufficient injection using kemapoxy 103 [16] with minimum losses. The compressive strength of concrete was measured by testing 158 x 158 x 158 mm cubes after 7 and 28 days. Table 2 shows the results of the standard crushing test for the three mixtures.

Table 1: Components of the different concrete mixes

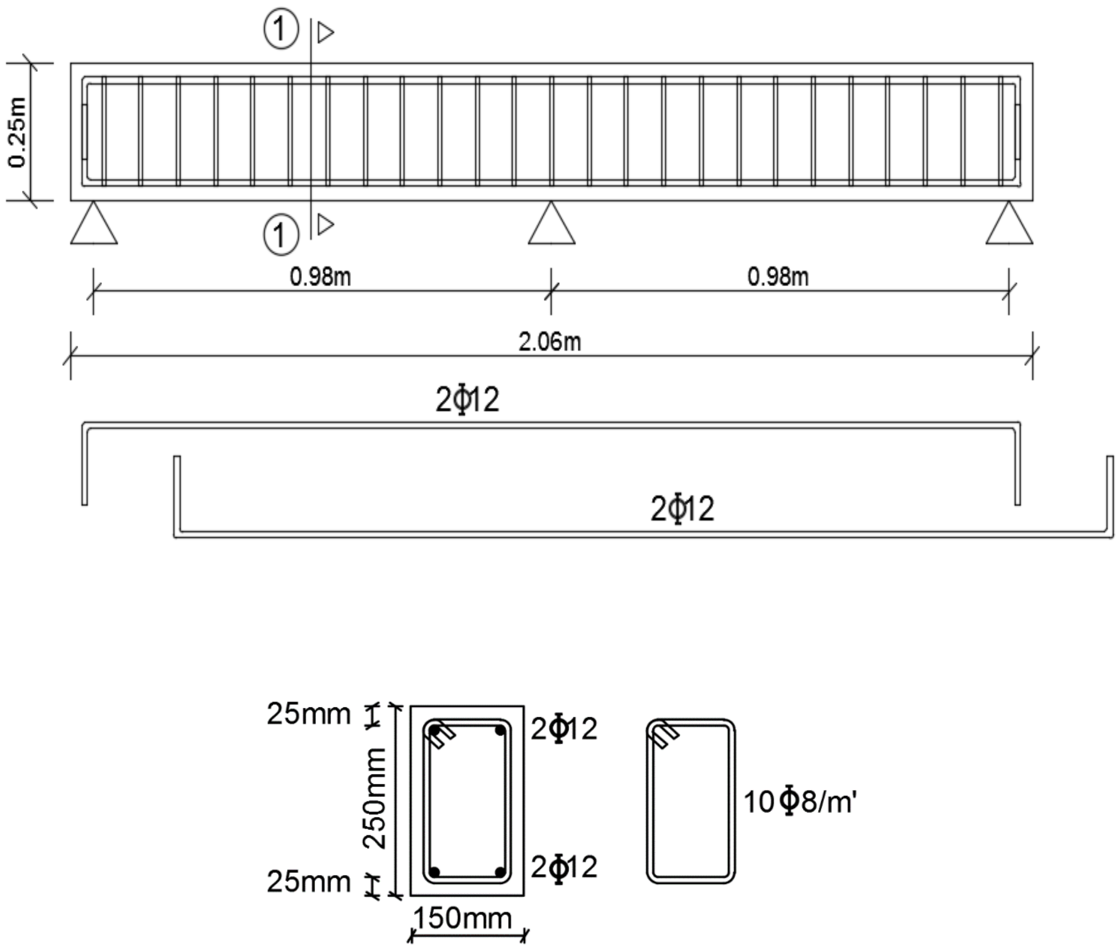
Content	0% RCA Weight/m^3	50% RCA Weight/m^3	100% RCA Weight/m^3
Cement	350	350	350
Water	200	210	210
Natural Coarse	1180	590	--
Recycled Aggregate	--	590	1180
Fine	650	650	650
BVF	3 Liter	3 Liter	3 Liter

Table 2: Average compressive strength for different concrete mixes

% Recycling	Average Compressive Strength	
	After 7 Days (N/mm^2)	After 28 Days (N/mm^2)
0%	24	31
50%	21	29
100%	22	32

