International Journal of Civil Engineering and Technology (IJCIET)
Volume 10, Issue 1, January 2019, pp.188–201, Article ID: IJCIET_10_01_018
Available online at http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

EXPERIMENTAL STUDY ON THE BEHAVIOR AND STRENGTH OF REINFORCED CONCRETE CORBELS CAST WITH SELF-COMPACTING CONCRETE INCORPORATING RECYCLED CONCRETE AS COARSE AGGREGATE

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ABSTRACT

This paper deals with the effect of using recycled concrete aggregate as a partial replacement of coarse aggregate in self-compacting concrete, on the structural behavior of reinforced concrete corbels. From the previous researches, there is no studies deals with the effect of using this type of aggregate on the structural behavior of corbels, and also the use of RCA has an economical and environmental benefits Three replacement ratios were considered 25%, 50% and 75%. All mixes (with and without RCA) have almost same compressive strength at age of 28days which is equal to (35MPa) with a tolerance of (±3MPa).For this purpose, an eleven reinforced concrete corbels were cast and divided in to three groups (A, Band C). Each group deals with specific problem. Different parameters which effect the behavior of corbels were studied and include replacement ratios of natural coarse aggregate by recycled concrete aggregate (RCA), amount of horizontal reinforcement (A_h) and amount of main tension reinforcement (As_{main}).

In order to get same compressive strength of concrete mixes made with natural and with recycled concrete aggregates, the quantity of cement was increased by (1.25%, 3.75% and 10%) for mixes containing (25%, 50% and 75%) recycled concrete aggregate respectively compared with SCC made with natural coarse aggregate.

The experimental results of corbels show that the ultimate load capacity of corbels in group Atested with a/d of 0.34 and made from SCC with (25%, 50 and 75%) RCA was decreased by (2.22%, 7.4%, and 12.34%) respectively compared with corbel made from SCC without RCA. While in group ***B,*** *all corbels casted with 50%RCA and have the same main tension reinforcement, a/d=0.34, corbel dimensions and concrete compressive strength and the only difference was in the amount of horizontal reinforcement. The results showed that when the amount of horizontal reinforcement (stirrups) was increased from zero to 2Ø6mm, the ultimate load increased by*

(15.55%). While when the horizontal reinforcement was increased from 2Ø6mm to 3Ø6mm the ultimate load increased by 50%. Also the ultimate load was increased by 76.22% when the amount of horizontal reinforcement increased from zero to 4Ø6mm.

In group C, all corbels were casted with50% RCA and tested under a/d=0.6. All corbels having the same geometry, horizontal reinforcement and a/d ratio and the only difference was in the main tension reinforcement. From the results it was noted that the increase in main tension reinforcement from 2Ø10mm to 3Ø12mm causes an increase in ultimate load by about 19.04%. When the main tension reinforcement was increased from 2Ø10mm to 2Ø16mm, the ultimate load was increased by 22.61%.

There for it can be concluded that the recycled concrete aggregate can be used as a partial replacement of natural coarse aggregate to produce self-compacting concrete mixes and the behavior of corbels cast with SCC containing RCA is acceptable.

Key words: Recycled concrete aggregate, ultimate strength, corbel.

Cite this Article: Emadaldeen A. Sulaiman, Dr. Jamal A. Samad Khudair, Experimental Study On The Behavior and Strength of Reinforced Concrete Corbels Cast with Self-Compacting Concrete Incorporating Recycled Concrete as Coarse Aggregate, International Journal of Civil Engineering and Technology (IJCIET), 10 (1), 2019, pp. 188–201.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1

1. INTRODUCTION

Concrete is defined as a primary building material produced by mixing of cement, coarse aggregate fine aggregate and water. It is generally used in all types of civil engineering works like, tall and short building, concrete pavement and substructure. There are many types of concrete that is classified according to the material used such as normal concrete, high strength concrete, self-compacting concrete, fibers concrete, green concrete recycled aggregate concrete etc.

In this study, Self-compacting concrete was used. Self-compacting concrete (SSC) is defined as an innovative concrete that doesn't need any type of vibration for compaction and placing. Through casting, this type of concrete has the ability to fill the formwork under it is own weight even with the existence of congested reinforcement. **(Hassan and K.N.Kadhim, 2018 &EFNARC, 2002)[(1)]**.

