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NON-LINEAR ANALYSIS OF HYBRID REINFORCED T- BEAM WITH PARTIAL SUBSTITUTION RECYCLED RUBBERIZED CONCRETE

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Abstract

At present, the need to make use of industrial waste materials is increasing due to their harmful effects on the environment. In the present work, the behavior of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete is studied. The finite element modeling by using ANSYS version 15 program. It contains also all the required steps needed to create the concrete models that were prepared to study the behavior of beams with partial substitution recycled rubberized concrete (RRC). The reinforcement of beams was various combinations of polymer GFRP and steel bars. The Rubberized concrete mixes were prepared by partial substitution 7.5 %, 10 %, and 12.5 % replacements by volume. The ratio of GFRP to steel reinforcement at mid-span section was the second parameter investigated. Due to the large number of parameters affecting the behavior of Hybrid Reinforced T- Beam with partial substitution Recycled Rubberized Concrete, an extensive parametric study was performed using ANSYS version 15 program. Three parameters were investigated namely; Bottom RFT, compressive strength of concrete, and the existence of opening. The analytical results agree well with the experimental results in terms of mode of failure and the failure load values. The results indicated that although the flexural capacity of the tested specimen decreased with the addition of Crumb Rubber and reduced its self-weight. The failure load of the beam with partial substitution recycled rubberized concrete increases with bottom reinforcement by the GFRP bar or CFRP bar. Also, reinforced beams by CFRP bars had a higher failure load than reinforced beams by GFRP bars. Having an opening in hybrid reinforced T-Beam with partial substitution recycled rubberized concrete reduced the beam load capacity and maximum deflection. Also, using GFRP bars, and CFRP bars in the vicinity of openings in hybrid reinforced T-Beams increased the load capacity of these beams.

Keywords:

GFRP bars;
T-beams;
Rubberized recycled concrete (RRC);
Finite element method;
Non-linear analysis.

1 Introduction

In the last few years, the need for expired tires to be reused in various structural engineering applications increased dramatically to overcome problems such as powerful environmental problems around the world [1]. Researches are currently aimed at obtaining sustainable concrete using expired tires [2]. These studies replaced different proportions of sand aggregates with rubber concrete in the members' concrete mix. The results showed that the increase in the percentage of rubber replacement reduces the mechanical properties of concrete and workability [3]. However, other studies showed that the use of rubberized recycled concrete improved the toughness, ductility, and reduction of self-weight [4, 5]. Ismail et al. [6] replaced 5 to 15 % of fine aggregate with rubber concrete in the concrete mixture for beams subjected to bending moments. The results showed that the use of crumb rubber reduces the crack widths, self-weight of concrete, and toughness. Mendis et al. [7] tested large scale beams with and without shear reinforcements to study the effectiveness of various ratios of crumbed rubber. The results showed that the rubberized recycled concrete affected the shear capacity. However, the relationship between the rubber ratio and shear capacity was not sufficient for the estimation. The term hybrid has been defined by Mohankar et al. [8] as a mixture of two or more different types of materials. Nes et al. [9] performed an experimental program to study the behavior of a hybrid reinforced Beam with Fiber-Reinforced LWAC. Oloke et al. [10] performed a virtual simulation to demonstrate hybrid concrete construction. Coventr [11] performed an experimental program to study the impact resistance of concrete using recycled rubber. Li et al. [12] examined the flexural behavior of the isolated hybrid structure. The results showed that the structure response to load was reduced by using rubberized recycled concrete. Also, Al-Tayeb [13] performed an experimental and nonlinear program to study the behavior of Hybrid Powder Rubberized-Normal Concrete subjected to Impact Load. Norman [14] tested small-size beams with partial substitution recycled rubberized concrete under static and dynamic load. Norman [14] replaced 5 %, 10 %, 15 %, 17.5 %, 20 %, 22.5 %, and 25 % of sand with rubber concrete in the concrete mixture for tested beams. The rubberized concrete was placed at the top. The results exhibit that using the rubberized top layer reduces the flexural energy under the impact load. Mohd et al. [15] performed a comparative study between the (RRC) beam and the hybrid reinforced concrete beam. The results showed that the behavior of these beams during the first crack loading were the same. However, the stiffness of the hybrid beams was higher than the rubberized concrete one. Mohamed Essam [16] investigated of performance of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete. Eight specimens with 200 x 300 mm dimensions, 540 mm flange width, and 100 mm slab thickness were loaded to failure. The reinforcement of beams was various combinations of polymer GFRP and steel bars. Mohamed Essam [16] replaced 7.5 %, 10 % and 12.5 % of sand with rubber concrete in the concrete mixture for beams subjected to bending moments. The results show that adding Crumb Rubber as a rubberized concrete improved the ductility, and the increased percentage of C.R in hybrid beams has increased the number of cracks compared with the hybrid beams with 0 % C.R. Maciej et al. [17] performed an analytical program to study the reduction of dynamic impacts in block made of concrete – rubber composites. The results exhibit that using the embedded rubber pads increased the protection against the transversal dynamic load.

In a non-linear analysis of concrete structures, Sucharda et al [18] examined the behavior and performance of RC beams without shear reinforcement. For this purpose, the researcher used stochastic modelling (Valašík et al [19]; Strauss et al [20]; Wu, et al [21]). Kozielova et al [22] used Newton-Rapson method for modelling of interaction of a RC slab with subsoil. Newton-Rapson method shows the change of stiffness after the creation of cracks.

The current research aimed to reach a proposed analytical finite element model of hybrid reinforced T-beam structures to estimate the performance of these T-beams with partial substitution recycled rubberized concrete produced by Mohamed Essam [16] by using Ansys 15 and to evaluate of the flexural ductility indices of the normal aggregate concrete (NAC) and rubberized recycled concrete (RRC) T-beams.

