International Conference on Advances in Structural and Geotechnical Engineering

ICASGE'17

27-30 March 2017, Hurghada, Egypt

Shear Strength of Fiber Reinforced Concrete Beams Made of Recycle Aggregate

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ABSTRACT

This paper presents the findings of an experimental program conducted in order to investigate the shear behavior of fiber reinforced concrete beams made of recycled aggregate. The studied parameters were the replacement ratio of the recycled aggregate (15, 30 and 45%) and the fiber volumetric ratio (1, 1.5 and 2%). Thus, a total of six simply supported recycled concrete beams along with one control conventional beam, with shear span-to-depth ratio of 2, were prepared and tested under incremental static loading. The studied criteria were the mid-span deflection, crack pattern, failure mode and shear strength. It was noticed that the crack patterns of all beams having recycled aggregate were similar to that for conventional concrete beam. Furthermore, at the same loading level, it was observed that the mid-span deflection increased when replacement ratio of recycled aggregate increased. It could be concluded that the shear strength decreased when the replacement ratio of recycled aggregate increased, however, the shear strength increased with increasing the fiber volumetric ratio.

Keywords: Recycled aggregate concrete, Shear strength, Shear strain, Fiber.

INTRODUCTION

Nowadays, the amount of demolition waste resulting from concrete buildings is becoming an environmental problem. Thus, recycling of concrete represents a new way to get a new resource from the demolitions' waste of concrete. It is well known that coarse aggregate represents about 75% of concrete volume where it is the main component which affects strength and the overall performance of concrete member. Consequently, any investigation conducted on recycled aggregate concrete should be influenced by replacement ratio of the recycled aggregate in mix. Many investigations have been conducted to study the feasibility of using recycled aggregate in concrete and particularly its influence in shear behavior that feature the aggregate interlock effect [1-11]. It was concluded that there was no agreement on constant relation between shear strength and the replacement ratio of recycled aggregate.
Katkhuda and Shatarat [12] carried out a treatment technique on recycled aggregate by soaking it in hydrochloric acid (HCL) for 24 hours then impregnated with sodium metasilicate pentahydrate solution for one hour. The hydrochloric acid (HCl) removed the adhere mortar on recycled and the sodium metasilicate pentahydrate solution filled the pores which increased the compressive strength as well as the shear strength. Sadati et al. [13] studied the shear behaviour of recycled aggregate beam made with high volume fly ash. Kim et al. [14] investigated the size effect of recycled aggregate beams. The test results showed that the shear strength of recycled aggregate beams decreased with increased effective depth.

The current paper presents an experimental program in order to study the effect of both replacement ratio of the recycle aggregate (15, 30 and 45%) and the volumetric ratio of the provided fiber (1, 1.5 and 2%) on the shear behavior of RC beams made of recycled aggregate.

EXPERIMENTAL PROGRAM

Test Specimens

The experimental work program consisted of one conventional reinforced concrete beam along with six reinforced concrete beams made of recycled aggregate contains different replacement ratios as well as different volumetric ratios of the provided short fibers as listed in Table 1. All beams had the same concrete dimensions where the total length was 2000 mm and the cross-sectional dimensions of 150 mm width by 300 mm total depth as shown in Fig. 1. The main steel of all beams were four high tensile steel bars of 16 mm diameter, while the secondary steel contained two high tensile steel bars of 16 mm diameter. The stirrups were made of mild steel bars of 8 mm diameter and spaced every 100 mm as shown in Fig. 1 where one shear span side was left unreinforced in order to eliminate the effect of the vertical stirrups from the shear resistance of all beams.

Table 1: Test Matrix

Group No.	Specimen	Replacement ratio (RCA %)	Fiber volume ratio (%)	Average compressive strength, f_{cu} (MPa)	Objectives
G1	BI-0-0	0%	0%	28.8	Reference beam
G2	BII-15-0	15%	0%	28.2	Studying the effect of replacement ratio of the recycled coarse aggregate
	BII-30-0	30%	0%	26.9	
	BII-45-0	45%	0%	25.2	
G3	B III-30-1	30%	1%	28.2	Studying the effect of volumetric ratio of the provided fiber
	B III-30-1.5	30%	1.5%	29.3	
	B III-30-2	30%	2%	31.9	