This type of concrete was discovered by professor Okamura in 1986and the first prototype was produced in 1988 in japan. In 1990, the japan country began to produce and utilize self-compacting concrete commercially **(Okamura, 2003)[(2)]**. At the last two decades, the SCC become widely utilized in civil engineering projects. **(Goodier, 2001)** [(3)] showed that the SCC have the following properties:

- high flow ability- high segregation resistance
- adequately filling the form work under it is own weight without need any type of vibration
- has noiseless work during construction due to the avoiding of vibration
- rapid rate of concrete placement with less time
- have uniform concrete strength due to the minimizing in void spaces
- SCC has a very high level of homogeneity

Based on the benefit of SCC, The hardened concrete is homogeneous, dense and has the same engineering properties and durability as traditional vibrated concrete **(Khayat, 1999)** [(4)].

Aggregates are occupying about 70% of the volume of the mix, so the mechanical properties of concrete were mainly affected by the type of aggregate. If the waste materials such as (old concrete or bricks) are crushing and transforming in to different size, it can be used as fine or coarse aggregates and finally known as recycled aggregate (RA).If the recycling material was made from the crushing of old concrete it is known as recycled concrete aggregate (RCA). The mass density of the recycled aggregate concrete was lower than that of original aggregates and the first have high porosity and water absorption values compared with original aggregates. Finally, a suitable mix design is needed to specify the quantities required in the production of concrete made with RCA.

2. REINFORCED CONCRETE CORBELS

Corbels or brackets are short hunched cantilevers that initiate from the face of columns and are usually utilized in precast concrete construction to carry heavy load from girder or beam. Due to the predominance of precast concrete, the design of bracket or corbel become very important **(ACI 318-14)** [(5)]**.**

(Yang and Ashour2012) [(6)] showed that the **Corbel** is usually refers to a cantilever beam with shear span to effective depth ratio less than unity. The small ratio of (a/d) leads to make the corbel strength usually controlled by shear, which is similar to deep beams. So the shear deformations affect the behavior of corbels in the elastic and inelastic stages and the shear strength become the major factor.

Until the 1960's, corbels were designed as short cantilevers using the shear and flexural provisions derived for beams of normal proportions. This is surprising as these procedures are not applicable to deep beams which have much in common with corbels **(S.J Foster and RE Powell, 1994)** [(7)].

The 1960's saw the development of two new methods of corbel design. The Americans introduced two empirically based methods while the Europeans developed an approach based on the truss analogy. With the rapid expansion of research into the design and behavior of corbels, it became clear that many corbels failed prematurely due to inadequate methods of detailing. Later, various standard detailing procedures were developed, particularly in the areas of main steel anchorage, bearing pad size and placement, and the provision of secondary reinforcement.

Corbels must be designed to resist a three types of loading which are:

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

-Horizontal load (Nuc): results from breaking load, temperature change, creep and shrinkage. The effect of horizontal force can be avoided by using elastomeric pad.

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

An angles or steel bearing plates are usually utilized on the top surface of the corbel in order to provide a uniform distribution of the load (reaction). A similar angles or steel bearing plates are also provided at the lower corner of the beam. Frictional forces will develop due to volumetric change even with the using of elastomeric bearing pads. The nonlinear stress distribution of the short member, even in the elastic range, was affected by shear deformation and the shear strength becomes an important parameter in the design of RC corbels. **(A.H. Mattock et al.,1976)** [(8)].

(Aziz and Othman 2010) [(9)] presented an experimental study to investigate the behavior and strength of high-strength R.C corbels subjected to the effect of vertical load only. The experimental work consisted of fourteen high-strength R.C corbels. The studied variables were shear reinforcement (stirrups), the ratio of outer depth to the total depth of the corbel, main reinforcement ratio and the concrete compressive strength. The experimental results indicated that ultimate strength of corbels was increased with increase in the compressive strength of concrete. Also they showed that the behavior of corbel made with high or normal strength concrete are the same while the strength is different. They also showed that the increase in the main tension reinforcement, horizontal reinforcement and tapering ratio leads to increase the load carrying capacity of corbel.

This paper is mainly deals with the behavior and strength of self-compacting reinforced concrete corbels that made from either natural coarse aggregate or from recycled concrete aggregate. The main variables that studied in this paper include: effect of using RCA on the behavior and strength of R.C corbel, amount of horizontal reinforcement (A_h) and amount of main tension reinforcement (As main).

