Nonlinear FE analysis of R.C corner joints made by different ratios of tire strips aggregate

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Abstract

Use of waste rubber in concrete mix and RC structures has attracted great attention in recent decades. However, attention has been paid to reuse the tire strips in RC parts. In the current study, a finite element (FE) modeling has been proposed for the non-linear analysis of six RC joints with tire strips aggregate. The model includes of the effects of difference ratios of the tire strips replacing aggregate and the size of the strips. As for the credibility of the method, some available experimental works were modeled and non-linearly analyzed using ANSYS 10. The results showed that the model can predict the experimental works with good accuracy. At the end and as a case study, the reference joint specimen was the best accuracy with the FE analysis the other

specimens results were accrued with the experimental results less than the reference specimen, the difference between the FE analysis and the experimental analysis increased as the ratio of the tire strips increased with different size of strips.

Keywords–finite element;nonlinear analysis; RC corner joint;
waste tire; ANSYS 10

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Introduction

Many of the wastes produced today will remain in the environment for several years with larger grows accumulation with a waste disposable crisis. One of the active solution for this problem lies in recycling waste into useful products with continuous decreasing of the number of landfill materials by reusing them again. Chips and grounded from waste tires are different from other waste materials with a potential for re-use because their production method is now well developed. The reuse of this material in concrete could have both environmental advantage and at the same time ensure economic viability with improvement. The characteristic design properties of concrete mix. Previous researches have shown that the use of waste tires particles in concrete mixes decreases the compressive strength of hardened concrete , also shown the improvement of mechanical properties according to several studies[1,2] for different concrete mix design and their replacement type concentration and their civil engineering applications[1].

Rubber tire in construction applications

Tomas developed a concrete mix with a pelletized cut rubber tire as substituted to coarse aggregate for construction applications[2]. Malek use the crumb rubber in developing the strength of concrete mix, where Parveen et al studied the use of rubber waste as partial replacement of fine aggregate to produce rubberized concrete in M30 mix.Nadim et al explore the possibility of reusing worn and damaged vehicle tires in concrete mixture and developed their mechanical properties. Mavronlidon et al, used rubber particles partially replaceing natural aggregate to increase the ductility of concrete,but Ahmed et al investigated the use of recycled tire products in several traditional civil engineering materials by use of both chips and crumb rubber, on other hand Ruiliun et al had recycled tires as coarse aggregate in concrete pavement mixtures in order to present the effect of low and high volume tire chips on fresh and hardened concrete properties[3].

Yunping et al utilized solid wastes (waste glass, and waste rubber particles) as aggregate in concrete mix by use of DOE method .Johnn have a utilization of recycled and waste materials for various construction application by use of swine manure, animal fat, silica fume, roofing shingle, empty palm fruit bunch, citrus peels, cement kiln dust, fly ash, foundry sand, slag glass, plastic, carpet, tire scrap, in order to study the current practice of the use of waste and recycle materials in the construction industry . Carme Carmen A. , have a modification of Portland cement concrete with scrap rubber by w/c ratios , then checked their mechanical properties “ compressive , indirect tensile strength, and flexural strength with different weight ratios of rubber wastes(3).

Beam-Column concrete Joints

Numerical study of the behavior of exterior beam-column joints using ANSYS was performed by Vollum (1998). The influence of varying the element size, shear transfer coefficient for open cracks, modeling of reinforcement and load step and convergence criteria were investigated in this study. Vollum (1998) modeled concrete by ANSYS solid element (Solid65), which is an 8-node brick element that employs William and Warnke (1975) model for the triaxial behavior of concrete. The steel reinforcements were modeled by link elements that were connected to the nodes of the solid elements (4), all of them concluded that the numerical results were acceptable as compared with experimental results.

Test Program

The experimental program conducted by Jarallah(5) was selected to validate the simulations presented in this paper. In his study, the experimental program was carried out to investigate the effect of tire strips addition on the strength and behavior of reinforced concrete (RC) joints. The aim of the research was to study the failure characteristics, strain, deflection behavior and general performance by useing the tire rubber as an aggregate as partial replacement of coarse aggregate at magnitudes of (5%, 15%, 25%) by weight. A total of ten reinforced concrete joints were tested under two points load with different tire ratios replacing as coarse aggregate. The geometrical properties, reinforcement details and compressive strengths are illustrated in Tables (1, 2, 3, 4 and 5) and Figures (1, 2, 3 and 4) showed all the details and testing set up.

Table (1) Experimental Work Variables

Joint No.	Tire strips ratio (%)	Tire strips length (cm)
CR	-	-
2C5	5	2
2C15	15	2
2C25	25	2
4C5	5	4
4C15	15	4
4C25	25	4
6C5	5	6
6C15	15	6
6C25	25	6

Table (2) Steel Properties

Bar type	Modulus of elasticity (kN/m^2)	Yield strength (fy) (MPa)	Ultimate strength (fu) (MPa)
Main Reinforcement	200000	533	610
Shear Reinforcement	200000	433	471

Table (3)Percentages and Dimensions Worn-out rubber tires used.