RCA%= Replacement ratio of the recycled coarse aggregate

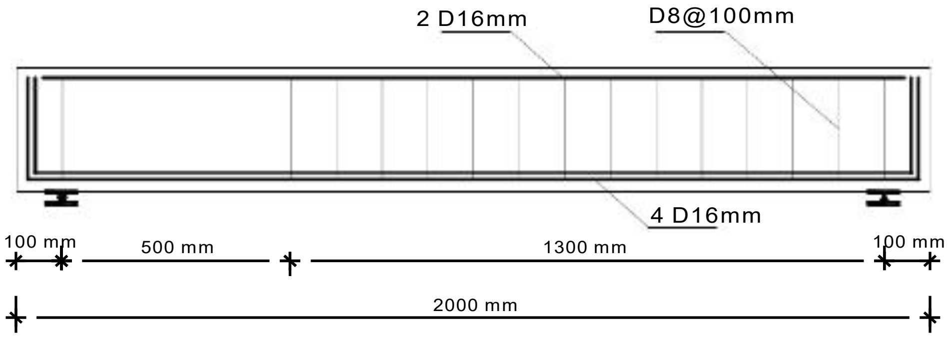


Fig. 1: Concrete dimensions and reinforcement.

Material properties

One natural aggregate concrete mix and six recycled aggregate concrete mixes were prepared in order to account for the studied variables as listed in Table 2. All mixtures have cement content of 350 kg and constant water to cement ratio of 0.5. The target compressive strength of all test mixtures was 25 MPa. Test mixtures have three recycled aggregate replacement ratio of 15, 30, and 45% and three volumetric ratios of polypropylene fiber that were implemented with replacement ratio of 30%. Three standard concrete cubes of side length of 150 mm were casted for each mix in order to determine the actual compressive strength for each beam at the testing day according to the Egyptian code of Practice (ECP 203-2007) [15] as given in Table 1. Compressive strength was adversely influenced by replacement ratio of recycled aggregate. It was noticed that the compressive strength decreases with increasing the replacement ratio of the recycled course aggregate. In addition, providing internal short fibers improves the compressive strength of recycled aggregate concrete cubes compared to that without internal fibers.

For the natural aggregate concrete, crushed dolomite was used as the coarse aggregate of a maximum aggregate size of 19 mm. On the other hand, the recycled aggregate was made by hand crushing of some collected tested cubes from the Reinforced Concrete and Heavy Weights Laboratory of the Structural Engineering Department, Faculty of Engineering, Tanta University. It is worth mentioning that the used cubes for producing the recycled aggregate were selectively chosen from cubes that gave an average concrete strength in the range of 25 to 30 MPa. After crushing the old cubes, the sieve analysis was conducted in order to choose the recycled aggregate passing from sieve No. ¾'' of the opening size of 19 mm. That is to have blended aggregate for different replacement ratio of the same maximum aggregate size. Fig. 2(b) shows the recycled aggregate after preparation to be used for different concrete mixes.


(a) Natural dolomite aggregate (b) Recycled coarse aggregate

Fig. 2: Coarse aggregates used for control conventional specimens as well as the specimens made of recycled aggregate for different replacement ratios.

Due to the high water absorption characteristics of the recycled coarse aggregate, it was concluded that the recycled aggregate should be wetted before using it in the concrete mix [16]. If the recycled aggregate is not humid, it would absorb water from the paste. Therefore, the design water content would be decreased leading to reduced workability. In the current study, the prepared recycled aggregate was spread on plastic sheet and then wet cured for about 24 hours before using it in the concrete mix.

Per each concrete mix, the weights of both natural coarse aggregate and the recycled aggregate were prepared and mixed manually as shown in Fig. 3. After that a conventional blade-type mixer was used for mechanical mixing of each specimen. The materials were poured into the mixer according to following sequence: half of cement weight and half of water weight were mixed until reaching a uniform consistency. And then, the fine aggregate was added and mixed into the rotating mixer drum for three minutes. After that, the remaining of cement and water weights were added and the mixing continued for another three minutes. Finally, the blended coarse aggregate (natural and recycled) was added while mixing was continued for until the patch become homogeneous. For the concrete mixes including fibers, after getting homogenous mixture of the concrete patch, typical polypropylene short fibers (Fiber mesh 300) were added to the rotating drum in a gradual manner until they were well-dispersed in the fresh concrete.


(a) Before mixing recycled to natural aggregate (b) After mixing recycled to natural aggregate

Fig. 3: Preparation of the blended coarse aggregate used for each mix.