The finite element model and the results of this research can be welfare in considering the performance of hybrid reinforced T-beams and the design of the structures.

2 Research significance

The objective of this study was to focus a more useful analytical understanding of the performance of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete. Thereby, we must focus on obtaining the maximum strength of hybrid reinforced members due to using different types of concrete. Therefore, the main objective was the nonlinear finite element analysis (Ansys 15 software) of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete. The specimens' behavior include: the ultimate load, the deflection, the cracking pattern, ductility and stiffness. The analytical results are compared with the previously investigated experimental models presented by Mohamed Essam [16]. A parametric study was performed using nonlinear finite element analysis to investigate more variables affecting the behavior of the beams.

Mohamed Essam's experimental program [16] includes testing of eight hybrid reinforced T-Beam subjected to two line loads. Beams TCH1 and TCH2 were used as a reference specimen without recycled rubberized concrete. Six tested beams with partial substitution recycled rubberized concrete. Table 1 shows the details of the tested beams. Dimensions and reinforcement details of the tested specimens are shown in Fig. 1. Table 2 shows the weights required to cast one cubic meter of concrete.

Table 1: Details of tested beams.

Model	Bottom RFT.	Top RFT	Notes bottom RFT	Notes top RFT.	Bottom steel RFT. /Total RFT.	Crumb rubber (C.R) by volume of sand [%]
TCH1 Control	2Ø10S+2φ10F	2Ø10	Steel +GFRP	Steel	0.5	0 %
TCH2 Control	2Ø10S+2φ12F	2Ø10	Steel +GFRP	Steel	0.41	0 %
BRH3	2Ø10S+2φ10F	2Ø10	Steel +GFRP	Steel	0.5	7.5 %
BRH4	2Ø10S+2φ12F	2Ø10	Steel +GFRP	Steel	0.41	7.5 %
TRH5	2Ø10S+2φ10F	2Ø10	Steel +GFRP	Steel	0.5	10 %
TRH6	2Ø10S+2φ12F	2Ø10	Steel +GFRP	Steel	0.41	10 %
TRH7	2Ø10S+2φ10F	2Ø10	Steel +GFRP	Steel	0.5	12.5 %
TRH8	2Ø10S+2φ12F	2Ø10	Steel +GFRP	Steel	0.41	12.5 %

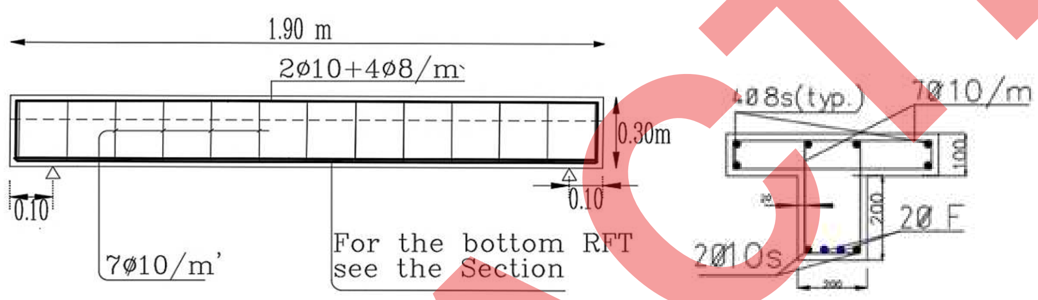


Fig. 1: Dimensions and reinforcement details of the tested specimens.

Table 2. Mix design of concrete per meter cube.

Cement	Water	Fine aggregate (sand)	Coarse aggregate	Crumb rubber
Weight [kg]	Weight [kg]	Weight [kg]	Weight [kg])	Weight [kg]
400	172	672	1120	Percentage by volume of sand

3 Methodology and analytical model

In order to validate the results of Mohamed Essam's study [16] and give the opportunity to future parametric studies, the nineteen tested beams were analyzed by ANSYS version 15. Concrete is modeled by the SOLID 65 element, which has the ability to crack in tension and crush in compression.

The element is defined by six faces and eight nodes; each node has three degrees of freedom. The most important properties of this element are that it can behave nonlinearly. Fig. 2 shows a typical brick element in global Cartesian and local intrinsic coordinates. Concrete material is defined in ANSYS by its linear behavior with poison's ratio of 0.2, and modulus of elasticity of 4400 $(f_{cu})^{0.5}$. Moreover, the non-linear behavior is defined by open shear coefficient of 0.3 and closed shear coefficient of 0.8. Also, the tensile strength of concrete was defined as 0.6 $(f_{cu})^{0.5}$. The actual values of compressive strength f_{cu} obtained from cube testing were used as input which changes with changing percentage of recycled rubber used in the concrete mix.

Rubber concrete material is defined in ANSYS by its multi-linear behavior. The model used in this analysis of relation between stress-strain curves of rubber concrete obtained from cube testing were used as input, Table 3.

Table 3: The material properties of concrete used in ANSYS program.

