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Behavior of hybrid concrete beams with waste rubber

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Abstract. The studies on the applications of waste materials in concrete have been increased in Iraq since 2003. In this research, rubber wastes that resulting from scrapped tires was added to concrete mix with presence of superplasticizer. The mechanical properties of concrete and workability of concrete mixes were studied. The used rubber were ranging in size from (2-4) mm with addition percentages of (0.1% and 0.2%) by volume of concrete. The results of mechanical properties of concrete show that rubber enhance the ductility, and compressive and tensile strength compared to concrete without it. Also, the flexural behavior of hybrid strength concrete beams (due to using rubber at the bottom or top layer of section) was investigated. The rubber concrete located at bottom layer gives higher values of ultimate loads and deflections compared to the beam with top layer. A similar response to fiber concrete beam (all section contains 0.1% rubber) was recognized. Finite element modeling in three dimensions was carried for the tested beams using ABAQUS software. The ultimate loads and deflection obtained from experimental and finite elements are in good agreements with average difference of 8% in ultimate load and 20% in ultimate deflection.

Keywords: reinforced concrete; waste rubber; experimental test; finite element analysis; hybrid section

1. Introduction

Many kinds of waste materials are considered to be an enhancement in concrete. These materials may contain; plant cellulose, silica fume, rubber from disposed tires and fly ash. Rubber may be considered to be as the latest recycled materials that have been studied and investigated due to its availability and needful use in the building field. Different research works were carried out on hybrid concrete or using rubber as additive or replacing the aggregate in concrete as given in the next paragraph.

Zhang *et al.* (2006) studied analytically and experimentally the flexural response of layered ECC-concrete beams. Flexural tests (under four points) were made on concrete beams with ECC layer. This layer is positioned at beam section tensile side. The purpose of introducing this layer was to increase the bending strength. The thickness of this layer effects the results.

Ganjian *et al.* in 2009 studied the effect of replacing aggregate by tire rubber on concrete mixtures.

The obtained results show that the strength in compression is reduced if the percentage of rubber replacement in concrete is increased without noticeable changes in other concrete properties.

Al-Tayeb *et al.* (2013) prepared rubberized concrete specimens by using 5%, 10 % and 20% alteration of fine aggregate (sand) by waste rubber. The dimensions of the prepared samples were 50×100×500 mm which are subjected to static and impact loads (3 point load). The samples were made with, single layer natural concrete or single layer rubberized concrete or two layers (top layer with rubberized concrete and bottom layer natural concrete). The samples were loaded until failure was recognized. The load deflection curves were plotted and energy gained were calculated for each sample. LUSAS software was used to model the problem numerically. The rubber samples show higher resistance to impact load.

Katzer (2013) made an experimental study on using multiple waste materials to produce cement mortars. Natural Waste sand was used as aggregate. Ceramic waste fume was implemented to alter partially the binder in mortar mixtures. The fresh mixes and hardened mortars properties were obtained. Different mechanical concrete properties such as: mortar density, cube compressive strength and prism flexural strength were investigated. These mortars can be used in members which required lower concrete mechanical characteristics.

Bing and Ning (2014) carried out an experimental study based on using tire rubber particles as an alteration in concrete for coarse aggregate. The replacement reduced the compressive strength and modulus of elasticity. Also, the flexural strength of concrete was reduced with increasing replacement percentage in concrete.

Zarrin an Khoshnoud (2016) carried out a study on the effect of using steel fibers in reinforced self-compacted concrete members. A superplasticizer of 1% and 2% by volume friction were used in the study concrete mixes. The used fibers were of 60/30 (length/diameter) fibers and the used percentages were 0.0%, 1.0%, 1.5% and 2%. The mechanical and flexural properties of members were found to be increased with increasing the steel fiber percentages by volume in the study. This was due to the improvement in

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the post-cracking behavior that results from using fibers.

Hind *et al.* (2016) carried out a numerical analysis on a group of short fiber concrete members. The experimental results obtained from previous researches were used in the comparison to check the developed model. The numerical or finite element method in three dimensions was used to study the nonlinear behavior of such members. The obtained results showed that the simulation of such problems can be adequately modeled by finite elements in terms of behavior and cracking phenomena

Al-Azzawi (2017) studied the shear behaviors of RC beams with rubber fibers and having opening. It was shown that the voids in beams minify the shear and flexural strength of members in accordance to the waste rubber content, location of void and shear reinforcement area.

All previous studies on replacement of aggregate by waste rubber showed that the rubber particles adversely affect the mechanical properties of concrete when used as aggregate (Zheng *et al*. 2008, Ganjian, *et al. 2009*, Bing and Ning 2014, Gupta *et al*. 2015). In contrast, Al-Azzawi (2017) showed that the lightweight coarse aggregate concrete mixture had increased mechanical properties with the addition of waste rubber fibers.

Seitl *et al.* (2017) studied the properties of cement based composites with different percentages of recycled aggregate. Six mixtures were made with different aggregate (natural sand and red waste ceramic aggregate). The fracture parameters of such composite were the main task of the study. Other parameters such as compressive and tensile strengths were studied also. The use of ceramic aggregates in concrete was proved to be effective by the researchers.

