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Behavior of Lightweight Coarse Aggregate RC Beams with Circular Opening

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Abstract: This pressent research investigates the mechanical properties of Waste Rubber Fibers Lightweight Coarse Aggregate Concrete (WRFLWAC) mixture. Also, the shear behaviors of 12 RC beams contain opening are investigated. The main study parameters are: The opening location, the waste rubber fiber ratio and the shear reinforcement. Deflection values and cracks are registered at each load step; also the cracking or service and failure loads are recorded. The existing of an opening in beams lessens the strength and shear and flexural rigidity of beams with a percentage depending on the position of opening, shear reinforcement and waste rubber fiber ratio. The position of opening influence the strength of tested beams and the most critical case noticed when the opening made near the support. The increase in waste rubber ratio is found to be significant on service (cracking) and ultimate loads of tested concrete beams. The numerical (finite element) technique is used trace the behavior with increasing opening size. It is find that the service (cracking) and ultimate loads decreased with increasing opening size. The laboratory and analytical results are obtained to be in good agreements.

Keywords: Beams, Experimental, Finite Elements Lightweight, Opening, Reinforced Concrete, Rubber Fiber

Introduction

There are very serious problems with the disposal of waste tires in Iraq. Waste tires were used in concrete previously through chips and fibers forms. There was a decrease in the concrete compressive strength as stated by previous researchers; however there was growing in the concrete toughness. It was concluded by previous studies that waste tire fibers were more suitable as additives than waste tire chips this is due to the highest toughness they produce.

Opening in is a facility made in beams to allow for the utility line to pass through the structure. This method helps the designer to reduce the height of the building story and as a result thee structure which leads to reduce the construction cost. The boundary of the opening is under the condition of stress concentration as a result of sudden changes in the cross section of the beam and this will leads to increase transverse cracks in the beam.

Vengatachalapathy and Ilangovan (2010) tried to trace the behavior and the magnitude of ultimate load of steel fiber RC deep beams having openings and subjected to two-point loading experimentally. Nine concrete beams were tested to failure by applying monotonic increased load. The obtained results showed that the beam behavior is affected by the opening locations and the amount of horizontal reinforcement, which is either in the form of steel discrete fibers or as continuous steel reinforcement.

Arshi *et al.* (2012) carried out experimental tests on reinforced concrete beams with circular openings. About 11 beams with simple supports and having openings near the beam support (at the shear span) were tested using four point loading procedure. The test variables were opening dimensions, openings location and shear span to effective depth ratio. The obtained laboratory results showed linear reduction in the beams ultimate strength for increased size of openings.

The effect of opening with circular shape on the behavior and failure loads of beams was investigated by Saksena and Patel (2013). The increase of openings size and locations are the frontier parameters of their study. The results showed that, the addition of diagonal and shear reinforcement at top and bottom of opening is more significant.

Experimental Program

Properties of Materials

Ordinary Portland Cement (OPC) (Type-I) conform to the Iraqi Specification No. 5, (1984) is used in the present study.

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Natural sand was used in the concrete mix. The sand has maximum aggregate size of (4.75 mm) with fineness modulus of (2.84). The fine aggregate sulfate content and grading conform to the Iraqi Specification No. 45, (1984).

Local crushed clay brick in Iraq was used as coarse aggregate. The units were firstly crushed into smaller size by means of hammer and jaw crusher was used to give the finished product of (12.5 mm) maximum size. Then the crushed brick were sieved on a standard sieve.

Waste rubber fibers were prepared from old vehicle tire. The rubber fibers were shredded to a size of 5×10 mm. The fibers were added to concrete at ratio of 0 and 0.5% by weight of concrete to form the Waste Rubber Fiber Lightweight Aggregate Concrete (WRFLWAC).

Tensile test of steel reinforcement was carried out on (φ6 and φ12 mm) steel bars. The results of tensile test for bars confirmed with the ASTM A615 (2005).

Master Glenium 51 which is a high performance super plasticizer concrete admixture was used in this research. It satisfy the requirements for super plasticizer according to ASTM C 494 (2005) Type F. The main purpose for adding super plasticizer is to improve workability, facilitates extreme water reduction, flow ability and increase the strength of concrete.

Properties of Concrete

Material Proportion

The strengths of concrete beams are obtained in accordance with trail mixes of (25 MPa) nominal 28-day cylinder compressive strength of. Mixture details are given in Table 1. It was found that the used mixtures produce good workability and uniform mixing of concrete without segregation. M_1 is used for beam numbers 1 to 3 and 7 to 9 while M_2 is used for beam numbers 4 to 6 and 10 to 12.

Mechanical Properties of Hardened Concrete

Compressive Strength

The cube compressive strength of concrete (f_{cu}) test was carried out in accordance with BS1881-116 (1997), using (150 mm) cubes to estimate the compressive strength. The cylinder compressive strength of concrete $\left(f_c^{'}\right)$ test was carried out in accordance with ASTM C 39 (2004), using (150×300 mm) cylinders to estimate the compressive strength. The results, of both cube and cylinder compressive strengths, are given in Table 2. The cube and cylinder compressive strength for lightweight concrete is increased by 10 and 6% respectively when 0.5% of rubber fibers are used.