Material	Element type	Material properties	
Rubber concrete	Solid 65	**Linear Isotropic**	
		Modulus of elasticity (EX) f_{cu} [N/mm^2]	4400 $(f_{cu})^{0.5}$
		Passion ratio (PRXY)	0.26
		Concrete properties	
		Open shear-coefficient	0.3
		Closed shear-coefficient	0.8
		Uniaxial cracking stress (f_{ctr}) [N/mm^2]	0.6 $(f_{cu})^{0.5}$
		Uniaxial crushing stress (f') [N/mm^2]	0.8 f_{cu}
		Multi-linear isotropic	
		Strain	Stress [MPa]
		from cube testing	from cube testing

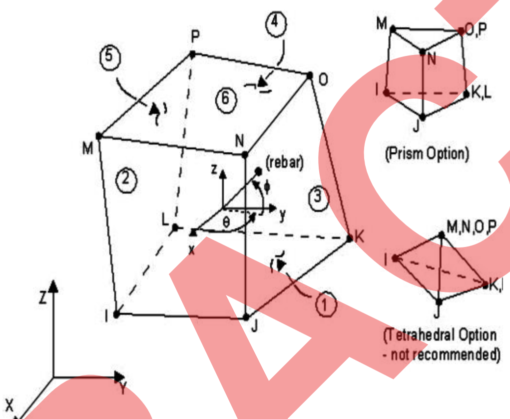


Fig. 2: Solid 65 element [23].

The steel rebar and GFRP rebar were modeled by the LINK180 element. This element is uniaxial compression-tensile element with 2 nodes having 3 degrees of freedom. It also includes plasticity, stress stiffness, and deflection, Fig. 3.

The material definitions for this steel element are assumed linearly as poison's ratio of 0.3 and elasticity modulus of 200 MPa. The yield stress is taken as 540 MPa for flexural reinforcement and 240 MPa for stirrups. The material definitions for GFRP element are assumed linearly as poison's ratio of 0.3 and elasticity modulus of 40 MPa. The yield stress is taken as 910 MPa for GFRP rebar.

Load plate and supports are modeled by the SOLID 45 element. The element consists of 8 nodes having 3 degrees of freedom, Fig. 4.

The concentrated load used in this study was applied at the top of two transverse rollers. The load was divided into a series of loads at the top mesh joint in the y direction. There are two boundary conditions needed to be applied at the concrete model, where there are two supports (hinged and roller supports) as shown in Fig. 5.

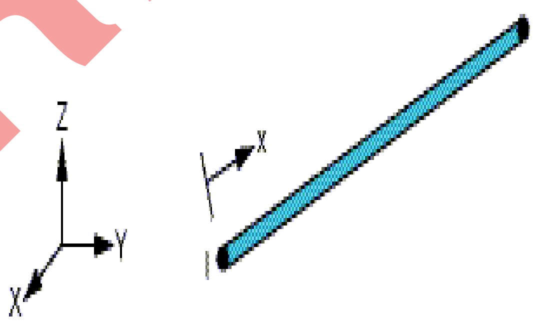


Fig. 3: Discrete element LINK180 [23].

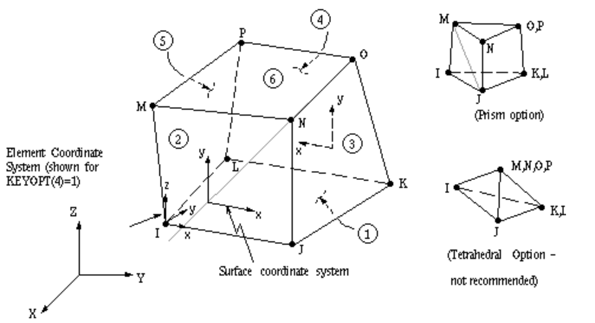


Fig. 4: SOLID 45 element [23].