Ge *et al.* (2018) developed a method or technique to obtain the moment capacity for different cases of ECC beams having steel bars. The cracking, yielding and ultimate moments are determined using a formula developed by the authors and experimentally.

The aim of present study is to introduce an environmental friendly technology through studying the flexural behavior of hybrid concrete beams with waste rubber at the bottom and top layers of beam section to obtain the optimum rubber percentage and preferred fiber concrete location if it is implemented in beam section. The effect of opening in beam al also investigated in the existence of rubber

2. Research program

2.1 Experimental study

All beam specimens were simply supported with width (0.1 m), depth (0.15 m) and total length of (1.25) m and subjected to one point loading test. Shear span to effective depth ratio (*a/d*) was kept constant with the value of 4 for the tested beams as shown in Figs. 1 and 2. The beams were loaded gradually to failure. The load increment during test was about one tenth of the expected ultimate load. The study investigates the flexural response or behavior of the seven concrete beams with constant flexural and shear reinforcement and having different compressive strength through beam section due to rubber content used in the mix, as shown in Fig. 1 and Table 1. The beams without rubber were designed in accordance with ACI-318, (2011) code. The reinforcement values was chosen in order to obtain bending failure (Maalej and Li 1995). The main bending reinforcement consisted of (2 φ 6 mm) (steel ratio 0.46%)

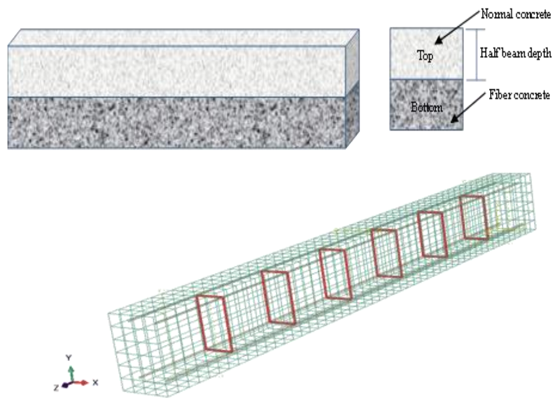

Fig. 1 Beam specimens

Fig. 2 Testing machine

Table 1 Designation and properties of test specimens

Beam No	Rubber percentage (%)	Location of rubber concrete	Opening
N0	0.1	Top and bottom	-
N1	0.1	Bottom only	-
N2	0.2	Bottom only	-
N3	0.2	Top only	-
N4	0.1	Top only	-
N5	0	No fibers	-
N6	0.1	Bottom only	Central opening

Table 2 Chemical composition of cement

Compound	Weight,%	ASTM C150 (2012)
Cao	64.12	-
SiO_2	20.86	-
Al_2O_3	3.73	6.0% maximum
Fe_2O_3	4.51	6.0% maximum
SO_3	2.09	3.0% maximum
Mg O	1.01	6.0% maximum
Insoluble residue	0.73	0.75% maximum
Loss on ignition	1.97	3.0% maximum
Lime saturation factor	0.96	5.0% maximum
C_3 S	21.29	-
C_2 S	52.31	-
C_3 A	6.19	8.0% maximum
C_4 A F	9.31	-

Table 3 Cement physical properties

Test	Value	ASTM C150 (2012)
Fineness, (m^2/kg)	335	≥260
Setting time, (hrs:min)		
Initial setting	2:30	≥00:45
Final setting	4:15	≤ 6:15
Compressive strength, (MPa)		
Three days	20.30	≥7.00
Seven days	26.23	≥12.00
Autoclave expansion, (%)	0.13	≤ 0.80

Table 4 Gradation of coarse and fine aggregate

Sieve size, mm	Iraqi Standard No.45 (1984) (5-40) mm	ASTM C33 (2005)	Coarse aggregate
37.5	95-100	90-100	100
20	35-60	25-60	54.72
10	10-40	10-30	16.98
4.75	0-10	0-15	8.03
Sieve size, mm	**Iraqi Standard No.45 (1984) (zone 2)**	**ASTM C33 (2005)**	**Fine aggregate**
10	100	100	100
4.75	90-100	95-100	100
2.36	75-100	80-100	95.17
1.18	55-90	50-85	84.45
0.60	35-59	26-60	49.62
0.30	8-30	5-30	22.03
0.15	0-10	0-10	6.68

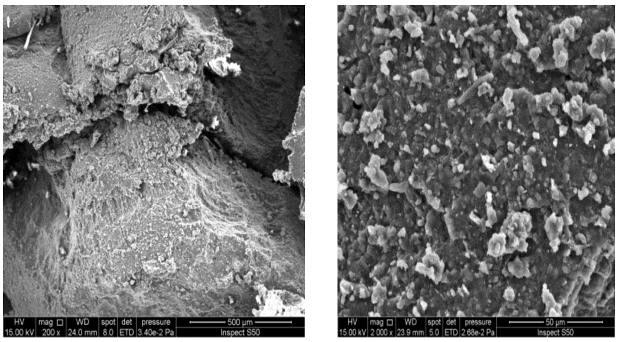

Fig. 3 Rubber microscope view

and top bending reinforcement of (2 φ 6 mm). The beams had 6 stirrups of (φ6 @176 mm *c/c*). Fig. 1 shows the reinforcement distribution of the section. Beam (N6) had central rectangular opening of size 50 × 100 mm. This specimen was selected in order to study the stress distribution in beams with opening.

