Basrah Journal for Engineering Sciences, Vol. 23, No. 1, (2023), 26-32

Original Article

Journal homepage: www.bjes.edu.iq
ISSN (Online): 23118385, ISSN (Print): 18146120

OPEN ACCESS

Structural Behavior of Reinforced Concrete Hollow Core Slabs Cast with Self-Compacting Concrete Containing Recycled Concrete as Coarse Aggregate

Mustafa Raheem Hassan [1,*], Jamal Abdulsamad Khudhair [2]

[1,2] *Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq*

E-mail addresses: mostafa_rheem90@yahoo.com , jamal.khudhair@uobasrah.edu.iq

Received: 17 July 2022; Revised: 20 October 2022; Accepted: 9 November 2022; Published: 2 July 2023

Abstract

This paper investigates the possibility of recycled aggregate use in concrete slabs with hollow cores. The main variables considered in the experimental study for the slabs were the recycled aggregate percentage and the hollow core number. Six slabs with dimensions of (1000 × 500 × 120) mm was fabricated and tested. The results showed that the addition of recycled aggregate in the concrete slabs affected the ultimate strength, ductility, and energy absorption of the concrete members. An increase of the recycled aggregate percentage to 25 % decreased the ultimate strength capacity by 3.54 %, but the increase of recycled aggregate to 50 % led to a decrease in the ultimate strength of about 6.64%. The existence of a hollow core reduced the cracking and ultimate load capacity of the RCA slabs, and this reduction was according to the core number which the fabrication of more cores caused more decrement.

The ductility and energy absorption were decreased when the replacement ratio of the recycled aggregate increased. Also, the core number affected the ductility and energy absorption. The energy absorption was the most property affected by the core number increase which caused an average reduction of 71.5 % when the core number increased from two to three hollow cores.

Keywords: Hollow-core slabs, Self-compacting concrete (SCC), Recycled concrete aggregate (RCA).

https://doi.org/10.33971/bjes.23.1.4

1. Introduction

Population growth, continuous industrial development, construction of infrastructure and house-building activities create huge amounts of construction and demolition (C and D) waste and hence, the dire need for waste recycling. The construction industry is a major consumer of natural resources and the global aggregate production almost doubled from 21 billion tons in 2007 to 40 billion tons in 2014. Countries such as China, India, Indonesia, Malaysia, Thailand, Gulf States, Turkey, Russia, Brazil and Mexico have recorded some of the strongest increases in the demand for waste recycling. Hence, the progressive depletion of natural resources and growing awareness of sustainable waste management by developed and emerging economies, have given ever-increasing relevance to recycling and re-using C and D waste in civil engineering projects [1]. The replacement of aging infrastructures and buildings results in large quantities of construction waste, especially concrete waste. Concrete waste generated from demolition work contains many aggregates. Because aggregates occupy the majority of the concrete volume, it is reasonable to investigate reusing the aggregates from concrete waste to create new concrete [2-4]. Recycled coarse aggregates (RCA) have been used in many laboratory experiments [5-7]. Due to the potential economic and environmental benefits, interest in technology for processing waste concrete and the use of RCA is rapidly increasing [8], [9]. The advantages of using RCAs include a reduction in the use of natural coarse aggregate (NCA) resources and a decrease in the amount of waste disposed of in landfills, thereby diminishing environmental pollution. Despite the high demand, RCAs are primarily used in road bases and nonstructural concrete. Only a small percentage of RCAs are used in structural concrete because the quality of RCAs is less reliable than that of NCA. Comprehensive experimental research has been performed to assess the properties of both NCA and RCA concrete at the material level [10-15].

Recycled concrete aggregates (RCA) are made of natural aggregates (NA) and cement mortar adhered to the latter. The main difference between the two types of aggregates is the presence of cement mortar in RCA. This mortar increases the RCA's surface roughness, porosity and water absorption compared to NA, but decreases their mechanical properties [16]. The incorporation of RCA in concrete, due to their higher water absorption, requires a higher apparent water/cement ratio in order to keep workability constant. This procedure can affect the properties of concrete, moreover when the replacement ratio of NA by RCA increases and the fine fraction of the aggregates is replaced [16], [17]. The compressive strength, the tensile strength and, even more, the modulus of elasticity tend to decrease with the incorporation of RCA [18], [19]. The durability, shrinkage and creep of concrete are also usually negatively affected by the incorporation of RCA [20], [21]. However, some studies have reported lower cracking loads and wider cracks in elements made of recycled aggregate concrete [24]. According to

González- Fonteboa and Martínez-Abella [25], this latter trend can be attenuated by decreasing the spacing of the stirrups. In that study, by Rao et al. [26], six mixes with 0 %, 20 %, 40 %, 60 %, 80 % and 100 % replacement ratios of NCA by RCA were used to cast 1100 × 1100 × 50 mm slabs. The authors obtained a consistent reduction of concrete's mechanical properties and slabs' punching strength with the RCA content. For 100 % replacement, the compressive and splitting tensile strengths decreased by respectively 23 % and 17 %, leading to a 15 % reduction of the cracking and ultimate loads and 2 % reduction of the uncracked stiffness, all relative to the reference mix/slabs.