Batch number	Types	Worn-out Tires Ratio by Weight of Gravel (%)	Fiber Dimensions (cm)		
			Length	Thickness	width
1	**CR**	**0%**	**-**	**-**	**-**
2	**2C5**	**5%**	**2**	**0.7**	**1**
3	**2C15**	**15%**	**2**	**0.7**	**1**
4	**2C25**	**25%**	**2**	**0.7**	**1**
5	**4C5**	**5%**	**4**	**0.7**	**1**
6	**4C15**	**15%**	**4**	**0.7**	**1**
7	**4C25**	**25%**	**4**	**0.7**	**1**
8	**6C5**	**5%**	**6**	**0.7**	**1**
9	**6C15**	**15%**	**6**	**0.7**	**1**
10	**6C25**	**25%**	**6**	**0.7**	**1**

Table (4) Compressive Strength of Rubberized concrete**.**

Specimen Designation	Average Compressive Strength $fc`$ (MPa)	$fc`/fc`$**CR%**	Reduction in $fc`$(%**)**
CR*	**28.05**	**100**	**-**
2C5**	**26.44**	**94.3**	**5.7**
2C15	**21.5**	**76.6**	**23.4**
2C25	**11.52**	**41**	**59.0**
4C5	**17.75**	**63.2**	**36.8**
4C15	**14.35**	**51.1**	**48.8**
4C25	**10.77**	**38.4**	**61.6**
6C5	**14.92**	**53.2**	**46.8**
6C15	**13.41**	**47**	**53.0**
6C25	**8.88**	**31.6**	**62.4**

*** CR Reference corner **2C5 The length of fiber 2cm, with fiber ratio of 5%**

Table (5), Measured and Predicted Static Modulus of Elasticity

Specimen Designation	Measured static modulus of elasticity (GPa) (rEC)	Predicted static modulus of elasticity (GPa) (ACI 318) = 4700 $\sqrt{f'c}$ (EC)	rEC/ EC	Reduction in rEC(%)
CR*	**21.91**	**24.9**	**0.88**	**12%**
2C5	**21.51**	**24.17**	**0.89**	**11%**
2C15	**18.85**	**21.18**	**0.89**	**11%**
2C25	**14.4**	**16.0**	**0.90**	**10%**
4C5	**17.82**	**19.8**	**0.90**	**10%**
4C15	**16.02**	**17.8**	**0.90**	**10%**
4C25	**13.88**	**15.42**	**0.90**	**10%**
6C5	**16.34**	**18.154**	**0.89**	**11%**
6C15	**15.49**	**17.21**	**0.90**	**10%**
6C25	**12.61**	**14.01**	**0.86**	**14%**