2.2. Specimens Details

Seven continuous RC beams with two spans were tested. All beams had the same rectangular cross section of 150 x 250 mm and 2060 mm length supported on three hinges as shown in Figure 1. The reinforcement of all beams was 2Φ12 top reinforcement, 2Φ12 bottom reinforcement with cover of 25 mm, and closed stirrups Φ8 with spacing of 100 mm. Two main variables was considered in this research, the ratio of RCA, and the preloading level. The specimens had one control beam (B1) and the remaining beams were categorized into two groups with three beams in each. The first group include beams with 50% RCA, and the second group had beams with 100% RCA with different levels of preloading of 60%, 80%, and 100% of the ultimate capacity of B1 as shown in Table 3.



Section (1-1)

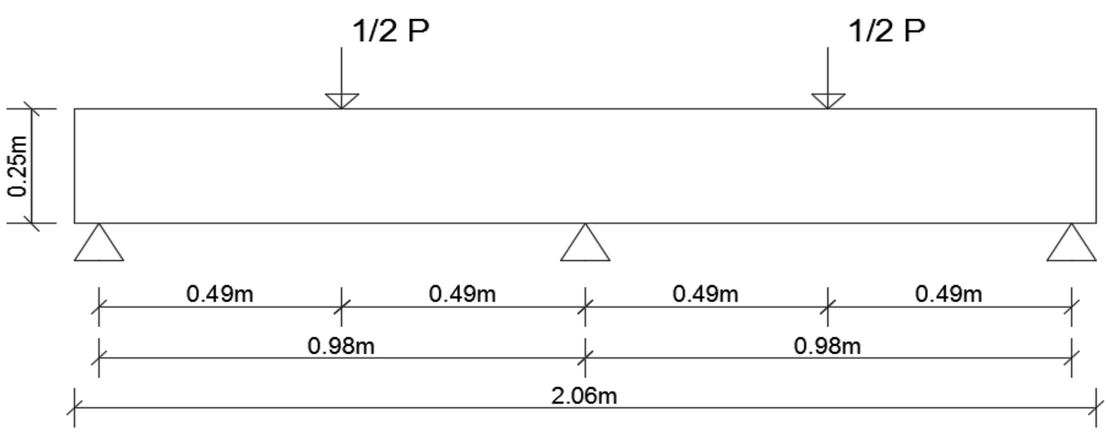
Figure 1: Reinforcement details for all tested Beams

Table 3: Dimensions and details tested Beams

Beam	Dimensions (mm)		Reinforcement		Parameters	
	b mm	h mm	Top	Bottom	%Recycled	%Preloaded
B1	150	250	2Φ12	2Φ12	--	100%
B2	150	250	2Φ12	2Φ12	50%	100%
B3	150	250	2Φ12	2Φ12	50%	60%
B4	150	250	2Φ12	2Φ12	50%	80%
B5	150	250	2Φ12	2Φ12	100%	100%
B6	150	250	2Φ12	2Φ12	100%	60%
B7	150	250	2Φ12	2Φ12	100%	80%

2.3. Test setup

Each beam was subjected to two concentrated load at the mid spans as shown in Figure 2. Before repairing of beams, B1, B2, and B5 were preloaded till failure and B1 was considered as control specimen. Beams B3, and B6 were preloaded till 60% of B1 capacity. Beams B4, and B7 were preloaded till 80% of B1 capacity. Figure 2 shows the loading setup for the tested continuous RC beams.



(a) Schematic Load Setup

(b) Testing Load setup

Figure 2: Load setup for the tested specimens

2.4. Repairing of beams

After applying the assigned level of preloading for each beam, the cracks had been widened at the surface using grinding machine to remove the disassembled parts then the fine resulting material was removed using blower machine. kemapoxy 165 [15] was applied at other sides of the beams to contain and allow the injection epoxy to fill the internal cracks and not to spill out of beam. After the hardening of kemapoxy 165 [15] according to the manufacturer report, kemapoxy 103 [16] with low viscosity was used as an injection material to fill the internal gaps. Figure 3 shows the steps of repairing the tested beams.