2.1.1 Used materials

The ordinary concrete mix comprise the use of type I cement (ordinary Portland cement) complies with the requirements of ASTM C150 (2012) (as illustrated in Tables 2 and 3), coarse aggregate (CA) (crushed gravel), and fine aggregate (FA) (sand). The maximum coarse aggregate size was 10 mm, natural sand used as fine aggregate. Table 4 showed the gradation of them according to Iraqi Standards No. 45 (1984) and ASTM C33 (2005).

The rubber tires waste (RF) obtained by mechanical cutting of scrap tires to sizes (2-4) mm as shown in Fig. 3 is

Table 5 Properties of aggregate and waste rubber

Property	Coarse Aggregate	Fine aggregate	Rubber
Specific gravity	2.73	2.65	1.06
Absorption capacity (%)	0.71	0.97	-
Bulk density (kg/m^3)	1687	1738	651

Table 6 Chemical compositions of waste rubber

Component	% by weight
Palladium	49.05
Carbon	21.66
Antimony	9.18
Tungsten	6.90
Calcium	4.51
Sulfur	4.08
Zinc	3.23
Silicon	1.41

Table 7 Properties of concrete mix and strength

Parameter	Mix (MS)	Mix (MSF)	Mix (MSF1)
Rubber (kg/m^3) (% by volume)	zero	2 (0.1%)	4 (0.2%)
Water/cement ratio	0.3		
Water (kg/m^3)	120		
Cement (kg/m^3)	400		
Fine aggregate (FA) (kg/m^3)	764		
Coarse aggregate (CA) (kg/m^3)	1300		
Superplasticizer (SP) (lit/m^3)	2		
Compressive strength (MPa)	22	30	27
Split strength (MPa)	2.1	2.8	2.5
Slump (mm)	40	35	30

used in the present study. Admixture as a superplasticizer (SP) was used to improve the strength and workability of concrete mix and Table 5 illustrated the specification of it. The chemical composition of waste rubber used is given in Table 6.

2.1.2 Concrete mix

Three sets of mix were designed with addition of (SP) at 0.5% by weight of cement and with 0.3 water cement ratio as given in Table 7. The first set of concrete mix contains no rubber RF. The second contains RF with 0.1% by volume of concrete. The third one has 0.2% RF by volume of concrete. From each set, 3 cubes (150mm) were tested for compressive strength and two cylinders (150×300 mm) were tested. It is obvious from the Table 7 that the cube compressive strength increased by 45% with increasing rubber content from 0 to 0.1%. After that the compressive strength decreased by 13%. Similar behavior was obtained for the tensile strength of concrete. The reasons for the increase in compressive and tensile strength observed for the material with the addition of rubber waste in the amount of 0.1% by volume of concrete was due to the nature of