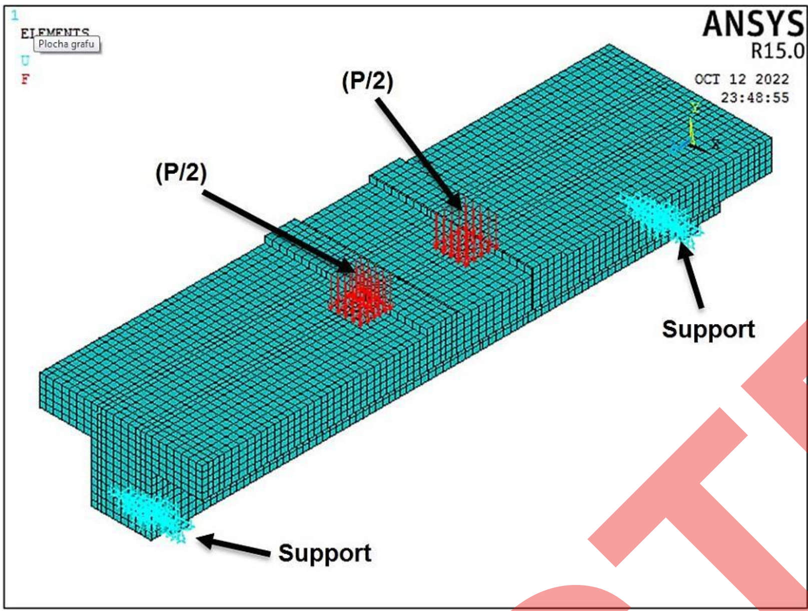


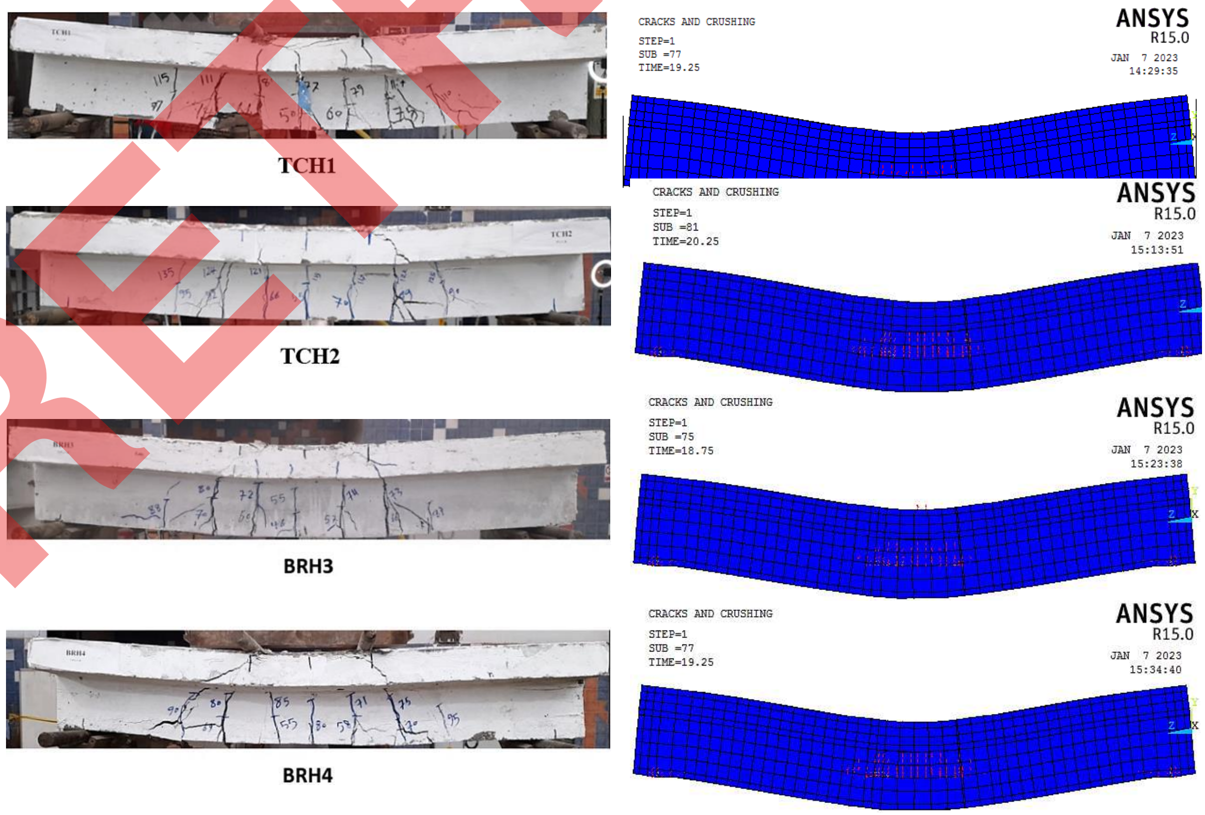
Fig. 5: Boundary conditions and loads applied to beams.

4 Validation of analytical model

The comparison consists of the tests performed by Mohamed Essam [16] and the analytical results by ANSYS version 15. The analytical model showed valuable results regarding the behavior of the T-beam such as failure load, maximum central deflection, crack pattern, ductility and stiffness.

4.1 Crack patterns

Fig. 6 shows the crack pattern after failure, obtained by both the analytical and experimental results for all beams. The load was applied gradually until failure of the beam. The final failure occurred near the mid-span. The analytical results agree well with the experimental results in the crack pattern.



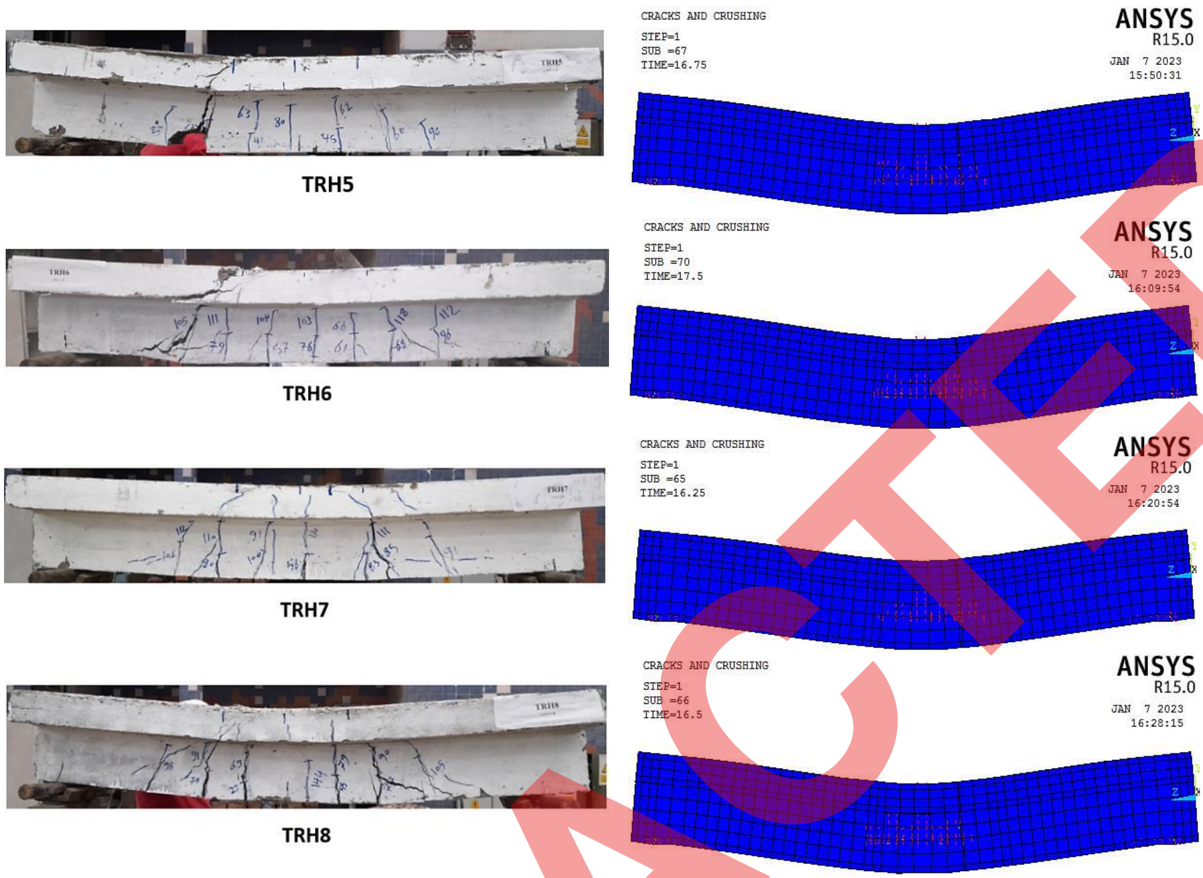


Fig. 6: Analytical and experimental crack patterns for beams.