Deformed steel bars of 420 MPa yield strength were used for both tensile and compressive longitudinal reinforcement while smooth bars of 270 MPa yield strength were used for vertical stirrups.

Table 2: Test Mix

Mix No.	Coarse aggregate			Fine Aggregate, kg	Cement, kg	W/C %	Fiber volumetric ratio %
	Natural, kg	Recycled, kg	RCA%				
Mix (1)	1279	0	0%	535	350	175	0%
Mix (2)	1087	192	15%	535	350	175	0%
Mix (3)	895	384	30%	535	350	175	0%
Mix (4)	703	576	45%	535	350	175	0%
Mix (5)	895	384	30%	535	350	175	1%
Mix (6)	895	384	30%	535	350	175	1.5%
Mix (7)	895	384	30%	535	350	175	2%

RCA%= Replacement ratio of the recycled coarse aggregate, W/C %= Water to cement ratio.

Test Setup and Instrumentation

All beam were tested under four point loading scheme where the shear-to-span ratio was kept constant for all beams, which equals to 2. At the un-reinforced shear span side, two Linear Variable Differential Transformers (LVDTs) of 100 measuring length were arranged at right angle in order to obtain the developed shear strain. In addition, one LVDT of 50 mm measuring length was in order to measure the developed mid-span deflection as shown in Fig. 4. The developed tensile normal strain on the main tensile steel was used by 6 mm gauge length strain gauge, while the two Pi gauges of 100 mm gauge length were used to measure the developed deformations on the concrete surface at both tension and compression sides as shown in Fig. 4. The beams were loaded incrementally at two points through a loading steel beam. Therefore in several steps the beam was loaded up to failure. The load on the beam was measured by a load cell of 400 KN capacity. After each loading step, the vertical mid-span deflections, the Pi-gauge readings, the developed normal strains in the longitudinal steel bars were recoded and stored using an automatic data logger unit (TDS-150).

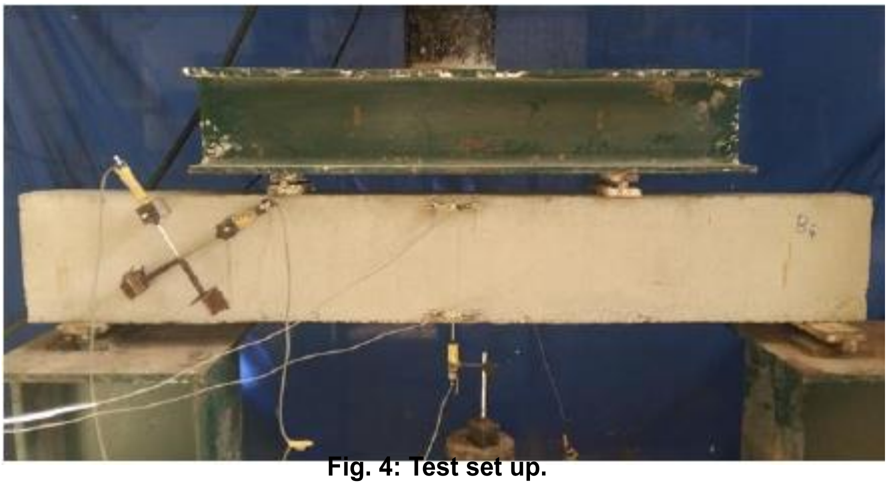


Fig. 4: Test set up.

RESULTS AND DISCUSSION

Table 3 summarizes the recorded experimental results for all beams. In addition, detailed analysis is conducted on the controlling failure criteria for all beams.

Table 3: Experimental results of beam specimens

Group No.	Specimen	$P_{cr,\,f}$ (kN)	$P_{cr,\,sh}$ (kN)		P_u (kN)	δ_{max} (mm)	$\varepsilon_{s\,max}$ (micro-strain)	W_{cr} (mm)	N
			Plain concrete side	Vertical stirrups side					
G1	BI-0-0	75	120	130	178	5.1	1711	1.523	3
G2	BII-15-0	69	111	119	164	6.37	1387	1.93	3
	BII-30-0	55	73	100	153	7.4	1362	2.12	3
	BII-45-0	39	71	92	144	7.92	2263	2.99	3
G3	B III-30-1	72	95	132	202	7.12	2987	1.9	4
	B III-30-1.5	74	98	135	205	6.07	2094	1.63	3
	B III-30-2	79	104	141	217	5.65	1044	1.51	3

$P_{cr,\,f}$ = First flexural cracking load, $P_{cr,\,sh}$= First shear cracking load, P_u= Failure load, δ_{max} = Maximum mid-span deflection, $\varepsilon_{s\,max}$ = Maximum tensile normal strain on the main tension steel, W_{cr}= Crack width for major shear crack at failure, N= Number of cracks.