*** CR Reference corner**

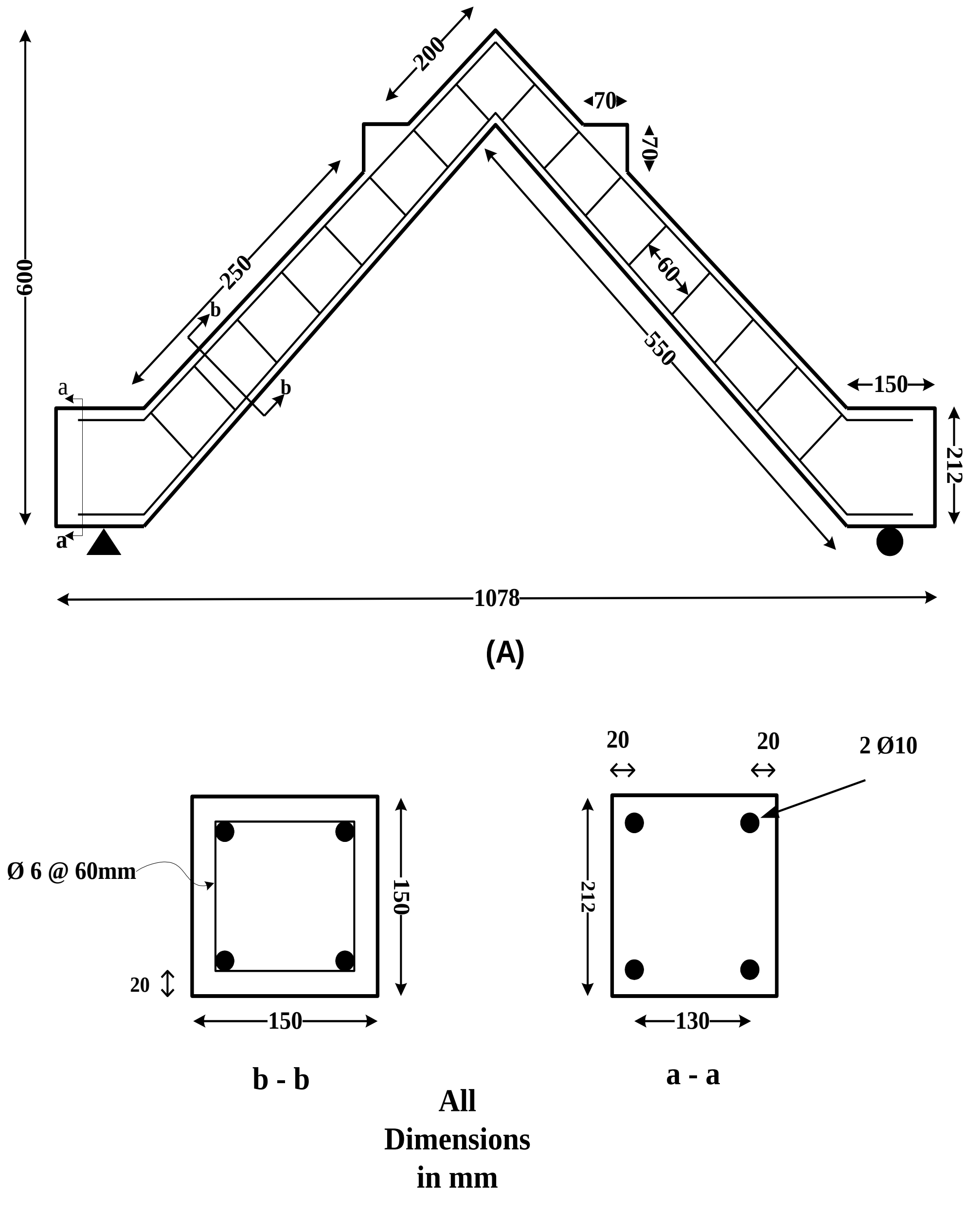


Figure (1), Details of Tested Corners: (A) Overall Dimensions (B) Leg Cross Section (C) Corner Base Cross Section

Figure (2), Corner Set up Figure (3).Concrete corner reinforcement

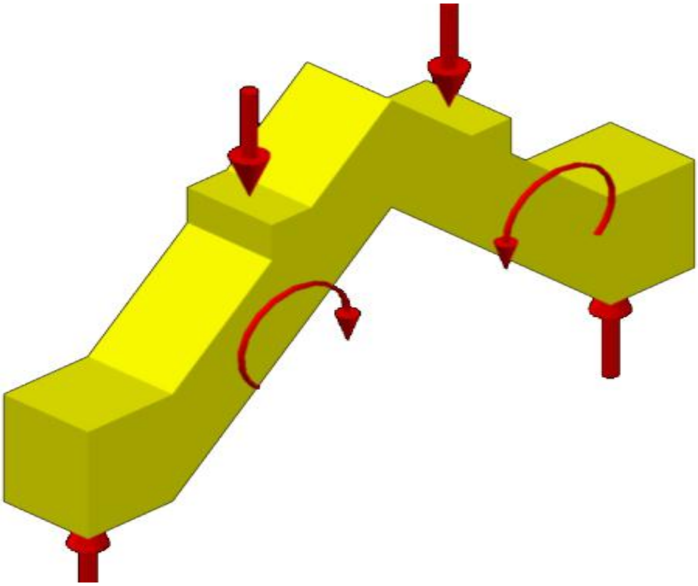


Figure (4), Details of Corner under Testing

Finite Element Modeling

In this paper choose six specimens were chose for FE analysis (CR, 2C5, 2C15, 2C25, 4C5 and 4C15) ,in the other specimens the compressive strength reduction were very highly that the decreasing by 60% and more so this case unsupported structurally so select these specimen to FE analysis.
For non-linear finite element analysis, ANSYS 10 software was used. To model the characteristics of concrete, SOLID65 element was used. This element is capable of simulating the cracking and crushing of concrete, and considers the reinforcement as volume fraction in 3 perpendicular directions, which could account for the modeling of the transverse reinforcement in the members. Furthermore, to model the reinforcement LINK8 element was used.

Some important parameters to perform the failure envelope in the model are the compressive strength of concrete, the modulus of rupture, and the shear transfer coefficients for open and closed cracks. The latter coefficients may be taken as 1.0 and 0.4 to 0.5 for closed and open cracks, respectively. Since the crushing of concrete under pure compression rarely happens, the crushing could be eliminated from the concrete elements for better convergence in the analysis. In this study, the main flexural and shear steel reinforcements in the finite element models were assumed to be an isotropic linear elastic material until the yield point. The ultimate and yield strengths are summarized in Table (2). The Poisson's ratio of steel was taken as 0.3.Concrete properties are selected as (fc'=variables according to joint no. and the Poisson's ratio of concrete was taken as 0.2), figures (13 and 14) shows the mesh and the applied loads at Ansys analysis.

Materials Modeling

SOLID65 isotropic element is used to represent the concrete material, since it has defined by 8 nodes with three degrees of freedom at each node; translations in the nodal x, y, and z directions, see Figure below.

LINK8 element (a uniaxial tension-compression member) is used to represent the reinforcing steel (main and stirrups steel). LINK8 element is defined by two nodes with three degree of freedom at each node; translations in the nodal x, y, and z directions, see Figure below.