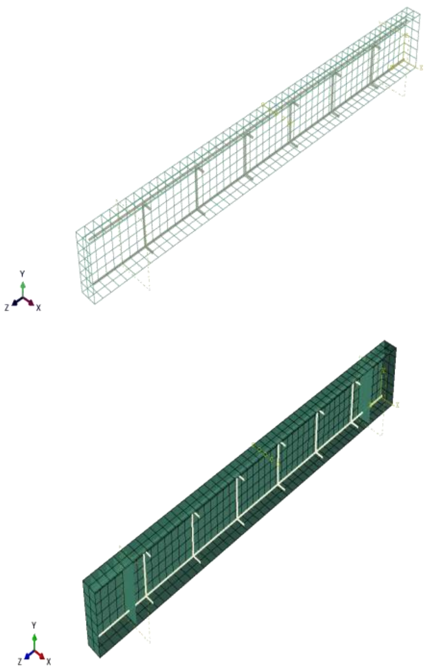

Fig. 4 Finite element mesh

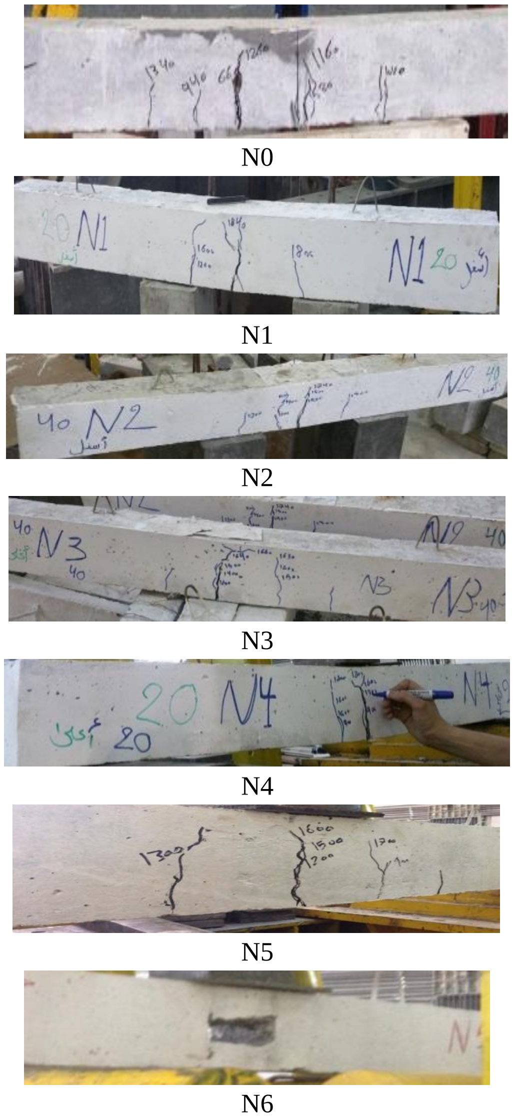

Fig. 5 Crack pattern for the tested beams

used enhancement material and their elasticity. And reduction of these properties when the addition of rubber waste is 0.2% may be due to the increased voids in concrete.

Tensile test of steel bars was executed on (φ6 mm) bars it shows that bars confirmed with the ASTM A615 (2005).

2.2 Finite element study

Finite element method has the capability to solve problems with complicated geometry and material nonlinear behaviour. Three dimensional (3D) finite element model is used in this research. ABAQUS 6.10 software is used to model reinforced concrete beams using 20 node brick elements and 3 node truss element to model the flexural and shear reinforcement. The finite element mesh is shown in Fig. 4. The damage plasticity model is used to model concrete and the steel is modelled as elastic perfectly plastic. The rubber concrete is modelled through the improved material properties when rubber is added especially the tensioning stiffening effect. The parameters used in ABAQUS are taken from the experimental work.

3. Results and discussion

3.1 Experimntal study

Pictures of the tested beams are given in Fig. 5. The crack pattern and response were comparable for all tested members. The members were failed in bending.

The specimens are failed gradually as the flexural cracks developed at the bottom face of the beams and then propagate towards the compression zone. The ultimate load carrying ability of the tested beams override the cracking load capacity by a magnitude varying from 256 to 227% depending on the rubber content, the location of the rubber in beam section and the existence of central rectangular opening as shown in Table 8. After first crack caused by a force of 5 to 8 kN, the force-deflection relationship still retains the quasi linear character and this is due to waste rubber elasticity.

The effect of rubber content is obvious from the comparison of beams N1 and N2 (bottom layer rubber) or N3 and N4 (top layer rubber) with the reference beam N5 (no rubber) test results. As the rubber content is increased from 0 to 0.1% the cracking load is increased by 20 % and ultimate load increased by 29% for bottom layer rubber. The cracking deflection is increased by 12% and ultimate deflection is increased by 48 % for the same case. While for top layer fiber, the cracking load is increased by 10 % and ultimate load increased by 21% if the rubber content is increased from 0 to 0.1%. The cracking deflection is increased by 6 % and ultimate deflection is increased by 32 % for this case. If the rubber content is increased from 0.1 to 0.2% the cracking load is increased by 14% and ultimate

Table 8 Tested beams results (flexural mode of failure)

Beam No.	P_{cr} (kN)	Δ_{cr} (mm)	P_u (kN)	Δ_u (mm)	P_{cr}/P_u	Δ_{cr}/Δ_u
N0*	7.8	1.22	17.8	9.8	0.43	0.12
N1	7.3	1.05	17.49	8.2	0.41	0.12
N2	8.3	0.86	16.56	6.88	0.5	0.12
N3	6.8	1.05	15.76	6.95	0.43	0.15
N4	6.7	1.0	16.4	7.3	0.4	0.14
N5 **	6.1	0.94	13.56	5.53	0.44	0.16
N6	5.2	0.85	13.2	3	0.39	0.28

* first reference beam with 0.1% fibers all section
** second reference beam without fibers

