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EFFECT OF USING RECYCLED CONCRETE AGGREGATE ON BEHAVIOR OF R.C CORBELS CAST WITH SELF-COMPACTING CONCRETE (EXPERIMENTAL AND ANALYTICAL STUDY)

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ABSTRACT

Due to repeated wars against Iraq as well as the terrorist operations lead to demolition of many government and commercial buildings and thus necessitating the demolition of these buildings and throwing them as a rubble. Also any concrete structure reaches its end life, it is either repaired or demolished and transformed to waste. The waste materials were transferred to landfill and no longer used. These waste will increase with time and cause an environmental problem. So, this study was prepared to examine the ability of crushing and reusing of the demolition waste as a coarse aggregate in the production of new concrete known as a Recycled Aggregate Concrete.

This study consists of two parts: experimental and theoretical parts. Both parts dealt with the effect of using recycled concrete aggregate (RCA) as a partial replacement of natural coarse aggregate in self-compacting concrete, on the structural behavior of reinforced concrete corbels. The replacement percentages were used in this study (0%, 25%, 50%, and 75%). The experimental part consists of casting and testing of ten self-compacting reinforced concrete corbels which made with either natural coarse aggregate or with a partial replacement of natural coarse aggregate by recycled concrete aggregate then the experimental results was compared with the analytical results (finite element results). The analytical part was carried out by using ANSYS program (version 18). In ANSYS program three types of elements were used in the modeling of each corbel specimen. The elements are Solid65, Link180 and Solid185. Solid 65 element was used to represent of concrete while link180 element was used to represent of steel reinforcement and finally solid185 element was used to represent the steel plates at supports and under the applied load.

The ANSYS software is used to simulate the load bearing capacities of the reinforced concrete corbel and then compared with the experimental results. The results show that there is a good coincidence between the experimental and analytical results. Therefor the ANSYS software can be used to predict the shear strength of SCC corbels containing RCA with acceptable accuracy.

KEY WORDS: FEM, Corbel, Recycled Concrete Aggregate, Self-Compacting Concrete

1. INTRODECTION

Concrete is considered as a construction material consists of cement, coarse aggregate, fine aggregate and water. There are many types of concrete like normal concrete, high strength concrete, self-compacting concrete, steel fiber concrete, green concrete, recycled aggregate concrete … etc. In this study two types of self-compacting concrete were produced. First natural coarse aggregate was used and second recycled concrete aggregate was used.

Self-compacting concrete (SCC) is defined as a concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity (Efnarc, 2002).

Also the SCC is defined as a high flowable , non-segregating concrete which is spread into place, fill the formwork, and encapsulate the reinforcement without needs to the mechanical consolidation (ACI Committee 237R-07). Self-placing concrete, and self-leveling concrete which are all subsets of SCC (Al-Shaarbaf et al., 2014).

Other authorities define the SCC as a concrete which has excellent deformability, high resistance to segregation and can be filled into heavily reinforced areas without vibration (Shindoh and Matsuoka, 2003).

Normal aggregate, sand, crushed stone and natural gravel are used to produced normal concrete or self-compacting concrete. Normal aggregate form 60% of SCC volume and it has an acceptable effect on determining the strength, durability and workability of concrete.

In addition, the cost production of SCC also effected by the quantity of aggregate. Lower cost of aggregate is desirable to produce SCC. The availability of the normal aggregate is considered limited therefore, the usage of the recycling waste material is a proper solution to produce the concrete. Especially, the large amount of waste or by-product materials from industry that are going to landfills and have been increasing with time. Reusing and recycling of the waste material is considered as an available option in construction waste management.

Till now there are no specific techniques used for recycling of demolition waste. Also, the existing techniques might vary from country to others. The characteristics of recycled concrete aggregates are mainly affected by the recycling process. Japan has created a technology to give a high quality recycled aggregate from demolition waste by utilizing rubbing and heating method. Toward that technology those aggregates might be reused likewise a raw materials used in the preparing of concrete mixes. Fine powder results from the crushing of old cement paste may be reused as a crude material for soil stabilization or cement admixtures.

Recycled aggregate is formed from demolition waste and crushing construction materials. When it is obtained from crushing of old concrete then it is called a recycled concrete aggregate (RCA) which is required high equipment technology and energy (Yoshimi and Hirokazu, 2005).

2. REINFORCED CONCRETE CORBEL

Corbels or brackets are cantilevers with shear span to effective depth ratio (a/d) lower than unity. The small ratio of (a/d) leads to make the corbel strength are usually controlled by shear, which is similar to deep beams. So the shear deformations affect on the behavior of corbels in the elastic and inelastic stages and the shear strength becomes the major factor (Yang et al., 2012).

Until the 1960's, corbels were designed as a cantilevers using the shear and flexural provisions derived for beams of normal proportions. This procedure is inapplicable to deep beams which have much in common with corbels.

In 1960's, two methods of corbel design were developed. First the two empirically based methods which introduced by the American institute. However, the Europeans developed an approach based on the truss analogy. Due to the rapid expansion of the corbels design and behavior, many applications failed due to inadequate methods of detailing. Accordingly, several standard procedures were developed particularly in the areas of the provision of secondary reinforcement and the steel anchorage bearing pad size with placement. While the different empirical design approaches were developed by the American such as truss analogy which becomes more applicable (S.J Foster and RE Powell, 1994).

According to the (ACI 318-14) the corbel is designed to resist three types of loading:

i-Vertical load (Vu) : is resulted from the reaction at the ends of precast girder or beam.

ii-Horizontal load (Nuc) : is resulted from breaking load, temperature change, creep and shrinkage which can be avoided by using elastomeric pad.

iii-Bending Moment (Mu) : is resulted from the combined effect of vertical and/or horizontal forces which has a maximum value at the column-corbel interface.

To design the corbels two methods are used which are shear – friction theory according to ACI Code and the strut and tie models according to European code (S.J Foster and RE Powell, 1994). In addition, there are four types of failure in reinforced concrete corbel which are flexural failure, compression failure, shear failure along the interface and secondary or local bearing close to the bearing plate failure (ACI 318-14).

3. MATERIALS AND EXPERIMENTAL WORK

The experimental program consisted of laboratory tests for aggregates and plain concrete to characterize the properties of self-compacting concrete such as filling and passing ability and segregation resistance for fresh state. In addition to the mechanical properties in hardened state. Ten reinforced concrete corbels were cast and tested which were divided to group A, B and C.

3.1. Materials

Ordinary Portland Cement type I with natural fine aggregate (sand) were used. Two types of coarse aggregate, natural aggregate and recycled concrete aggregate were used which have same gradation zone and satisfying (Iraqi specification No.45/1984). High range water reducer (HRWR) with tap water from water-supply network were used to get a suitable workability. Limestone powder locally named AL-Gubra was used as a filler material in producing the SCC. Ukrainian deformed steel reinforcing bars with different diameters (Ø6mm, Ø8mm, Ø10mm and Ø12mm) were used.