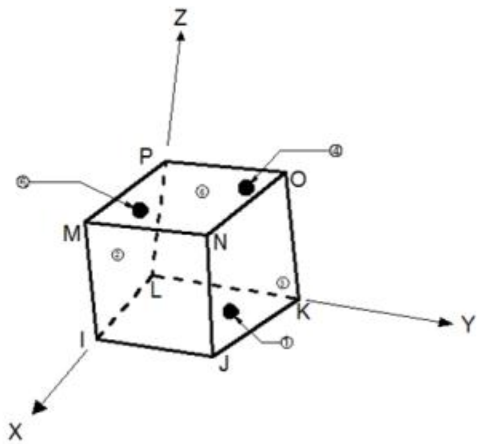
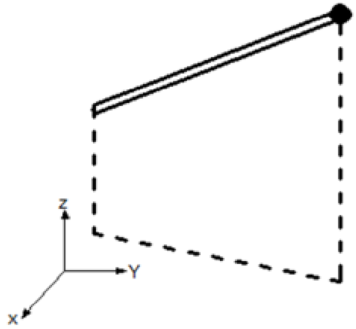


Figure (5) Solid 65 element



Figure(6) Link 8 element

Real Constants

The real constants for these models are shown in Table below

Table (6) Real Constant

Real constant set	Element type	Constant			
1	SOLID65 concrete		Real constant for Rebar 1	Real constant for Rebar2	Real constant for Rebar 3
		Material number	0	0	0
		Volume ratio	0	0	0
		Orientation angle	0	0	0
2	LINK8 Reinforc e-ment	Steel Bar Diameter	$(\phi 10\, mm)$		
		Cross-sectional area (mm^2)	78.54		
		Initial strain (mm/mm)	0		
3	LINK8 Reinforc e-ment	Steel Bar Diameter	$(\phi 6\, mm)$		
		Cross-sectional area (mm^2)	28.26		
		Initial strain (mm/mm)	0		

Material Properties

The material properties for these models are shown in Table below:

Table (7) Materials Properties

<table>
<tr><th>Material model number</th><th>Element type</th><th>Material properties</th></tr>
<tr><td>1</td><td>SOLID65</td><td>
<table>
<tr><th colspan="2">Linear Isotropic</th></tr>
<tr><td>EX</td><td>21910</td></tr>
<tr><td>PRXY</td><td>0.2</td></tr>
</table>
<table>
<tr><th colspan="3">Multilinear Isotropic*</th></tr>
<tr><td></td><td>Strain</td><td>Stress</td></tr>
<tr><td>Point 1</td><td>0.000464</td><td>15</td></tr>
<tr><td>Point 2</td><td>0.001</td><td>20</td></tr>
<tr><td>Point 3</td><td>0.00158</td><td>24</td></tr>
<tr><td>Point 4</td><td>0.0018</td><td>27</td></tr>
<tr><td>Point 5</td><td>0.003</td><td>28.05</td></tr>
</table>
*assumed value according to the experimental test
<table>
<tr><th colspan="2">Concrete</th></tr>
<tr><td>ShrCf-Op</td><td>0.4</td></tr>
<tr><td>ShrCf-Cl</td><td>0.5</td></tr>
<tr><td>UnTensSt</td><td>2.97</td></tr>
<tr><td>UnCompSt</td><td>-1</td></tr>
<tr><td>BiCompSt</td><td>0</td></tr>
<tr><td>HydroPrs</td><td>0</td></tr>
<tr><td>BiCompSt</td><td>0</td></tr>
<tr><td>UnTensSt</td><td>0</td></tr>
<tr><td>TenCrFac</td><td>0</td></tr>
</table>
</td></tr>
<tr><td>2</td><td>LINK8</td><td>
<table>
<tr><th colspan="2">Linear Isotropic</th></tr>
<tr><td>EX</td><td>200000</td></tr>
<tr><td>PRXY</td><td>0.3</td></tr>
</table>
<table>
<tr><th colspan="2">Bilinear Isotropic</th></tr>
<tr><td>Yield Stress</td><td>533</td></tr>
<tr><td>Tang Mod.</td><td>0</td></tr>
</table>
</td></tr>
</table>

3	LINK8		Bilinear Isotropic	
			Yield Stress	433
			Tang Mod.	0
			Linear Isotropic	
			EX	200000
			PRXY	0.3

Results and Discussion

Failure Load:

After the data was analyzed and carefully studied, it can be said that the collected data of the failure load obtained from the numerical solution for all joints is approximately equal to the experimental load and all the joints failed by flexure. The final loads for the ANSYS10 finite element method a the last applied load step before the solution diverges due to numerous cracks and large deflections.

Through an extensive comparison between the normal specimen and other specimens with different rubber of tire ratios, it can be concluded that the specimens with rubber have failure loads less than normal specimen without rubber just like the experimental results. Also, the increasing of rubber ratio causes a decrease in the carrying capacity to bending stresses, because the decrease in the compressive strengths.

The comparison between experimental and numerical failure loads is shown in table (8).

Load-Deflection Relationship

The numerical results for all specimens are displayed and compared with the experimental results. Figures below contain load-deflection curves predicted by ANSYS 10 and the test results for all specimens examined by Jarallah(5). The results of ANSYS10 converge to the normal specimens more than other specimens with rubber ratios because of not taking the actual behavior of the rubber material inside the concrete and the slip between the concrete mortar and the rubber strips with different ratios and different strips size. Also, the ratio of difference between theoretical and experimental results was increased as the ratio of the rubber replacing increased.