3. EXPEREMENTAL PROGRAM

3.1. Materials

Ordinary Portland cement and natural fine aggregate (sand) were used. Two types of coarse aggregate where used in this study, natural aggregate and recycled concrete aggregate. Both of them having same gradation zone and satisfying (**Iraqi specification No.45/1984**)[10] requirements. The recycled aggregate was prepared by manually crushing old concrete cubes. The crushed concrete was divided into two size fractions (10 to 14 and 5 to 10 mm) by utilizing sieves, these two fractions were mixed in proportions to obtain grading comparable to that of natural aggregate, Table (1)and Figure (1).Tap water from the water-supply network was used. The high range water reducer (HRWR), Sika Viscocrete 4100, was utilized to get a suitable workability. Limestone powder locally named AL-Gubra was bought from local market and used as a filler material in the production of SCC. Ukrainian deformed steel reinforcing bars with different diameters (Ø6mm, Ø8mm, Ø10mm, Ø12mm, and Ø16mm) which satisfy the(**ASTM A615/ A615M-05**)[11]were used.

Table (1) grading of recycled concrete aggregate

Sieve Size (mm)	Cumulative Passing %	IQS 45-84 limits Size (5-14) mm
20	100	100
14	97.4	90 - 100
10	59.73	50 - 85
5	4.17	0 - 10
pan	0	---------

Table (2): physical properties of RCA

property	Values
Bulk specific gravity, oven-dry (GS	2.39
Absorption	6.2

Figure (1) Steps of Manufacturing of Recycled Aggregate Concrete

3.2. Concrete Mixes

Four types of SCC mixes were used. Mix one was made with natural coarse aggregate and the remaining three mixes contain RCA as a partial replacement of natural coarse aggregate at replacement ratios of (25%, 50% and 75%). All SCC mixes were made to have same compressive strength at 28-dayage with a tolerance of ±3MPa. Many trial mixes where triedinorder to get same compressive strength of concrete mixes made with natural and with recycled concrete aggregates, the quantity of cement was increased by (1.25%, 3.75% and 10%) for mixes containing (25%, 50% and 75%) recycled concrete aggregate respectively compared with SCC made with natural coarse aggregate as shown in Table (3).

Table (3) Concrete Mixes

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	5.3	0.47
3	SCC-R50	415	93	775	413	413	190	6	0.457
4	SCC-R75	440	88	775	206	619	190	6.5	0.432

3.3. Corbels Groups and Detailing

The experimental program consisting of casting eleven reinforced concrete corbels which were divided in to three groups (A, B and C). Group (A) has four specimens (A1, A2, A3 and A4) which deals with the effect of using recycled concrete as a partial replacement from natural coarse aggregate on the behavior of reinforced concrete corbel. Three replacement ratios (25%, 50% and 75%) were adopted in this group. Specimen (A1) was made with natural coarse aggregate while the other specimens (A2, A3 and A4) contain (25%, 50% and 75%) RCA respectively.

Group (B) consist of four specimens (B1, B2, B3 and B4) and deals with the effect of increasing horizontal reinforcement. The horizontal reinforcement was taken as a percent of main tension reinforcement. So corbel B1 has (A_h= 0% As_{main}) while corbels B2, B3 and B4 have (A_h= 50% As_{main}, A_h= 75% As_{main}, A_h= 100% As_{main}) for B2, B3 and B4 respectively.

While group (C) consist of three specimens (C1, C2 and C3) and deals with the effect of increasing main tension reinforcement (As_{main}) where C1 has 2Ø10mm while C2 and C3 having 3Ø12mm and 2Ø16mm respectively. The dimensions and reinforcement of corbels are presented in Table (4) and Figure (2)

Table (4) shows the specimens details in all group

Corbel NO.	Type of Concrete	Corbel Symbol	a/d ratio	Main tension reinforcement (As)	Secondary reinforcement(Ah)
1	SCC-R0	A1	0.34	2Ø12	2Ø8
2	SSC-R25	A2	0.34	2Ø12	2Ø8
3	SCC-R50	A3	0.34	2Ø12	2Ø8
4	SCC-R75	A4	0.34	2Ø12	2Ø8
5	SCC-R50	B1	0.34	2Ø12	0
6	SCC-R50	B2	0.34	2Ø12	2Ø6
7	SCC-R50	B3	0.34	2Ø12	3Ø6
8	SCC-R50	B4	0.34	2Ø12	4Ø6
9	SCC-R50	C1	0.6	2Ø10	2Ø8
10	SCC-R50	C2	0.6	3Ø12	2Ø8
11	SCC-R50	C3	0.6	2Ø16	2Ø8