Failure Modes and Cracks Patterns

Figure 5 shows crack patterns for all tested beams at failure. All beams started to exhibit flexural cracks at the mid-span zone. With further loading the flexural cracks spread on the tension side, then the flexural shear cracks appeared and became inclined towards neutral axis of the beam. Proceeding with loading resulted in the development of shear cracks at the unreinforced side of the beam and then started to show up at the reinforced side with vertical stirrups. Finally, the sudden shear failure controlled the failure mode for all beams at the side that did not provided by vertical stirrups. As listed in Table 3, increasing the replacement ratio of the coarse aggregate results in accelerating the appearance of both flexural and shear cracks. On contrary, providing internal fibers resulted in hindering the appearance of cracks compared to that of beam made of recycled aggregate with internal fibers.

Figure 6 shows the relationships between the jacking load and the major crack width for all specimens up to complete shear failure. The results showed that the crack width of recycled aggregate concrete beams became wider as the replacement ratio increased. Also, the crack width of recycled aggregate concrete beams with fiber decreased with increasing the fiber volumetric ratio owing to the bridge effect of discrete fibers.

Load deflection

Figure 7 shows the relationships between the Jacking load and the mid-span deflection for all beams. It could be noticed that increasing the replacement ratio of the coarse aggregate results in increase the mid-span deflection at the same loading level as depicted in Fig. 7(a). On contrary, increasing the volumetric ratio of the added internal short fibers results in decrease the mid-span deflection as depicted in Fig. 7(b). For both groups, it can be noticed that the relationship between the jacking load and the mid-span deflection is almost linear relationship till the occurrence of the sudden shear failure. Then, the resisting load dropped suddenly except that the beams provided by internal fibers showed some softening plateaus before failure owing to the bridging effect as depicted in Fig. 7(b). In addition, as the replacement ratio increases the ultimate capacity decreases for all beams of group II. The percentages of decreases are 8%, 14% and 19% respectively for beams BII-15-0, BII-30-0 and BII-45-0, respectively, compared to that of control beam BI-0-0. Whereas, providing internal short fibers led to increase the ultimate load comparing to that of recycled beam without fiber BII-30-0. The percentage of increases are 40%, 42% and 51%, respectively, for beams BIII-30-1, BIII-30-1.5, and BIII-30-1.5.