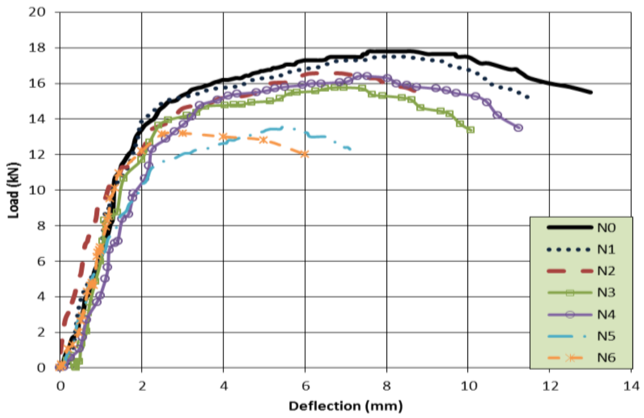

Fig. 6 Load deflection curves for the tested beams

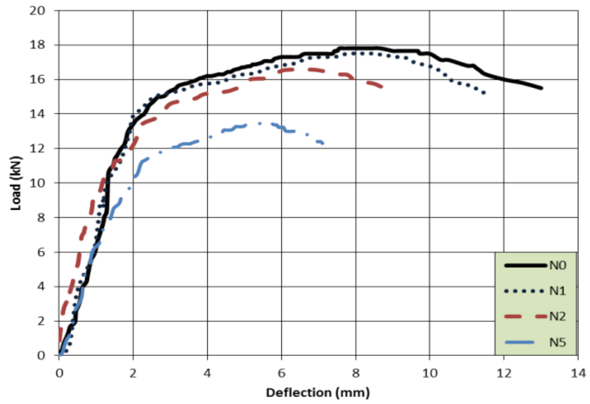

Fig. 7 Load deflection curves for the tested beams with bottom fiber concrete

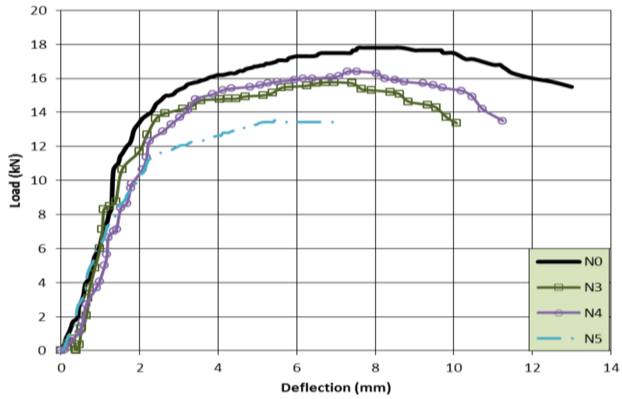

Fig. 8 Load deflection curves for the tested beams with top fiber concrete

where P_{cr} is the cracking load, P_u is the ultimate load Δ_{cr} is the cracking deflection, Δ_u is the ultimate deflection load is decreased by 5% for bottom layer rubber. Here, the cracking deflection is decreased by 18% and ultimate deflection is decreased by 16%. While for top layer rubber, the cracking load is increased by 1.5% and ultimate load decreased by 4% if the rubber content is increased from 0.1 to 0.2%. Here, the cracking deflection and ultimate deflection are decreased by 5%.

The effect of rubber concrete location for the same rubber content is obvious from the comparison of beam N1 (bottom layer fiber) or N4 (top layer fiber) with the reference beam N0 (fiber content 0.1%) test results. As the fiber concrete is used only in bottom layer, the cracking load is decreased by 7% and ultimate load decreased by 2%. The cracking deflection is decreased by 14% and ultimate deflection is decreased by 16% for the same case. If the rubber concrete is used only in top layer, the cracking load is decreased by 14% and ultimate load decreased by 8%. The cracking deflection is decreased by 18% and ultimate deflection is decreased by 26% for the same case.

The effect of central rectangular opening for the rubber concrete used at bottom layer with 0.1% rubber content is shown from the comparison of beam N1 with beam N6 test results. It is obvious that the existence of opening in the beam will reduce the cracking load by 29% and the ultimate load by 25%. While the cracking deflection is reduced by 19% and the ultimate deflection is reduced by 63%. This is due to the decrease in beam stiffness at maximum moment location

Fig. 6 shows the applied point load versus the mid span deflection of all tested beams in this research. The beam with rubber concrete N0 (0.1% rubber content in all section) demonstrates roughly a linear response until beam cracks. After that, the strength and deformation of specimen N0 becomes different from other tested beams and failed with larger value for ultimate load and deflection.

The effect of rubber content in rubber concrete bottom layer is obvious from the comparison of beams N1, N2 and N5 load deflection curves of Fig. 7. The rubber content effect is found to be small on the load deflection response of beams at early stage of load and the effect will be larger for higher load values. As the rubber content increased from 0 to 0.1% at bottom layer, the ultimate load and ultimate deflection are increased by 22% and 33% respectively. This means that the ductility increased. If the rubber content increased from 0.1 to 0.2% at bottom layer, the ultimate load and the ultimate deflection are decreased by 5% and 16% respectively. Here the ductility is decreased.

The effect of rubber content in rubber concrete top layer is obvious from the comparison of beams N3, N4 and N5 load deflection curves of Fig. 8. The rubber content effect is found to be small on the load deflection response of beams at early stage of load and the effect will be larger for higher load values. As the rubber content increased from 0 to 0.1% at top layer, the ultimate load and ultimate deflection are increased by 17% and 32% respectively. This means that the ductility increased. If the rubber content increased from