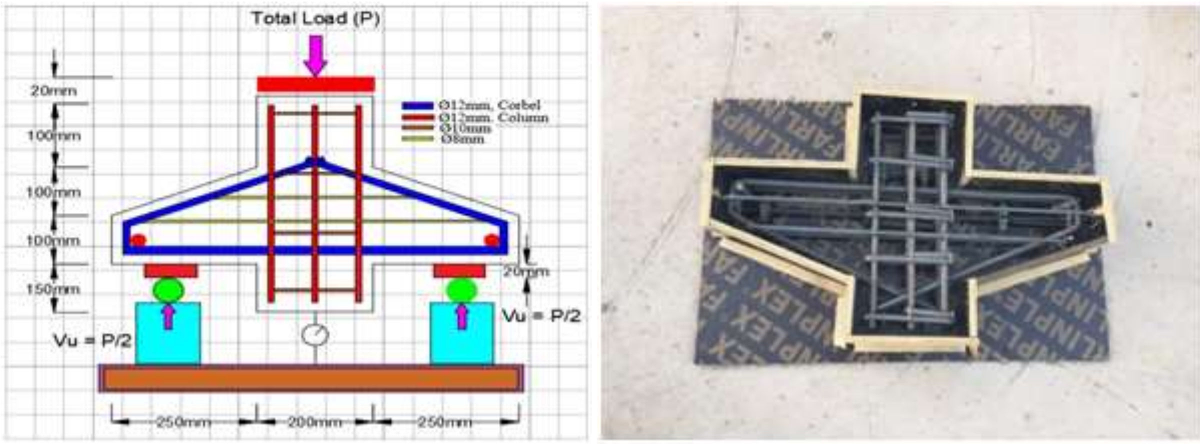

Figure (2) Corbel dimensions and reinforcement

3.4. Mixing Procedure

The mixing process was performed in a drum laboratory mixer of 0.05 m^3, the mixer must be clean, moist and free from water. In this study the following mixing procedure is adopted in order to achieve the required workability and homogeneity of SCC mixes, SP was mixed with water in advance. This procedure is described by the following items:

- The fine aggregate is added to the mixer with 1/3 quantity of water and dosage of superplasticizer, mixed for 1minute.
- The cement is added with another 1/3 quantity of water and dosage of superplasticizer. Then the mixture is mixed for 0.5 minute.
- After that, half coarse aggregate is added with the last 1/3 quantity of water and dosage of superplasticizer, and mixing lasts for 0.5 minute.

- Then the remaining half of coarse aggregate is added to the mixer. The total time of mixing was about 5 minutes. as shown in Figure (3).

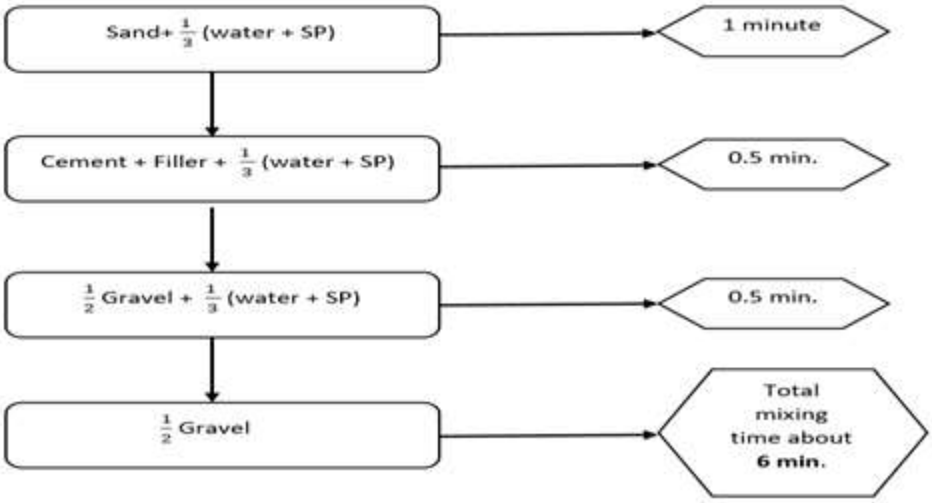

Figure (3) Mixing procedure

3.5. Casting and Curing

Eleven wooden molds were designed and fabricated for casting of all corbels in one batch as shown in Figure (4). Three control cubes of 150 by 150mm, and six cylinders of 150mm in diameter and 300mm heights were cast for each corbel to evaluate the compressive strength, modulus of elasticity and the splitting tensile strength of concrete.

Figure (4) Casting and Curing of R.C. corbels

For SCC mixes which require no compaction work, the mixes being poured into the molds until it's fully filled without any compaction. All molds were prepared for casting by oiling along the interior surfaces of the mold in order to prevent adhesion with concrete after hardening. All specimens were de-molded after 24 hr. and cured in tap water until the test age.

3.6. Testing of Corbel

Hydraulic universal testing machine having a capacity of (2000 kN) was used to test the corbel specimen, as shown in Figure (5). The deflections were measured by electronic dial gauge. Strain of concrete measured by using demic point and dial gauge with accuracy of (0.001mm). Also, cracks width was measured by micro cracks reader with accuracy of (0.02mm).