(a) Widening surface of cracks using grinder machine

(b) Removing of fine suspending materials using blower machine

(c) Applying kemapoxy 165 [15] at cracks surface to allow for injection

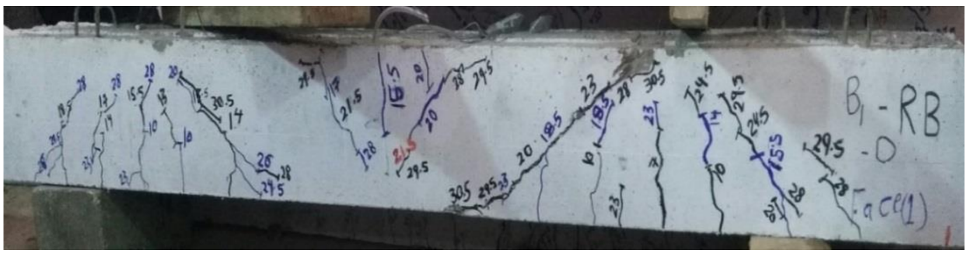
(d) Injecting cracks with kemapoxy 103 [16]

Figure 3: Steps of repairing using injecting epoxy

3. Results and Discussion

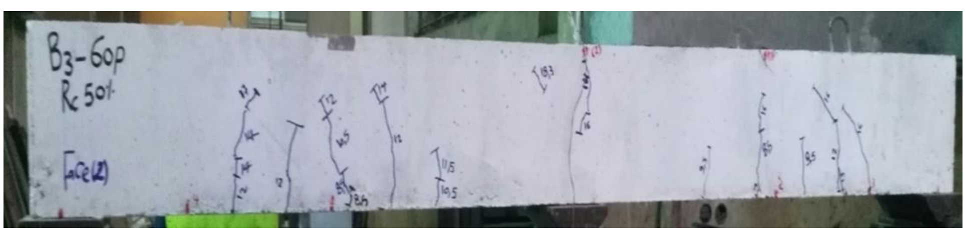
3.1. Group of 50% Recycled RC Beams

After repairing of B1, B2, B3, and B4, the beams are subject to concentrated loads at the mid of two spans till reaching the failure point. At the mid span of the four beams, the flexural cracks began to expand as the applied load increased till reaching the compression zone. For B1 and B3, the ultimate loads capacity were 321 kN, and 353 kN, respectively and both of beams experienced shear failure and crushing of concrete. The ultimate load capacity for B2 was 171 kN with shear-flexural failure. Finally, B4 reached ultimate load of 300 kN and failed due to the critical shear failure of the beam. Figure 4, and Figure 5 show the crack propagation for 50% RCA beams before and after repairing, respectively.

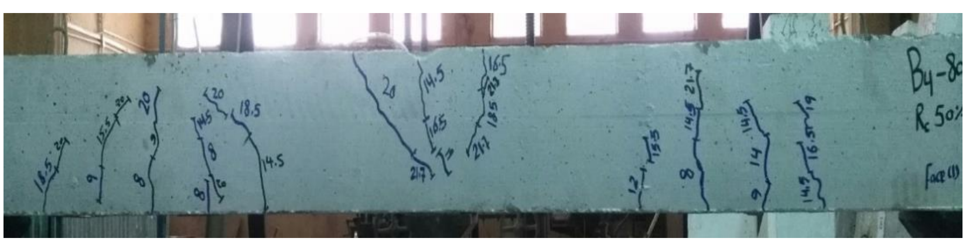


(a) B1 control beam before repairing

(b) B2 100% preloading before repairing



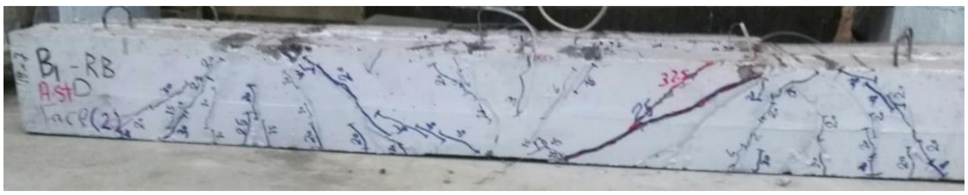
(c) B3 60% preloading before repairing



(d) B4 80% preloading before repairing

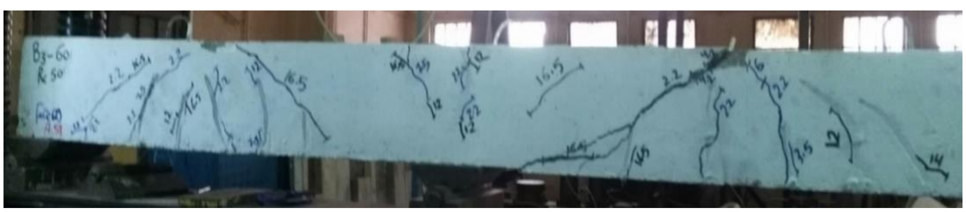
Figure 4: Crack propagation for 50% RCA beams before repairing