Splitting Tensile Strength (f_{ct})

The splitting tensile strength tests were performed on concrete specimens in accordance with ASTM C 496 (2004). Split cylinder strength tests were made on 2 (150×300 mm) cylinders. Table 3 represents the splitting tensile strength for the concrete specimens and the values obtained by ACI Committee 318 (2011) code equations. As given in Table 3, the ACI equation for normal aggregate concrete overestimates the split tensile strength of lightweight aggregate concrete by approximately 11 and 21% for concrete with and without rubber fibers respectively. A modification factor (λ) equal to 0.887 and 0.803 can be used to obtain light weight aggregate concrete tensile strength from ACI equation for concrete with and without rubber fibers respectively. The splitting tensile strength for lightweight concrete is increased by about 15% when rubber fibers are used.

Modulus of Rupture (f_r)

Concrete prisms of dimensions (100*100*400 mm) were casted according to ASTM C 78 (2002) specification. Table 4 represents the modulus of rupture strength for the concrete specimens and the values obtained by ACI Committee 318 (2011) code equation. As given in Table 4, the ACI equation underestimates the modulus of rupture of lightweight aggregate concrete by approximately 23 and 26% for concrete with and without rubber fibers respectively. The modulus of rupture strength for lightweight concrete is increased by 10% when 0.5% of rubber fibers are used.

Modulus of Elasticity (E_c)

The test was performed according to ASTM C 469 (2002) specifications using concrete cylinders of dimensions (150×300 mm). The cylinders are examined by applying compression stress at constant strain. As given in Table 5, the ACI equation overestimates the modulus of elasticity of lightweight aggregate concrete by approximately 5 and 8% for concrete with and without rubber fibers respectively. The modulus of elasticity strength for lightweight concrete is increased by 7% when rubber fibers are used.

Testing of Beams (Two Point Flexural Test)

After curing for 28 days, the WRFLWAC beams are ready to perform four point flexural test to investigate the behavior of the twelve concrete beams with different opening locations, shear reinforcement and rubber fiber ratios as shown in Table 6. The beams were designed in accordance with ACI Committee 318 (2011) Code. The main reinforcement consisted of (2 φ 12 mm) and compression reinforcement of (2 φ 6 mm). Each beam had 10 stirrups of (φ6 @170 mm c/c). Figure 1 shows the reinforcement arrangement of the beams. The opening size kept constant with diameter equal to 100 mm.

Table 1. Properties of concrete mixes

	M_1	M_2
Cement (kg/m^3)	450.00	450.0
Fine aggregate (kg/m^3)	400.00	400.0
Lightweight coarse aggregate (LWA) (kg/m^3)	600.00	600.0
Water/cement ratio	0.35	0.35
Super plasicizer (% by weight of cement)	0.60	0.8
Waste rubber fibers (%)	0.00	0.5
Density (γ_c)(kg/m^3)	1930.00	1940.0

Table 2. Compressive strength of WRFLWAC at 28 days

Beam No.	1	2	3	4	5	6	7	8	9	10	11	12
f_{cu} (MPa)	31	30	31	33	34	33	30	31	30	34	35	33
$f_c^{'}$ (MPa)	24	23	24	25	26	24	23	23	23	25	26	25
$\frac{f_c^{'}}{f_{cu}}$	0.78	0.76	0.77	0.76	0.76	0.73	0.77	0.74	0.77	0.73	0.74	0.76

Table 3. Splitting tensile strength

Beam no.	f_{ct} (MPa)	$f_c^{'}$ (MPa)	$f_{ct} = 0.56\sqrt{f_c^{'}}$ (MPa)	$\lambda = \frac{f_{ct})\exp}{f_{ct})ACI}$
1	2.20	24	2.74	0.80
2	2.15	23	2.69	0.79
3	2.23	24	2.74	0.81
4	2.52	25	2.80	0.90
5	2.55	26	2.86	0.89
6	2.49	24	2.74	0.91
7	2.19	23	2.69	0.81
8	2.15	23	2.69	0.80
9	2.18	23	2.69	0.81
10	2.44	25	2.80	0.87
11	2.53	26	2.86	0.88
12	2.43	25	2.80	0.87

Table 4. Modulus of rapture strength

Beam no.	f_r (MPa)	$f_c^{'}$ (MPa)	λ	$f_r = 0.62\lambda\sqrt{f_c^{'}}$ (MPa)	$\frac{f_r)ACI}{f_r)\exp}$
1	3.30	24	0.80	2.43	0.74
2	3.25	23	0.79	2.35	0.72
3	3.24	24	0.81	2.46	0.76
4	3.62	25	0.90	2.79	0.77
5	3.63	26	0.89	2.81	0.77
6	3.54	24	0.91	2.76	0.78
7	3.21	23	0.81	2.41	0.75
8	3.25	23	0.80	2.38	0.73
9	3.32	23	0.81	2.41	0.73
10	3.51	25	0.87	2.70	0.77
11	3.54	26	0.88	2.78	0.79
12	3.49	25	0.87	2.70	0.77