All the tested corbels were white painted to facilitate detection of cracks. The specimens were tested under monotonically load up to failure. The load was applied in small increments. Each increment of loading was 5kN up to 60kN and then 10kN up to the ultimate load. The initial small increments of load were used to predict the load that causes the first crack and also to measure the concrete strain before appearance of the first crack. At each increment, deflection reading were recorded manually, while the width of crack and concrete strain were recorded at selected load levels of 20kN or 30kN and observations of crack development on the concrete corbels were traced by marker. After failure, the cracks were outlined by thick dark marker pen and the corbel was photographed.

Figure (5) Represent of Corbels Specimens and Testing Machine

4. EXPERIMENTAL WORK RESULTS

4.1. Fresh and Hardened Properties of SCC with or without RCA

The fresh and hardened properties of SCC are shown in Tables (5) and (6) respectively. In fresh state there are three types of tests are required to satisfy SCC requirements. These tests include slump-flow test, J-ring test and column segregation test. These tests were done according to **(ACI-237R-07)** [11] while in the hardened stage, the compressive strength, tensile strength, modulus of elasticity and modulus of rapture were determined.

Table (5) Shows the results of fresh properties of SCC with and without RCA

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%

Table (6) Shows the results of Hardened Properties of SCC with and without RCA

Concrete Type	f'c (MPa)	ft (MPa)	Ec (MPa)	fr (MPa)
SCC-R0	39.4	3.78	34351	5.8
SCC-R25	36.6	3.84	33600	5.6
SCC-R50	37.1	3.56	29349	5.2
SCC-R75	36.3	3.25	26512	4.4

4.2. Results and Discussion

Test results are presented in Table (7). The effect of different parameter such as (quantity of replacement of natural coarse aggregate by RCA, amount of horizontal reinforcement and amount of main tension reinforcement) on the cracking load, ultimate load and mode of failure in R.C. corbels are discussed below:

Table (7) shows the cracking and ultimate loads of all R.C. corbels

Corbel Symbol	Replacement Ratio of RCA (%)	a/d	Main Tension Reinf. (As_{main})	Horizontal Reinforcement Stirrups (Ah)	Cracking Load (kN)	Ultimate Load (kN)	Mode of failure
A1	0	0.34	2Ø12	2Ø8	120	810	S
A2	25	0.34	2Ø12	2Ø8	120	792	S
A3	50	0.34	2Ø12	2Ø8	100	760	S
A4	75	0.34	2Ø12	2Ø8	65	710	S
B1	50	0.34	2Ø12	zero	90	450	S
B2	50	0.34	2Ø12	2Ø6	110	520	S
B3	50	0.34	2Ø12	3Ø6	125	780	S
B4	50	0.34	2Ø12	4Ø6	144	793	S
C1	50	0.6	2Ø10	2Ø8	43	420	DS
C2	50	0.6	3Ø12	2Ø8	48	500	DS
C3	50	0.6	2Ø16	2Ø8	55	515	DS

4.3. Load – Deflection Curves

The load versus deflection curves for Self-compacting reinforced concrete corbels with and without RCA are needed to describe the structural behavior of reinforced concrete corbels under loading. One electronic dial gauge was used with a maximum capacity equal to 50 mm to measure the average deflection at the center of the bottom face of column. The effect of increasing of recycled concrete aggregate, horizontal reinforcement and main tension reinforcement is shown in Figure (5).

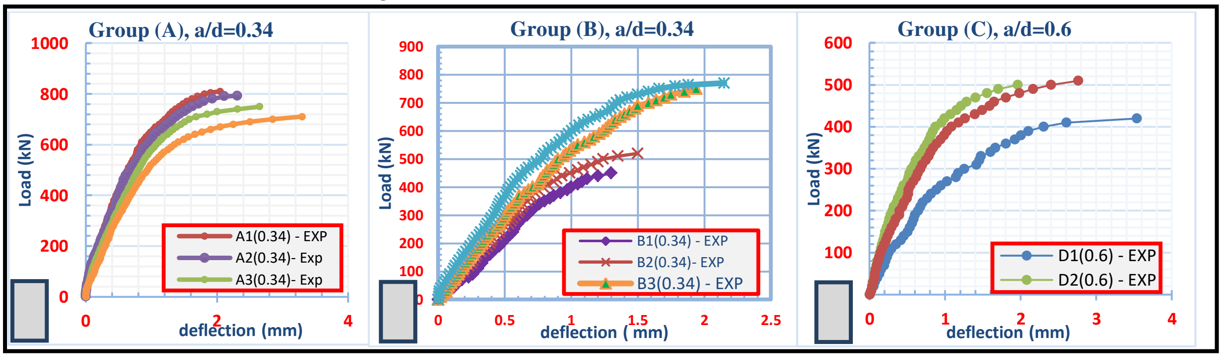

Figure (6) The load deflection curves of each group.