Therefore, the purpose of this study was to explore the structural behaviour of RCA concrete slabs under flexure. A total of six concrete slabs were fabricated and then tested under two-point bending loads. The main variables considered in the experimental study for the slabs were recycled aggregate percentage and hollow core number. The results were in terms of load-deflection curves, ductility, energy absorption, stiffness, and crack pattern.

2. Concrete mixes and materials properties

Proportions of the mix to produce concrete are presented in Table 1. The concrete mix included the use of natural and recycled aggregate, cement, sand, water, silica fume, and superplasticizer. Before the concrete components mix, the material must be checked physically and chemically. The inspection of materials included testing of cement according to the Iraqi standards while the other testing such as the sieve analysis, grading, and compressive strength were tested according to the ASTM C109 [27], ASTM C-136 [28], and Iraqi standards No. 45/1984 [29] respectively. Concerning the physical and chemical properties, Iraqi standard specification No. 45/1984 [29] was used. grey condenser grade 920 D silica fume was used. Regarding the additives, the superplasticizer that is used is confirmed and checked according to ASTM C494-99 [30]. Reinforced concrete with compressive strength of 32-44.3 MPa. Regarding the steel reinforcement, rebar with a diameter of Ø10 mm was used to reinforce the slab. These rebars have yield stress equal to 420 MPa respectively as revealed in Table 2.

Table 1. Concrete mixes details.

Material (kg/m^3)	Mix 1	Mix 2	Mix 3
Cement	414	414	414
Coarse aggregate kg/m^3	778	389	194.5
Super PS. Kf/m^3	4	4	4
Fine aggregate	826	826	826
Limestone	178	178	178
w/c	0.25	0.22	0.22
E (GPa)	31.24	28.94	25.67
Replacement ratio	0 %	25 %	50 %
fcu (28 days)	44.32	38.63	32.11
ft	3.96	3.43	3.12
fr	5.34	4.86	4.21

Table 2. Properties of reinforcing bars.

Test results ASTM A615/A615M-06b [28] limits						
Bar size (mm)	Yield stress (N/mm^2)	Ultimate Strength (N/mm^2)	Elongation (%)	Yield stress min. (N/mm^2)	Ultimate strength min. (N/mm^2)	Elongation min. (%)
10	500	650	14	420	620	9

Fig. 1 Fabricating and casting laboratory test specimens.

3. Slabs details and casting procedure

Six samples were used in this work. The dimensions of these samples are the same dimensions as the fabricated slabs which were (1000 × 500 × 120) mm. They were cleaned and oiled using a scraper and a steel brush to facilitate simple demolding. Forms for the slab specimens were prepared using 20 mm plywood sheets cut and assembled very carefully to ensure, accurate vertical sides and to provide 90 degrees corners with plywood formed at the bottom, as shown in Fig. 2. The small scale of models is selected according to many considerations which must be enough to obtain a result which a near to the true behaviour of the full model with real dimensions. The optimum scale factor was chosen according to the feasibility study carried out to satisfy the conditions such as the weight and dimensions which should be compatible with laboratory equipment. The second constraint is the ultimate capacity of the testing machine which has a maximum load of 300 kN. The concrete was mixed with a 100 kg mixer. Before inserting the reinforcement, cage or casting control specimens, the forms and control molds were oiled. To guarantee that the right cover was maintained, steel bars were put inside the forms and kept in place. All the ingredients were weighed and packed in a clean metal container before being mixed. As shown in Fig. 2, casting the concrete was done using plywood forms for molds and steel forms. After mixing and casting, the forms were removed after 24 hours, and the specimens were immersed in water for 28 days. Samples were taken and poured into concrete cubes and cylinders for the purpose of estimating the concrete properties of the cast samples.

Fig. 2 Molds of the specimens.

Table 3. Details of slabs.