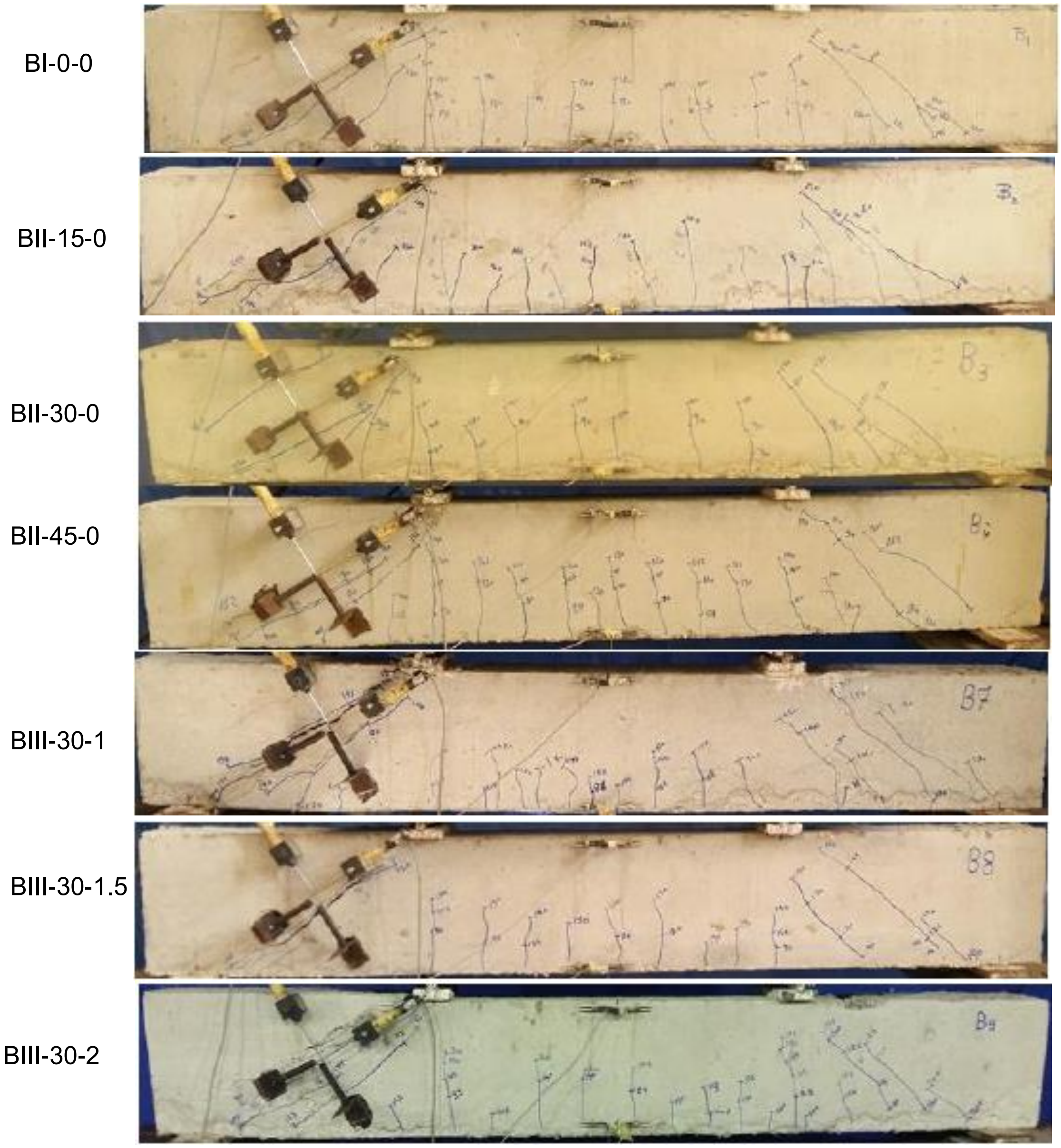
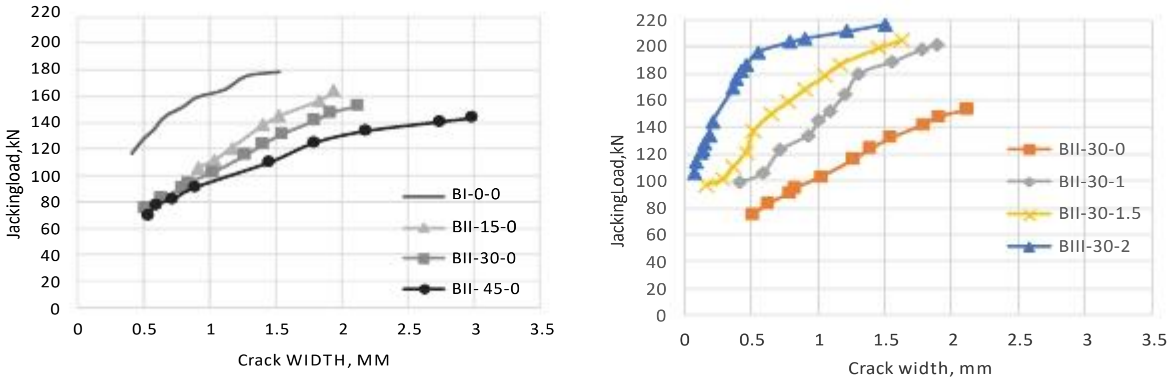