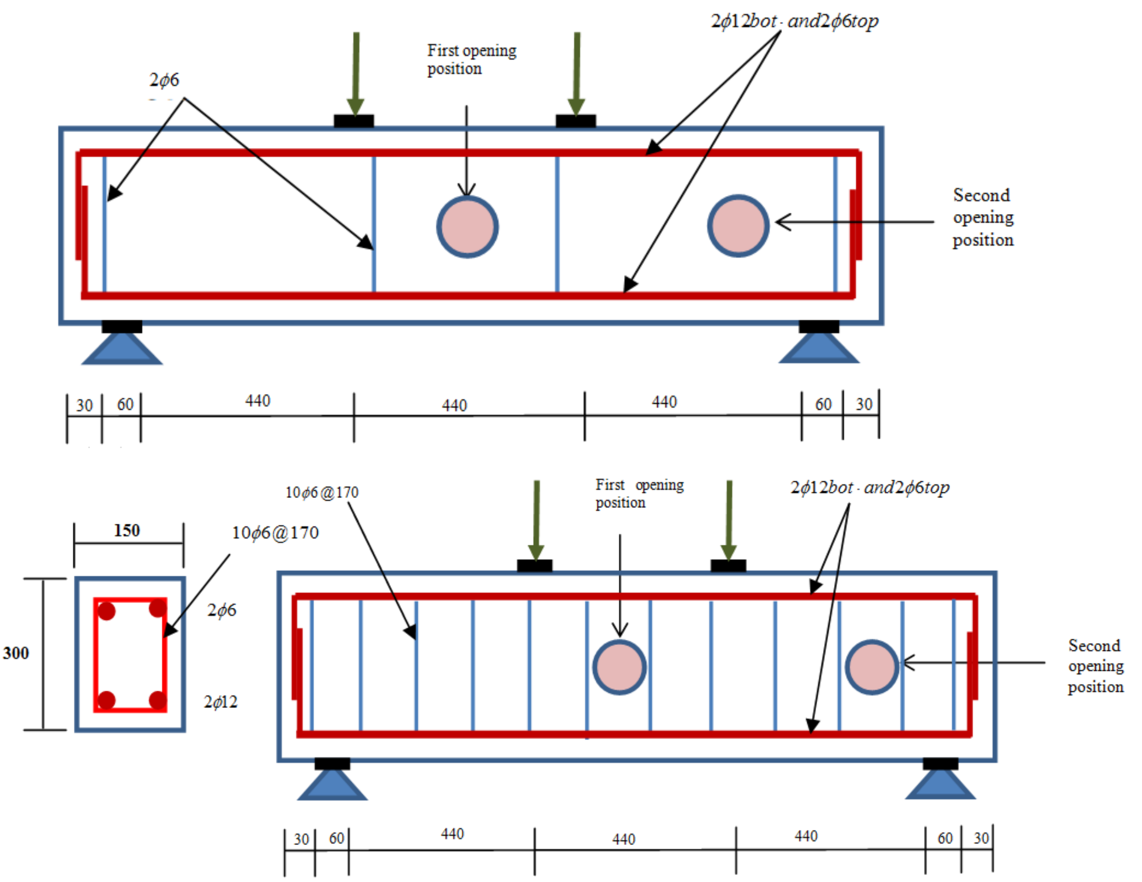
Table 5. Modulus of elasticity

Beam no.	E_c (GPa)	$f_c^{'}$ (MPa)	γ_c (kg/m^3)	$E_c = \gamma_c^{1.5} 0.043\sqrt{f_c^{'}}$ (GPa)	$\frac{E_c)ACI}{E_c)\exp}$
1	16.33	24	1930	17.86	1.09
2	16.12	23	1934	17.54	1.08
3	16.35	24	1933	17.90	1.09
4	17.32	25	1943	18.41	1.06
5	17.56	26	1942	18.76	1.06
6	17.22	24	1944	18.06	1.05
7	16.19	23	1933	17.53	1.08
8	16.23	23	1932	17.51	1.08
9	16.15	23	1934	17.54	1.09
10	17.44	25	1939	18.36	1.05
11	17.88	26	1943	18.78	1.05
12	17.55	25	1944	18.49	1.05

