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Flexural Behavior of Reinforced Concrete T-Beam Cast with Self-Compaction Concrete Incorporating Recycled Concrete Aggregate

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ABSTRACT
This study investigates (experimentally and analytically) the flexural behavior of six T-section beams cast with self-compacting concrete (SCC) which contain recycled concrete aggregate as a partial replacement of coarse aggregate. The beams have two concentrated loads. Beams have two longitudinal steel ratios of ($\rho 1$=0.0004 and $\rho 2$=0.00077). The tested beams were divided into two groups-depending on span to effective depth (a/d) ratio the longitudinal steel ratio . Each group was casted using three type of mixtures with different RCA replacement ratio (0% ,50%, 75%). The SCC T-beams have (a/d) ratio of 3 and total length of (2.1 m) and all beams have gross section area of (0.504) m2. As well as ANSYS-14 program was used to analyze these beams by nonlinear finite element method. Test results showed that, when increasing the RCA replacement ratio to 50% the cracking load decreased by average 15.5% and ultimate load was not affected. When increasing the RCA replacement ratio to 75% the cracking load and ultimate load decreased by average 31% and 9.4% respectively, the deflection and crack width of the tested beams increases with increasing RCA replacement ratio, when the steel ratio increased from $\rho 1$ to $\rho 2$ the first cracking load and ultimate load increased by average 20.5% and 46.2% respectively. The deflection and crack width of the tested beams decreases with increasing longitudinal steel ratio. The finite element model gives good agreement with the experimental results with difference within 8%.

سلوك الانحناء للعتبات الخرسانية المسلحة على شكل مقطع (T) وباستخدام خرسانة ذاتية الرص وركام خرساني معاد التدوير

الكلمات المفتاحية
عتبات على شكل مقطع**T** , خرسانة ذاتية الرص, اعادة تدوير الخرسانة , تصرف الانحناء

الخلاصة
تناولت هذه الدراسة تحري (عملي وتحليلي) لتصرف الانحناء لستة عتبات على شكل مقطع (T) المصبوبة بخرسانة ذاتية الرص والحاوية على الركام الخرساني المعاد التدوير كنسب استبدل من الركام الخشن . العتبات تمتلك نسبتين من حديد التسليح الطولي ($\rho 1$=0.0004 and $\rho 2$=0.00077). العتبات قسمت الى مجموعتين بالاعتماد على نسبة الحديد الطولي . كل مجموعة تم صب ثلاث انواع من الخلطات الخرسانية ذاتية الرص وباستخدام نسب مختلفة من نسب الاستبدال للركام معاد التدوير (0%,50%,75%). نسبة (a/d) للعتبات ذاتية الرص هي 3 والطول الكلي للعتب هو 2.1م ومساحة المقطع لكل العتبات هي 0.504 م2 . اضافة إلى ذلك تم استخدام طريقة العناصر المحددة(برنامج) ANSYS 14 لتحليل العتبات المفحوصة . اظهرت النتائج عند زيادة نسبة الاستبدال للخرسانة المعاد تدويرها الى 50% حمل التشقق يقل بمعدل 15.5% وحمل الفشل لا يتأثر . عندما تزداد نسبة الاستبدال للخرسانة المعاد تدويرها الى 75% حمل التشقق وحمل الفشل يقل بمعدل 31% و 9.4% على التوالي, الانحناء وعرض التشقق يزداد بزيادة نسبة الاستبدال للركام معاد التدوير. عند زيادة نسبة الحديد الطولي من $\rho 1$ الى $\rho 2$ حمل التشقق الاولي وحمل الفشل يزداد بمعدل 20.5% و 46.2% على التوالي للعتبات ولنسب الاستبدال للركام معاد التدوير (0%, 50%, 75%) , الانحناء وعرض التشقق يقل بزيادة نسبة الحديد الطولي السفلي . أعطت نتائج التحليل اللاخطي للعتبات بطريقة العناصر المحددة توافق جيد مع النتائج العملية مع اختلاف في حدود 8%.

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1. Introduction

The construction of buildings, bridges, and roadways continues to increase in the twenty-first century, especially in areas with ever-growing populations. Existing structures and highways require repair or replacement as they reach the end of their service life or simply no longer satisfy their intended purpose due to the growing population. As modern construction continues, two pressing issues will become more apparent to societies: an increasing demand for construction materials, especially concrete and asphalt aggregates, and an increasing production of construction and demolition waste. With such a high demand for new aggregates, the concern arises of the depletion of the current sources of natural aggregates and the availability of new sources. Currently, this waste is most commonly disposed of in landfills .

To address both the concern of increasing demand for new aggregates and increasing production of waste, many states have begun to recognize that a more sustainable solution exists in recycling waste concrete for use as aggregate in new concrete, or recycled concrete aggregates (RCA). The solution helps address the question of how to sustain modern construction demands for aggregates as well as helps to reduce the amount of waste that enters already over-burdened landfills [1].

Self-compacting concrete (SCC) is one of the most important innovations in the concrete technology. It arrived as a revolution in the field of concrete technology. Its spread worldwide because of its very attractive properties in the fresh state as well as after hardening. It is a highly workable concrete that can flow through densely reinforced or geometrically complex structural elements under its own weight and sufficiently fills voids without segregation or excessive bleeding without the need for vibration to consolidate it [2].

Ali M. A. (2009) [3] Studied the properties of concrete made with Recycled Concrete Aggregate (RCA) as a partial or total replacement of coarse aggregate. Two types of mixes were made, normal concrete aggregate and recycled concrete aggregate as a partial replacement of coarse aggregate (30%). It was found the presence of recycled aggregate in the mix reduces concrete workability due to the high absorption capacity of recycled aggregate. The compressive strength of recycled aggregate concrete depends on the strength of original concrete from which the recycled aggregates are obtained.

2. Experimental Program

The test program consists of six SCC T- beams with RCA designed to fail in flexural. The beams are divided into two groups depending on the longitudinal steel ratio ($\rho1=0.0004$ and $\rho2=0.00077$). Each group was casted using three type of mixtures with different replacement ratio (0% ,50%, 75%). All beams have same length of 2100 mm to obtain shear span to effective depth ratio (a/d) of 3, as shown in Fig. (1).