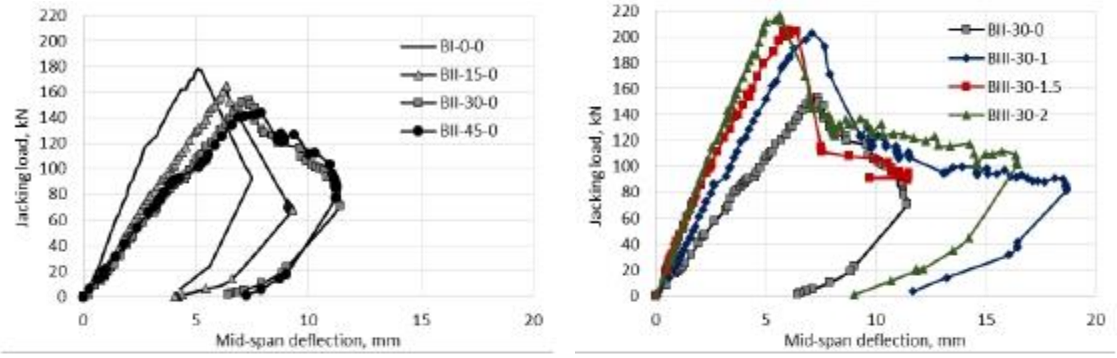
Fig. 5: Crack patterns of tested beams after complete failure.



(a) Group G2

(b) Group G3

Fig. 6: Experimental results of load with crack width



(a) Group G2 (b) Group G3

Fig. 7: Jacking load versus mid-span deflection for all beams.

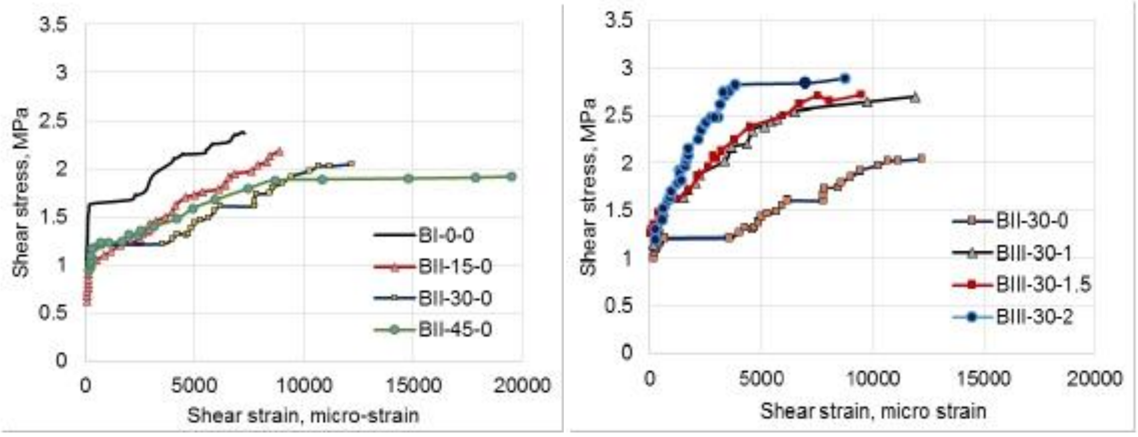
Shear Strain

For all specimens, the developed shear strains were measured using the sidemounted LVDTs as illustrated in Figs. 4 and 5 with the aid of Eq. 1 [17].

$$\gamma = \frac{\delta_2 - \delta_1}{\sqrt{L_2^2 + L_1^2}} \tag{1}$$

Where γ is the shear strain, δ_2 is the LVDT's readings in the direction parallel to the developed shear cracks, δ_1 is the LVDT's readings in the perpendicular direction, L_1 and L_2 are the distances between the fixed points of the LVDTs in the perpendicular and parallel directions of the shear cracks ($L_1 = L_2 = 200$ mm). The shear stress was calculated as the shear force divided by the beam's width times the beam's effective depth.

As shown in Fig. 8(a), increasing the replacement ratio of the coarse aggregate results in increase the developed shear strain. These increases are directly proportional to the replacement ratio. That could be attributed to the reduced effect of the aggregate interlock. On the other hand, for the same replacement ratio of 30%, increasing the volumetric ratio of the added short fibers results in decrease the developed shear strain significantly as depicted in Fig. 8(b). The decreased shear strain due to the added fiber is owing to the bridging effect of the internal fiber where this effect increases as the volumetric ratio of the added fiber increases as depicted in Fig. 8(b).



(a) Group G2 (b) Group G3

Fig. 8: Shear stress versus shear strain for all beams.