Table 6. Designation and properties of test specimens

Group no.	Beam no.	Specimen designation	Opening location	Shear reinforcement	Rubber fiber percentage	Cylinder compressive strength (MPa)
1	1	SR0-F0	without			24
	2	OMR0-F0	at mid span		0	23
	3	ODR0-F0	near the support	without		24
	4	SR0-F1	without			25
	5	OMR0-F1	at mid span		0.5	26
	6	OSR0-F1	near the support			24
2	7	SR1-F0	without			23
	8	OMR1-F0	at mid span		0	23
	9	ODR1-F0	near the support	with		23
	10	SR1-F1	without			25
	11	OMR1-F1	at mid span		0.5	26
	12	ODR1-F1	near the support			25

where,
S: Concrete beam without opening
O: Concrete beam with opening
M: Opening at mid span
D: Opening near the support
R0: Without shear reinforcement
R1: With shear reinforcement
-F0: Without rubber fiber
-F1: With rubber fiber
FE: Finite elements



Note: all dimensions are in mm

Fig. 1. Details of tested beams

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Finite Element Analysis

The finite element analysis has been performed to study samples of tested beams. ANSYS release (15.0) computer program is used for this purpose. In the analysis, LINK180 element was utilized to model the discrete steel reinforcement bars. This element is a 3 dimensional truss element and it has two nodes with 3% of freedom per node. SOLID65 element was utilized to model the concrete material. The element has 8 nodes with 3% of freedom per node. The element is capable of tracing nonlinear concrete material properties as shown in Fig. 2. Perfect bond between the concrete and steel reinforcement considered.

Experimental and Finite Element Results

Photographs of the tested beams are shown in Fig. 3 and the test results are given in Table 7. The general cracking pattern and behavior were similar for all beam specimens with no shear reinforcement (group 1) (with and without fibers) which are failed in shear with diagonal tension mode of failure. Figure 3 shows the crack patterns and mode of failure. The crack pattern development shows short vertical flexural cracks in the shear span of the beam and then the cracks propagate in curved lines to the beam compression face towards the pure moment zone. Finally, failure occurs quite suddenly. The ultimate load capacity of the tested beams in this group exceeds the cracking load capacity by an amount varying from 30 to 42% for different opening position and rubber fiber ratio. Figures 4 and 5 show the applied load versus the mid span deflection of group 1. It can be observed from these curves that the beams without shear reinforcement exhibits almost linear behavior until first inclined shear cracking occur. After first inclined shear cracking occur the strength and deformation of specimens start to differ because of the change in the fiber ratio and opening position. The effect of fiber was in increasing cracking and ultimate loads and delay failure and the crack pattern show more flexural cracks. Good agreement between laboratory and finite element load deflection curves for the studied case.

All beam specimens in the group of beams with shear reinforcement (group 2) are failed in shear compression mode of failure. Figure 3 shows the crack patterns and mode of failure. The crack pattern development shows vertical flexural cracks at the bottom of the beam. At shear span inclined shear cracking observed and cracks propagate in curved lines to the beam compression face towards the pure moment zone. Finally, failure occurs is gradually because of the yielding of stirrups allows the inclined shear crack to be more wide. The ultimate shear capacity of the tested beams in this group exceed the inclined shear cracking capacity by an amount varying from 50 to 60% for different core position and fiber ratio. Mid span deflection of tested beams in this group are shown in Fig. 6 and 7. These plots show that beams with shear reinforcement exhibits both linear and nonlinear behavior and this due to the ductility provided by shear reinforcement associated when first cracking occur. Also, the strength and deformation of specimens start to differ because of the change in the fiber ratio and opening position. The effect of fiber here is more significant in increasing cracking (service) and ultimate loads and delay failure and the crack pattern show more flexural cracks.