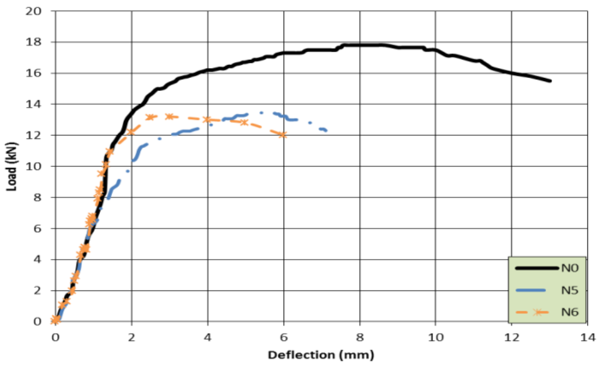

Fig. 9 Load deflection curves for the tested beams N0, N5 and N6

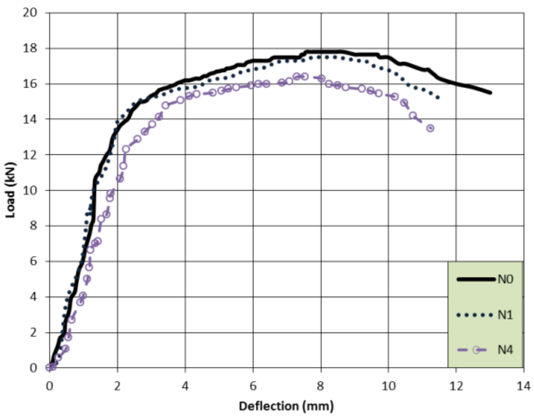

Fig. 10 Load deflection curves for the tested beams with different fiber concrete location N0, N1 and N4

0.1 to 0.2% at top layer, the ultimate load and the ultimate deflection are decreased by 4% and 5% respectively. Here the ductility is decreased.

The effect of rubber content and opening in rubber concrete layer is obvious from the comparison of beams N5 and N6 load deflection curves of Fig. 9. The rubber content effect is found to be very small on the load deflection response of beams at early stage of load and the effect will be larger for higher load values. As the rubber content increased from 0 to 0.1% at bottom layer, the ultimate load will be the same while the ultimate deflection will be less in case of opening exists in the beam as it is located at the maximum moment postion.

The effect of rubber concrete location is shown in the load deflection curves of Fig. 10. The effect is found to be small at early stage of load and after that the effect will be larger for higher load values. The rubber concrete location at bottom layer gives higher values of ultimate load and deflection compared to beam with top layer. Also, it shows similar response to fiber concrete beam in all section.

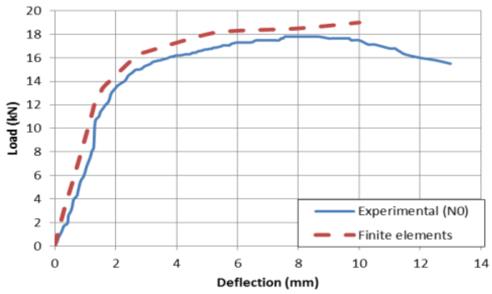

Fig. 11 Load deflection curves for the tested beam N0

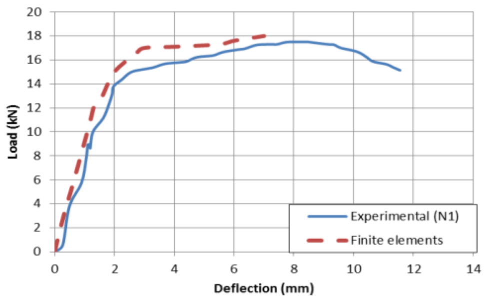

Fig. 12 Load deflection curves for the tested beam N1

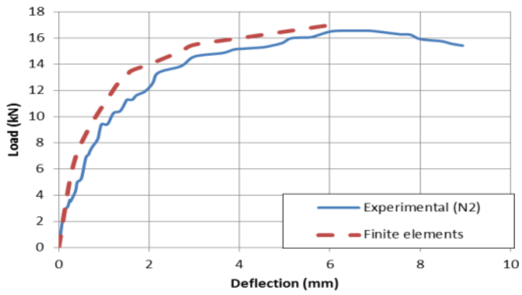

Fig. 13 Load deflection curves for the tested beam N2

Comparisons between experimental and theoretical loads for hybrid beams are made. The theoretical loads have been estimated using the ultimate and cracking moments equations developed from the study of Ge *et al.* (2018). The results are given in Table 9 which indicated a good agreement between them. The equations developed by Ge *et al.* (2018) overestimate the cracking loads by 7.5% and underestimated the ultimate loads by 12%. Therfore it may be used to predicate the strength of hybrid concrete beams with waste rubber.

The experimental analysis verified that the waste rubber with percentage less than 0.2% used at the bottom layer (in the tension zone) can enhance greatly the flexural behavior of hybrid beams in terms of load deflection and cracking. The percentage of waste rubber equal and higher than 0.2% can enlarge ultimate loads but reduce the ductility of the

Table 9 Comparison between experimental and theoretical loads for the bottom layered hybrid beams

Beam No.	Experimental P_{cr} (kN)	Theoretical P_{cr} (kN)	Experimental P_{cr}/ Theoretical P_{cr}	Experimental P_u (kN)	Theoretical P_u (kN)	Experimental P_{cr}/ Theoretical P_{cr}
N1	7.3	8.1	0.9	17.49	15.71	1.11
N2	8.3	8.7	0.95	16.56	14.62	1.13