3.2. Concrete mix and preparation

First, the cement, sand, gravel, SP and water are mixed together according to the mixing procedure shown in Fig. 1. The mix preparation of varying of SCC is shown in Table 1. Four types of SCC mixes were used. Each mix was either made with natural coarse aggregate or with RCA. Mix No. one was made with natural coarse aggregate while mixes No. two, three and four were made with 25%, 50% and 75% replacement of normal coarse aggregate by RCA respectively. The target compressive strength of all SCC mixes was (38MPa ± 2MPa).

Table 1. Mix Proportions of Varying of SCC.

Mix NO.	Mix Symbol	Cement kg/m^3	Filler kg/m^3	F.A kg/m^3	N.C.A kg/m^3	RCA kg/m^3	Water L/m^3	S.P L/m^3	W/C
1	SCC-R0	400	100	775	825	0	190	5	0.475
2	SCC-R25	405	97	775	619	206	190	5.2	0.47
3	SCC-R50	415	93	775	413	413	190	5.7	0.457
4	SCC-R75	440	88	775	206	619	190	6.0	0.432

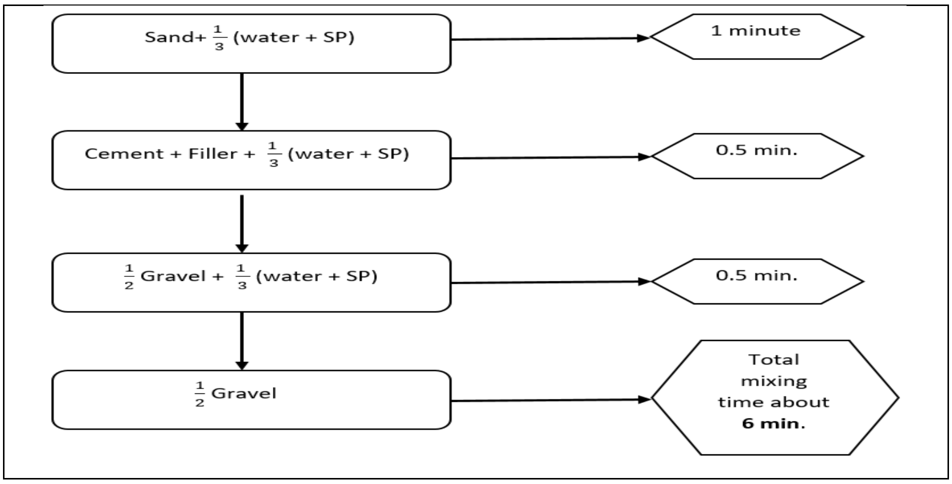


Fig. 1. Mixing Procedure.

3.3. Test specimens with corbels details

The compressive strength of concrete was determined by using a hydraulic compression machine of 2000kN capacity available in the laboratory of Civil Engineering Department / Kufa university. For each concrete pach, three cubes of 150 * 150 * 150 mm were tested according to (BS 1881: Part 121: 1993), and three cylinders of 150 * 300 mm were tested according to ASTM (C39/39M-03). While the splitting tensile strength and modulus of elasticity were determined by utilizing a cylinder with 150 * 300 mm. And finally, a prism with (100*100*400) mm was used to determine the flexural strength. For each combination of the parameters, three specimens were tested and the mean value is reported.

Ten reinforced concrete corbels were cast which were divided in to three groups (A, B and C) as shown in Table 2. In group A, recycled concrete was used as a partial replacement of natural coarse aggregate with the ratio of 0, 25, 50 and 75 % as shown in Table 2. However, Group B consisted of B1, B2 and B3 where the secondary reinforcement (A_h) was increased from 0Ø6 to 4Ø6 as shown in Table 2. In Group (C) the tapering ratio (h/H) was increased from 0.25 to 0.75 as shown in Table 2.

The main tension reinforcement (As_{main}) and shear span to effective depth ratio were constant in all the reinforced concrete corbels. Fig. 2 shows the reinforcement details and dimensions of reinforced concrete corbels.

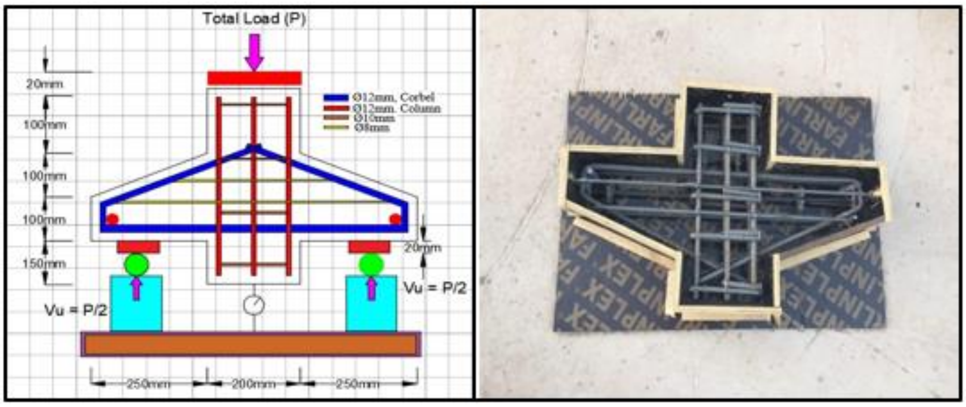


Fig. 2. The Reinforcement Details and Dimensions of R.C Corbels.

Table 2. Corbels Details.

Corbel NO.	Type of Concrete	Corbel Symbol	a/d Ratio	Main tension Reinforcement (As_{main})	Secondary Reinforcement (A_h)	Tapering Ratio (h/H)
1	SCC-R0	A1(0.9)	0.90	2Ø12	2Ø8	0.5
2	SSC-R25	A2(0.9)	0.90	2Ø12	2Ø8	0.5
3	SCC-R50	A3(0.9)	0.90	2Ø12	2Ø8	0.5
4	SCC-R75	A4(0.9)	0.90	2Ø12	2Ø8	0.5
5	SCC-R50	B1(0.9)	0.9	2Ø12	0	0.5
6	SCC-R50	B2(0.9)	0.9	2Ø12	2Ø6	0.5
7	SCC-R50	B3(0.9)	0.9	2Ø12	4Ø6	0.5
8	SCC-R50	C1(0.9)	0.90	2Ø12	2Ø8	0.25
9	SCC-R50	C2(0.9)	0.90	2Ø12	2Ø8	0.75
10	SCC-R50	C3(0.9)	0.90	2Ø12	2Ø8	1

Then all the specimens were painted with a white color to detect the cracks direction. The load was applied with small increments. Each load increment was increased by 10kN up to the failure. Deflection was recorded manually while, the concrete strain and crack width were recorded at loads of 20kN or 30kN. Then the development of the cracks on the concrete corbels were observed through the markers. After failure, the cracks were painted out as shown in Fig. 3.