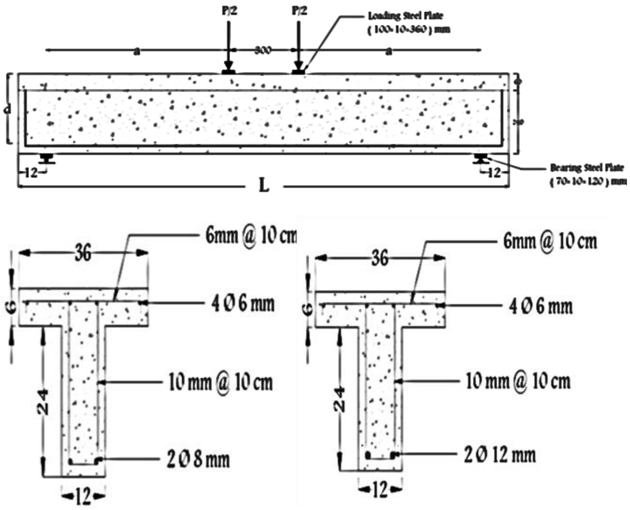


Figure 1. Details of the tested beams (all dimensions in cm)

3. Materials Properties

The properties of materials used in the preparation of the tested reinforced SCC T-beams with RCA are described below.

3.1 Cement

Ordinary Portland cement available in local markets is used in this work. Tables (1) show the physical properties of cement used throughout this work. Test results indicate that the used cement conforms to the Iraqi specification No.5/ 1984[5].

3.2 Fine Aggregate (Sand)

Natural sand from Zubair area in Basrah governorate city used as fine aggregate for concrete mixes in this study. The fine aggregate was sieved on sieve size (4.75mm) to separate the aggregate particle of diameter greater than (4.75mm). The sand was then washed and cleaned with water several times, later it was spread out and left to dry in air, after which it was ready for use. The sand properties are shown in Table (2). It conform to Iraqi specification No. 45/1984 [6].

Table (1) : Properties of sand.

Physical property	Test results	Limit of I.Q.S No. 5/1984
Specific surface area (Blaine method), m^2/kg	322	230 (Min.)
Setting time (Vicat apparatus), hr:min Initial	2:05	00:45 (Min.)
Final	4:17	10:00 (Max.)
Compressive strength		
3-day (MPa)	20.2	15 (Min.)
7-day (MPa)	29.5	23 (Min.)

Table (1): Physical properties of cement.

No.	Sieve size (mm)	(%)Passing	(%)Passing Iraqi specification 45/1984 for zone No.(2)
1	4.75	100	90-100
2	2.36	77.3	75-100
3	1.18	58	55-90
4	0.6	36	35-59
5	0.3	14	8-30
6	0.15	2	0-10

3.3 Coarse Aggregate

Two types of coarse aggregate were used:

3.3.1 Gravel

Crushed gravel of maximum size (20 mm) from Jabal Sanam region in Basrah was utilized. Table (2) shows the grading of this aggregate, which conforms to the Iraqi Specification No.45/1984[6]. Table (3) shows the properties of the coarse aggregate.

3.3.1 Recycled Concrete Aggregate

Recycled Concrete Aggregate which was used in this study was obtained from the demolition of concrete cubes which have been brought to the laboratory for testing. The maximum size of this aggregate was 20mm. The RCA grading is within the requirements of Iraqi Specification No. 45/1984 [6]. Table (3) shows the specific gravity and absorption of the utilized RCA.

Table (2): Grading of coarse aggregate

No.	Sieve size mm	Passing (%) by weight		
		NCA	RCA	Limits of IOS No.45/1984
1	20	100	100	100-95
2	14	82	-	-
3	10	38	35	30-60
4	5	2	0	0-10
5	2.36	1	0	

3.4 Limestone Powder (LSP)

This material is locally named as Al-Gubra, which has been brought from local market and used to increase the amount of powder (cement + filler). The specific gravity of the (LSP) was 2.4.

Table (3): Properties of coarse aggregate

Physical properties	NCA	RCA	Limits of IOS No.45/1984
Specific gravity	2.63	1.65	-
Sulfate content(SO_3) %	0.066	-	≤ 0.1 %
Chloride content(Cl) %	0.085	-	≤ 0.1 %
Absorption %	0.72	3.92	-
Loose bulk density kg/m^3	1520	975	-

3.5 Steel Reinforcement

Steel reinforcing deformed bars of 6,8,10,12 and 16 mm diameter were used for the longitudinal reinforcement and stirrups. Three tensile specimens of each size of bars were tested. Test results indicated that the bars conformed to the ASTM A615/A615M-04b[7].

3.6 Superplasticizer

Glenium 51 has been primarily developed for applications in the premixed and precast concrete industries where the highest durability and performance is required. Glenium 51 is free from chlorides and complies with ASTM C494 type a[8]. Table (4) shows the properties of Glenium 51.

Table (4): Properties of Glenium51

Form	Viscous Liquid
Commercial name	Glenium 51
Chemical composition	Sulphonated melamine and naphthaline formaldehyde condensates
Subsidiary effect	Increased early and ultimate compressive strength
Form	Viscous liquid
Color	Light brown
Relative density	1.1 gm/cm^3at 20 ºC
pH	6.6
Viscosity	128 ± 30 cps @ 20º C
Transport	Not classified as dangerous
Labeling	No hazard label required
Chloride content	None

4. Design of Concrete Mixes

There is no standard method for SCC mix design. Mix designers often use volumes as a key parameter because of importance of the requirement to overfill the voids between the aggregate particles. Self-compactability is largely affected by the characteristics of materials and the mix proportions. Okamura and Ouchi [9]planned a simple mix proportioning system assuming general supply from ready- mix concrete plant. The coarse and fine aggregate contents are fixed, so that the self-compactability can be easily achieved by adjusting the water/ powder ratio and superplasticizer dosage only. The employed methods to achieve self compactibility are shown below :

- The coarse aggregate content in concrete is fixed at 50% of the solid volume.
- The fine aggregate content is fixed at 40% of the mortar volume.
- The water / powder ratio in volume is assumed as 0.9- 1.0 depending on the properties of the powder.
- The superplasticizer dosage and the final water / powder ratio are determined so as to ensure self-compactability.