In general, the normal joint was stiffer than the other specimens with rubber ratios. In every stage of loading application, the deflections are increased significantly come to the reduced stiffness of the joints.

Figures (7, 8, 9, 10, 11 and 12) Experimental and numerical Load - Deflection Curve for joints.

Table (8) Experimental and numerical failure load.

Model	Centerline Deflection (mm)		Ultimate load(kN)		$(P_{theo}-P_{exper})/p_{exper}$ %
	Exper[5].	Numerical	Exper[5].	Numerical	
CR	8.3	8.1	55	58	5.4
2C5	18.5	19	43	46	6.9
2C15	12	14	38	42	10.4
2C25	10	11	30	35	16.6
4C5	14.5	16	38	41	7.8
4C15	8.3	9	32	35	9.3

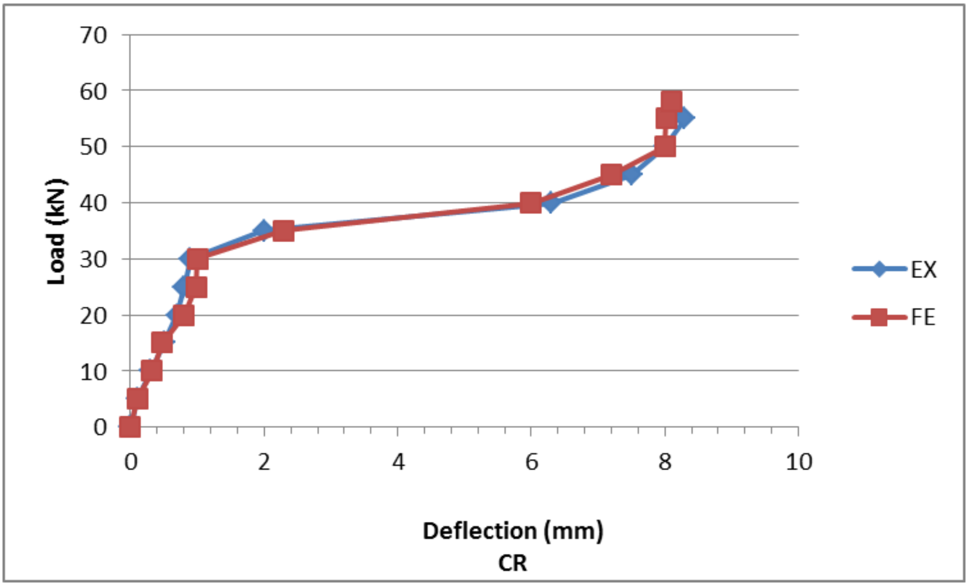


Figure (7) Load- Deflection curve for joint CR

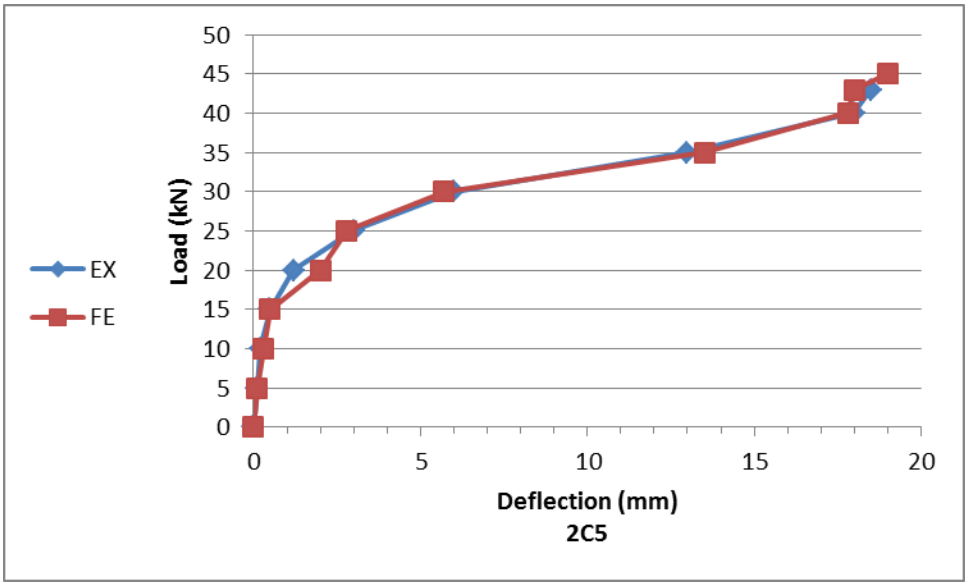
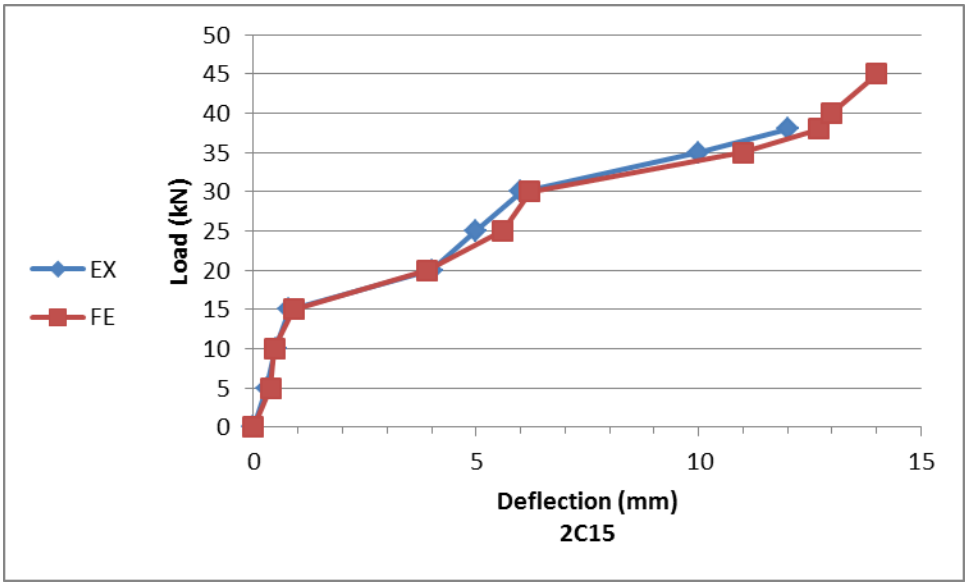