While testing the specimens, the relation between the load - deflection for each beam was recorded. The maximum deflections were 1.7, 5, 3.1, 12.5 mm for B1, B2, B3, and B4, respectively. It was recognized that the highest ultimate load was observed in B3 by 353 kN, and the highest mid-span deflection was recorded in B4 by 12.5 mm. Figure 6 shows a comparison between 50% RCA beams in ultimate loads and deflections. By increasing the level of preloading, the load capacity decreased as observed in B2, B3, and B4. Figure 7 shows the load-deflection curves for 50% RCA beams in comparison with the control specimen B1. To evaluate the effect of preloading levels, the ultimate load of B2 before repairing was considered as control specimen to eliminate the effect of changing RCA replacement ratio. The ultimate capacity of B2 before repairing was 273 kN and it was increased after repairing beams by 10%, and 29% for 80%, and 60% preloading, respectively, while it was reduced by 37% in case of 100% preloading.

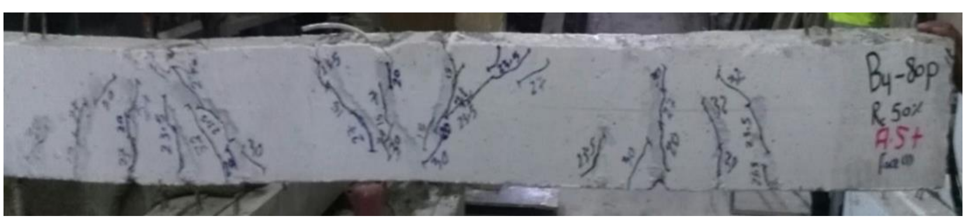


(a) B1 control beam after repairing