Shear capacity

In order to verify the effect of replacement ratio of the coarse aggregate on the ultimate shear strength of RC beams made of recycle aggregate, the experimental results are compared with the obtained results available in literature as depicted in Fig. 9. It could be noticed that as the replacement ratio increases the normalized shear strength exhibits scattered trend, which is illogical. The rational trend should be that as the replacement ratio of the coarse aggregate increases the shear strength would be decreased as the aggregate interlock decreases. The scattered trend of the previous results may be due to non-uniformity of the blended aggregate in concrete patch.

As for the current experimental study, the shear strength decreased as the replacement ratio of coarse aggregate increased. The percentages of decreases are 8%, 14% and 19%, respectively, for beams BII-15-0, BII-30-0 and BII-45-0 compared to that of control beam without recycled aggregate. In addition, the added short fibers showed enhanced effect on the shear strength since the shear strength exceeded the shear strength of the beam BI-0-0 without recycled aggregate. Furthermore, as the volumetric ratio of the internal fibers increased, the manifested shear strength increased. The percentages of increases are 13%, 15% and 22%, respectively for beams BIII-30-1, BIII-30-1.5 and BIII-30-2, respectively, compared to that of the beam BI-0-0 without recycled aggregate.

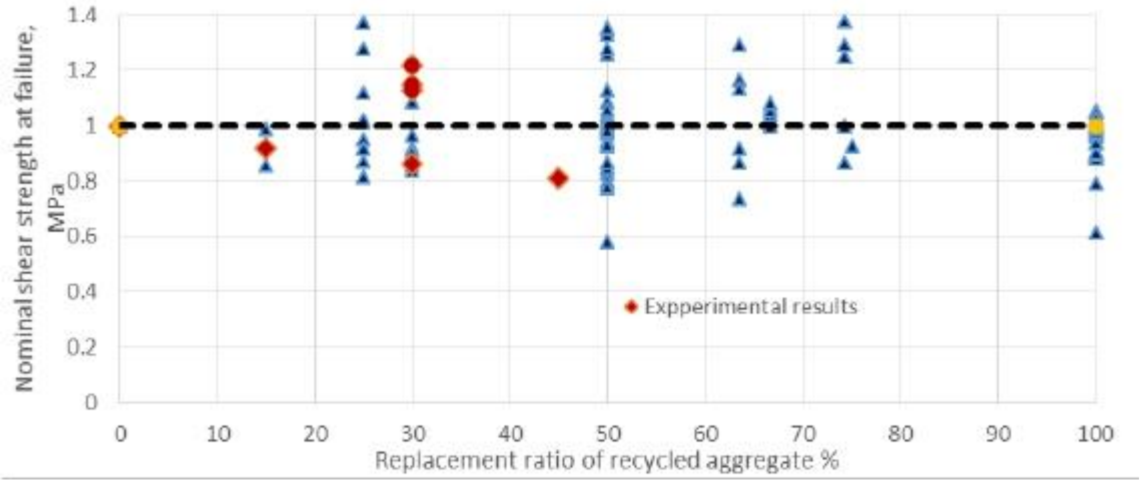


Fig. 9: Normalized shear strength versus replacement ratio of the coarse aggregate.

CONCLUSION

The effect of replacement ratio of recycled coarse aggregate and fiber volumetric ratio on the shear strength was investigated. Based on considered concrete dimensions, shear span-to-depth ratio (a/d = 2), replacement ratios of the coarse aggregate (15%, 30% and 45%) and the fiber volumetric ratios (1%, 1.5% and 2%) the following conclusions could be drawn:

1. The recycled coarse aggregate showed insignificant effect on the crack pattern and failure mode of reinforced concrete beams made of recycled aggregate. In contrary, it showed significant effect on the ultimate shear strength as well as the major crack width. Thus, the major crack width of recycled aggregate concrete beams becomes wider than that of the control beam owing to the weak bonding between the old cement paste covering the recycled aggregate and new mixture.
2. Increasing replacement ratio of the recycled coarse aggregate resulted in accelerating the appearance of both flexural and shear cracks compared to those of control virgin beam without any recycled aggregates.

3. Increasing the volumetric ratio of the added short fibers resulted in hindering the appearance of both flexural and shear cracks compared to that of the control beam made of recycled aggregate without any fibers.
4. Increasing the replacement ratio of the recycled coarse aggregate results in decrease the shear strength proportionally. However, the decreases in the shear strength could be compensated by providing internal short fibers. Accordingly, increase the volumetric ratio of the internal fibers resulted in increase the shear strength and decrease the corresponding major crack width compared with RC beam made of recycled aggregate without internal fibers.
5. Increasing the replacement ratio of the recycled aggregate resulted in decreasing the shear stiffness proportionally, where the shear strain increases significantly with increasing the replacement ratio of the recycled aggregate at the same shear stress level. On contrary, for the recycled aggregate beam, increasing the fiber volumetric ratio resulted in decreasing the shear strain at the same shear stress level.

