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Shear Strength of Self Compacting Concrete made with Recycled Concrete as Coarse Aggregate

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Abstract

The chief objective of this research is to investigate the shear behaviour of self-compacting concrete (SCC) beams made with recycled concrete aggregate as coarse aggregate. All tested beams have same cross- section (220 x 320 mm). The studied parameters were percentage of RCA (0 and 50 %), shear span to effective depth ratio (1, 1.5, 2, 2.5) and percentage of web reinforcement (0, 0.26, 0.51 %). The tested beams were divided into four groups, each group consisted of four beams with a/d of (1, 1.5, 2, 2.5) for each beam. First group (A) made with normal coarse aggregate and without web reinforcement, the second group (B) made with recycled coarse aggregate (50 %) and without web reinforcement, third group (C) made with recycled coarse aggregate (50 %) and with percentage of web reinforcement 0.26 % and fourth group (D) made with recycled coarse aggregate (50 %) and with percentage of web reinforcement 0.52 %. Test results indicated that, using (RCA) in group (B) leads to decreases in the cracking and ultimate shear strengths by average ratios of 6.04 % and 17.58 % respectively. the increases in (a/d) ratio from (1 to 1.5), (1.5 to 2) and (2 to 2.5) in all groups lead to decreases in ultimate shear strengths by average ratios of 24.42 %, 23.26 % and 15.23 % respectively. The increases in the vertical web reinforcement ratio (pv) from 0 % in group (B) to 0.26 % in group (C) and from 0.26 in group (C) to 0.51 % in group (D) lead to an increases in the ultimate shear capacity by average ratio of 51.23 % and 15.75 % respectively. The experimental shear capacities of the beams were compared with Zsutty,s equation, Arabzad et al. equation, ACI 318M-14

Code. Zsutty,s equation and ACI 318M-14 Code showed better agreement with the experimental results as compared with the other used methods.

Keywords: self-compacting concrete, shear, Recycled Concrete.

مقاومة القص للخرسانة ذاتية الرص المصنوعة باستخدام الخرسانة المعادة كركام خشن

الخلاصة

إن الهدف الرئيسي من هذا البحث هو تحري سلوك القص للعتبات الخرسانية ذاتية الرص المصنوعة من الركام المعاد كركام خشن. جميع العتبات كانت تملك نفس مقطع (220 x 320 ملم). المتغيرات كانت نسبة فضاء القص الى العمق الفعال (1, 1.5, 2, 2.5), نسبة الركام الخشن المعاد (0 , 50 %) و نسب تسليح القص العمودي (0 , 0.21 , 0.51 %). قسمت العتبات المفحوصة إلى اربع مجموعات، كل مجموعة تكونت من اربع عتبات مع نسبة فضاء قص الى العمق الفعال (1, 1.5, 2, 2.5). المجموعة الأولى مصنوعة مع ركام خشن طبيعي و بدون تسليح قص, المجموعة الثانية مصنوعة مع ركام خشن معاد و بدون تسليح قص, المجموعة الثالثة مصنوعة مع ركام خشن معاد ومع نسبة تسليح 0.21 %, المجموعة الرابعة مصنوعة مع ركام خشن معاد ومع نسبة تسليح 0.51 %. نتائج الفحص اظهرت, ان استخدام الركام المعاد في المجموعة الثانية يؤدي الى نقصان مقاومة التشقق ومقاومة القص النهائية بمعدل نسبة 6.04 %, 17.58 % على التوالي مقارنة مع المجموعة الاولى المصنوعة مع الركام الخشن الطبيعي. الزيادات في (a/d) من (1 الى 1.5), (1.5 الى 2) ومن (2 الى 2.5) تؤدي الى انخفاض في مقاومة القص النهائية بمعدل نسبة 23.26 %, 24.42 % و 15.23 % على التوالي. الزيادات في حديد القص من 0 % في المجموعة الثانية الى 0.26 % في المجموعة الثالثة و من 0.26 % في المجموعة الثالثة الى 0.51 % في المجموعة الرابعة تؤدي الى زيادة في مقاومة القص النهائية بمعدل نسبة 51.23 % و 15.75 % على التوالي. مقاومة القص النهائية للعتبات قُرنت مع معادلة Zsutty, معادلة Arabzad واخرين, طريقة مدونة المعهد الأمريكي للخرسانة لسنة 2014 (ACI 318M-14 Code). معادلةZsutty و طريقة مدونة المعهد الأمريكي بينت توافقا افضل مع النتائج العملية مقارنة مع الطرق الاخرى المستخدمة.

الكلمات المفتاحية: الخرسانة ,الخرسانة ذاتية الرص, القص, الركام المعاد.

1. Introduction

SCC is one of the most outstanding advances in concrete technology through the previous decades. It may contribute to important improvement of the characteristics of concrete structures and open up different fields for the application of concrete because of its specific properties. SCC refer to a concrete that is able to compact itself only by means of its own mass without any additional vibration. It fills all reinforcement spaces, gaps and voids, even in highly reinforced concrete members and flows free of segregation. At first, developed in 1980s in Japan, SCC is spread around the world with a consistently increasing number of utilizations [1]. The basic materials of SCC are like to those of traditional concrete[2].