Fig. 3. Casting and Curing Methods of the Reinforced Concrete Corbels Specimens.

4. FINITE ELEMENT ANALYSIS

The finite element analysis (FEA) is a numerical method of solving a certain problem in science and engineering. FEA can be used to solve the linearity and nonlinearity behavior of any structural problem. Several FEM software packages are available for non-linear analysis, such as ABAQUS, ANSYS, MATLAB, and ADINA, which can be used to solve simple to complex problems in engineering.

Before design a model in the FE program, it is essential to assign the type of analysis, type of element, real constant and materials models. ANSYS version-18, is a powerful engineering program based on the finite element method which can solve problems.

Three elements SOLID65, LINK180 and SOLID185, which provided in the ANSYS software, are used to model the tested corbel specimens. SOLID65 element was used to represent concrete while LINK180 and solid185 were used to represent the reinforcement and load steel plates respectively (Al-Hadad Waseem,2016).

To reduce the computational time requirements, only a quarter of each specimen was modeled and analyzed. Each tested specimen has two planes of symmetry in the x–y and y-z planes, which halving the specimen longitudinally and transversely as shown in Fig. 4. Therefore, the applied load was equal to the one fourth (¼) of the total load.

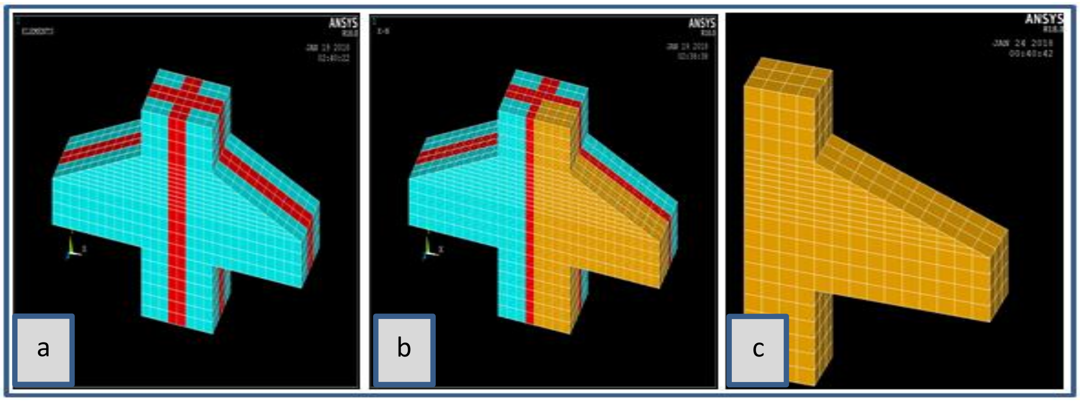


Fig. 4. The Applied loads on The Specimens.

(a) Total Specimen (b) Divided in to Four Parts (c) One-Fourth of Specimen

4.1. Calibration of the ANSYS program:

Before start model and compare the experimental results with theoretical results. The adequacy and accuracy of the ANSYS program should be check. Therefore, double sided of the specimens were used for calibration which were A1, A3 and C3 as shown in Fig. 5. After validation, the material properties were replaced by those in Table 3. The bending failure of the corbels specimens were simulated and the load deflection curves, cracking load, ultimate load and cracks pattern at failure were studied.

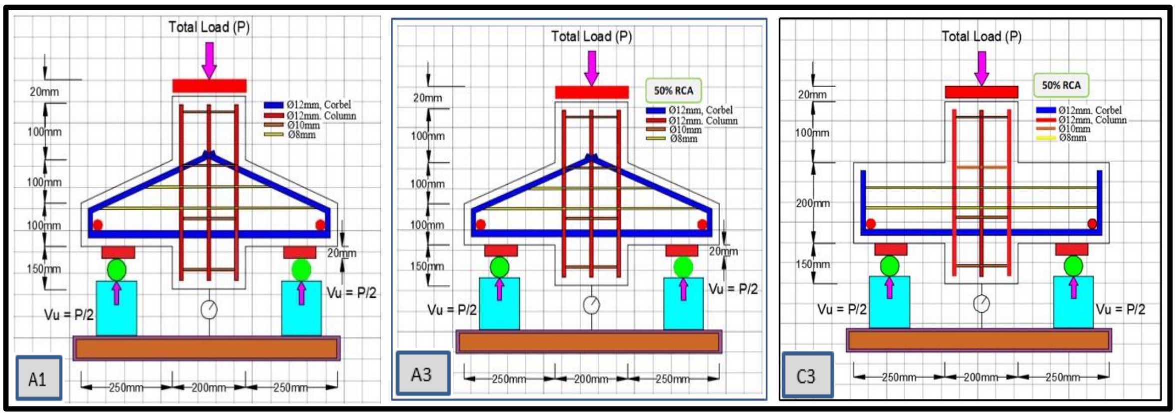
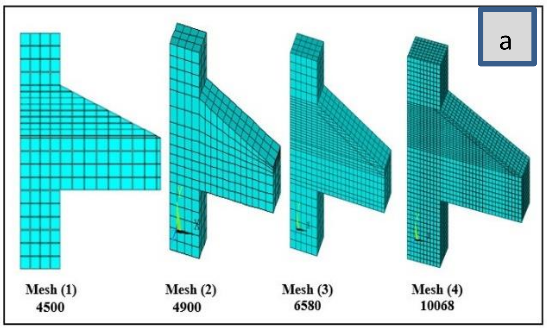


Fig. 5. Geometry and Dimensions of Corbels A1, A3 and C3 Respectively.

4.2. Mesh size

In the FEM, mesh density is considers as an effective parameter to obtain preferable and more accuracy results with economical computation time. In this study, four types of mesh size were utilized to find the more suitable mesh for the three control corbel specimens. In reference corbel, A1, four types of mesh size were used to study its effect on the predicted deflection at the center of the bottom face of column. The results showed that the preferable one was mesh four when the number of elements for one-quarter of the control specimen was equal to (10068) as shown in Fig. 6. The numbers of element in each analytical models are shown in Table 3.