4. 4. Behavior and Ultimate load of R.C. Corbels

4.4.1. Effect of RCA on the Behavior and Ultimate Load of Self-compacting R.C. Corbels:

The effect of RCA on the behavior of Self-Compacting RC corbels was studied in group (A). Figure (5-a) shows the effect of different percentages of recycled aggregate concrete on the deflection of reinforced concrete corbel. From Figure (6-a) it can be noted that the increase in the recycled aggregate percentage leads to increase deflection. At a/d=0.34it is noted that corbel A1 (having 0%RCA) has smaller deflection compared with that made with (25%, 50% and 75%) RCA. The reason of the increase in deflection of corbels made from RCA was return to that the RCA have lower stiffness than normal aggregate.

In terms of ultimate load,it is noted that the increase in the quantity of RCA leads to decrease the ultimate load capacity of corbel. From Figure (7-a) it can be shown that the ultimate load capacity of corbels A2, A3 and A4 was decreased by (2.22%, 7.4% and 12.34%) respectively compared with corbel made with natural coarse aggregate (A1).

4.4.2. Effect of Horizontal Reinforcement (Ah) on the Behavior and Ultimate Load:

Group (B) deals with the effect of horizontal reinforcement on the behavior of reinforced concrete corbel. In this group the horizontal reinforcement is taken as a percentage from the main reinforcement as shown below:B1 (A_h = 0% As_{main}) , B2 (A_h = 50% As_{main}) , B3 (A_h = 75% As_{main}), and B4 (A_h = 100% As_{main}).

For SCC corbels having same amount of RCA, main tension reinforcement and shear span to the effective depth ratio, the results in Figures (6-b) and (7-b) show that the increase in the amount of horizontal steel reinforcement from zero in (B1) to A_h=As_{main} in (B4) the ultimate load capacity at a/d=0.34 increased by (6.67% , 73.34% , and 76.23%) for B2, B3 and B4 respectively compared with B1.Also it is noted that the increase in the amount of horizontal reinforcement leads to change the mode of failure from brittle to more ductile.

4.4.3. Effect of Main Reinforcement (As_{main}) on Behavior and Ultimate Load Capacity:

Group C include corbels (C1, C2, and C3) employed to study the effect of main tension reinforcement (As_{main}) on load carrying capacity of reinforced concrete corbel, the results are presented in Figures (5-c) and (6-c). At a/d=0.6, it was found that the increase in main tension reinforcement from 2Ø10mm to 3Ø12mm and then to 2Ø16mm leads to increase the ultimate load capacity by (19.04% and 22.62%) respectively compared with corbel D1 (0.6).

The increase in the amount of main steel reinforcement leads to improve the ultimate capacity of corbels because the main reinforcement contributes with concrete to increase the strength and delay the failure of corbel by splitting due to the increase in the shear and bending stiffness of RC corbel.

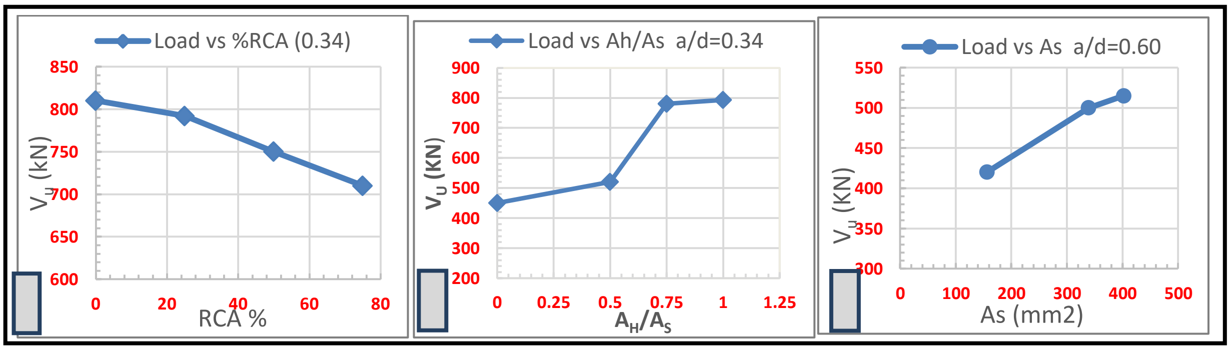

Figure (7) showed the effect of different parameter on the behavior of RC corbels

4.5. Load - Crack Width Relationship

The load – crack width relationships for the corbels are presented in Figure (8). From the Figure it can be concluded that the increase in RCA contain leads to increase in the crack width while the increase in both horizontal or main tension reinforcement leads to decrease the width of crack .