(b) B2 after repairing



(c) B3 after repairing



(d) B4 before repairing

Figure 5: Crack propagation for 50% RCA beams after repairing

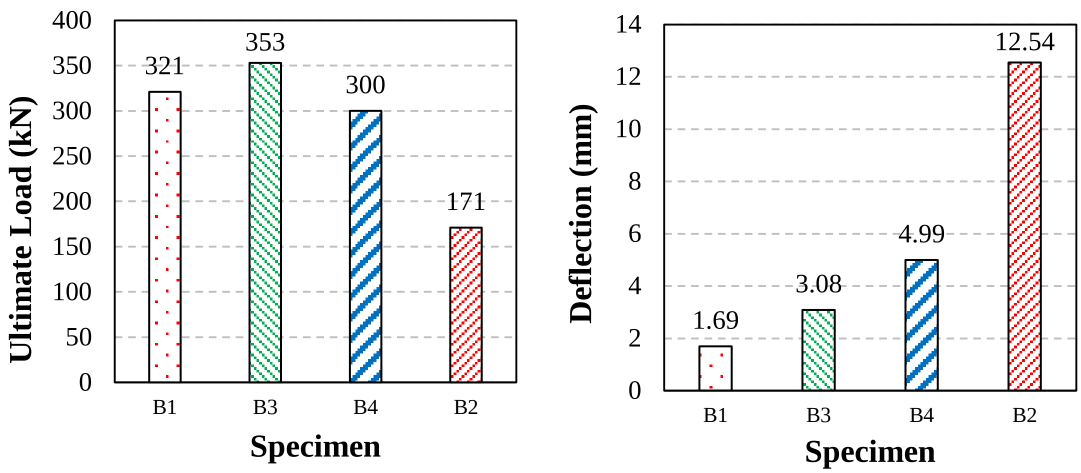


Figure 6: Ultimate loads and deflections for 50% RCA beams

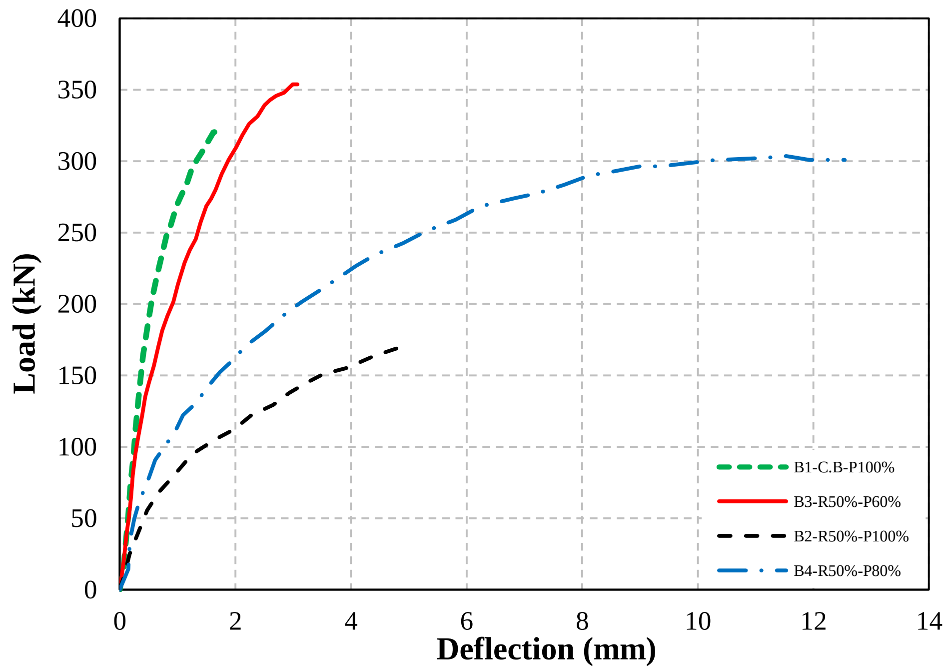
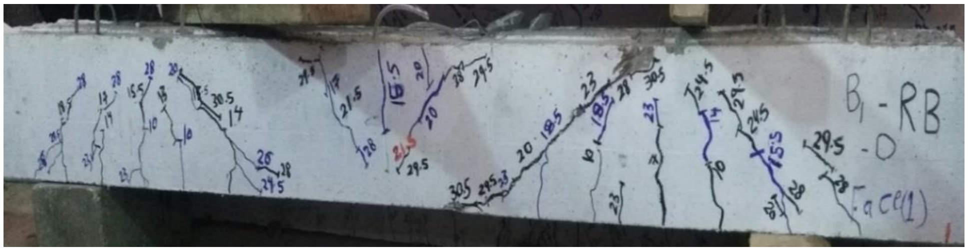


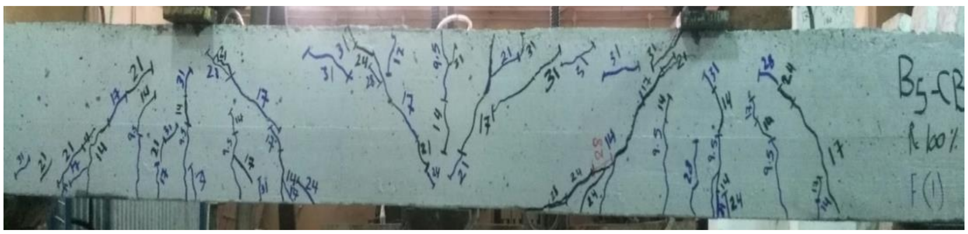
Figure 7: Load – Deflection relation for 50% RCA beams after repairing

3.2. Group of 100% Recycled RC Beams

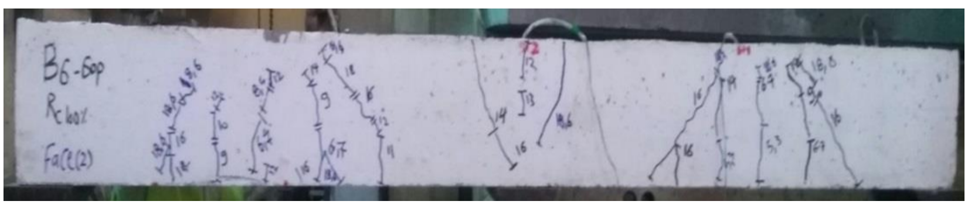
The beams B5, B6 and B7 containing 100% RCA were repaired then loaded till failure. For all beams, the crack began at the tension zone just beneath the loading point at the mid span, then the crack extended vertically with the appearance of inclined cracks starting from the tension zone directed to the loading point causing shear-flexural cracks with peeling of concrete. Figure 8, and Figure 9 show the crack propagation for 100% RCA beams before and after repairing, respectively. The recorded ultimate loads were 321, 263, 331, and 302 kN for B1, B5, B6, and B7, respectively.