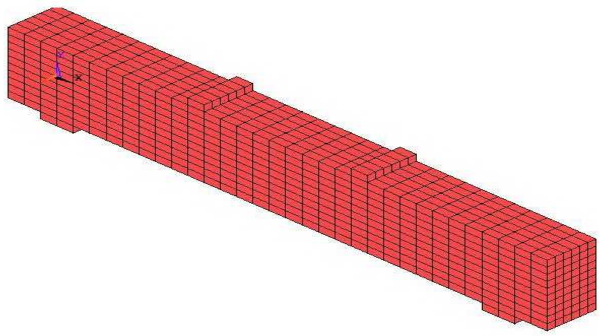

Fig. 2. Finite element mesh

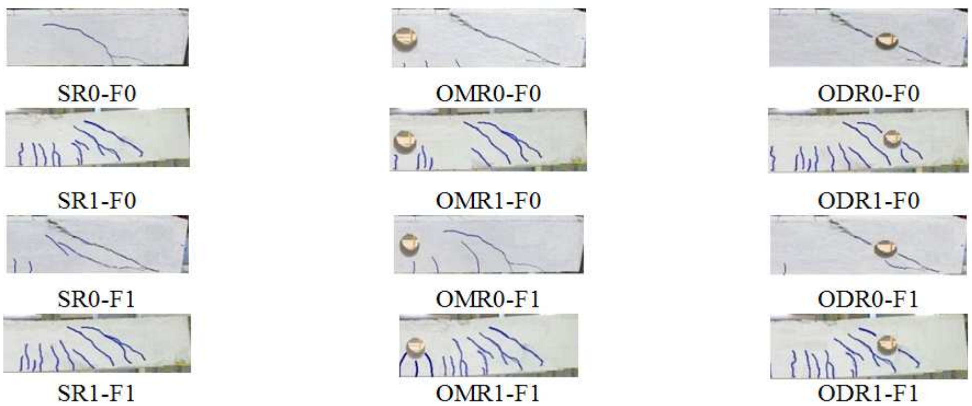

Fig. 3. Crack patterns for the tested beams

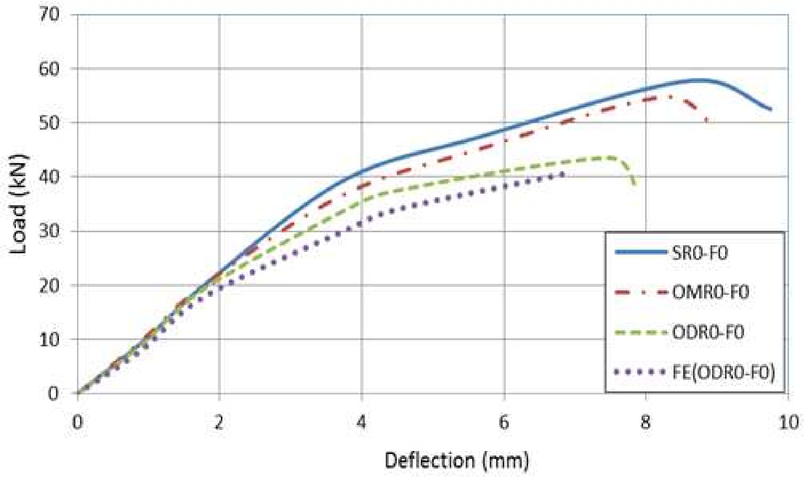

Fig. 4. Load mid span deflection curves for beams without shear reinforcement (no rubber fibers)

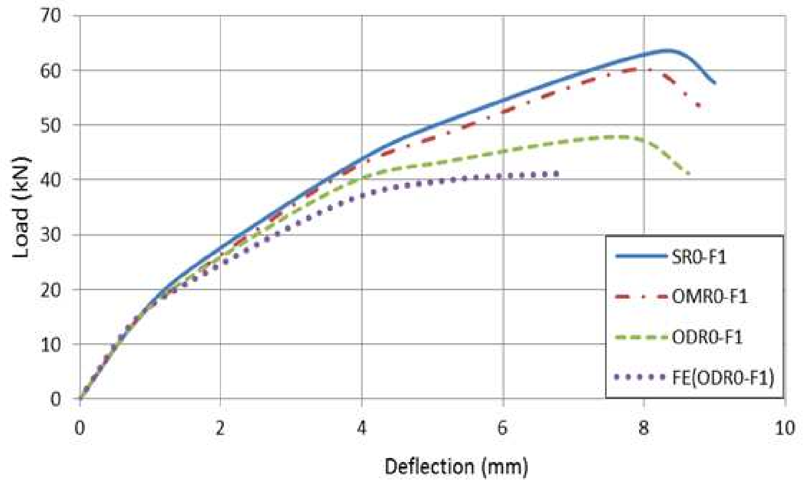

Fig. 5. Load mid span deflection curves for beams without shear reinforcement (0.5% rubber fibers)

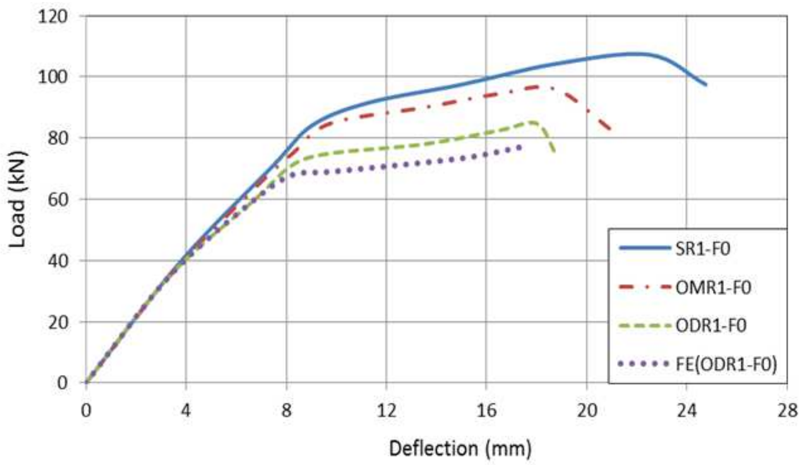

Fig. 6. Load mid span deflection curves for beams with shear reinforcement (no rubber fibers)