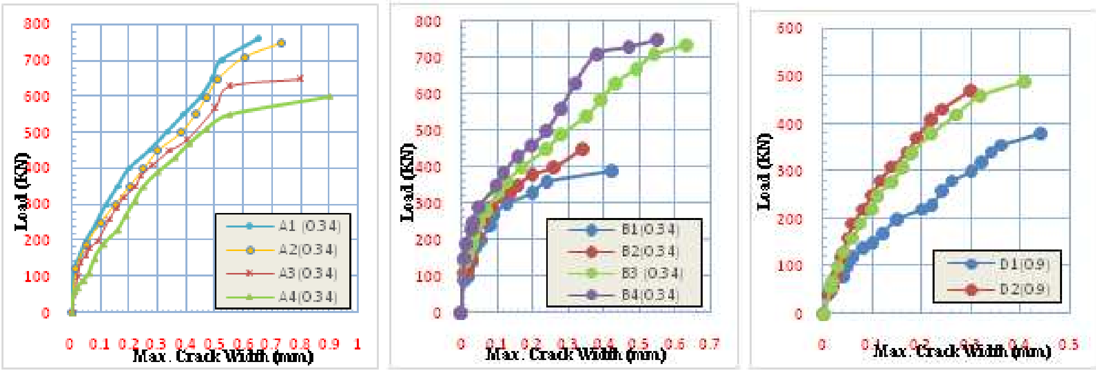

Figure (8) Results of Load-crack width of all Corbels

4.6. Crack Pattern and Mode of Failure

The crack patterns and mode of failure for all corbels are explained in Figure (9) and Table (7). From the three groups results, it can be noted that the increase in the RCA contain leads to make the corbels having more cracks and more crack width than the corbel made from natural coarse aggregate. Also the increase in horizontal and main tension reinforcement leads to increase the number of cracks and decrease the cracks width (i.e. increase the ductility of corbels).

In term of group (A) noted that the increase in the quantity of RCA from zero to 25% then to 50% and 75% leads to make the corbel more brittle than that made from natural coarse aggregate because the old mortar in RCA has lower stiffness than the new mortar and coarse aggregate. Also in group (B) noted that the specimen with zero horizontal reinforcement (B1)was fail suddenly under loading while this type of failure was reduced with increasing the horizontal reinforcement ratio.

And finally in group D noted that the increase in main tension reinforcement leads to decrease the cracks width(i.e like the behavior of corbels in group B) . Both main tension and horizontal reinforcement work together to reduce the width of crack.

Figure (9) Cracks Pattern of Corbels

4.7. Concrete Strains

The strains in the concrete at a section close to column face and along the diagonal strut of the tested corbels were measured by using nine to ten lines of demic discs distributed along the column-corbel junction and along the diagonal strut. Figure (10) show the concrete strain distribution over the corbel depth for some corbels at different load levels. In these figures, it can be seen that the strain distribution was approximately linear in tensile and compressive zones at low load levels, and then became increasingly nonlinear at the tension zone at higher loads due to cracking effect. For all tested corbels, the neutral axis was shifting upwards significantly after increasing the load greater than the load at first crack. The strains in the tension zone were measured by including widths of cracks within gauge length (not true strains).In some cases, at higher level of loading, some of demec discs were removed from its location, there for the strain reading of that points after that load were neglected.