Slab No.	RCA %	Main R.	Shrinkage R.	SLAB D.	Core Size and Shape
S0S1	0	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 2 mm
S0S2	0	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 3 mm
S25S1	25	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 2 mm
S25S2	25	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 3 mm
S50S1	50	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 2 mm
S50S2	50	Φ10@100	Φ10@150	1000 × 500 mm	C. dia. = 50 × 3 mm

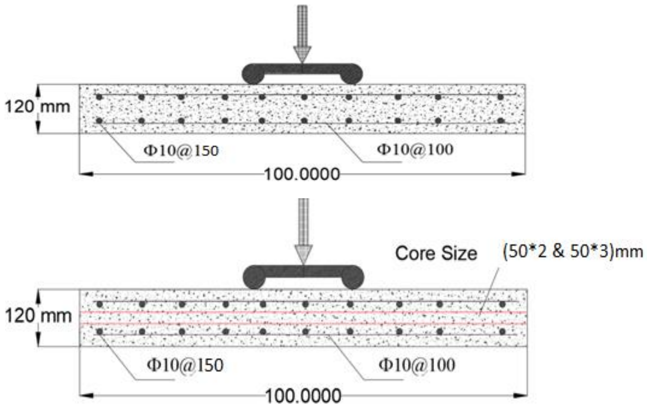


Fig. 3 Dimensions of the RC slabs.

Fig. 4 Crack pattern and failure mode of analyzed RC slabs.

4. Results and discussion

4.1. Failure mode

Fig. 4 shows the representative failure mode in each slab which is observed during the tests. The shear failure occurred for the one-way slabs that had shear resistance lower than flexural strength and that occurred for the slab with recycled aggregate for all replacement ratios. While the slabs with natural aggregate, the concrete slabs showed flexural failure by cracks developed at the midspan and extended towards the top half of the slab. The failure in such slabs was ductility in which the crack propagated along the slab. The addition of recycled aggregate enhanced the ductility and caused the development of more cracks with less width. The cores number increase caused more appearing of single large cracks causing the failure. The crack width of the test slabs is revealed in Table 4. The replacement ratio was the most effective variable on the crack width of the tested RCA slab which increase of replacement ratio to (25 %) caused an increase in the crack width by (44 % and 40 %) for slabs (S25S1 and S0S1) and (S25S2 and SS0S2). The creation of two and three 50 mm cores led to caused reduction in the crack width by (6 %, 8.5 %, and 5.5 %) for slabs (S0S2 and S0S1), (S25S2 and S25S1), and (S50S2 and S50S1). Maximum crack width occurred at the slabs with core size (3 No. 50 mm) and recycled aggregate ratio of (50 %).

Table 4. Crack width of the tested slabs.

Slab No.	Wu (mm)
S0S1	0.9
S0S2	0.85
S25S1	1.3
S25S2	1.19
S50S1	0.74
S50S2	0.7

4.2. General behavior of slabs

The second series involved testing six RC slabs with and without circular hollow cores fabricated with several ratios of recycled aggregate. These slabs tested to failure under static loads. The results exhibited that the obtained strengths results ranged between (83-113) kN as shown in Table 5. The variance in the ultimate strength capacity was due to the change in the replacement ratio and the number of cores. In addition to finding the cracking and ultimate loads, the ductility index and the energy absorption were estimated so that the full behavior of the specimens under the load can be installed. The symbols in your equation have been defined before the equation appears or immediately following.

Table 5. Test results of concrete slabs.

Slab ID	Pcr (kN)	Pu (kN)	Pcr/Pu	Failure Mode
S0S1	50.7	113	44.9 %	Flexural Failure
S0S2	44.1	85.4	51.6 %	Flexural Failure
S25S1	44.9	109	41.2 %	Shear Failure
S25S2	45	83	54.2 %	Shear Failure
S50S1	38	105.5	36 %	Shear Failure
S50S2	35.7	82.2	43.3 %	Shear Failure