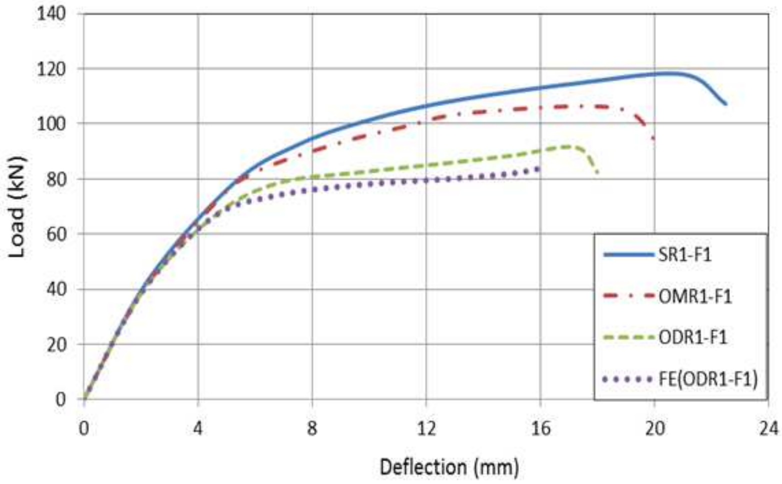

Fig. 7. Load mid span deflection curves for beams with shear reinforcement (0.5% rubber fibers)

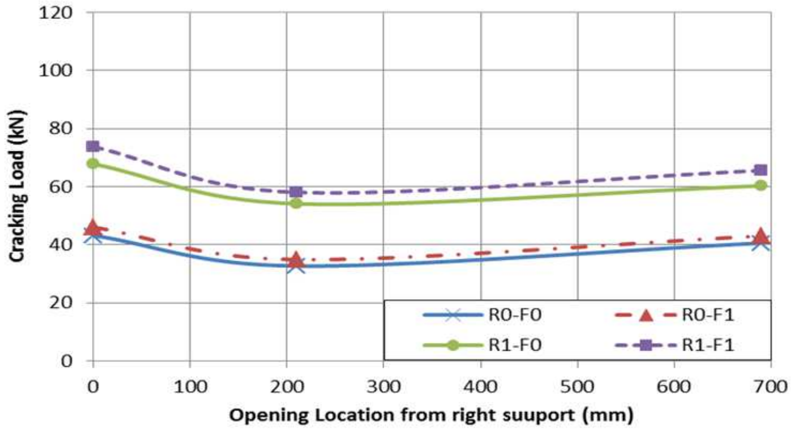

Fig. 8. Effect of opening location on cracking load

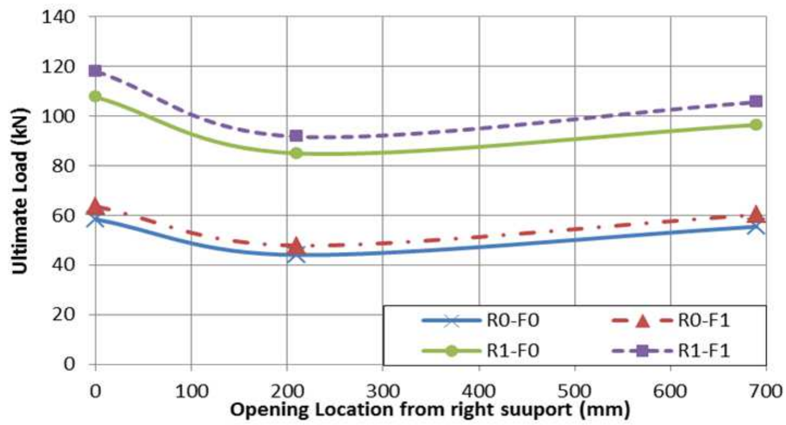

Fig. 9. Effect of opening location on ultimate load

Good agreement between laboratory and finite element load deflection curves for the studied case. The difference between experimental and finite elements results for all tested beams in terms of cracking (service) load, ultimate load and ultimate deflection are 4.5, 7 and 10% respectively as shown in Table 7.

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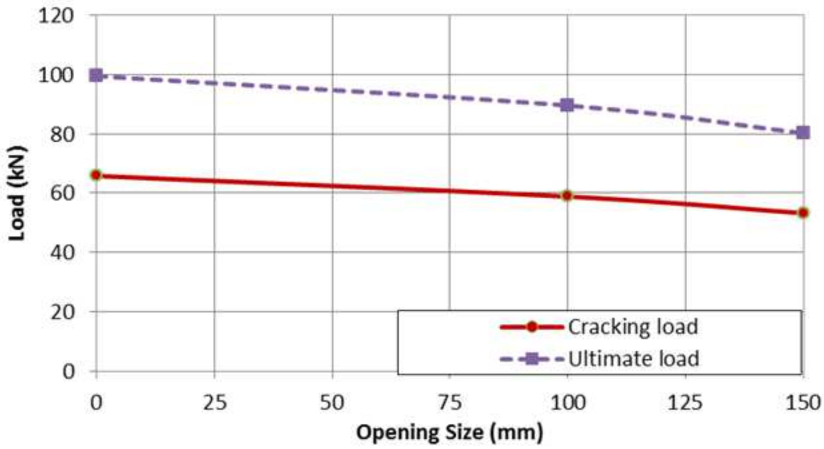