Figure (8) Load- Deflection curve for joint 2C5



Figure(9) Load- Deflection curve for joint***2C15***

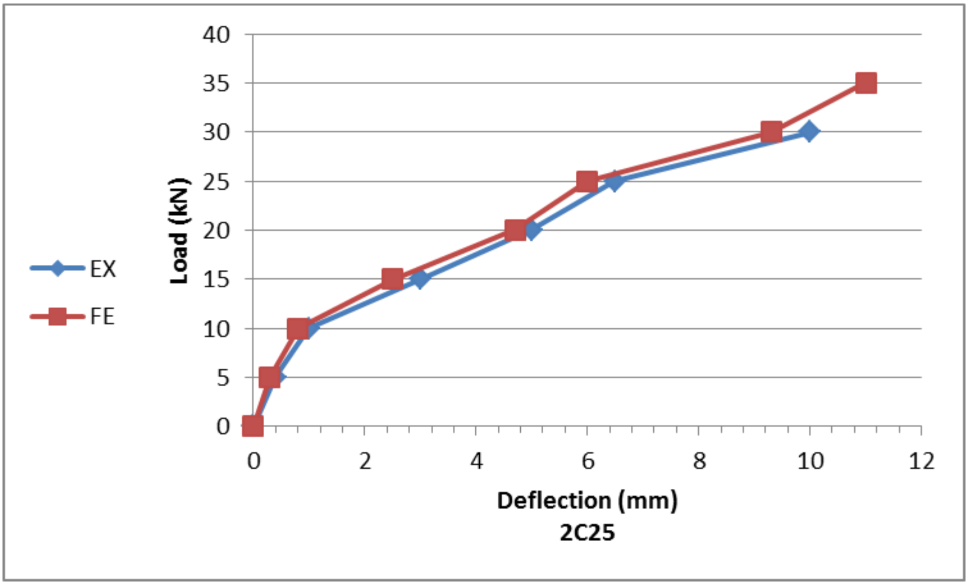


Figure (10***)*** Load- Deflection curve for joint ***2C25***

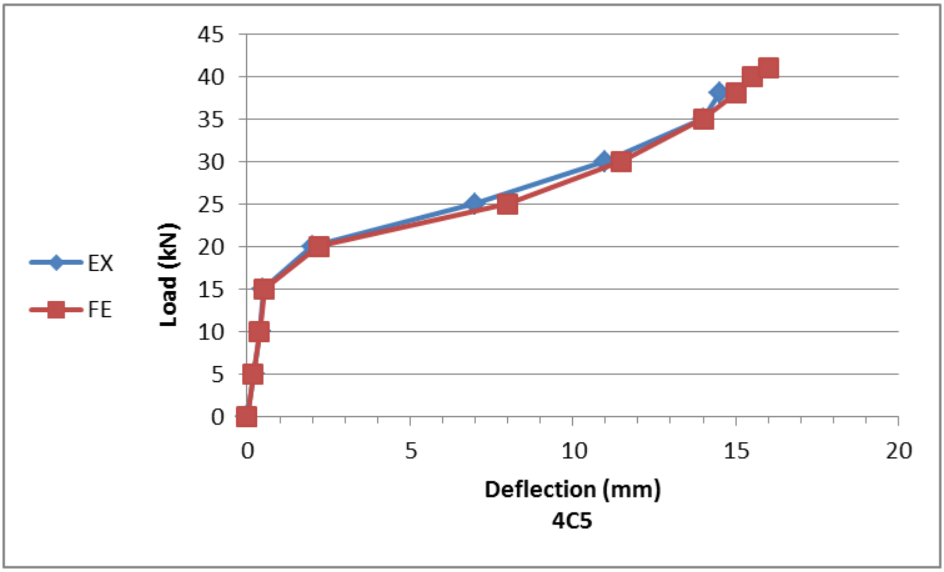