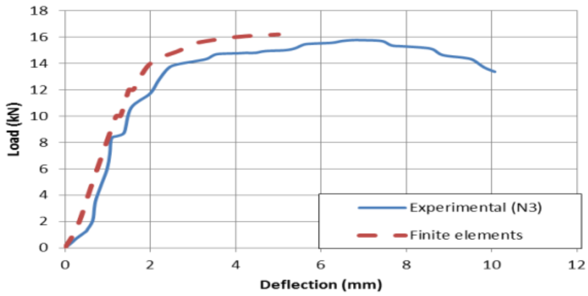

Fig. 14 Load deflection curves for the tested beam N3

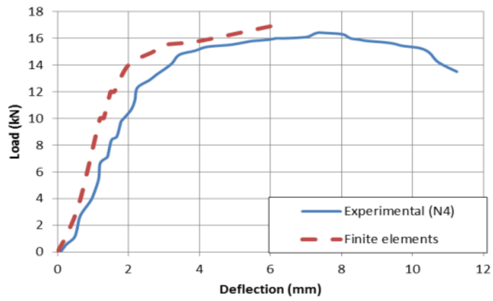

Fig. 15 Load deflection curves for the tested beam N4

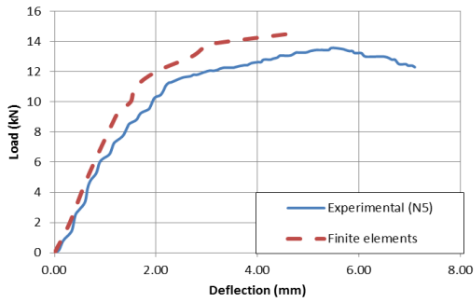

Fig. 16 Load deflection curves for the tested beam N5

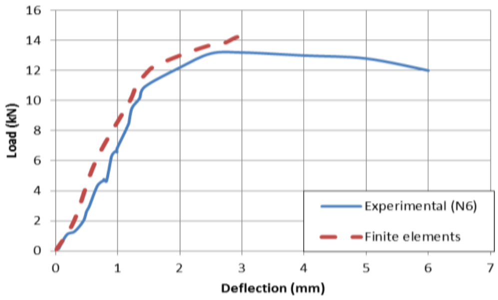

Fig. 17 Load deflection curves for the tested beam N6

member. Also, the durability of concrete expected to be decreased with increasing waste materials.

3.2 Finite element study

The numerical results obtained from finite elements have been compared with experimental beam test results to check the accuracy of the finite element solution obtained from this study. Figs. 11 to 17 show the load deflection curves obtained from experimental and finite elements. Good agreements are obtained between them.

Table 10 Tested beams experimental and finite elements results

Beam No.	Exp. P_u (kN)	Exp. Δ_u (mm)	FE. P_u (kN)	FE. Δ_u (mm)	Exp P_u/ FE P_u	Exp Δ_u/ FE Δ_u
N0	17.8	9.8	18.9	10.06	0.94	0.97
N1	17.49	8.2	18.1	7.1	0.96	1.15
N2	16.56	6.88	16.2	6.02	1.02	1.14
N3	15.76	6.95	16.9	6.1	0.93	1.13
N4	16.4	7.3	16.89	6.05	0.97	1.2
N5	13.56	5.53	14.5	4.60	0.93	1.2
N6	13.2	3	14.3	2.95	0.92	1.01

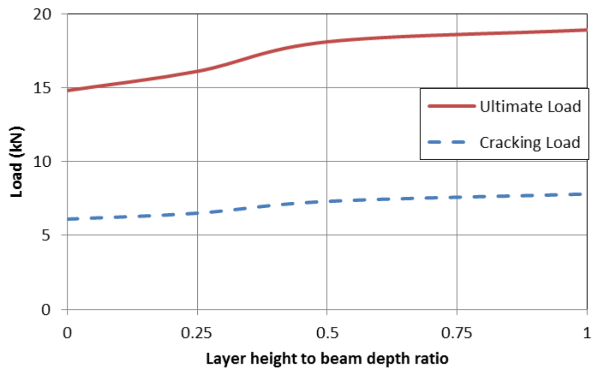

Fig. 18 Effect of layer height to beam depth on cracking and ultimate loads

Table 10 shows the ultimate loads and deflection obtained from experimental and finite elements. Good agreements are obtained with average difference of 8% in ultimate load and 20% in ultimate deflection.

A parametric study is carried out using finite elements considering the following parameters:

1-Bottom layer height to beam depth ratio

2- Main reinforcement ratio

3- Bottom layer compressive and tensile strengths

To study the first parameter, the same properties of beam N1 (0.1% waste rubber bottom layer) were selected except that layer depth was varied (0, 37.5, 75 and 150 mm). Fig. 18 shows the effect of layer height to beam depth on cracking and ultimate loads. As the layer height increased, the cracking and ultimate loads increased by 28%. The reason for that increase is due to the increase in the concrete strength with increasing waste rubber content. Flexural mode of failure was obtained for different layer depth.

To study the second parameter, the same properties of beam N1 (0.1% waste rubber bottom layer) were selected except that the main reinforcement ratio was varied (0.24, 0.46 and 1.5%). Fig. 19 shows the effect of main reinforcement ratio on cracking and ultimate loads. As this ratio increased from 0.24 to 1.5%, the cracking and ultimate loads increased by 205 and 250% respectively. The reason for that increase is due to the increase in the moment capacity of the section. Flexural mode of failure was obtained for steel ratio less than 1.2% and shear compression failure was obtained for steel ratio greater than 1.2%.