From these guidelines and after many trials, one concrete mix has been selected which satisfy the conditions of self-compacting concrete. Table (5) shows the content of the used mix materials.

Table (5): Concrete mix constituents

Material	Content, kg/m^3
Cement	414
Lime Stone Powder	178
Coarse Aggregate	778
Fine Aggregate	826
Water	183
SP	4

5. Fresh Concrete Tests

In fresh state SCC is required to have three characteristics; filling ability, passing ability and segregation resistance. Therefore several test trials are implemented in this study in order to ensure that SCC mixes meet these requirements as shown in Table (6).

Table (6): Properties of fresh SCC

Slump Test			
RCA (%)	Slump flow (mm)	EFNARC Guideline	
		Min.	Max.
0	700	650	800
50	660	650	800
75	610	650	800
Slump T500 Test			
RCA (%)	T 500 (sec)	EFNARC Guideline	
		Min.	Max.
0	2.66	2	5
50	2.72	2	5
75	3.02	2	5
V-funnel Test			
RCA (%)	V-funnel (sec)	EFNARC Guideline	
		Min.	Max.
0	8.27	8	12
50	8.56	8	12
75	9.41	8	12
L-Box Test			
RCA (%)	L-Box	EFNARC Guideline	
		Min.	Max.
0	0.94	0.8	1.00
50	0.93	0.8	1.00
75	0.89	0.8	1.00

6. Mechanical Properties of Hardened SCC

To evaluate the mechanical properties of all types of concrete used in this work, control specimens are cast from the same mixes used for the SCC T-beams. Three mechanical properties are evaluated here: compressive strength of cubes (fcu) ,splitting tensile strength (ft), and modulus of elasticity (Ec). Three specimens are used for each mixture of any property and the average value of the three results are adopted, the results are presented in Table(7).

Table(7): Properties of hardened SCC.

Mix No.	RCA Replacement Ratio	f_{cu} (MPa)	f_t (MPa)	Ec (GPa)
1	0%	44.32	3.96	31.24
2	50%	38.63	3.43	28.94
3	75%	32.11	3.12	25.67

6. Test Results and Discussion

6.1 General Behavior and Crack Patterns

The first visible flexural cracks were noticed at 41 to 66.7 % of failure load as shown in Table (8). These cracks were vertical, started from the bottom side of the T-beam between the applied two- point loads. As the load increased other cracks were formed outside the region between the two applied loads. These cracks propagated diagonally towards the point loads as a flexural-shear cracks. Crack patterns are presented in Figure (2). As the load was increased further, several flexural cracks initiated in the tension face at intervals throughout the T-beam, gradually increased in number, became wider and moved upwards reaching the compression face of the T-beam.

Table (8): First crack and ultimate loads of SCC T-beams failed in flexure.

Beam No.	Replacement ratio %	Flexural steel ratio (ρ)	Pcr kN	Pu kN	Pcr/Pu
FR0ρ1	0	ρ1	58.86	88.29	0.667
FR50ρ1	50	ρ1	49	88.29	0.55
FR75ρ1	75	ρ1	39.24	78.48	0.5
FR0ρ2	0	ρ2	68.67	127.53	0.54
FR50ρ2	50	ρ2	58.86	127.53	0.46
FR75ρ2	75	ρ2	49	117.72	0.41

Figure 2. crack pattern for the T-beams failed in flexure

6.2 Effect of using RCA on SCC T-beams

6.2.1 First Cracking and Ultimate Loads

It can be observed that the first cracking load and ultimate load were decreased with increasing the replacement ratio. For beams with longitudinal steel ratio of ρ1=0.0004, and when increasing the RCA replacement ratio to 50%, the cracking load decreased by 16.75% and ultimate load did not effected. When increasing the RCA replacement ratio to 75% the cracking load and ultimate load decreased by33.33% and11.11% respectively.

While beams with longitudinal steel ratio of ρ2=0.00077 and when increasing the RCA replacement ratio to 50%, the cracking load decreased by 14.28% with no reduction in the ultimate load, when increasing the RCA replacement ratio to 75% the cracking load and ultimate load decreased by 28.64% and 7.69% respectively as shown in the Figure (3).

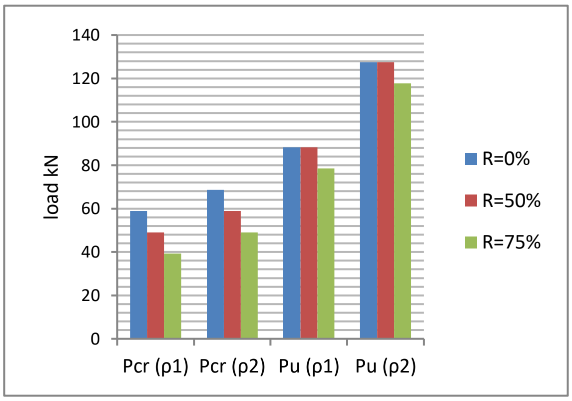


Figure 3. First Cracking and Ultimate Loads

6.2.2 Deflection

Figures (4) and (5) present a comparison between deflection in SCC T-beams for longitudinal steel ratio of ρ1 and ρ2. It can be observed that, at the same load level, T-beams with the higher replacement ratio of RCA exhibited slightly higher deflection and this is valid for both steel ratios. when increasing the RCA replacement ratio to 50% the deflection of ρ1 and ρ2 at load of 70kN increased 15% and 8.7% respectively and when increasing the RCA replacement ratio to 75% the deflection of ρ1 and ρ2 at load of 70kN increased 40% and 30% respectively. The increase in deflection for T-beams with increasing the replacement ratio of RCA is attributed to the lower modulus of elasticity of concrete with RCA compared to normal concrete.