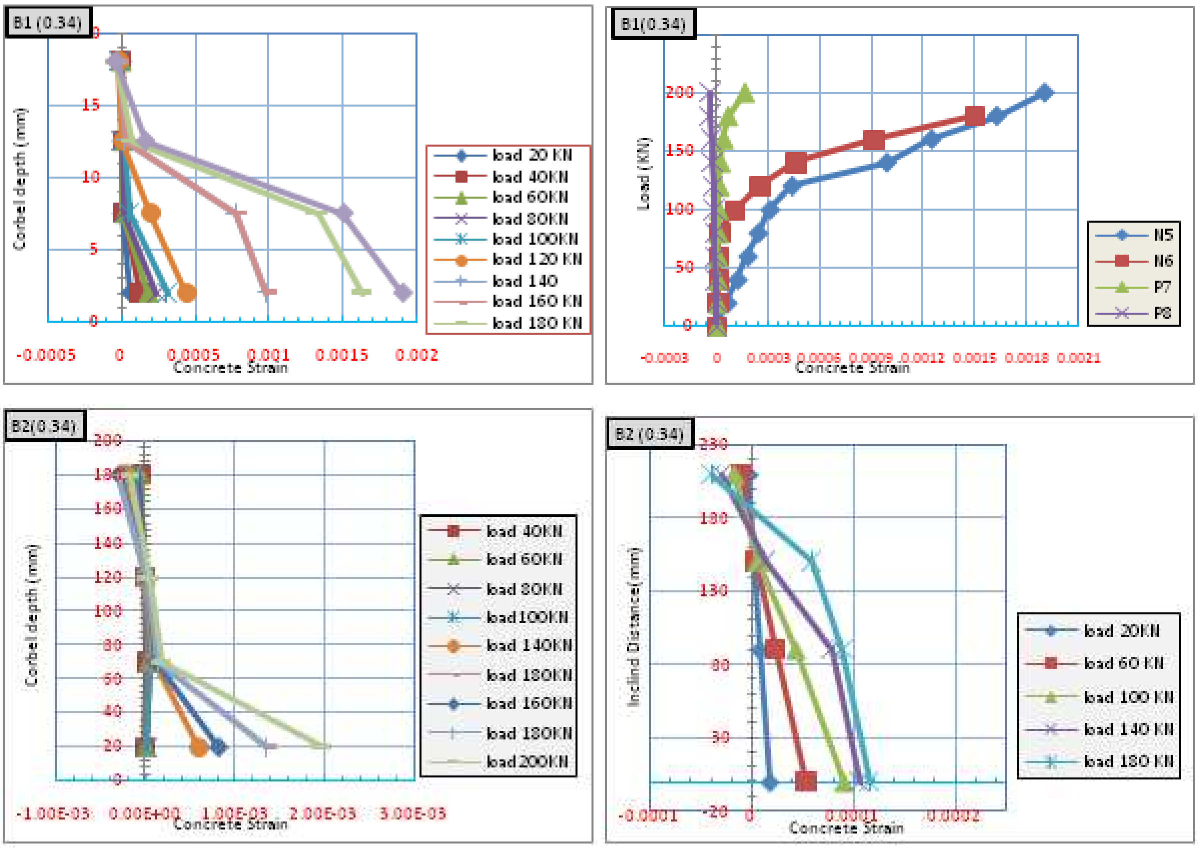

Figure (10) Concrete Strains

5. CONCLUSIONS

Based on the experimental results carried out in the present work, the following conclusions can be drawn with respect to the results obtained concerning the behavior, strain, cracking and ultimate load of recycled and non-recycled reinforced self-compacting concrete corbels.

- The workability of SCC mixes decreases with the increase in the replacement ratio of coarse recycled concrete aggregate.
- Test results showed that it is possible to use recycled concrete aggregate as a partial replacement of natural coarse aggregate to produce self-compacting concrete mixes having the same compressive strength compared with mixes made with natural coarse aggregate. But, in order to get the same compressive strength, the quantity of cement must be increased by an amount depends on the quantity of replacement of natural aggregate by recycled concrete aggregate.
- The ultimate load capacity of tested corbels with a/d=0.34 and made with SCC having (25%, 50 and 75%) RCA was decreased by (2.22%, 7.4%, and 12.34%) respectively compared with corbel made with SCC without RCA.
- The presence of recycled concrete in the mixes leads to make the first cracking load to be appeared earlier than other mixes made with natural aggregate.

- The use of horizontal reinforcement in the corbels leads to increase the cracking and ultimate loads. For corbels with a/d ratio of 0.34, and when 2Ø6mm stirrups were used, the corbel show an increase in the cracking and ultimate loads of 15.55% and 22.22% respectively compared to corbel without stirrups.
- The mode of failure of corbels without horizontal reinforcement was sudden and more brittle than other corbels contained horizontal reinforcement.
- It was found that for corbels made from 50% RCA and a/d=0.6, the increase in main tension reinforcement from 2Ø10mm to 3Ø12mm causes an increase in cracking and ultimate load by about 11.62% and 19.04% respectively. When the main tension reinforcement was increased from 2Ø10mm to 2Ø16mm, the cracking and ultimate load increased by 27.9% and 22.61% respectively.
- Corbels made with recycled concrete aggregate have higher concrete strains and crack widths compared with corbel made with natural coarse aggregate. The concrete strains and crack widths are decreased with increasing the horizontal reinforcement, main tension reinforcements and tapering ratio.

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