4.3. Cracking and ultimate load

4.3.1. Effect of the replacement ratio of recycled aggregate

In order to investigate the effect of the replacement ratio of the recycled aggregate, three ratios (0 %, 25 %, 50 %) were used. The effect of the recycled aggregated seemed significant on the flexural strength of the SCC slabs. The hollow slab with (2No. 50 mm) diameter core (S0S1) showed an ultimate load carrying capacity of (113) kN which decreased to (109) kN and (105.5) kN which is equal to a decrement of (3.54 %) and (6.64%) when the replacement ratio increased to (25 %) and (50 %) respectively. The cracking load also decreased by (13.5% and 25 %) when the replacement ratio of the recycled aggregate reached (25 % and 50 %) as revealed in Table 5. The outcomes illustrated that the cored slabs with different replacement ratio didn't affect by the replacement by high percentages, which means the possibility of the use of recycled aggregate in high ratios as an alternative of the natural aggregate. Regarding the effect of the replacement ratio for the cored slabs with 3 No. 50 mm cores, the replacement ratio effect was less than those of the cored slabs with (2 No. 50 mm). The transfer from the zero ratios of recycled aggregate content to (25 % and 50 %) revealed a slight decrement in the ultimate load (3 % and 7.5 %) when comparing the specimens (S25S2 and S50S2) with the slab (S0S2). Regarding the cracking load, the replacement ratio of (50 %) affected the cracking load by (19.66 %). The use of a replacement ratio of (25 %) didn't affect the cracking load as depicted in Table 5. In general, the recycled aggregate reduced the strength of the concrete slabs but in slight values which is considered an acceptable result and give the permission to replace the natural aggregate be recycled.

4.3.2. Effect of the core number

The effect of the core size was significant on the cracking and load ultimate cracking load capacity which create of (2 No. 50 mm) instead of the (2 No. 50 mm) decreased the cracking load from (50.7) to (44.1) kN which equal to (17 %) while the ultimate strength drops from (113) kN to (85.4) which equal to (24.5 %) as depicted in specimens (S0S1 and S0S2) in Table 5. While the slabs with recycled aggregate ratio (25 %) (S25S1 and S25S2), revealed a decrement of (24 %) in the ultimate load carrying capacity and no variation occurred in the cracking load capacity. Regarding the highest ratio of the recycled aggregate (50 %) especially the slabs (S50S1 and S50S1), the reduction in the ultimate strength was as by (22.1%) and (6 %) in the cracking and. In general, the increase in core number increase of possibility of developing a weak point causing the development of more cracks.

4.4. Deflection

4.4.1. Effect of the replacement ratio of recycled aggregate

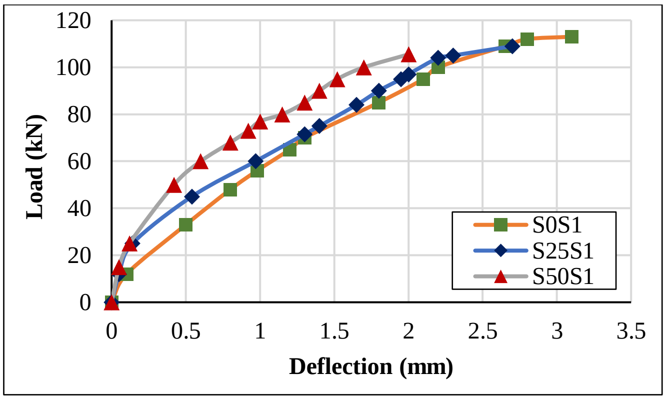
The effect of the recycled aggregated seemed significant on the flexural strength of the SCC slabs as depicted in Table 6 which the hollow slab with (2 No. 50 mm) mm diameter core (S0S1) showed a capacity reached deflection of (1.35) mm at working load (75 kN) which decreased to (1.25) mm and (0.75) mm which equal to a decrement by (7 %) and (44.4 %) when the replacement ratio increased to (25 %) and (50 %) respectively as revealed in Fig. 5 (a). The outcomes illustrated that the cored slabs with different replacement ratios affect simplicity when (25 %) replacement, the replacement by higher percentages which considered an index to the possibility of use of recycled aggregate in high ratios as an alternative of the natural aggregate. Regarding the effect of the replacement ratio for the cored slabs with a larger size of the core hollow core (3 No. 50 mm) mm, the replacement ratio effect was less than those of the cored slabs with (2 No. 50 mm) which the transfer from the zero ratios of recycled aggregate proportion to (25 % and 50 %) revealed a slight decrement in the deflection at workload 55 KN by (33 %) and (45 %) when compared the specimens (S25S2 and S50S2) with the model (S0S2) as depicted in Fig. 5 (b).

Table 6. Test results of concrete slabs.