Figure (11) Load- Deflection curve for joint ***4C5***

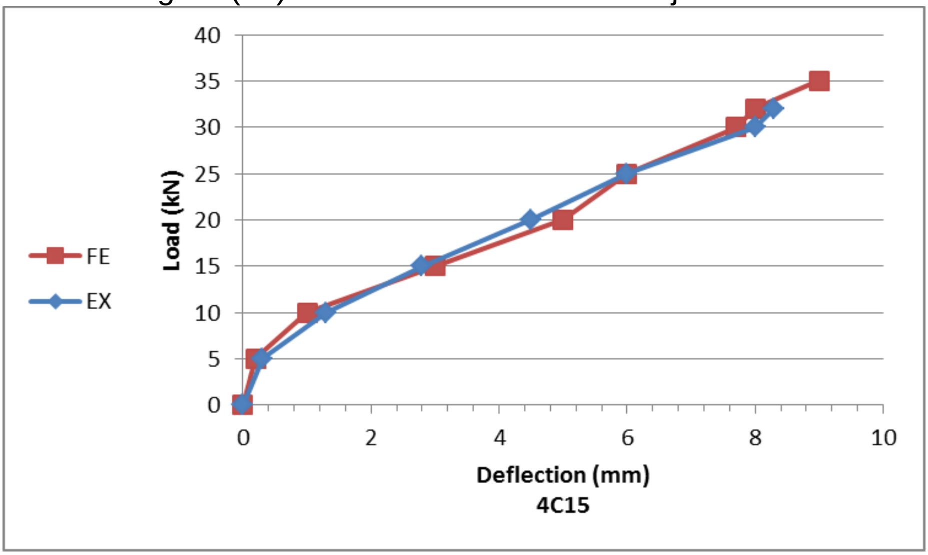


Figure (12) Load- Deflection curve for joint ***4C15***

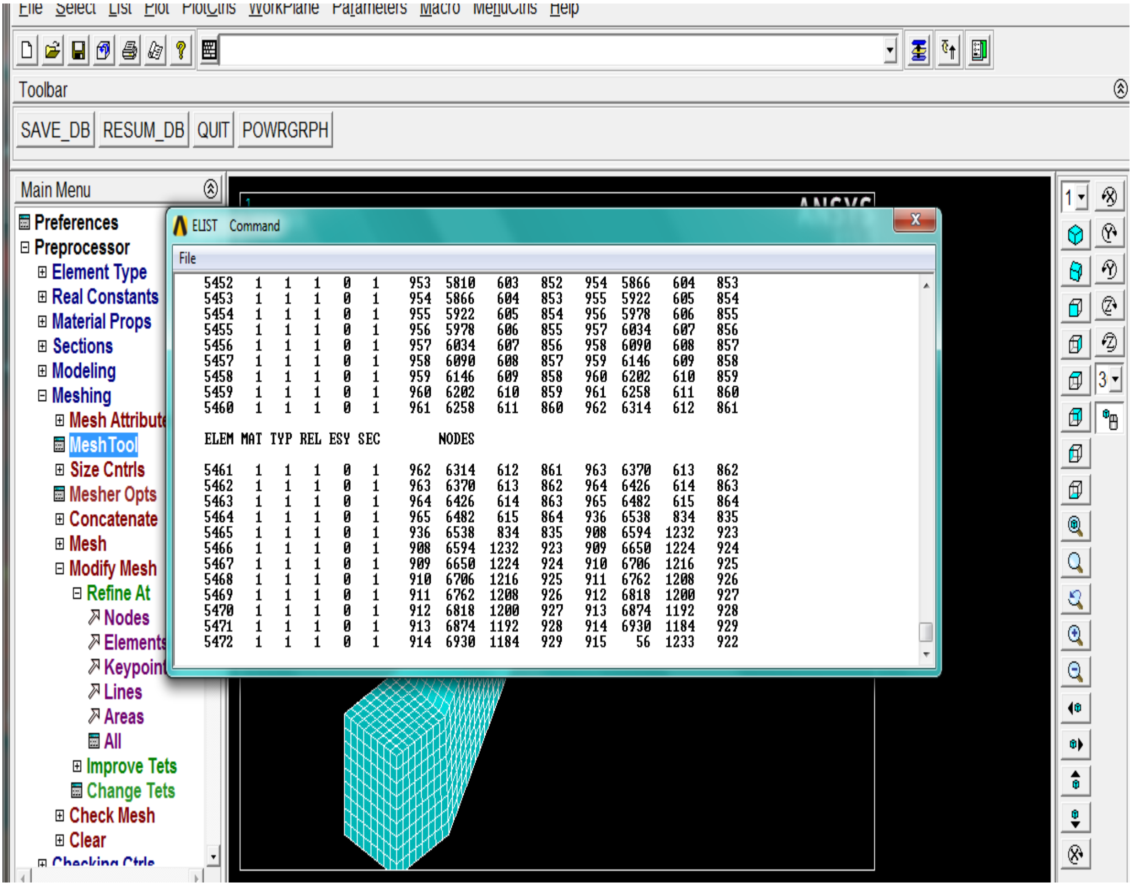


Figure (13)Ansys mesh and the number of element (5472 elements).