4.2 Failure load and maximum central deflection

Tables 4 and 5 show the comparison of the failure load and maximum central deflection respectively. The results obtained by the analytical model are compared to the results obtained experimentally by Mohamed Essam [16]. An increase in the failure load values of analytical model by approximately 8.6 % compared to the experimentally obtained one is observed. In addition, a difference in the central deflection values by 16 % is obtained. The deflection results for all beams are shown in Fig. 7 to 10. It can be seen that all beams had linear behavior from initial loading up to the first crack, followed by a nonlinear response after cracking.

Table 4: Comparison of the failure load results.

Specimen	Failure load [kN]		Difference [%]
	Design	Experimental	
TCH1	192.5	183	5.2
TCH2	202.5	195	3.8
BRH3	187.5	174	7.8
BRH4	192.5	180	6.9
TRH5	167.5	155	8.1
TRH6	175	168	4.2
TRH7	162.5	150	8.3
TRH8	165	152	8.6

Table 5: Comparison of the maximum central deflection results at collapse.

Specimen	Maximum central deflection [mm]		Difference [%]
	Design	Experimental	
TCH1	42.5	46.2	-8.0
TCH2	49	55.4	-11.6
BRH3	38.6	44.7	-13.6
BRH4	45.4	51	-11.0
TRH5	32	38.1	-16.0
TRH6	35.4	39.8	-11.1
TRH7	28	31.3	-10.5
TRH8	31.5	35.5	-11.3

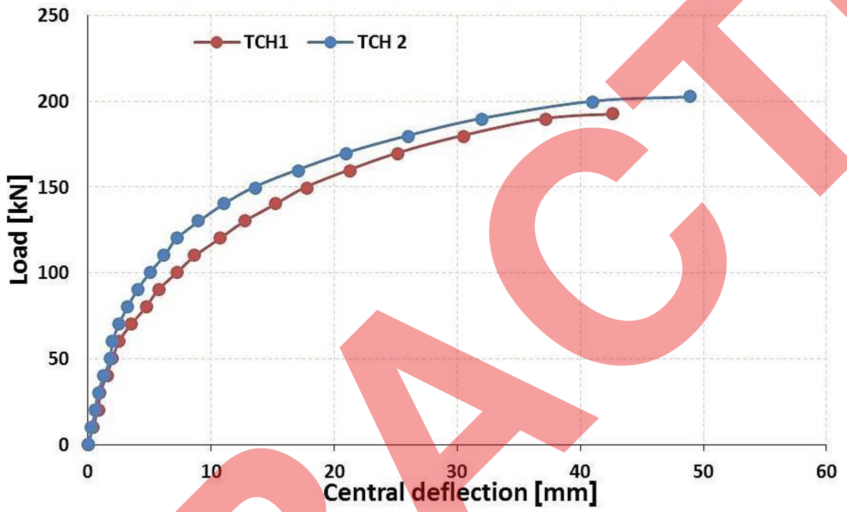


Fig. 7: Analytical load–deflection curve of specimen TCH1 and TCH2.

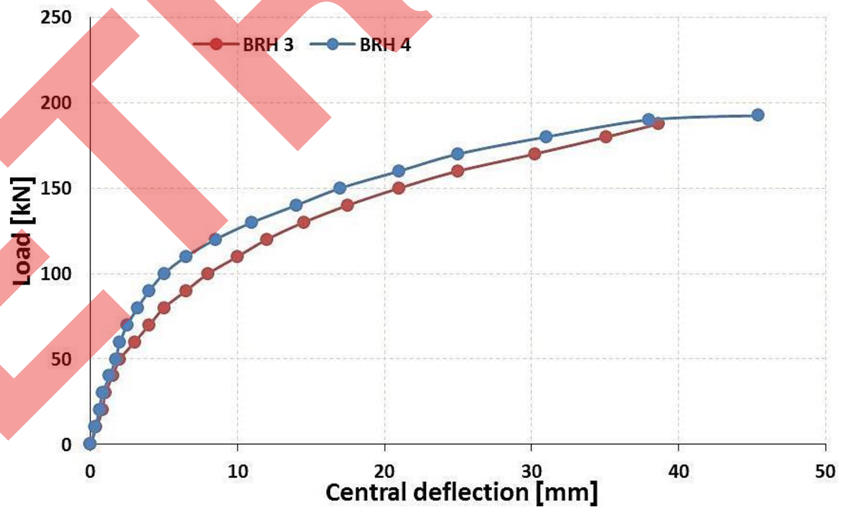


Fig. 8: Analytical load–deflection curve of specimens BRH3 and BRH4.