Fig. 10. Effect of opening size located at mid span on cracking and ultimate loads for beams with stirrups

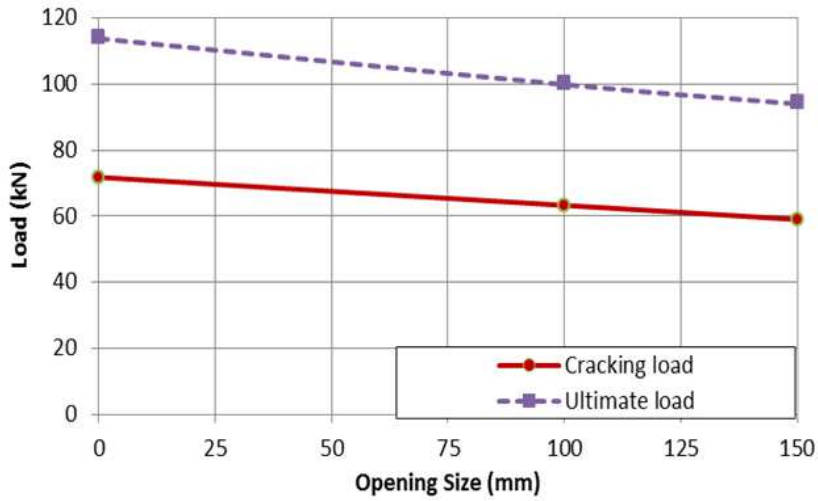

Fig. 11. Effect of opening size located at mid span on cracking and ultimate loads for beams with stirrups

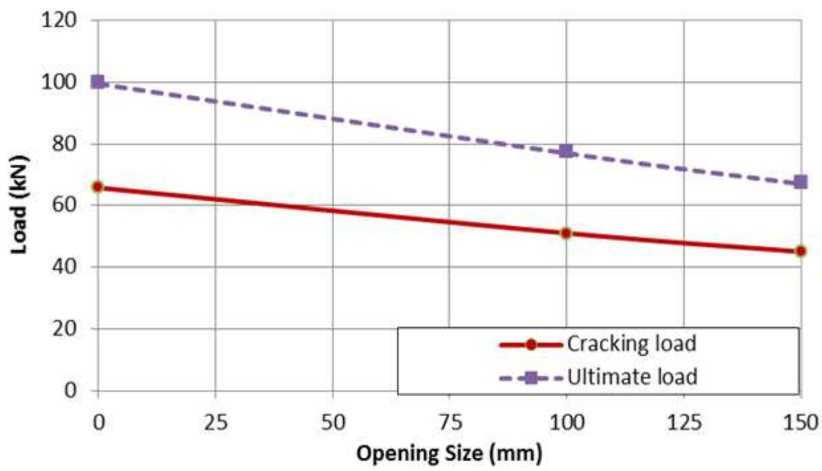

Fig. 12. Effect of opening size located near the support on cracking and ultimate loads for beams with stirrups

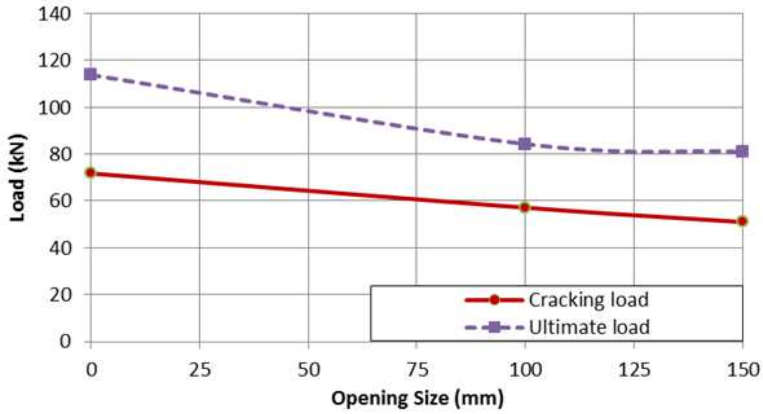

Fig. 13. Effect of opening size located near the support on cracking and ultimate loads for beams with stirrups

Table 7. Experimental and finite elements results of tested beams

Beam designation	Experimental results				Finite elements results		
	P_{cr} (kN)	P_u (kN)	Δ_{cr} (mm)	Δ_u (mm)	P_{cr} (kN)	P_u (kN)	Δ_u (mm)
SR0-F0	43.22	58.35	4.8	8.63	40.11	53.23	7.57
OMR0-F0	40.61	55.42	3.91	8.26	37.26	50.64	7.39
ODR0-F0	32.71	44.02	3.62	7.89	30.53	40.69	6.91
SR0-F1	46.03	63.52	5.28	8.27	44.24	60.78	7.22
OMR0-F1	43.02	60.22	5.05	7.88	42.55	57.76	6.95
ODR0-F1	34.92	47.85	4.41	7.72	31.99	43.88	6.99
SR1-F0	67.8	107.62	6.17	22.56	65.77	99.49	20.77
OMR1-F0	60.3	96.45	4.52	18.84	58.8	89.52	16.86
ODR1-F0	54.12	84.97	4.02	18.08	51.04	76.95	17.31
SR1-F1	73.73	117.97	6.79	21.1	71.78	113.83	19.54
OMR1-F1	65.58	105.6	5.98	18.78	63.28	99.88	17.5
ODR1-F1	58.05	91.72	5.19	17.78	57.15	84.33	16.22