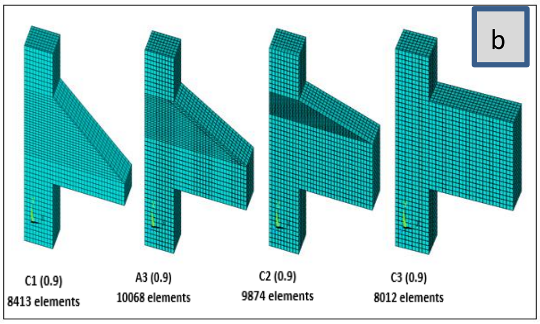


Fig. 6. Different Types of Mesh size

(a) Mesh Size of Control Specimens in Group A; (b) Number of Elements in Group C

Table 3. Numbers of Element in Each Analytical Models.

Groups of Corbels	Solid 65	Link 180	Solid185	Total Number of Elements
Group (A)	9600	340	128	10068
Group (B)				
B1(0.9)	9600	243	128	9962
B2(0.9)	9600	309	128	10037
B3(0.9)	9600	377	128	10105
Group (C)				
C1(0.9)	8000	285	128	8413
C2(0.9)	9450	296	128	9874
C3(0.9)	7600	284	128	8012

4.3. Loads and boundary conditions

A displacement boundary conditions are needed to constrain the model. To ensure that the similarity behavior of the mode's specimen to the experimental and reduce the required time for modeling, boundary conditions are applied at points of symmetry where the supports and loadings existed. In addition, the nodes at the planes of symmetry needed to be fixed in the direction normal to the plane as shown in Fig. 7.

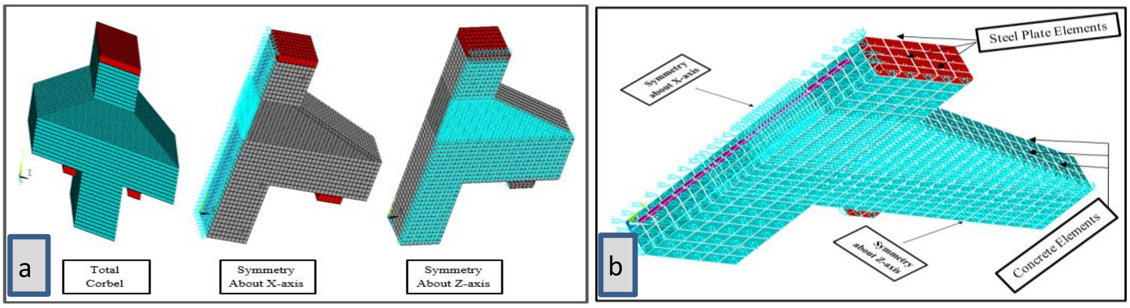


Fig. 7. Total Specimen: (a) Symmetry About X and Z Axes and (b) Constrained Model.

The external load was applied on all nodes of the loading steel plate which located on the top face of each corbel. The full load (P) was applied at the middle node while quarter of the load (P/4) was applied on the corner nodes. But, half of the applied load (P/2) was applied on the circumference's nodes as shown in Fig. 8.

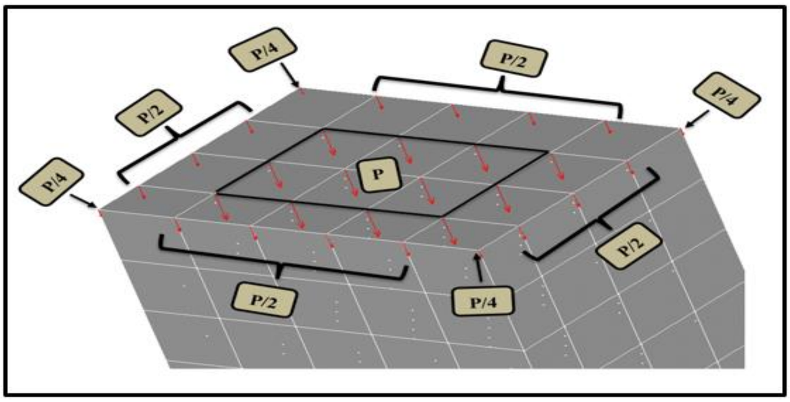


Fig. 8. Details of the Applied Load at the Loading Plate.

The application of the loads up to failure was done incrementally as required by the Newton-Raphson procedure. Therefore, the total applied load was divided into a series of load increments (load steps). Within each load step, maximum of (100) iterations were permitted. At the analysis stage the load step was large at points of linearity in the response, whereas, it was small when cracking and steel yielding occurred. In all cases the convergence was achieved before reaching to the maximum (100) iteration. Failure of the models is defined when the solution for a minimum load increment still does not converge (convergence fails). The program then gives a message specifying that the models have been failed.

5. RESULTS AND DISCUSSION OF THE EXPERIMENTAL WORKS

The results of the slump flow, T-50, J-ring and column segregation are shown in Fig. 9 and Table 4.

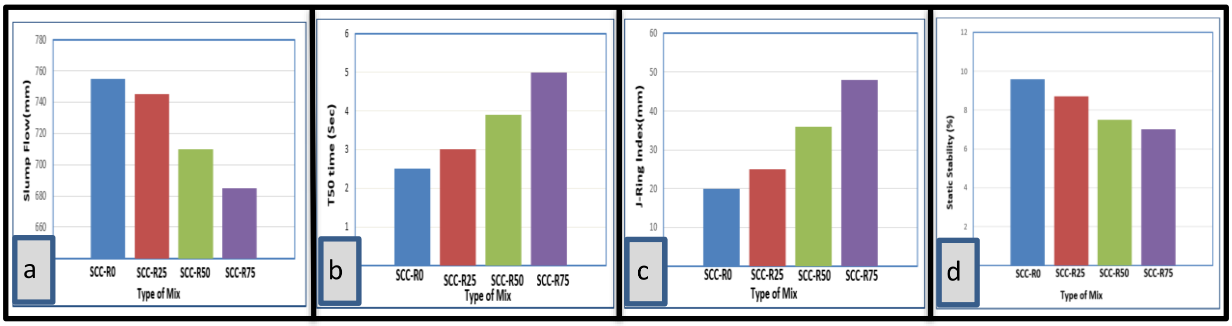


Fig. 9. Fresh Properties of SCC: (a) Slump Flow, (b)T-50, (c)J-ring and (d)Column Segregation.

Table 4. Fresh Properties of Varying of the SCC.