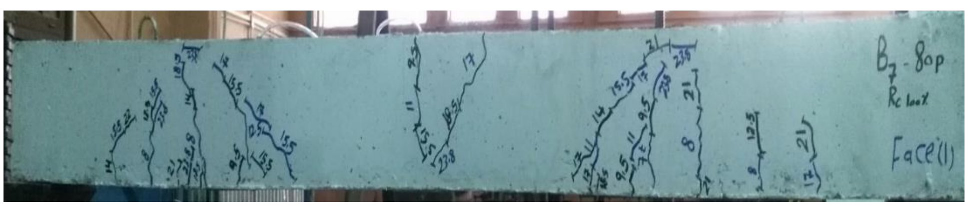
(a) B1 control beam before repairing



(b) B5 100% preloading before repairing



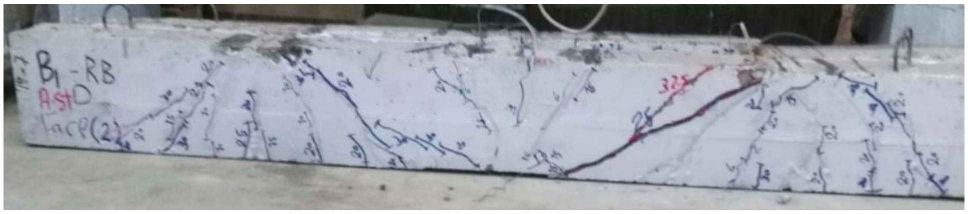
(c) B6 60% preloading before repairing



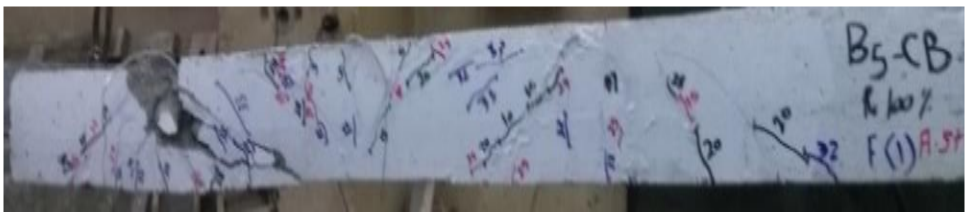
(d) B7 80% preloading before repairing

Figure 8: Crack propagation for 100% RCA beams before repairing

The observed deflections were 1.69, 6, 2.7, and 7.8 mm for B1, B5, B6, and B7, respectively. The highest ultimate load was for B6 by 331 kN, while the lower ultimate load was observed in B5 by 263 kN. The highest mid-span deflection was recorded in B7 by 7.8 mm. Figure 10 shows a comparison between 100% RCA beams in ultimate loads and deflections. Figure 11 shows the load-deflection relations for 100% RCA beams compared with the control specimen B1. To study the effect of changing the preloading levels, the ultimate load of beams has to be compared with B5 before repairing as control specimen to exclude the effect of changing RCA replacement ratio. The ultimate load of B5 before repairing was 325 kN and it was reduced after repairing beams by 19%, and 7% for 100%, and 80% preloading, respectively, while it was increased by 2% in case of 60% preloading.