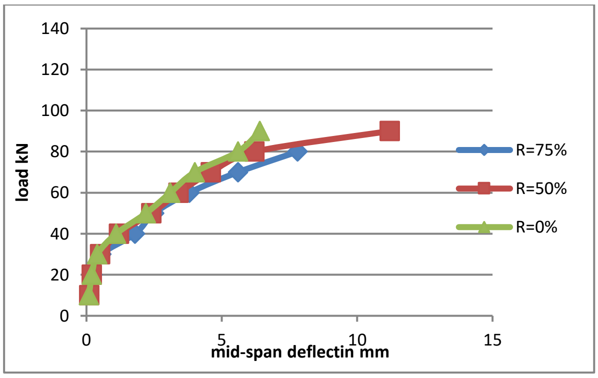


Figure 4. Experimental load versus mid- span deflection curve for T-beam with ρ1

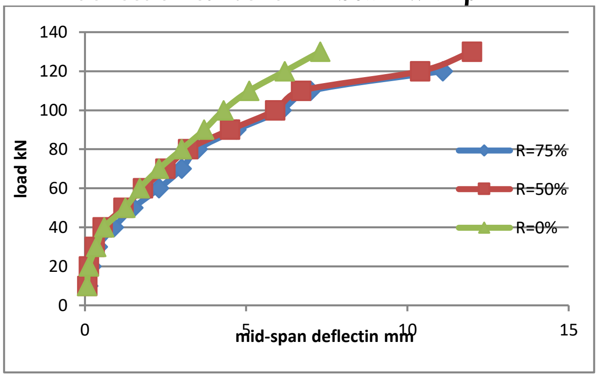


Figure 5. Experimental load versus mid- span deflection curve for T-beam with ρ2

6.2.3 Inclined Crack Width

For each load increment, crack width of the main inclined crack at mid-depth of the T-beam was measured by means of crack detection pocket microscope. Figures (6) and (7) show load versus crack width for each groups with different longitudinal steel ratio ρ1 and ρ2. when increasing the RCA replacement ratio to 50% the crack width of beams with ρ1 and ρ2, at load of 70kN, increased 33% and 60% respectively and when increasing the RCA replacement ratio to 75% the crack width of beams with ρ1 and ρ2, at load of 70kN, increased 70% and 140% respectively. The increase in crack width for T-beams with increasing the replacement ratio of RCA is attributed to the lower splitting tensile strength and modulus of elasticity of RCA compared to normal concrete.

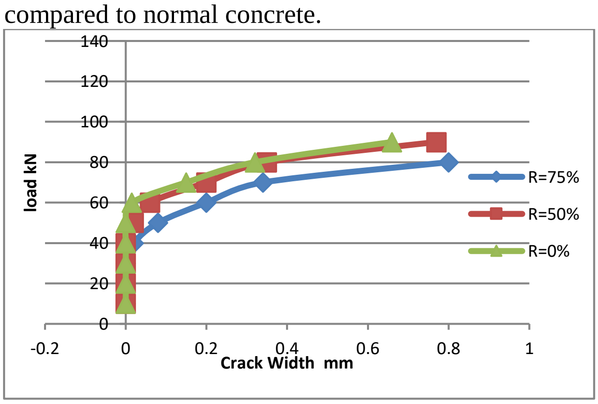


Figure (6): Load- Inclined Crack Width T-beam with ρ1

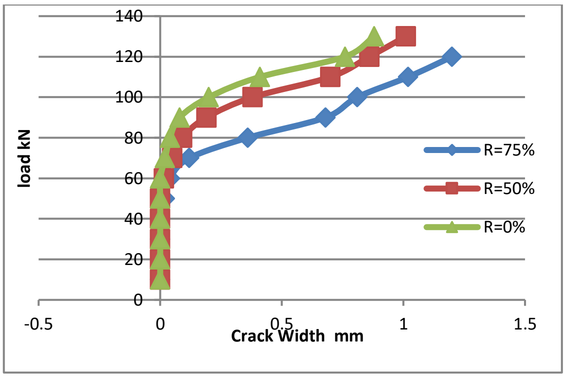


Figure (7): Load- Inclined Crack Width T-beam with ρ2

6.3 Effect of Longitudinal Steel Ratio

6.3.1 First Cracking and Ultimate Loads

The first cracking and ultimate loads are presented in Figure (8), for the various values of replacement ratio and longitudinal steel ratio. When the steel ratio increased from ρ1 to ρ2 the first cracking load and ultimate load increased by 16.7% and 44.4% respectively for T-beams without RCA. For T-beams with replacement ratio of 50% the first cracking load and ultimate load increased by 20% and 44.4% respectively. While T-beams with replacement ratio of 75% the first cracking load and ultimate load increase 24.8% and 50% respectively. Increasing the steel ratio will increase the stiffness of the T-beams and increase the resistance to crack formation. Furthermore, it will increase the moment capacity of the T-beams and hence higher ultimate load can be carried.

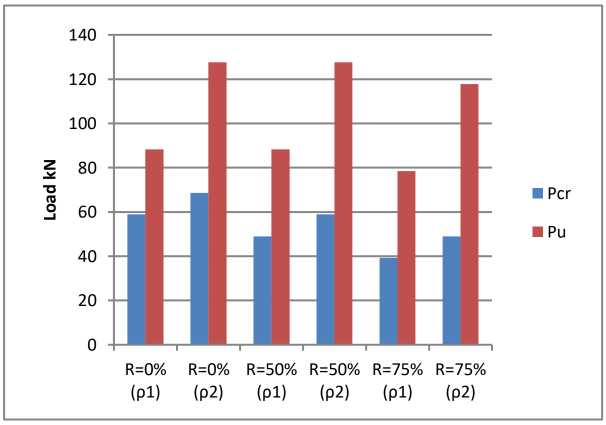


Figure (8): First Cracking and Ultimate Loads

6.3.2 Deflection

From Figures (9), (10) and (11), it can have deducted that when increasing the longitudinal steel ratio from ρ=0.0004 to ρ=0.00077, at load of 70kN, the deflection decrease 42.5% ,45.4% and 46.6% for replacement ratio 0% ,50% and 75 % respectively. This is because the increase in the longitudinal steel ratio caused increase in the stiffness of the beam.

6.3.3 Inclined Crack Width

When increasing the longitudinal steel ratio from ρ=0.0004 to ρ=0.00077 the crack width decrease 650% , 300% ,183 % for replacement ratio 0% , 50% 75 % respectively as shown in the Figures (12) ,(13) and (14) .