To study the third parameter, the same properties of

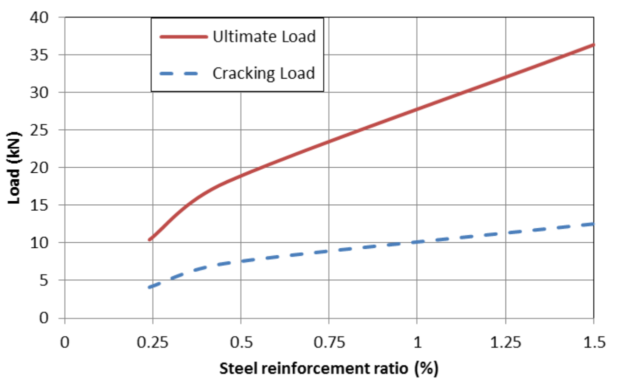

Fig. 19 Effect of main steel reinforcement ratio on cracking and ultimate loads

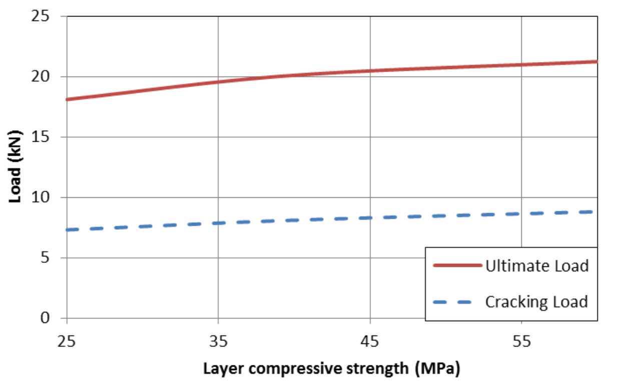

Fig. 20 Effect of layer compressive strength on cracking and ultimate loads

beam N1 (0.1% waste rubber bottom layer) were selected except that the layer compressive strength (and therefore the tensile strength) was varied (25, 40 and 160 MPa). Fig. 20 shows the effect of layer compressive strength on cracking and ultimate loads. As this strength increased from 25 to 60MPa, the cracking and ultimate loads increased by 20 and 17% respectively. The reason for that increase is due to the increase in the tensile strength of concrete layer. Flexural mode of failure was obtained for the selected range.

4. Conclusions

From this study, the main conclusions are given below:

• The ultimate loads and deflection obtained from experimental and finite elements are in good agreements with average difference of 8% in ultimate load and 20% in ultimate deflection.

• The ultimate load carrying capacity of the tested members override the cracking load capacity by a magntude varying from 256 to 227% depending on the rubber content, the location of the rubber layer and the existence of central rectangular opening.

• As the rubber content is increased from 0 to 0.1% the cracking load is increased by 20% and ultimate load increased by 29% for bottom layer rubber. The cracking deflection is increased by 12% and ultimate deflection is increased by 48% for the same case. The effect will be smaller for top layer rubber.

• If the rubber content is increased from 0.1 to 0.2 % the cracking load is increased by 14% and ultimate load is decreased by 5% for bottom layer rubber. Here, the cracking deflection is decreased by 18% and ultimate deflection is decreased by 16%. The effect will be smaller for top layer rubber.

• It is obvious that the existence of opening in beams for the rubber concrete used at bottom layer with 0.1% rubber content will reduce the cracking load by 29% and the ultimate load by 25%. While the cracking deflection is reduced by 19% and the ultimate deflection is reduced by 63% as the stiffness of beam reduced.

• The effect of rubber content in rubber concrete layer is obvious from the test results. The rubber content effect is found to be small on the load deflection response of beams at early stage of load and the effect will be larger for higher load values. The ductility is increased for rubber content 0.1%.

• The rubber concrete location at bottom layer gives higher values of ultimate load and deflection compared to beam with top layer and it shows similar response to fiber concrete beam (all section contains 0.1% fiber).

Comparisons between experimental and theoretical loads • for present study hybrid beams show that the equations developed by Ge *et al*. (2018) overestimate the cracking loads by 7.5% and underestimated the ultimate loads by 12%.Therfore it may be used to predicate the strength of hybrid concrete beams with waste rubber.

• The effect of layer height to beam depth ratio on cracking and ultimate loads was investigated. It shows that as this ratio increased, the cracking and ultimate loads increased by 28%. The reason for that increase is due to the increase in the concrete strength with increasing waste rubber content. Flexural mode of failure was obtained for different layer depth.

• The effect of main reinforcement ratio on cracking and ultimate loads was investigated. It shows that as this ratio increased from 0.24 to 1.5%, the cracking and ultimate loads increased by 205 and 250% respectively. The reason for that increase is due to the increase in the moment capacity of the section. Flexural mode of failure was obtained for steel ratio less than 1.2% and shear compression failure was obtained for steel ratio greater than 1.2%.

• The effect of layer compressive strength on cracking and ultimate loads was investigated. It shows that as this strength increased from 25 to 60 MPa, the cracking and ultimate loads increased by 20 and 17% respectively. The reason for that increase is due to the increase in the tensile strength of concrete layer. Flexural mode of failure was obtained for the selected range.

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