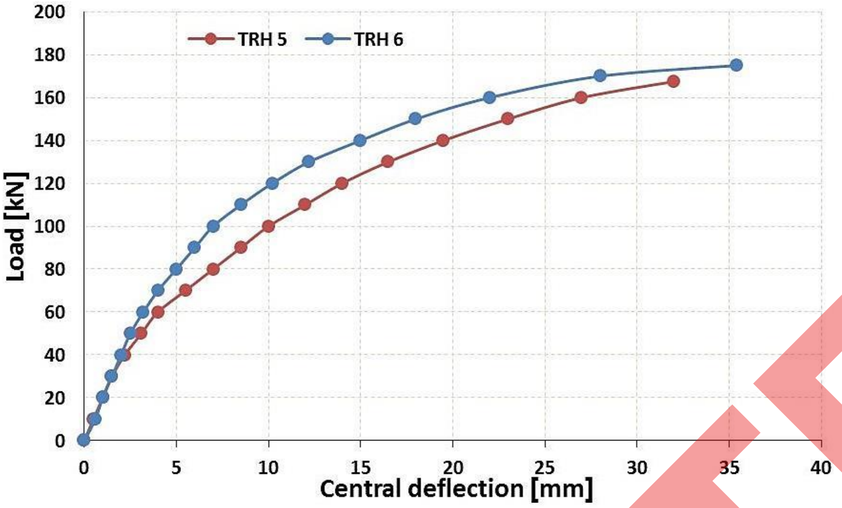


Fig. 9: Analytical load–deflection curve of specimens TRH5 and TRH6.

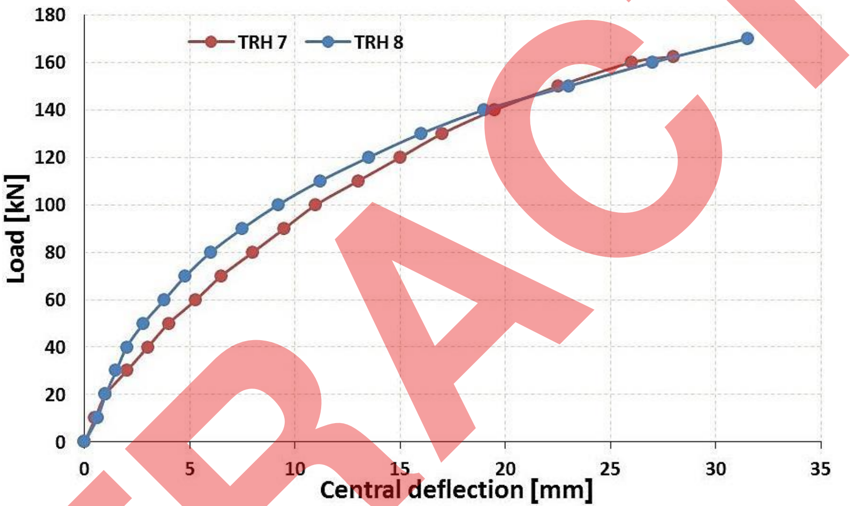


Fig. 10: Analytical load–deflection curve of specimens TRH7 and TRH8.

4.3 Ductility and stiffness

The scale of ductility is energy which equals the area under the load-deflection curve. The ductility factor is calculated as:

$$ductility\ factor = \frac{maximum\ deflection}{yield\ displacement}. \tag{1}$$

Stiffness is a material property that means the ability of the material to resist deformation under applied load. A stiff material deforms slightly under applied loads. A rigid material is a material that never deforms slightly under applied loads. The initial stiffness is calculated as:

$$Initial\ stiffness = \frac{load\ at\ yield\ displacement}{yield\ displacement}. \tag{2}$$

Tables 6 and 7 show the comparison of the ductility factor and initial stiffness respectively. The results obtained by the analytical model are compared to the results obtained experimentally by Mohamed Essam [16]. A reduction in the ductility factor values of analytical model by approximately 9.9 % compared to the results obtained experimentally obtained one is observed. In addition, a difference in the initial stiffness values by 10.9 % is obtained. The analytical results are in well agreement with the experimental results.

Table 6: Comparison of the ductility factor results.

Specimen	Ductility factor		Difference [%]
	Design	Experimental	
TCH1	2.80	2.95	-5.2
TCH2	3.63	3.87	-6.2
BRH3	2.66	2.91	-8.5
BRH4	5.34	5.51	-3.1
TRH5	3.20	3.55	-9.9
TRH6	5.06	5.32	-4.9
TRH7	3.50	3.77	-7.2
TRH8	5.25	5.49	-4.4

Table 7: Comparison of the initial stiffness results.

Specimen	Initial stiffness		Difference [%]
	Design	Experimental	
TCH1	9.21	8.51	8.2
TCH2	11.11	10.12	9.8
BRH3	8.97	8.12	10.4
BRH4	14.12	12.97	8.8
TRH5	10.00	9.42	6.2
TRH6	14.29	12.88	10.9
TRH7	9.89	9.41	5.1
TRH8	13.33	12.22	9.1

5 Parametric study

Due to the large number of parameters affecting the behavior of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete, an extensive parametric study was performed using ANSYS version 15.

Three parameters were investigated namely; Bottom RFT, compressive strength of concrete, and the existence of opening. These specimens were divided into three groups A, B, and C where each one of these groups is assigned to study one parameter. The layout of the parameters and specimens studied are shown in Table 8.

Table 8: Layout of the parameters.