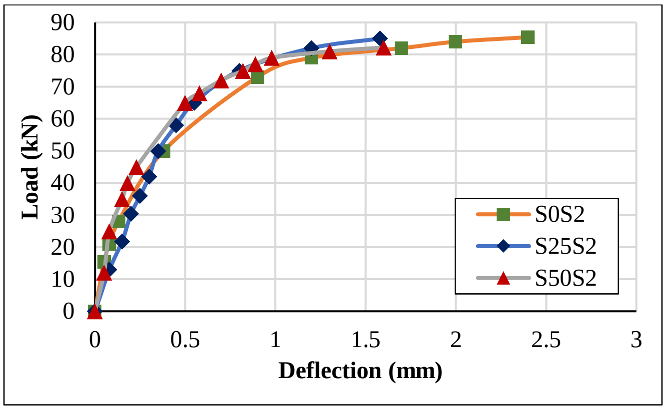
Slab ID	No. of Cores	Deflection (mm)
S0S1	2 No. 50 mm	3.1
S0S2	3 No. 50 mm	2.4
S25S1	2 No. 50 mm	2.7
S25S2	3 No. 50 mm	1.58
S50S1	2 No. 50 mm	2.0
S50S2	3 No. 50 mm	1.6

4.4.2. Effect of number of cores

The effect of the core size was significant on the deflection at working load which create (3 No. 50 mm) instead of the (2 No. 50 mm) revealing that the deflection had a significant effect on the deflection which showed decrement by (46.6 %) for the slabs with zero percentage of recycled aggregate as illustrated in Fig. 6 (a). Regarding the recycled aggregate slabs with (40 %) and (49 %) (S25S2 and S50S2). The core number reduced the deflection of the slabs due to the development of the weak point in the concrete causing a stress concentration in the concrete which made concrete crushing as seen in Fig. 6 (b) and (c).

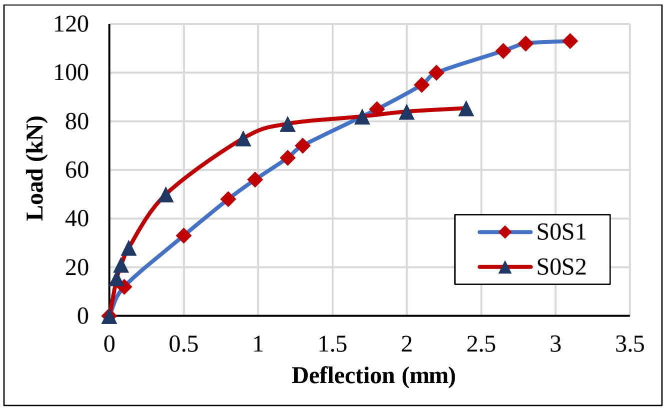


(a)

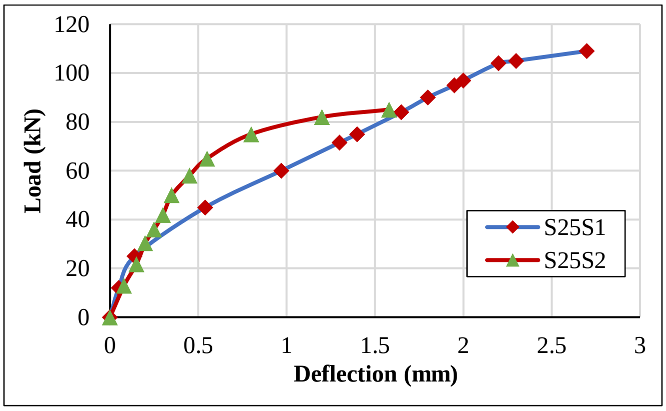


(b)

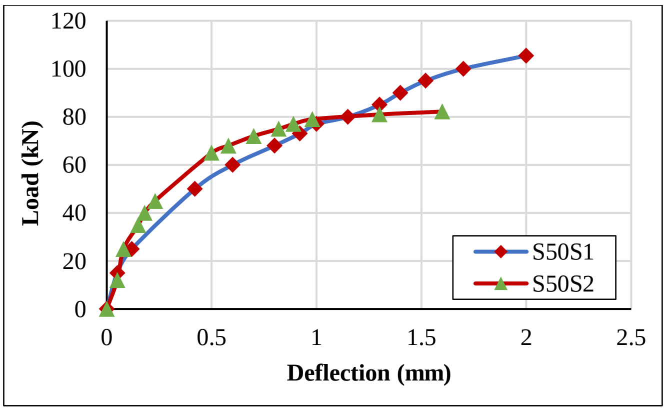
Fig. 5 load-deflection curve of specimens with variable replacement ratio.



(a)



(b)



(c)

Fig. 6 load-deflection curve of specimens with varied core sizes.

5. Ductility and energy absorption

5.1. Ductility of the tested slabs

All ductility and energy absorption results are shown in Table 7 and Fig. 7. The ductility index is calculated as the ratio between the ultimate deflection to the deflection at the yield point. To investigate the effect of the replacement ratio of the recycled aggregate on the ductility index, three ratios (0 %, 25%, 50 %) were used. The effect of the recycled aggregated seemed significant on the ductility of the SCC slabs.