Test Type	**Mix Notation**				**Limit of ASTM**
	SCC-R0	**SCC-R25**	**SCC-R50**	**SCC-R75**	
Slump flow (mm)	755	745	710	685	450-760
T-50 cm (sec)	2.5	3	3.9	5	2-5
J-ring (mm)	20	25	36	48	< 50
Column segregation (%)	9.6	8.7	7.5	7	< 10%

From the experimental results indicated in Fig. 9, it can be deducted that SCC with the higher replacement ratio of RCA has the higher time (T-50) and the lower slump compared to SCC without RCA. This can be attributed to the rougher and more angular particle shape of RCA compared to normal coarse aggregate. Also it can be noticed that the passing ability index (PAI) increases with the increase in replacement percentage of RCA. This is due to the rough and angular particle shape of RCA in addition to the adhered mortar on the surface of the RCA which lead to increase friction and reduce passing ability. While the static stability index decreases with the increase in RCA content which means that SCC with RCA have better segregation resistance compared to normal SCC. Also from Table 5 it can be concluded that the splitting tensile strength, flexural strength and the modulus of elasticity of SCC containing RCA was reduced compared with that made with normal coarse aggregate. The reason behind that is attributed mainly to the inherent inferior characteristics of the recycled aggregate particles, which normally consist of considerable amounts of porous old mortars of different qualities, hence form zones of weakness in the concrete composite. In addition, the presence of micro-cracks in some of the aggregate particles resulted from crushing the old concrete from which the recycled aggregate is generated, the above conclusion leads to make the strength of RAC mixes is lower than natural SCC (Tavakoli & Soroushian, 1983). When comparison is made between the surface of fraction of both conventional SCC and SCC with RCA, it can be noted that the failure in the natural aggregate concrete happened along the interface between aggregate particles and cement mortar, while in recycled aggregate concrete the plane of failure passes around or through aggregate.

Table 5. The Hardened Properties of the SCC.

Concrete Type	f'c (MPa)	ft (MPa)	Ec (MPa)	fr (MPa)
SCC-R0	39.4	3.78	34351	5.8
SCC-R25	36.6	3.71	33600	5.6
SCC-R50	37.1	3.56	29349	5.2
SCC-R75	36.3	3.25	26512	4.4

Where Ds and FC Represent of Diagonal Splitting and Flexure-Compression Failure Respectively

Fig. 10. The Crack Patterns of SCC Corbels under Vertical Loading After Testing.

5.1. Ultimate load capacity

The ultimate load capacity of corbels is affected by many factors such as RCA content, horizontal reinforcement and tapering ratio. In group A, the effect of using the RCA was studied. The results showed that the ultimate load capacity of corbels A2(0.9), A3(0.9) and A4(0.9) which were made with 25%, 50% and 75% RCA decreased by 10.27%, 16.21% and 21.62% respectively compared with corbel which was made with natural coarse aggregate A1(0.9) as shown in Table 6. The reduction in strength was due to that the RAC has lower stiffness than normal aggregate concrete (NAC).

However, in group B the effect of using different amounts of horizontal reinforcement on the behavior of corbel was studied. From results, it can be observed that the ultimate load capacity of corbels B2(0.9) and B3(0.9) increased by 64.28%, 164.2% respectively compared with corbel B1(0.9). It can also be concluded that the presence of horizontal reinforcement leads to increase ductility and make the corbel takes more load. Also the use of horizontal reinforcement leads to change the mode of failure from diagonal splitting as in B1 to flexure compression failure as in B2 and B3.

The effect of tapering ratio was studied in group C. The results indicate that the ultimate load capacity of corbels C2(0.9) and C3(0.9) increased by 47.82% and 56.52% respectively compared with C1(0.9) the reason is due to the increase in the width of the diagonal strut.

Table 6. The Experimental Cracking Load, Ultimate Load and Mode of Failure.

	Corbel Symbol	**RCA Content (%)**	**Main Tension Reinf. (As_{main})**	**Horizontal Reinf. Stirrups (A_h)**	**Tapering ratio (h/H)**	**Cracking Load (kN)**	**Ultimate Load (kN)**	**Mode of failure**
Group A	A1(0.9)	0	2Ø12	2Ø8	0.5	43	373	FC
	A2(0.9)	25	2Ø12	2Ø8	0.5	50	332	FC
	A3(0.9)	50	2Ø12	2Ø8	0.5	42	310	FC
	A4(0.9)	75	2Ø12	2Ø8	0.5	40	290	FC
Group B	B1(0.9)	50	2Ø12	0	0.5	40	140	DS
	B2(0.9)	50	2Ø12	2Ø6	0.5	44	230	FC
	B3(0.9)	50	2Ø12	4Ø6	0.5	80	370	FC
Group C	C1(0.9)	50	2Ø12	2Ø8	0.25	40	230	FC
	C2(0.9)	50	2Ø12	2Ø8	0.75	52	340	FC
	C3(0.9)	50	2Ø12	2Ø8	1.0	55	360	FC

5.2. Load - deflection curves :

The load-deflection curves of the tested corbels are shown in Fig. 11. From this Figure, it can be noted that the increase in the recycled concrete aggregate percentage leads to increase deflection.

At load 165kN the deflection increased by 2.34%, 6.17% and 14.54% respectively when the RCA increased it from (25-75) because of its lower stiffness than normal aggregate.

However, for group B the ultimate deflection of corbels B2(0.9) and B3(0.9) decreased by 64.78% and 80.43% respectively compared with corbel B1(0.9) at load of 130kN the horizontal reinforcement has a noticeable effect on the ultimate load and ultimate deflection of R.C corbels. The ACI 318-14 recommends that the horizontal reinforcement must not be less than one-half of the difference between the main reinforcement (As_{main}) and the direct tension reinforcement (A_n). ACI 318-14.

For group C, the ultimate deflection of corbels C2(0.9) and C3(0.9) decreased by 43.47% and 52.32% respectively compared with corbel C1(0.9) due to the increase in width of the diagonal compression strut.

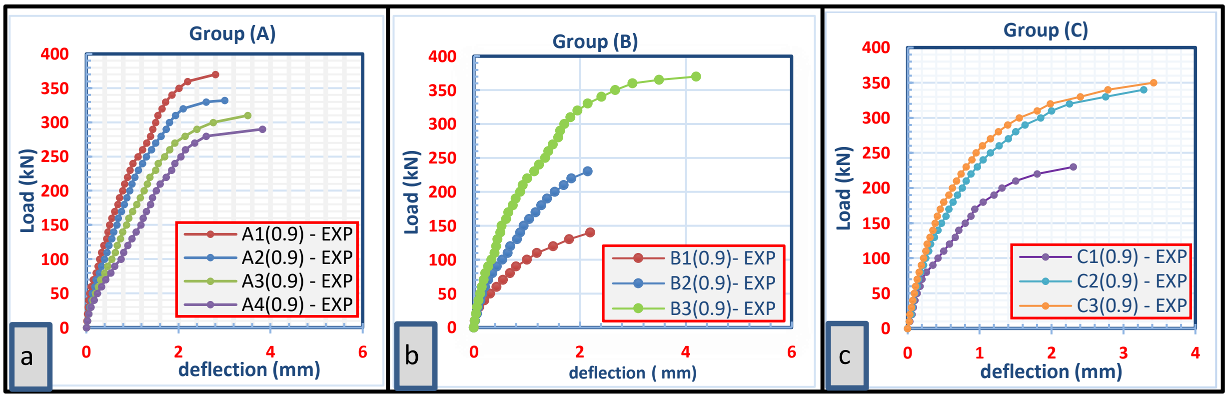


Fig. 11. The Load-Deflection Curves of the Corbels in All Groups.