(a) B1 control beam after repairing



(b) B5 after repairing

(c) B6 after repairing

(d) B7 after repairing

Figure 9: Crack propagation for 100% RCA beams after repairing

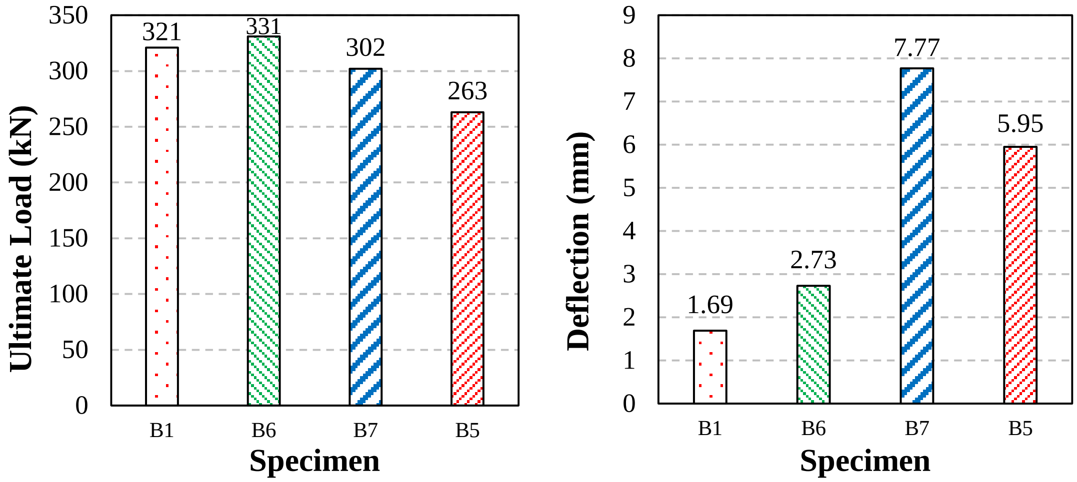


Figure 10: Ultimate loads and deflections for 100% RCA beams

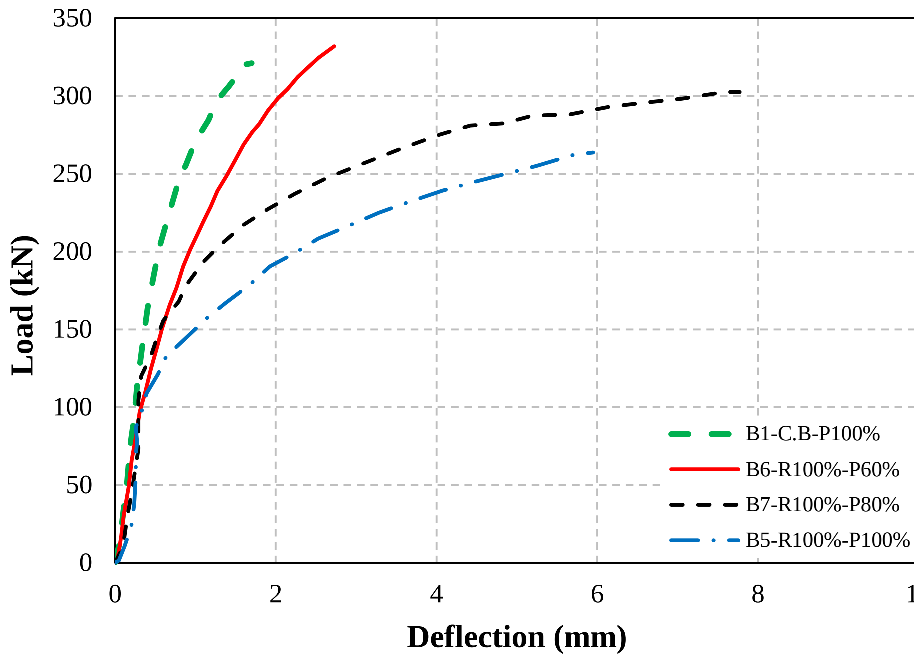


Figure 11: Load – Deflection relation for 100% RCA beams after repairing

3.2. Effect of changing RCA replacement ratio

The effect of changing RCA replacement ratio was evaluated by comparing the results of groups 1, and 2 with B1 as control specimen. In case of 60% preloading, the enhancement in ultimate capacity was reduced form 10% to 3% for cases 50%, and 100% RCA replacement ratio, respectively, while in case of 100% preloading, the reduction of ultimate load was reduced from 47% to 18% for cases 50%, and 100% RCA replacement ratio, respectively. In case of 80% preloading, the effect of changing RCA ratio was not significant with 7%, and 6% reduction in ultimate capacity for cases 50%, and 100% RCA replacement ratio, respectively.