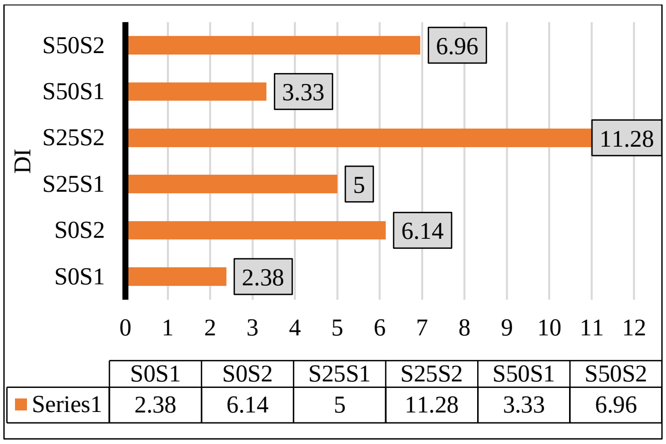
Table 7. Test results of concrete slabs.

Slab ID	No. of Cores	Ductility index	Energy absorption
S0S1	2 No. 50 mm	2.38	171.45
S0S2	3 No. 50 mm	6.14	64.06
S25S1	2 No. 50 mm	5	110.72
S25S2	3 No. 50 mm	11.28	22.27
S50S1	2 No. 50 mm	3.33	89.59
S50S2	3 No. 50 mm	6.96	43.77

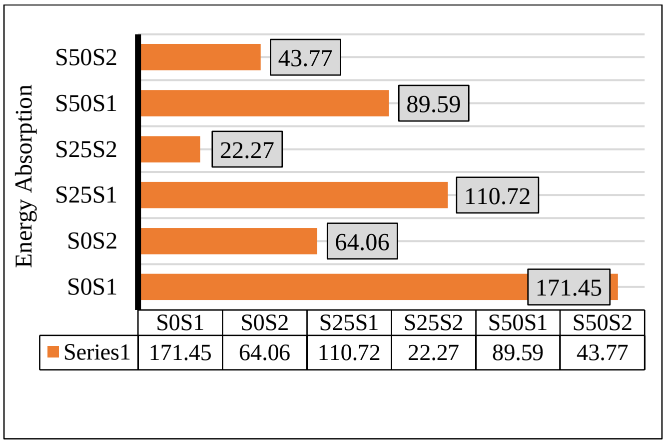
The hollow slab core (2 No. 50 mm) (S0S1) showed ductility reached (2.38) which increased to (5) and (3.33) which equates to an increment by (110 %) and (39.9 %) when the replacement ratio increased to (25 %) and (50 %) (S25S1 and S50S1) respectively as revealed in Fig. 7 (a). Regarding the specimens (S0S2, S25S2 and S50S2) that cored with 3 No. 50 mm, the effect of the replacement ratio on such slabs showed that the increase of recycled aggregate ratio to (25 % and 50 %) increased the ductility but with values less than occurred in slabs with a core of (2 No. 50 mm) which were by (83.7 % and 13.4 %). The effect of the hollow core on the ductility seemed notable concerning the slab with zero recycled aggregate (S0S1 and S0S1) which involved circular openings. The existence of the hollow core increased the ductility index which increased from (2.38) to (6.14) when comparing the specimens (S0S1 and S0S2) which is equal to (158 %). Concerning the slabs with higher replacement ratios (25 % and 50 %), the increase in the core size also increased the ductility index by (125.6 and 109 %) respectively as depicted in Fig. 7 (a).

6. Energy absorption

In this section, the replacement ratio and hollow core number are considered to investigate the effect of these variables on energy absorption. The energy absorption was calculated by measuring the area under the load-deflection curve. All results of the tested specimens are shown in Fig. 7 (b). The effect of the recycled aggregated seemed significant on the energy absorption of the SCC slabs which the hollow slab core (50 × 2 mm) (S0S1) showed energy absorption reached to (171.45) which decreased to (110.72) kN.mm and (89.59) kN.mm which were equal to a decrement by (35.5 %) and (47.8 %) when the replacement ratio increased to (25 %) and (50 %) (S25S1 and S50S1) respectively. Regarding the specimens (S0S2, S25S2 and S50S2) that cored with 3 No. 50 mm, effect of the replacement ratio on such slabs showed that the increase of recycled aggregate ratio to (25 % and 50 %) increased the energy absorption but with values higher than occurred in slabs with core of 50 mm which were by (65.3 % and 74.5 %) as depicted in Fig. 7 (b).