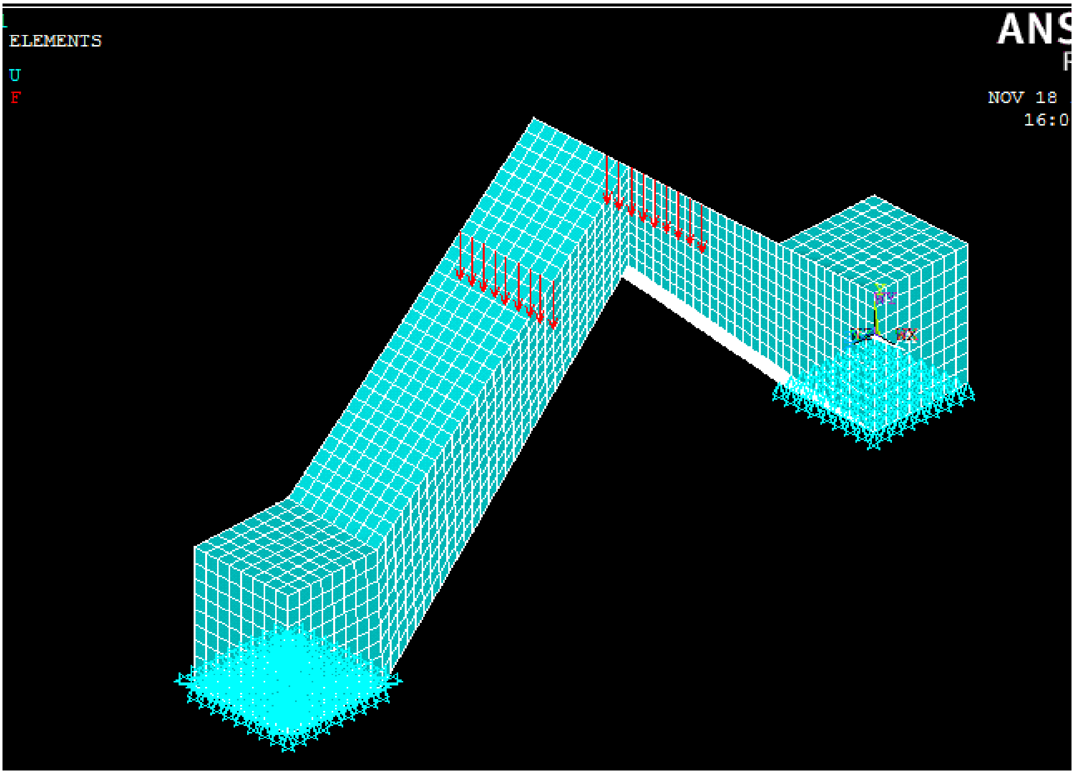


Figure (14)Ansys mesh and the applied loads.

Conclusions

From the results of this paper and comparing the numerical and experimental results we can conclude that:

1. At any given load level, the deflections are increased significantly there by increasing the ratio of rubber replacing.

2. All the joints failed with bearing of concrete at the corner block this failure called bearing failure at the experimental and numerical study.

3. The failure load of the reference specimen was more than other specimens with rubber replacing ratios.

4. The increasing of the rubber ratios increasing the difference ratio between numerical and experimental results, because of the represent of the element in the ANSYS 10 program depends on assumed cohesive and adhesive properties for concrete that is impossible be same the natural case.

5. The FE (solid 65) representing the normal concrete gives good agreement between nonlinear FE results and experimental results for the reference specimen, but, for the specimens with rubber this model cannot represent the rubber replacing aggregate and the bond between cement and the rubber strips, so the difference ratios increased as the rubber ratios increased (5.4%, 6.9% ,10.4% ,16.6% ,7.8% and 9.3%) respectively for CR,2C5 ,2C15 ,2C25 ,4C5 and 4C15).

References

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دراسة تحليلية لاخطية بطريقة العناصر المحددة للمفاصل الخرسانية المسلحة المحتوية على نسب مختلفة من ركام المخلفات المطاطية من الاطارات المستهلكة

م. نورا جاسم محمد* م.م. جاسم جار الله فهد*

المستخلص

ان استعمال المخلفات المطاطية في الخرسانة والاجزاء الخرسانية المسلحة اخذ حيزا كبيرا بالابحاث في الوقت الحاضرو كذلك استعمال المخلفات المطاطية من الاطارات المستهلكه في الاجزاء الخرسانية المسلحة في هذه الدراسة نموذج من العناصر المحددة انشئ للتحليل اللاخطي لكل نموذج من ستة مفاصل خرسانية مسلحة تحتوي على نسب مختلفة من القطع المطاطية من الاطارات ويأخذ بنظر الاعتبارفي النموذج النسب المختلفة للقطع المطاطية والحجم المختلف لها و من خلال هذه الطريقة التي تناولت بعض النتائج العملية وتمثيلها ببرنامج (الانسز)وتحليلها لاخطيا , اظهرت النتائج تقارب مع النتائج العملية خاصة للمفصل الرئيسي الذي لايحتوي على المطاط و هناك اختلافات بسيطة ازدادت مع ازدياد نسبة المطاط في المفصل ومختلف الاحجام للشرائح المطاطية.

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