5. Conclusions

o this research, preloaded RCA beam with different levels of preloading and RCA replacement ratio are In experimentally evaluated and the main outcome conclusions are as follows: -

- Repairing with curing additives improves strength, ductility, and dissipated energy of RC continuous beams. However, it decreases the mid-span deflection at ultimate load and affects the mode of failure of RC continuous beams.
- The modes of failure of recycled concrete 50%, and 100% RCA with different preloading levels are the same as conventional concrete, and shows shear failure, and shear flexural failure.
- Decreasing the preloading level improve the load - carrying capacity and the deflection of the repaired beams for 100% RCA compared to 50% RCA. In case of 50% RCA, the ultimate load was increased by 10 % in case of 60% preloading, and it was reduced by 47% in case of 100% preloading.
- The effect of changing RCA replacement ratio recorded high enhancement in reducing the reduction in ultimate capacity in case of 100% preloading. An increase in ultimate capacity was observed In case of 50% RCA replacement ratio up to 10% enhancement compared to control beam B1.

o

6. REFERENCES

[1] Levy, S.M., Helene, P., “Durability of recycled aggregates concrete: a safe way to sustainable development”, Cement, and Concrete Research 34 (2004) 1975-1980.

[2] Padmini, A.K., Ramamurthy, K., and Mathews, M.S., “Influence of parent concrete on the properties of recycled aggregates concrete”, Construction, and Building materials 23 (2009) 829-836.

[3] Malesev, M., Radonjanin, V., Marinkovic, S., “Recycled concrete as aggregate for structural concrete production”, Sustainability 2010, 2, 1204-1225.

[4] Etxeberria, M., Vazquez, E., Mari, A., Barra, M., “Influence of amount of recycled coarse aggregates, and production process of properties of recycled aggregate concrete”, Cement, and Concrete Research 37 (2007) 735-742.

[5] Crentsil, K.K.S., Brown, T., Taylor, A.H., “Performance of concrete made with commercially produced coarse recycled concrete aggregates”, Cement, and Concrete Research 31 (2001) 707-712.

[6] Buraczewska, B.S., Hunek, D.B., and Szafraniec, M., “Influence of recycled high-performance aggregate on deformation, and load-carrying capacity of reinforced concrete beams” Materials 2020, 13, 186.

[7] Wardeh, G., Ghorbel, E., “Shear strength of reinforced concrete beams with recycled aggregates”, Advances in Structural Engineering 2019, 1-14.

[8] Mohammed, T.U., Shikdar, K.H., Awal, M.A., "Shear strength of RC beam made with recycled brick aggregate", Engineering Structures 189 (2019) 497-508.
[9] Liu, C., Lv, Z., Zhu, C.,Bai, G., Zhang, Y., "Study on calculation method of long term deformation of RAC beam based on creep adjustment coefficient" Journal of Civil Engineering (2019) 23(1):260-267.
[10] Pei, C.C., Cui, X., Chi, C.P., "Effect of different blending ratio of waste polypropylene hybrid fiber on crack resistance of recycled concrete beams", Materials Science, and Engineering 631 (2019) 022053.
[11] Pradhan, S., Kumar, S., Barai, S.V., "Performance of reinforced recycled aggregate concrete beams in flexure: experimental, and critical comparative analysis", Materials, and Structures (2018) 51:58.
[12] Evangelista, L., and Brito, J.D., "Mechanical behavior of concrete made with fine recycled concrete aggregates", Cement & Concrete Composites 29 (2007) 397-401.
[13] Khatib, J.M., "Properties of concrete incorporating fine recycled aggregate", Cement, and Concrete Research 35 (2005) 763-769.
[14] Zhao, Z., Remond, S., Damidot, D., Xu, W., "Influence of fine recycled concrete aggregates on the properties of mortars" Construction, and Building materials 81 (2015) 179-186.
[15] Chemicals for Modern Building International "Kemapoxy 165", electronic dataset, (2017), Available at: http://cmbegypt.com/cmb/en/wp-content/pdf/Chemical_construction/06_construction_repair_strengthening/5.kemapoxy%20165/kemapoxy%20165.pdf (accessed 14 Feb 2021)
[16] Chemicals for Modern Building International "Kemapoxy 103", electronic dataset, (2017), Available at: http://cmbegypt.com/cmb/en/wp-content/pdf/Chemical_construction/06_construction_repair_strengthening/17.kemapoxy%20103/kemapoxy%20103.pdf (accessed 14 Feb 2021)