(a)



(b)

Fig. 7 Energy absorption of solid specimens with variable replacement ratio.

6. Conclusions

In this manuscript, the results of six RC SCC slabs with recycled aggregate are discussed and revealed. Based on these experimental studies, the following conclusions are drawn:

1. The addition of recycled aggregate in the concrete slabs redistributed the internal stresses and affected the ultimate strength, load-carrying capacity, ductility, and energy absorption of the concrete members.
2. A variation in the cracking and ultimate load was due to the change in the replacement ratio of the recycled aggregate.
3. Addition of the recycled aggregate reduced the ultimate strength of the RCA slabs, but the reduction percentage didn't exceed (4 %).
4. The increase in the number of the core caused a higher decrement in the cracking and ultimate load capacity in comparison with the replacement ratio.
5. The deflection of the RCA slab showed a reduction when the replacement ratio increased to (25 % and 50 %). A higher reduction occurred in slabs with recycled aggregate (50 %). The deflection of the RCA slab showed a reduction when the core number increased to (two and three cores). The higher reduction occurred in slabs with three cores of (50 mm).
6. The ductility and energy absorption are affected by the replacement ratio and cores number. The most affected property was the energy absorption which reduced when the replacement ratio and cores numbers increased.

References

[1] V. W. Y. Tam, M. Soomro, and A. C. J. Evangelista, "A review of recycled aggregate in concrete applications (2000-2017)", Construction and Building materials, Vol. 172, pp. 272-292, 2018. https://doi.org/10.1016/j.conbuildmat.2018.03.240

[2] S. Frondistou-Yannas, "Waste concrete as aggregate for new concrete", ACI Journal Proceedings, Vol. 74, Issue 8, pp. 373-376, 1977. https://doi.org/10.14359/11019

[3] M. Etxeberria, A. R. Marí, and E. Vázquez, "Recycled aggregate concrete as structural material", Materials and Structures, Vol. 40, Issue 5, pp. 529-541, 2007. https://doi.org/10.1617/s11527-006-9161-5

[4] A. D. Buck, "Recycled concrete as a source of aggregate", ACI Journal Proceedings, Vol. 74, Issue 5, pp. 212-219, 1977. https://doi.org/10.14359/11004

[5] V. Corinaldesi, "Mechanical and elastic behaviour of concretes made of recycled-concrete coarse aggregates", Construction and Building Materials, Vol. 24, Issue 9, pp. 1616-1620, 2010. https://doi.org/10.1016/j.conbuildmat.2010.02.031

[6] A. Ajdukiewicz and A. Kliszczewicz, "Influence of recycled aggregates on mechanical properties of HS/HPC", Cement and Concrete Composites, Vol. 24, Issue 2, pp. 269-279, 2002. https://doi.org/10.1016/S0958-9465(01)00012-9

[7] W. H. Bai and B. X. Sun, "Experimental Study on Flexural Behavior of Recycled Coarse Aggregate Concrete Beam", Applied Mechanics and Materials, Vols. 29-32, pp. 543-548, 2010. https://doi.org/10.4028/www.scientific.net/AMM.29-32.543

[8] K. Eguchi, K. Teranishi, A. Nakagome, H. Kishimoto, K. Shinozaki, and M. Narikawa, "Application of recycled coarse aggregate by mixture to concrete construction", Construction and Building Materials, vol. 21, Issue 7, pp. 1542-1551, 2007. https://doi.org/10.1016/j.conbuildmat.2005.12.023

[9] S. B. Huda and M. S. Alam, "Mechanical behavior of three generations of 100 % repeated recycled coarse aggregate concrete", Construction and Building Materials, Vol. 65, pp. 574-582, 2014. https://doi.org/10.1016/j.conbuildmat.2014.05.010

[10] S.-C. Kou, C.-S. Poon, and H.-W. Wan, "Properties of concrete prepared with low-grade recycled aggregates", Construction and Building Materials, Vol. 36, pp. 881-889, 2012. https://doi.org/10.1016/j.conbuildmat.2012.06.060

[11] S. W. Tabsh and A. S. Abdelfatah, "Influence of recycled concrete aggregates on strength properties of concrete", Construction and Building Materials, Vol. 23, Issue 2, pp. 1163-1167, 2009. https://doi.org/10.1016/j.conbuildmat.2008.06.007

[12] N. Deshpande, S. S. Kulkarni, and N. Patil, "Effectiveness of using coarse recycled concrete aggregate in concrete", International Journal of Earth Science and Engineering, Vol. 4, Issue 6, pp. 913-919, 2011.