(a) Group A (b) Group B (c) group C

6. THE COMPARISON BETWEEN THE EXPERIMENTAL AND FE RESULTS

6.1. Cracking and ultimate Loads

The results of the ultimate and cracking loads which are obtained from the experimental and FE are described in Table 7. The ultimate load for the finite element models represented the last applied load steps before the solution starts to diverge due to numerous cracks and large deflections at some nodes.

Table 7. The Ultimate Loads of the Experimental and Finite Element.

Corbel	Crack load (kN)			Ultimate load (kN)		
Name	$\mathbf{Pcr_{FEM}}$	$\mathbf{Pcr_{EXP.}}$	$\frac{\mathbf{Pcr_{FEM}}}{\mathbf{Pcr_{EXP}}}$ %	$\mathbf{P_{u\ EXP.}}$	$\mathbf{P_{u_{FEM.}}}$	$\frac{\mathbf{P_{u_{FEM}}}}{\mathbf{P_{u_{EXP}}}}$ %
A1 (0.9)	38	43	0.88	373	365.31	0.98
A2 (0.9)	37	50	0.74	332	360	1.084
A3 (0.9)	35	42	0.85	310	325	1.048
A4 (0.9)	32	40	0.8	290	310	1.06
B1(0.9)	40	40	1	140	142.92	1.02
B2(0.9)	41	44	0.93	230	229.88	0.999
B3(0.9)	71	80	0.887	370	430	1.16
C1 (0.9)	35	40	0.875	230	231	1.004
C2 (0.9)	36	52	0.692	340	349.12	1.026
C3 (0.9)	38	55	0.7	360	367	1.019
Average			0.835			1.04

It can be noticed that the results of first cracking and ultimate loads obtained from the finite element analysis are in agreement with the corresponding values of the experimental loads. The average ratio of $\frac{P_{cr_{FEM}}}{P_{cr_{EXP}}}$ about (0.83%) and $\frac{P_{u_{FEM}}}{P_{u_{EXP}}}$ (1.04%) for cracking and ultimate loads respectively.

6.2. Load Deflection Curves

The results of the load-deflection of the experimental works were obtained by using electronic dial gauge. This gauge was placed at the center of the bottom face of the column to measure deflection. In ANSYS program, the deflection was measured at the same point that adopted in the experimental test.

The results of the load-deflection curve which were obtained by the FEM were similar to the experimental results in elastic zone while, they moved significantly in inelastic zone. In addition, the results of all corbels were grater and relatively stiffer than the experimental results.

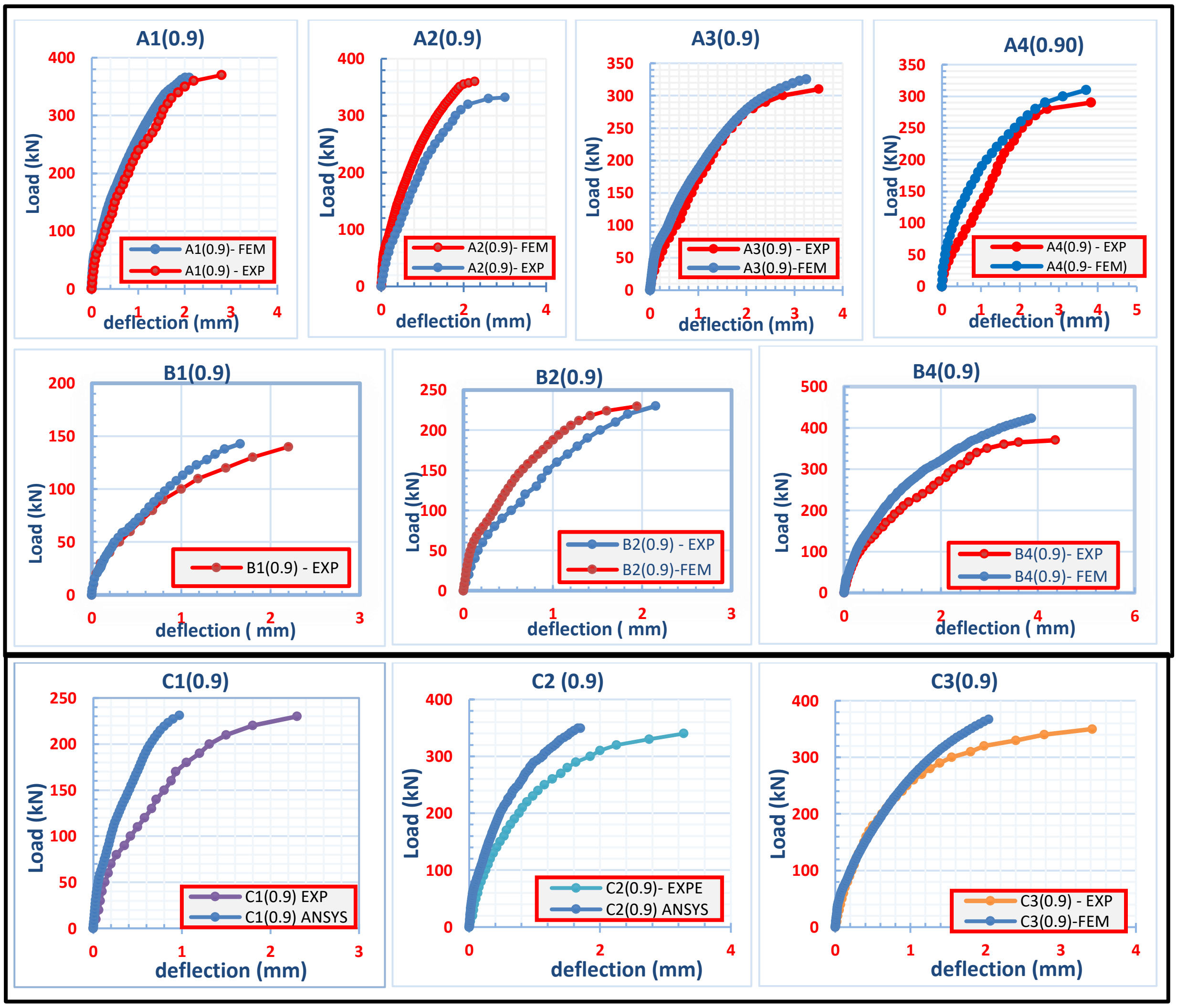


Fig. 12. Experimental and FEM Load – Deflection Curves of Tested Corbels.