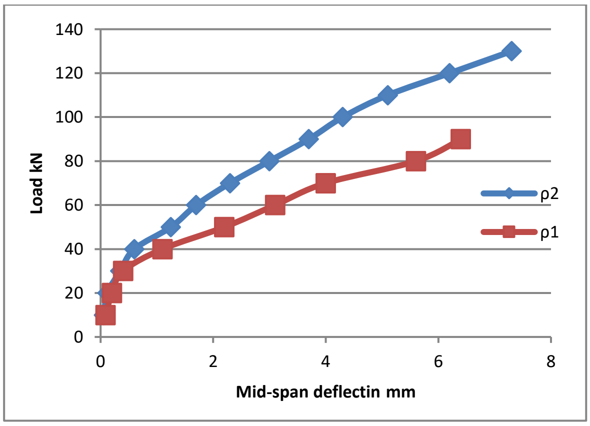


Figure (9): Experimental load versus mid- span deflection curve for T-beams with R=0%

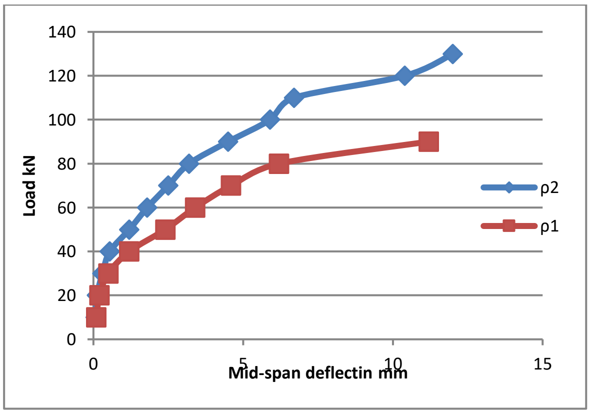


Figure (10): Experimental load versus mid- span deflection curve for T-beams with R=50%

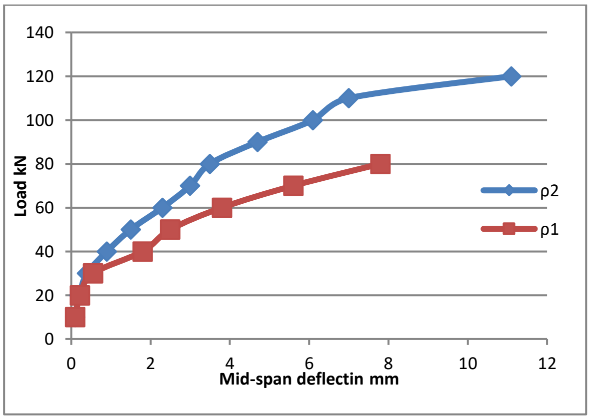


Figure (11): Experimental load versus mid- span deflection curve for T-beams with R=75%

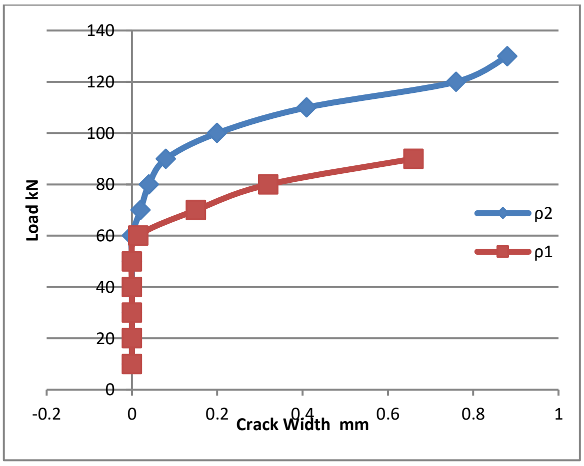


Figure (12): Load- Inclined Crack Width T-beam with R=0%

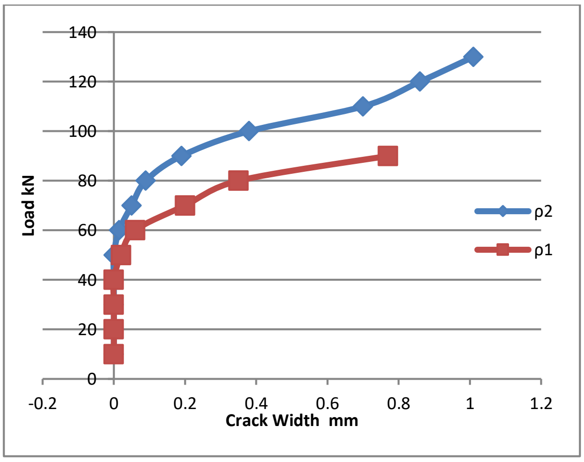


Figure (13): Load- Inclined Crack Width T-beam with R=50%

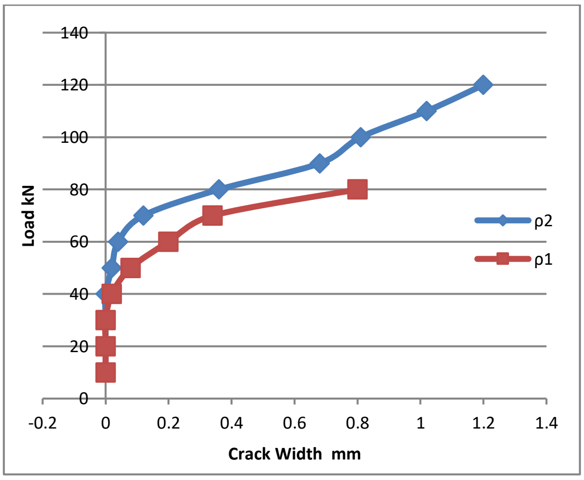
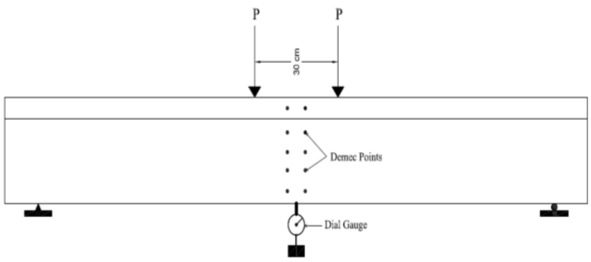


Figure (14): Load- Inclined Crack Width T-beam with R=75%

6.4 Concrete Surface Strains

The measured concrete strains were measured at points located in mid-span of the T-beams as presented in Figure (15). The strain was measured by a mechanical strain Gauge. It was used to measured surface concrete strain at every stage of loading.