Specimens	Group	Parameter under study	Bottom RFT	Concrete cube strength [MPa]	RFT around the opening
TCH1	A	Bottom RFT	2Ø10 S + 2Ø10 GFRP	46	-
TCH-Steel			4Ø10 S		
TCH-CFRP			2Ø10 S + 2Ø10 CFRP		
TCH1	B	Compressive strength of concrete	2Ø10 S + 2Ø10 GFRP	46	-
TCH1 (25)			2Ø10 S + 2Ø10 GFRP	25	
TCH1 (20)			2Ø10 S + 2Ø10 GFRP	20	
TCH1 (15)			2Ø10 S + 2Ø10 GFRP	15	
TCH2			2Ø10 S + 2Ø12 GFRP	46	
TCH2 (25)			2Ø10 S + 2Ø12 GFRP	25	
TCH2 (20)			2Ø10 S + 2Ø12 GFRP	20	
TCH2 (15)			2Ø10 S + 2Ø12 GFRP	15	
TCH1	C	Solid versus opening	2Ø10 S + 2Ø10 GFRP	46	-
T 10			2Ø10 S + 2Ø10 GFRP		2Ø10 S
T 11			2Ø10 S + 2Ø10 GFRP		2Ø10 GFRF
T 12			2Ø10 S + 2Ø10 GFRP		2Ø10 CFRF

5.1 Effect of bottom RFT

To study the effect of bottom RFT on the behavior of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete, three specimens with variable bottom RFT were analyzed. The compressive strength of concrete is equal in these beams. The results of these beams are shown in Fig. 11.

Beam TCH1 (reinforced by 2Ø10 Steel + 2Ø10 GFRP), Beam TCH-CFRP (reinforced by 2Ø10 Steel + 2Ø10 CFRP) had higher failure loads than Beam TCH-Steel (reinforced by 4Ø10 Steel), by 30.5 %, and 45.8 %, respectively. It can be seen that the failure load of the beam increases with bottom reinforcement by the GFRP bar or CFRP bar. Also, reinforced beams by CFRP bars had a higher failure load than reinforced beams by GFRP bars.

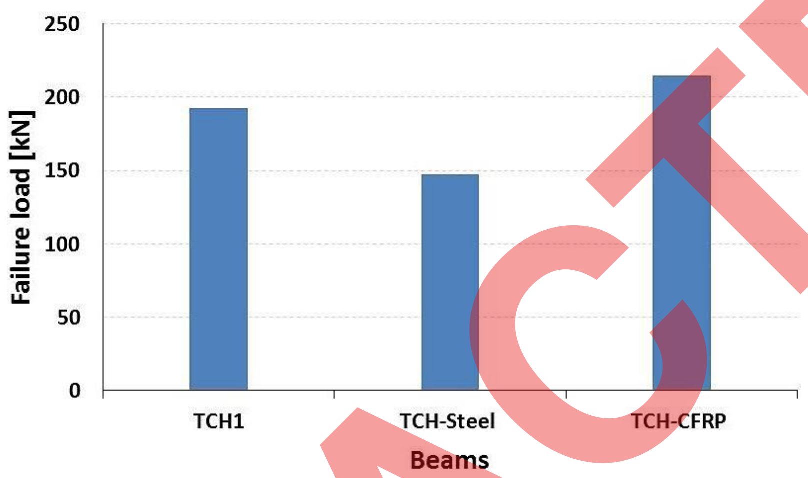


Fig. 11: Failure load for beams with different bottom RFT.

5.2 Effect compressive strength of concrete

The use of recycled rubber in the concrete mixture reduces the compressive strength f_{cu} of concrete. To study the effect of compressive strength of concrete on the behavior of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete, eight specimens with variable compressive strength of concrete and bottom RFT were analyzed.

Beams TCH1, TCH1 (25), TCH1 (20), and TCH1 (15) reinforced by 2Ø10 Steel + 2Ø10 GFRP (bottom RFT). Beams TCH2, TCH2 (25), TCH2 (20), and TCH2 (15) reinforced by 2Ø10 Steel + 2Ø12 GFRP (bottom RFT). The results of these beams are shown in Fig. 12.

Beam TCH1, f_{cu} = 46 MPa, Beam TCH1 (25), f_{cu} = 25 MPa, and Beam TCH1 (20), f_{cu} = 20 MPa, had higher failure loads than Beam TCH1 (15), f_{cu} = 15 MPa, by 57.1 %, 22.4 %, and 12.2 %, respectively.

Beam TCH2, f_{cu} = 46 MPa, Beam TCH2 (25), f_{cu} = 25 MPa, and Beam TCH2 (20,) f_{cu} = 20 MPa, had higher failure loads than Beam TCH2 (15), f_{cu} = 15 MPa, by 50 %, 18.5 %, and 9.3 %, respectively.

It can be seen that the failure load of the beam decreases with the increase in the use of recycled rubber in the concrete mix. Accordingly, larger diameter GFRP bars are recommended in bottom reinforcement if a large amount of recycled rubber is used in the concrete mix.

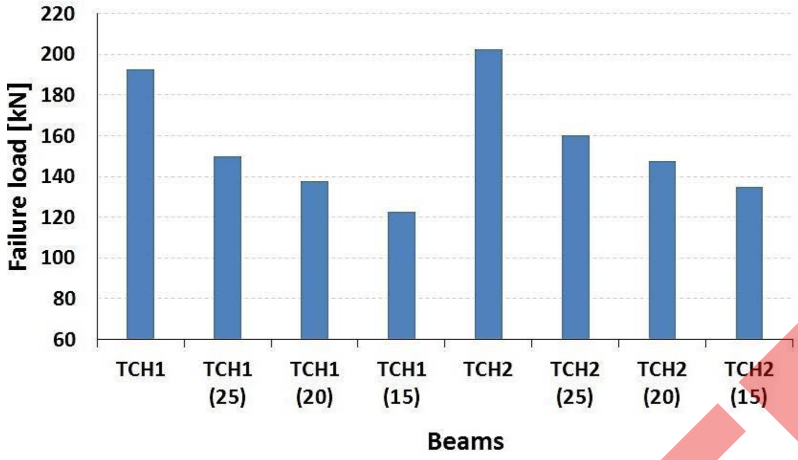


Fig. 12: Failure load for beams with different compressive strength of concrete.