At advanced stages of loading it can be noted that the numerical solution was a relatively stiffer than the experimental response. As in general, the load deflection plots for the corbels from the finite element analysis gave an acceptable approximation when compared with the experimental response.

6.3. Stresses and strains of concrete

For selected corbel specimens, the variation of stresses and strains of concrete in x, y, and xy directions were found. These results were obtained by using a numerical technique given by ANSYS computer program. In the ANSYS program, stresses and strains are calculated at integration points of the concrete solid elements. The principal stress, von-Mises stress, stress intensity and stress state ratio were presented in Figs. 13 and 14.

From the results it can be concluded that the stresses and strain in concrete was increase with the increase in RCA content while decrease with the increase in horizontal reinforcement and tapering ratio.

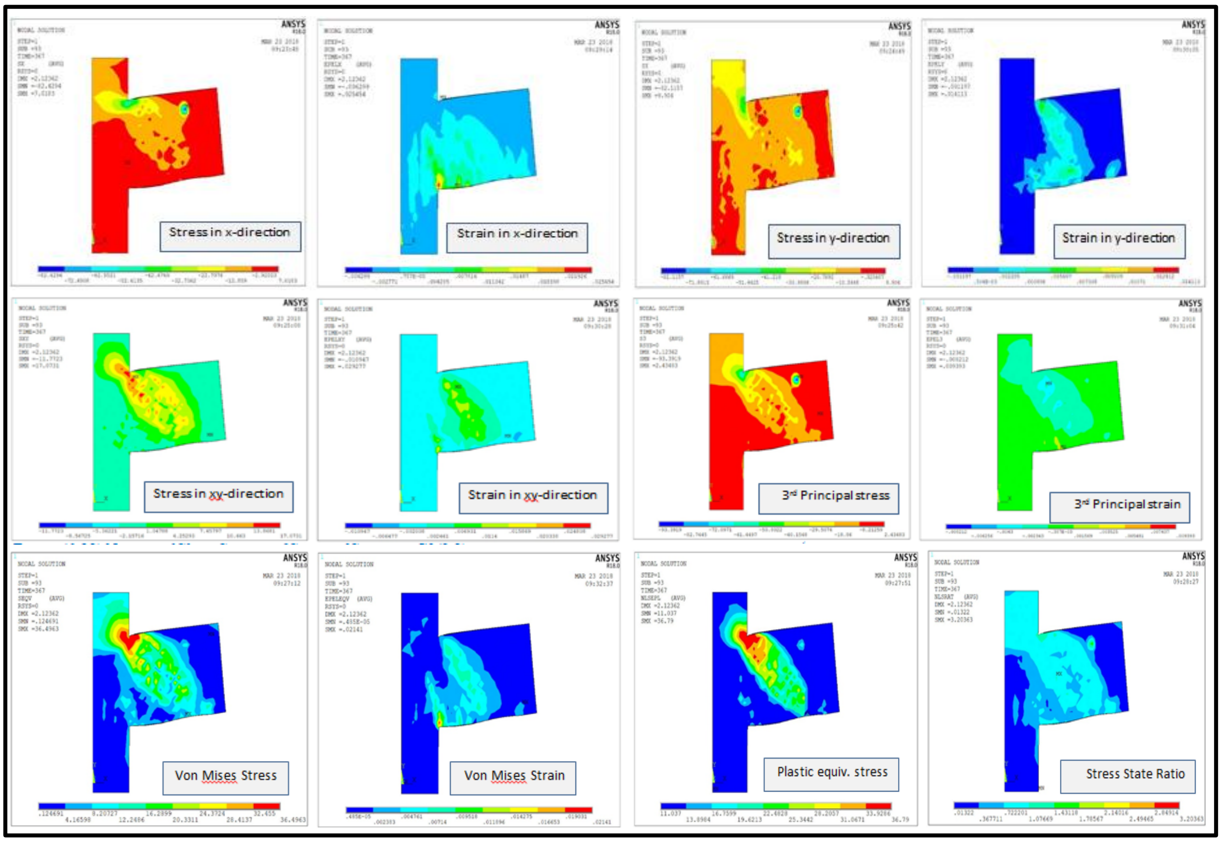


Fig. 13. Numerical Stresses and Strains for Specimen C3(0.9).

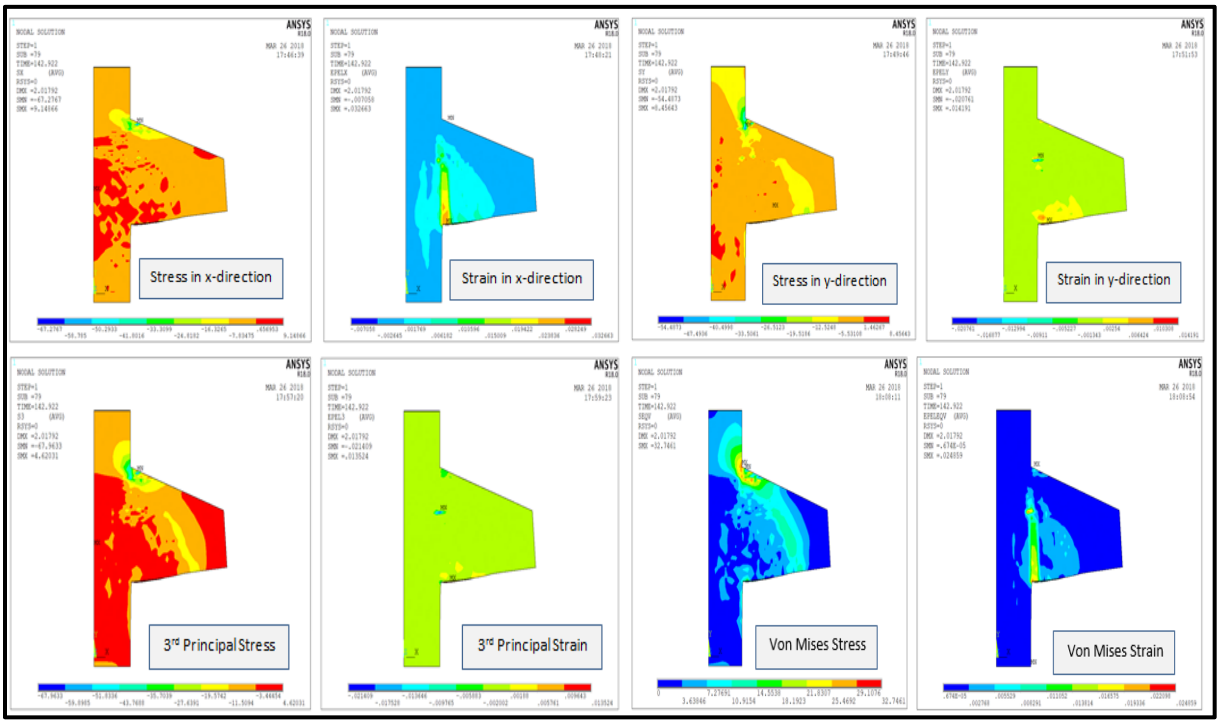


Fig. 14. The Stress and Strain of Specimen B1(0.9).