Strain distribution at mid span of all T-beams is shown in Figure (16). It can be observed that at the same load level, concrete strain increases with increasing the recycle concrete coarse aggregate ratio, this is because of decrease in stiffness of the T-beams hence the deformations will be increased. Also it can be observed that, at the same load level, concrete strain decreases with increasing 6 longitudinal steel.



Figure(15): location of demec point

4. Finite element modeling

As part of the research, a total of six FE models are established and the numerical solutions are correlated with the experimental results. The FE models are created using the finite element (FE) code ANSYS-14[8]. The models have the same geometry, dimensions, and boundary conditions of the tested concrete T-beam specimen.

By taking advantage of the symmetry of the beams, half of the beam was used for modeling. This approach reduced computational time and computer disk space requirements significantly. Half of the entire model is shown in Fig. (17).

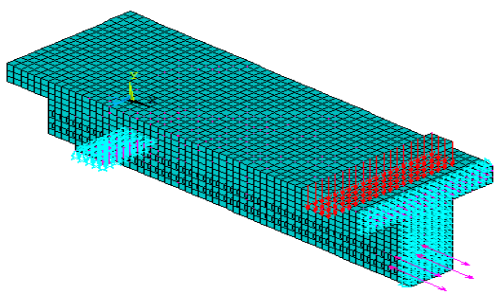


Figure 17. **Typical half symmetry finite element model**

For modeling RC beam, eight nodes Solid65 element with three degrees of freedom at each node (translations in the nodal x, y, and z directions), which handles nonlinear behavior, cracking in three orthogonal directions due to tension, crushing in compression and plastic deformation is used. For modeling reinforcement, two nodded Link180 spar element with three degrees of freedom at each node (translations in the nodal x, y, and z directions), which handles plasticity, creep, swelling, stress stiffening and large deflection is used. In order to avoid stress concentration problem, the supports and loading points are modeled with eight nodded Solid185 element with three degrees of freedom at each node (translations in the nodal x, y, and z directions), which handles plasticity, creep, swelling, stress stiffening, large deflection and strain.

7. Comparison of Experimental and Finite Element Results

7.1 Ultimate Loads

Tables (9) compare the experimental ultimate loads for the T-beams and the final loads from the finite element simulations. In general, the predicted ultimate loads obtained by ANSYS are in agreement with experimental result. In most of the T-beams, the finite element ultimate load overestimated the experimental results by (4% to 8%). There are several factors that may cause the higher strength in the finite element models. Microcracks produced by drying shrinkage and handling are presented in the concrete to some degrees. These would reduce the strength of the actual beams, while the finite element models do not include microcracks. Perfect bond between the concrete and steel reinforcement are assumed in the finite element analyses, but the assumption would not be true for the actual T-beams. As bond slip occurs, the composite action between the concrete and steel reinforcement is effected.

Table 9. Comparison between experimental and numerical analysis

RCA (%)	T-Beam No.	Numerical Failure loads (kN)	Experimental Failure loads (kN)	P(Num.)/P (Exp.)
0	FR0ρ1	91.83	88.29	1.04
50	FR50ρ1	93.6	88.29	1.06
75	FR75ρ1	83.9	78.48	1.07
0	FR0ρ2	135.2	127.53	1.06
50	FR50ρ2	137.75	127.53	1.08
75	FR75ρ2	127.14	117.72	1.08

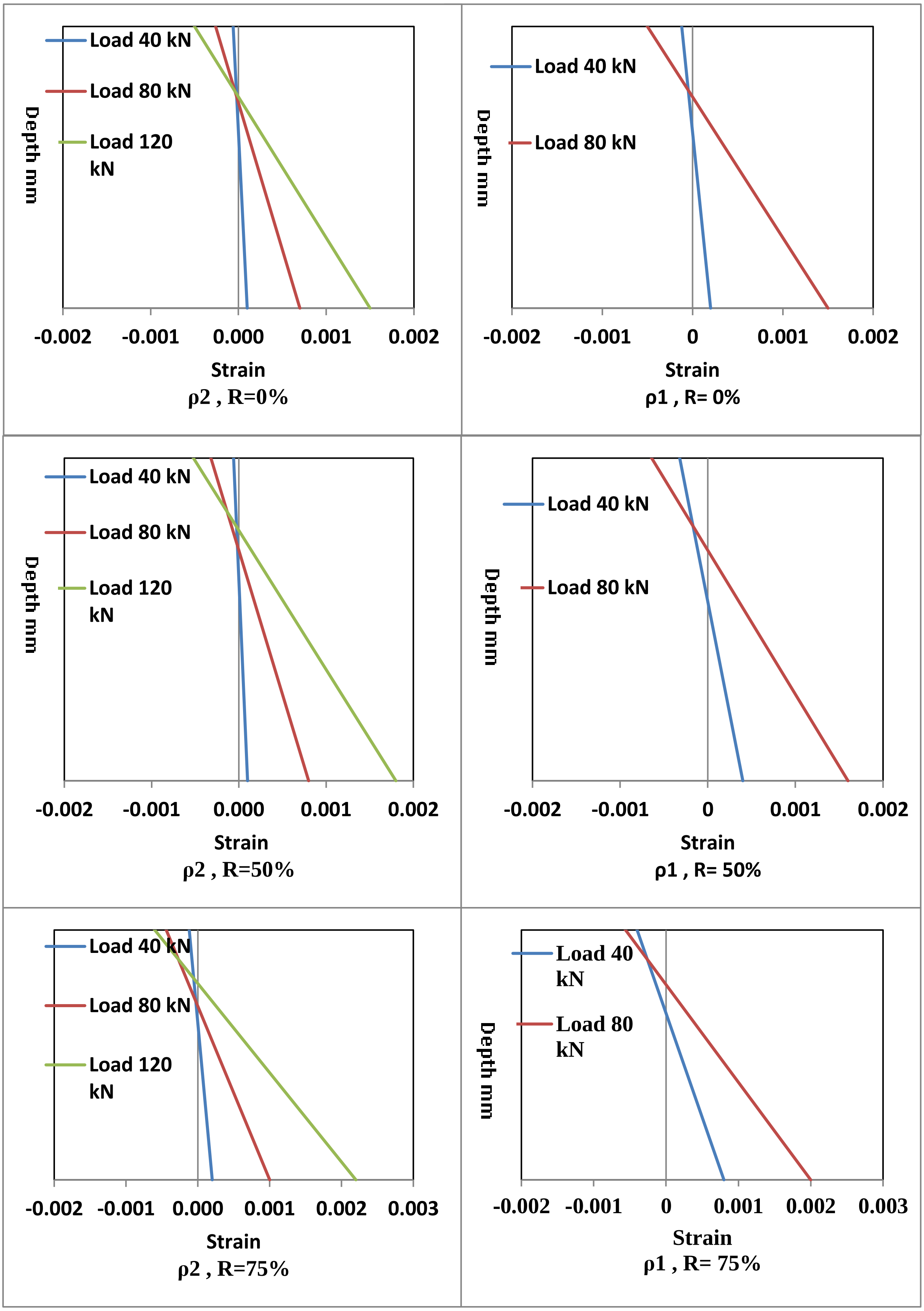


Figure16. Concrete strain distribution at mid-span of T-beam.