[13] A. Domingo-Cabo, C. Lázaro, F. López-Gayarre, M. A. Serrano-López, P. Serna, and J. O. Castaño-Tabares, "Creep and shrinkage of recycled aggregate concrete", Construction and Building Materials, Vol. 23, Issue 7, pp. 2545-2553, 2009. https://doi.org/10.1016/j.conbuildmat.2009.02.018

[14] L. Butler, J. S. West, and S. L. Tighe, "The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement", Cement and Concrete Research, Vol. 41, Issue 10, pp. 1037-1049, 2011. https://doi.org/10.1016/j.cemconres.2011.06.004

[15] M. Kikuchi, T. Mukai, and H. Koizumi, "Properties of concrete products containing recycled aggregate", in Proceedings of 2nd International Symposium on Demolition and Reuse of Concrete and Masonry, Vol. 2, pp. 595-604, Tokyo, Japan, November 1988.

[16] M. S. de Juan, and P. A. Gutiérrez, "Study on the influence of attached mortar content on the properties of recycled concrete aggregate", Construction and Building Materials, Vol. 23, Issue 2, pp. 872-877, 2009. https://doi.org/10.1016/j.conbuildmat.2008.04.012

[17] L. Evangelista, and J. de Brito, "Mechanical behaviour of concrete made with fine recycled concrete aggregates", Cement and Concrete Composites, Vol. 29, Issue 5, pp. 397-401, 2007. https://doi.org/10.1016/j.cemconcomp.2006.12.004

[18] M. L. Berndt, "Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate", Construction and Building Materials, Vol. 23, Issue 7, pp. 2606-2613, 2009. https://doi.org/10.1016/j.conbuildmat.2009.02.011

[19] N. Fonseca, J. de Brito, L. Evangelista, "The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste", Cement and Concrete Composites, Vol. 33, Issue 6, pp. 637-643, 2011. https://doi.org/10.1016/j.cemconcomp.2011.04.002

[20] L. Ferreira, J. de Brito, M. Barra, "Influence of the pre-saturation of recycled coarse concrete aggregates on concrete properties", Magazine of Concrete Research, Vol. 63, Issue 8, pp. 617-627, 2011. https://doi.org/10.1680/macr.2011.63.8.617

[21] S. C. Kou, C. S. Poon, "Enhancing the durability properties of concrete prepared with coarse recycled aggregate", Construction and Building Materials, Vol. 35, pp. 69-76, 2012. https://doi.org/10.1016/j.conbuildmat.2012.02.032

[22] X. Li, "Recycling and reuse of waste concrete in China: Part I. Material behaviour of recycled aggregate concrete", Resour Conserv Recycling, Vol. 53, Issue 1-2, pp. 36-44, 2008. https://doi.org/10.1016/j.resconrec.2008.09.006

[23] J. Xiao, W. Li, Y. Fan, X. Huang, "An overview of study on recycled aggregate concrete in China (1996–2011)", Construction and Building Materials, Vol. 31, pp. 364-383, 2012. https://doi.org/10.1016/j.conbuildmat.2011.12.074

[24] S. Schubert, C. Hoffmann, A. Leemann, K. Moser, M. Motavalli, "Recycled aggregate concrete: experimental shear resistance of slabs without shear reinforcement", Engineering Structures, Vol. 41, pp. 490-497, 2012. https://doi.org/10.1016/j.engstruct.2012.04.006

[25] B. González-Fonteboa, F. Martínez-Abella, "Shear strength of recycled concrete beams", Construction and Building Materials, Vol. 21, Issue 4, pp. 887-893, 2007. https://doi.org/10.1016/j.conbuildmat.2005.12.018

[26] American society of testing and materials (ASTM), "Standard test method for compressive strength of hydraulic cement mortars (using 50-mm cube specimens)", ASTM C-109, West Conshohocken, PA., 2002. https://doi.org/10.1520/c0109_c0109m-01

[27] American society of testing and materials (ASTM), ASTM C-136, West Conshohocken, PA., 2001. https://doi.org/10.1002/ep.670180104

[28] American society of testing and materials (ASTM), ASTM C191, West Conshohocken, PA., 2005. https://doi.org/10.1002/0471740039.vec0155

[29] Iraqi Standard No. (45) for the aggregation of natural resources, 1984.

[30] Standard specification for chemical admixtures for concrete, ASTM C494, Developed by Subcommittee: C09.23 Book of Standards Volume: 04.02.