Where:
P_{cr}: Load at first shear cracking (kN); P_u: Ultimate load capacity (kN)
Δ_{cr}; Δ_u: Cracking deflection at mid span at first cracking (service) and ultimate deflection in (mm) respectively.

From Table 7, it is recognized that the highest ultimate load is the load of beam (SR1-F1) with no opening and of 0.5% of rubber fiber and with shear reinforcement. This means that the opening exist in any specimen reduced the beam strength despite of its location and the most critical case is when the opening is near the support as shown in Fig. 8 and 9. If the opening in beams is near the support it will reduce the strength from 20-25% for all tested beams and, if the opening is at mid span it will reduce the strength from 5-10% for all tested beams. It is recommended to use waste rubber fibers and if necessarily, opening must be made in beams far from the expected failure location as the rubber fibers increase cracking (service) and ultimate loads.

Figure 10 to 13 show the results obtained from finite elements for changing opening size for beams having shear reinforcement. It is obvious that increasing opening size from 0 to 150 mm for opening located at mid span will decrease the cracking (service) and ultimate loads by about 20% for the case of no fibers and 16% for the case of using fibers. For opening located near the support, the increase of opening size from 0 to 150 mm will decrease the cracking (service) and ultimate loads by about 32% for the case of no fibers and 28% for the case of using fibers as the fiber ratio is low.

Conclusion

Based on the results obtained from the experimental work and finite element analysis of the WRFLWAC beams, the following points are concluded:

- The cube and cylinder compressive strength for lightweight concrete is increased by 10 and 6% respectively when 0.5% of waste rubber fibers are used
- The ACI equation for normal aggregate concrete overestimates the split tensile strength of lightweight aggregate concrete by approximately 11 and 21% for concrete with and without rubber fibers respectively. The splitting tensile strength for lightweight concrete is increased by 15% when rubber fibers are used

- The ACI equation underestimates the modulus of rupture of lightweight aggregate concrete by approximately 23 and 26% for concrete with and without rubber fibers respectively. The modulus of rupture strength for lightweight concrete is increased by 10% when 0.5% of rubber fibers are used
- The ACI equation overestimates the modulus of elasticity of lightweight aggregate concrete by approximately 5 and 8% for concrete with and without rubber fibers respectively. The modulus of elasticity strength for lightweight concrete is increased by 7% when rubber fibers are used
- The group of beams with no shear reinforcement is failed in shear with diagonal tension mode of failure. The ultimate shear capacity of the tested beams in this group exceed the inclined shear cracking capacity by an amount varying from 30 to 42% for different opening position and fiber ratio. The effect of fiber was in increasing cracking (service) and ultimate loads and delay failure and the crack pattern show more flexural cracks
- The group of beams with shear reinforcement is failed in shear with shear compression mode of failure. The ultimate shear capacity of the tested beams in this group exceed the inclined shear cracking capacity by an amount varying from 50 to 60% for different opening position and fiber ratio. The strength and deformation of specimens start to differ because of the change in the fiber ratio and opening position. The effect of fiber here is more significant in increasing cracking (service) and ultimate loads and delay failure and the crack pattern show more flexural cracks
- The absence of shear reinforcement changes the failure mode from ductile shear compression failure to diagonal tension failure. Also, the cracking (service) load and ultimate load are reduced by 30 and 40% respectively for the case with no shear reinforcement
- Good agreement between Good agreement between laboratory and finite element load deflection curves for the studied case. The difference between experimental and finite elements results in terms of cracking (service) load, ultimate load and ultimate deflection are 4.5, 7 and 10% respectively
- The opening in all specimens reduced the beam strength despite of its location and the most critical case is when the opening is near the support. The existing of opening near the beam support reduces the strength from 20-25% for all tested beams. While, the opening at mid span reduces the strength from 5-10% for all tested beams
- In finite elements, the increase opening size from 0 to 150 mm for opening located at mid span will decrease the cracking (service) and ultimate loads by about 20% for the case of no fibers and 16% for the case of using fibers. For opening located near the support, the increase of opening size from 0 to 150 mm will decrease the cracking (service) and ultimate loads by about 32% for the case of no fibers and 28% for the case of using fibers as the fibers percentage is low

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Ethics

This article is original. Author declares that are no ethical issues that may arise after the publication of this manuscript.

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