6.4. Stresses and strains in steel reinforcement

The results of the stresses and strains of the steel reinforcement of some corbels are shown in Fig. 15. The results showed that the maximum value of stress did not reach the yield strength of main reinforcement due to the brittle mode of failure which followed by small deflection and small crack width. So it can be concluded that the corbel failure was controlled by shear rather than flexure. Also at the same load level it can be concluded that the stress and strain of the steel reinforcement was decrease with the increase in both horizontal reinforcement and tapering ratio. While it was increase with the increase in the RCA content because the RAC has lower stiffness than normal aggregate concrete.

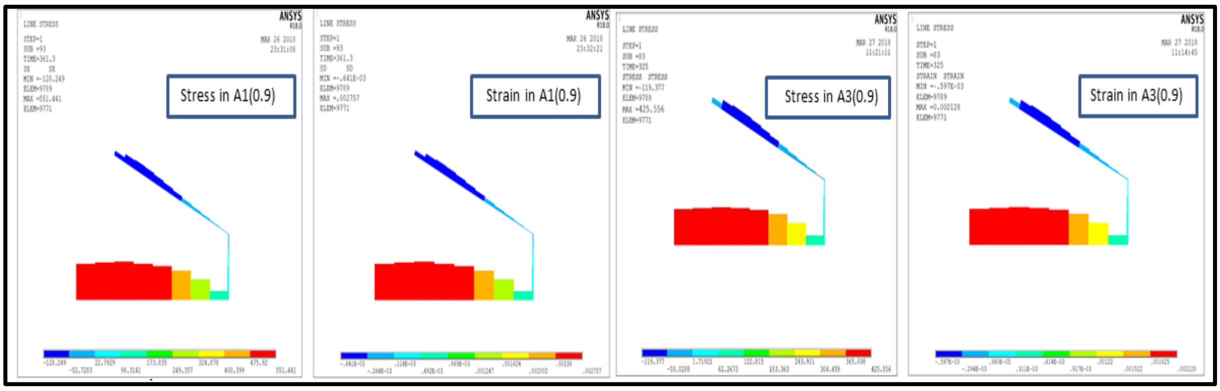


Fig. 15. Numerical Stress and Strain in Specimens A1(0.9) and A3(0.9) respectively.

6.5. Cracking patterns

The cracks pattern was recorded at each applied load and circles outlines were used to observe the cracking at a crack plane. However, octahedron outlines were used to observe the crushing. In addition, red circle outlines were used to characterize the first crack while green and blue colors were used to characterize the second and third cracks respectively as shown in Fig. 16.

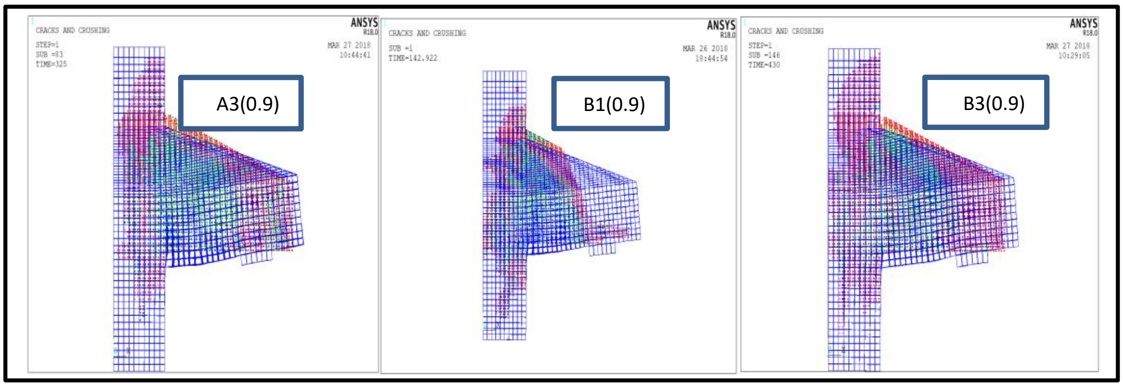


Fig. 16. Steel Stress and Strain in Some of Corbels Specimens.

7. CONCLUSIONS

Based on the experimental and FE results, the main conclusions of the recycled and non-recycled reinforced self-compacting concrete corbels are below:

1-The workability of SCC mixes decreased with the increasing of the coarse recycled concrete aggregate ratio.

2-The quantity of cement in mixes containing (25% , 50% and 75%) RCA have been increased by (1.25% , 3.75% and 10%) respectively compared with SCC without RCA in order to get the same compressive strength at 28 days.

3-The ultimate and crack loads capacity of corbels which made of SCC with (25%, 50% and 75%) RCA were less than that made with natural coarse aggregate. Because the RCA have lower stiffness than natural aggregate.

4-The addition of the recycled concrete aggregate caused the first crack and ultimate load appear earlier than that made with the natural aggregate because the RCA has lower stiffness.

5- The use of horizontal reinforcement in the corbels leads to increase the crack and ultimate loads. When 2Ø6mm stirrups were used, the corbels show an increase in the cracking and ultimate loads of 10% and 64.28% respectively compared to corbels without stirrups.

6- The mode of failure of corbels without horizontal reinforcement was sudden and more brittle than other corbels contained horizontal reinforcement.

7- The reinforced concrete corbel with the ratio of a/d is 0.9 and h/H is (0.75 and 1.0) has less influence on the behavior of corbel since the top outer corner is relatively unstressed.

8-The ultimate load capacity of the reinforced concrete corbel with h/H ratio of 0.5, 0.75 and 1.0 and a/d ratio of 0.9 increased by 34.78%, 47.826% and 56.52% respectively compared with that which has h/H ratio of 0.25.

9- A good agreement was obtained between the experimental and the analytical results in which the FE method was used to simulate deflection of self-compacting concrete with and without recycled concrete aggregate.

10-FEM can be used to analyse the behavior of the self-compacting concrete with and without recycled concrete aggregate elements confidently and such analytical modelling can be further used to analyse other concrete structure. Also, it considers as an available program which is used to decrease the time required and cost.

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