7.2 Crack Patterns

The ANSYS program records a crack pattern at each applied load step. In general, flexural cracks occur early at mid-span. When the applied loads are increased, the number and extend of the cracks increased. At a higher applied load, diagonal tensile cracks appear. Increasing applied loads induces additional diagonal and flexural cracks. Finally, compressive cracks appear at nearly the last applied load steps. Figures 18,19 shows the crack patterns of specimen's models of SCC beams fail in flexural. It can be observed that the predicted crack patterns are close to the experimental patterns, the cracks are concentrated at the region between two concentered loads, its start from the bottom and spread to the upper of beams.

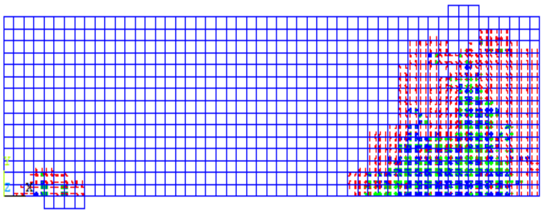


Figure18. Predicted crack pattern for beam with ρ1.

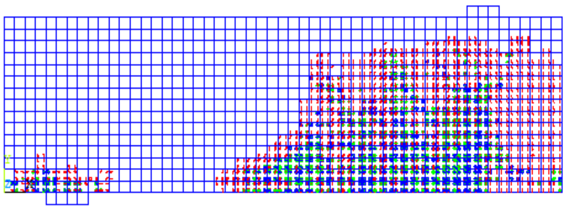


Figure19. Predicted crack pattern for beam with ρ2.

7.3 Load Deflection Curves

In ANSYS-14, deflection was evaluated at the same location as for the experimental T-beams. Figures (20) to (25) show the load deflection curves from the finite element analyses and the experimental results which showed that the load-deflection curves from the finite element analysis agreed well with the experimental data. In the linear range, the numerical load-deflection curve is stiffer than the experimental curve. The final load from the F.E model is higher than the experimental ultimate load and the deflection of the numerical model is lower than the experimental model at same load for the most of T-beams.

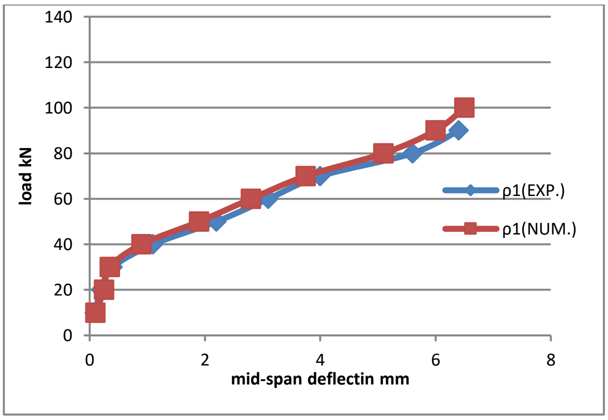


Figure 20. Numerical and experimental load deflection relationship for T-beam with R=0%

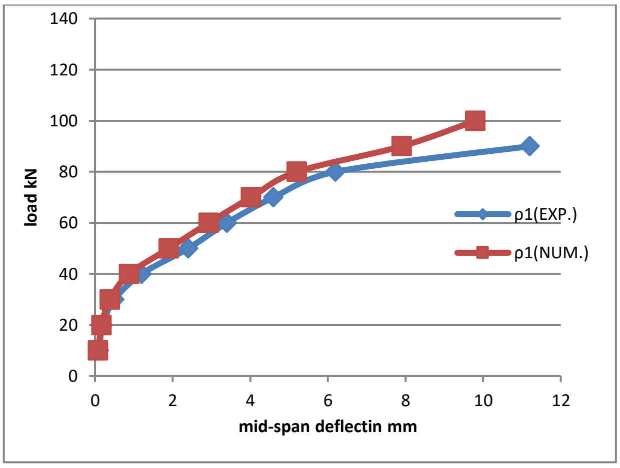


Figure 21. Numerical and experimental load deflection relationship for T-beam with R=50%

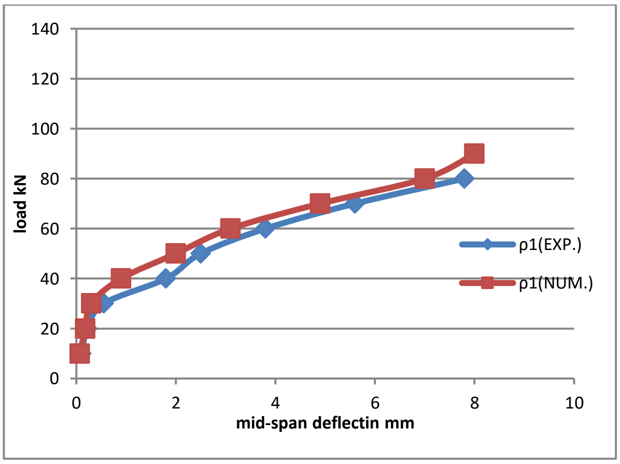


Figure 22. Numerical and experimental load deflection relationship for T-beam with R=75%