REFERENCES

1. Singh, R., Bansal, N., and Bedi, K., (2015), "Shear Behavior of Recycled Beams", International Journal of Scientific & Engineering Research, Vol.6, pp. 879-888.
2. Li, C., Li, G., Shao, W., Guo, Q., Liu, R., (2013), "Shear-crack Behaviors of Reinforced Full-recycled Aggregate Concrete Beams", Applied Mechanics and Materials, Vol. 438-439, pp. 794-799.
3. Yun, H., You, Y., Lee, D., (2011), "Effects of Replacement Ratio of Recycled Coarse Aggregate on the Shear Performance of Reinforced Concrete Beams without Shear Reinforcement", LHI Journal, Vol. 2, pp. 471-477.
4. Al-Zahraa, F., El-Mihilmy, M., Bahaa, T., (2011), "Experimental Investigation of Shear Strength of Concrete Beams with Recycled Concrete Aggregates", Int. J. Materials and Structural Integrity, Vol. 5, pp.291-310.
5. Fonteboa, B., Abella, F., (2007), "Shear Strength of Recycled Concrete Beams", Construction and Building Materials, Vol. 21, pp. 887-893.
6. Fathifazl, G., Razaqpur, A., Isgor, O., Abbas, A., Fournier, B., Foo, S., (2011), "Shear Capacity Evaluation of Steel Reinforced Recycled Concrete (RRC) Beams", Engineering Structures, Vol. 33, pp. 1025-1033.
7. Asamoah, M., Ampofo, J., Afrifa, R., (2009), "Flexural and Shear Behaviour of Reinforced Concrete Beams made from Recycled Materials", Journal of Ghana Institution of Engineers, Vol. 6, pp.57-66.
8. Knaack, A., Kurama, Y., (2014), "Behavior of Reinforced Concrete Beams with Recycled Concrete Coarse Aggregates", Journal of Structural Engineering, Vol. 12, pp. 401-409.
9. Choi, H., Yi, C., Cho, H., Kang, K., (2010), "Experimental Study on the Shear Strength of Recycled Aggregate Concrete Beams", Magazine of Concrete Research, Vol.62, pp. 103-114.
10. Aly, S., Ibrahim, M., and Khattab, M., (2015), "Shear Behavior of Reinforced Concrete Beams Casted With Recycled Coarse Aggregate", European Journal of Advances in Engineering and Technology, Vol. 2, pp. 59-71.
11. Khergamwala, P., Singh, J., Kumar, R., (2016), "Experimental Study on Shear Behavior of Reinforced Recycled Aggregate Concrete Beams", International Journal of Civil Engineering and Technology, Vol. 7, pp. 128-139.
12. Katkhuda, H., and Shatarat, N., (2016), "Shear Behavior of Reinforced Concrete Beams Using Treated Recycled Concrete Aggregate", Construction and Building Materials, Vol. 125, pp. 63-71.
13. Sadati, S., Arezoumandi, M., Khayat, K., Volz, J., (2016), "Shear Performance of Reinforced Concrete Beams Incorporating Recycled Concrete Aggregate and High-Volume Fly Ash", Journal of Cleaner Production, Vol. 115, pp. 284-293.
14. Kim, S., Jeong, C., Lee, J., Kim, K., (2013), "Size Effect in Shear Failure of Reinforced Concrete Beams with Recycled Aggregate", Journal of Asian Architecture and Building Engineering, Vol., pp. 323-330.

15. Egyptian code for design and construction of reinforced concrete structures (ECP 203–2007); 2007.
16. Etxeberria, M., Vazquez, E., Mari, A., Barra, M. (2007), “Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete” Journal of Cement and Concrete Research, Vol. 37, pp. 735-742.
17. Khaja, M. N., Sherwood, E. G. (2013), “Does the shear strength of reinforced concrete beams and slabs depend upon the flexural reinforcement ratio or the reinforcement strain? Canadian Journal of Civil Engineering, Vol. 40, pp. 1068–1081.