5.3 Effect of the existence of opening

To study the effect of the existence of opening on the behavior of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete, three specimens with central opening 200 x 100 mm were analyzed as shown in Fig. 13. The compressive strength of concrete and bottom RFT are equal in these beams. The results of these beams are shown in Fig. 14.

Beam TCH1 (without opening), Beam T12 (reinforced by 2Ø10 CFRP around opening), and Beam T11 (reinforced by 2Ø10 GFRP around opening), had higher failure loads than T10 (reinforced by 2Ø10 Steel around opening), by 35 %, 15.8 %, and 10.5 %, respectively.

Having an opening in hybrid reinforced T-Beam with partial substitution recycled rubberized concrete reduced the beam load capacity and maximum deflection. It can be seen that using GFRP bars, and CFRP bars in the vicinity of openings in hybrid reinforced T-Beam increased the load capacity of these beams.

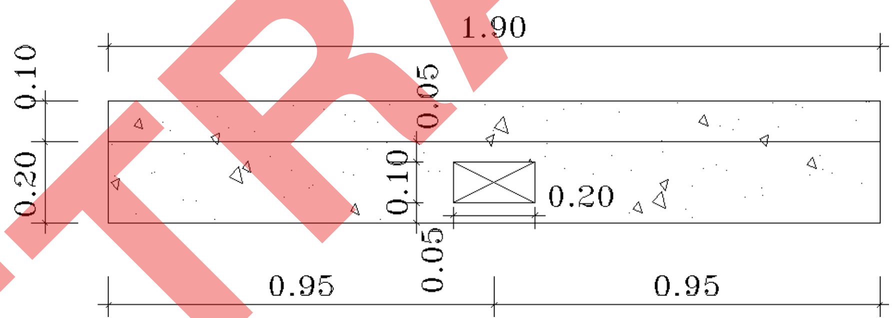


Fig. 13: Concrete dimensions of the tested specimens with opening.

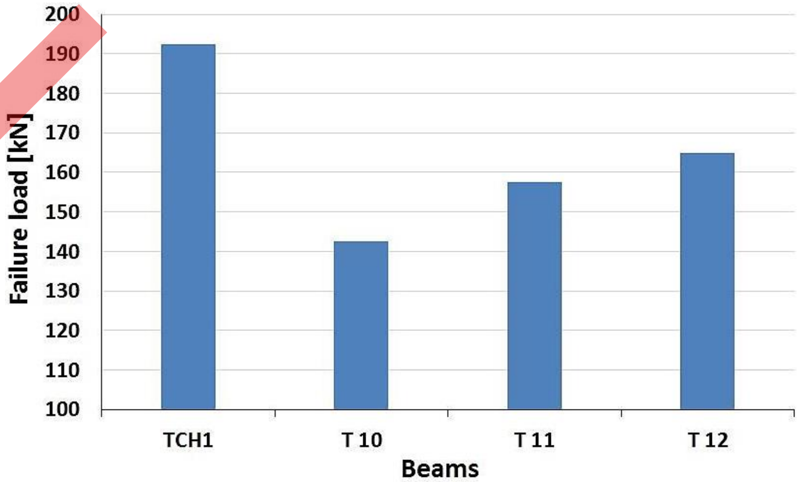


Fig. 14: Failure load for beam TCH1 (without opening) and beams with opening.

5.4 Summary

The numerical results shows that the failure load of the beam with partial substitution recycled rubberized concrete increases with bottom reinforcement by the GFRP bar or CFRP bar and decreases with the increase in the use of recycled rubber in the concrete mix. Also, reinforced beams by CFRP bars had a higher failure load than reinforced beams by GFRP bars. Having an opening in in hybrid reinforced T-Beam with partial substitution recycled rubberized concrete reduced the beam load capacity and maximum deflection. On the other hand, using GFRP bars, and CFRP bars in the vicinity of openings in hybrid reinforced T-Beams increased the load capacity of these beams.

It can be recommended to increase the number of researches on the non-linear behavior of rubber concrete to include other parameters such as lightweight concrete and prestressed concrete.

6 Conclusion

Based on the numerical study and experimentally available result, the following conclusions were drawn:

1) A nonlinear analysis by ANSYS version 15 program enables a detailed understanding of hybrid reinforced T-Beam with partial substitution recycled rubberized concrete, leading to a good agreement when compared to available full-scale test data.

2) The numerical results agree well with the experimental results in the crack pattern. The pattern failure and the cracks in the tension, and compression zones of all beam were the same in both approaches.

3) The numerical results showed an increase in the failure load values of analytical model by approximately 8.6 % compared to the experimentally obtained one is observed. In addition, a difference in the central deflection values by 16 % is obtained.

4) The numerical results showed a reduction in the ductility factor values of analytical model by approximately 10 % compared to the experimentally obtained one is observed. In addition, a difference in the initial stiffness values by 11 % is obtained.

5) The failure load of the beam with partial substitution recycled rubberized concrete increases with bottom reinforcement by the GFRP bar or CFRP bar. Also, reinforced beams by CFRP bars had a higher failure load than reinforced beams by GFRP bars.

6) The failure load of the beam decreases with the increase in the use of recycled rubber in the concrete mix. Accordingly, larger diameter GFRP bars are recommended in bottom reinforcement if a large amount of recycled rubber is used in the concrete mix.

7) Having an opening in hybrid reinforced T-Beam with partial substitution recycled rubberized concrete reduced the beam load capacity and maximum deflection.

8) The numerical results showed that using GFRP bars, and CFRP bars in the vicinity of openings in hybrid reinforced T-Beams increased the load capacity of these beams.

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