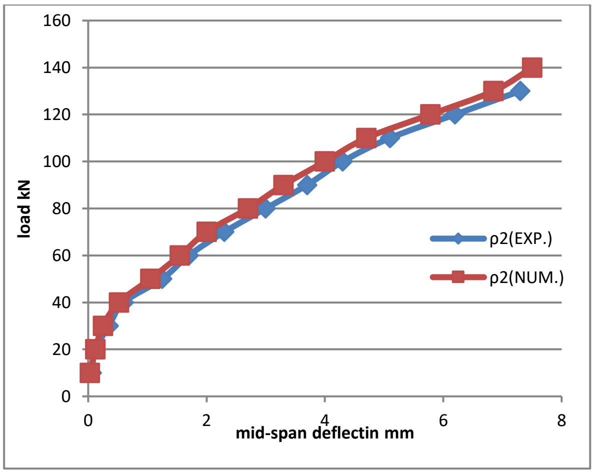


Figure 23. Numerical and experimental load deflection relationship for T-beam with R=0%

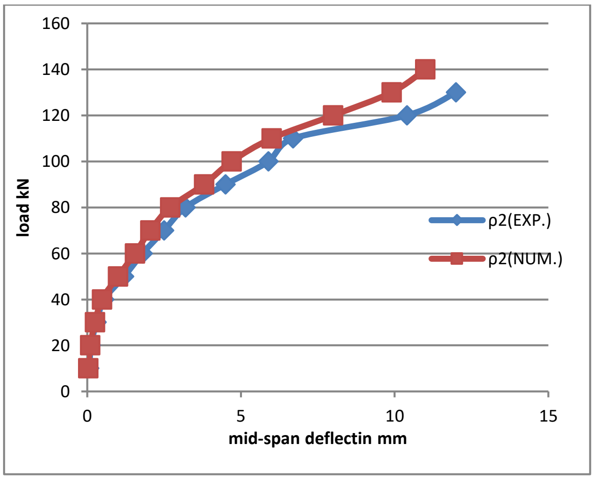


Figure 24. Numerical and experimental load deflection relationship for T-beam with R=50%

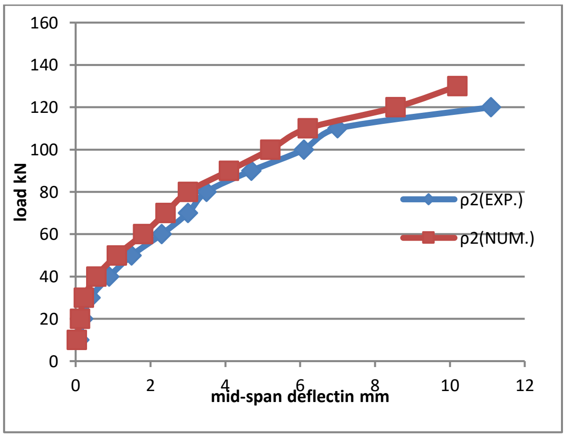


Figure 25. Numerical and experimental load deflection relationship for T-beam with R=75%

8. Conclusions

From this study the following conclusions can be drawn:

1- The use of recycled concrete aggregate (RCA) as a partial replacement of coarse aggregate have inversely affected the fresh properties of the self-compacting concrete but the resulting concrete remain within the limits specified for SCC.

2- Hardened concrete tests showed that, when increasing the replacement ratio to 50% the compressive strength decreased by 12.8%, the splitting tensile strength decreased by 13.3% and the modulus of elasticity decreased by 7.3%. When increasing the replacement ratio to 75% the compressive strength decreased by 27.5%, the splitting tensile strength decreased by 21.2% and the modulus of elasticity decreased by 17.8%.

3- When increasing the RCA replacement ratio to 50% the cracking load decreased by average 15.5% and ultimate load was not affected. When increasing the RCA replacement ratio to 75% the cracking load and ultimate load decreased by average 31% and 9.4% respectively.

4- For RCA replacement ratio to 50% the deflection at load of 70kN increased by average 12% and when increasing the RCA replacement ratio to 75% the deflection at load of 70kN increased by average 35%.

5- When increasing the RCA replacement ratio to 50% the crack width of beams at load of 70kN, increased by average 46.5% and when increasing the RCA replacement ratio to 75% the crack width of beams at load of 70kN, increased by average 105%.

6- when the steel ratio increased from ρ1 to ρ2 the first cracking load and ultimate load increased by 16.7% and 44.4% respectively for T-beams without RCA . For T-beams with replacement ratio of 50% the first cracking load and ultimate load increased by 20% and 44.4% respectively. While T-beams with replacement ratio of 75% the first cracking load and ultimate load increase 24.8% and 50% respectively.

7- when increase longitudinal steel ratio from ρ=0.0004 to ρ=0.00077, at load of 70kN, the deflection decrease 42.5% ,45.4% and 46.6% for replacement ratio 0% ,50% and 75 % respectively .When increasing the longitudinal steel ratio from ρ=0.0004 to ρ=0.00077 the crack width decrease 650% , 300% ,183 % for replacement ratio 0% , 50% 75 % respectively.

8- The predicted behavior of the beams by using the finite element method was in a good agreement with the experimental behavior.

9. References

1. Tviksta, L.G., "Guideline for SCC", Brite EuRam, Task 9 End Product, (2000), pp. 3-11.
2. Jeffery S. V. "Recycled Concrete Aggregate (RCA) for Infrastructure Elements", Report E: Flexural Behavior of RCA Concrete, June 2014.
3. Ali A. M.et. al," Properties of Concrete made with Recycle Aggregate ", MSc Thesis University of Basrah , college of engineering , 2009.
4. Gagan and Agam, "FLEXURAL BEHAVIOR OF REINFORCED RECYCLED CONCRETE BEAMS", International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308 (2015).
5. Iraqi Standards No.5/1984, "Ordinary Portland cement", Ministry of Housing and Construction, Baghdad,(2004).
6. Iraqi Standards No.45/1984, "Aggregate from Natural Sources for Concrete and Construction", Ministry of Housing and Construction, Baghdad,(2004).
7. ASTM A615/A615M-04b, "Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement", (2004), PP. 1−6.
8. Standard Specification for Chemical Admixtures for Concrete. ASTM-C494-05, American Society for Testing and Material, (2005).
9. Okamura, H., and Ouchi, M., (2003), "Self-Compacting Concrete", Journal of Advanced Concrete Technology, Vol.1, No.1, pp.(5-15).
10. ANSYS, (2005), "ANSYS Help" Release 1