Recycled aggregates are produced from crushing waste concrete and after that the coarse fraction could be used to replace normal coarse aggregates in the concrete construction. There are numerous researches studied the properties of RCA. It was explained that the mechanical properties does not become different significantly in concrete with a 75% replacement of their natural aggregates by RCA. Despite normal aggregates have higher density and lower absorption than recycle aggregates but recycle aggregates is able to make concrete with good performance by mix the suitable quantity of each concrete material. The utilization of recycled aggregates has an important environmental effect since fewer natural resources are exploited and building industry litters may be used [3].

When a beam is loaded shear forces and bending moment develop along the beam for carrying the load safely, the beam must be designed for both kinds of forces. One of the most significant and potentially risky failure mechanisms is shear, or diagonal tension failure [4].

2. Experimental program

The experimental program of shear behaviour of SCC beams consists of testing samples (sixteen beams). Each beam sample made with concrete mix having compressive strength of 38 MPa for SCC with 0% RCA and 35 MPa for SCC with 50% RCA. The samples were divided into four groups (A ,B, C and D) depending on coarse aggregate type and web reinforcement. Each group contains four ratios of shear span to the effective depth of (1, 1.5 , 2, 2.5). The length were (860, 1140, 1420, 1700) mm for ratios a/d (1, 1.5, 2, 2.5) respectively. Longitudinal steel ratio was (p) 0.0204, a section was (220 x 320) and the effective depth was 280 mm for all beams. The groups are divided as following :

First group (A): Involving four beams made with normal coarse aggregate and without web reinforcement.

Second group (B): Involving four beams made with recycled coarse aggregate (50 %) and without web reinforcement.

Third group (C): Involving four beams made with recycled coarse aggregate (50 %) and with web reinforcement with spacing 100 mm between stirrups.

Fourth group (D): Involving four beams made with recycled coarse aggregate (50 %) and with web reinforcement with spacing 50 mm between stirrups.

Table (1) demonstrates details of all sixteen beams with their related parameters.

Table (1) Details of tested beams and research parameters

Group	Beam Name	a/d	Total Span Mm	Aggregate Type	Long. Reinf.	Vertical shear reinf.
A	A-1	1	860	NCA	4ϕ20	----
	A-1.5	1.5	1140	NCA	4ϕ20	----
	A-2	2	1420	NCA	4ϕ20	----
	A-2.5	2.5	1700	NCA	4ϕ20	----
B	B-1	1	860	RCA	4ϕ20	----
	B-1.5	1.5	1140	RCA	4ϕ20	----
	B-2	2	1420	RCA	4ϕ20	----
	B-2.5	2.5	1700	RCA	4ϕ20	----
C	C-1	1	860	RCA	4ϕ20	ϕ□ □/ 100
	C-1.5	1.5	1140	RCA	4ϕ20	ϕ□ □/ 100
	C-2	2	1420	RCA	4ϕ20	ϕ□ □/ 100
	C-2.5	2.5	1700	RCA	4ϕ20	ϕ□ □/ 100
D	D-1	1	860	RCA	4ϕ20	□ϕ□ □/ 50

	D-1.5	1.5	1140	RCA	4ϕ20	□ϕ□ □/ 50
	D-2	2	1420	RCA	4ϕ20	□ϕ□ □/ 50
	D-2.5	2.5	1700	RCA	4ϕ20	□ϕ□ □/ 50

3. Materials:

3.1 Cement:

Conventional Portland cement made by Mabrouka cement company was utilized in this study. This cement comply with the Iraqi specifications number (5/1984) [5].

3.2 Water:

Potable water was utilized for both making and curing the samples of concrete.

3.3 Fine Aggregate

Normal sand from Al-Zubair, region in Basrah city was utilized. Before using it, the sieve analysis is performed at Material Laboratory in Engineering College of Al-Basra University for ensuring its validity for mixing. The fine aggregate was in region 2 of Iraqi specification number (5 / 1984) [5].

3.4 Coarse Aggregate

1-Gravel :

Crushed gravel from Al-Zubair, region in Basrah city with maximum size of 20 mm was utilized. Before using it, the sieve analysis is performed at Material Laboratory in Engineering College of Al-Basra University for ensuring its validity for mixing The results demonstrate that, the coarse aggregate grading is within the requirements of Iraqi specification No. 45 / 1984 [5].

2-Recycled Concrete Aggregate :

Recycled concrete aggregate which was utilized in this study was obtained from the destruction of concrete cubes which have been taken to the laboratory for testing. The results demonstrate that, the RCA grading is within the requirements of Iraqi specification No. 45 / 1984 [5]. The maximum size, of this aggregate was 20mm.

3.5 Superplasticizer:

A high performance concrete, superplasticizer (High Range Water Reduction Agent HRWRA) based on polycarboxylic technology, which is well-known commercially as Glenium 51, is utilized in these tests. Glenium 51 has been principally manufactured for applications in the precast and premixed concrete industries where the highest performance and durability are required. Glenium 51 is free of chlorides and complies with ASTMC494 type a [6].

3.6 Steel Reinforcement:

The longitudinal steel bars which are utilized in these tests have nominal diameter of 6.0 mm, 10 mm and 20.0 mm. Three 1000 mm long samples from each nominal diameter are tested for evaluating the ultimate strength (fu) and the yield stress (fy) and the results are demonstrated in table (2).

Table (2) Properties of reinforcing steel

Diameter (steel bar) Mm	f_y MPa	f_u Mpa	Elongation %
20	500	718	12
10	490	630	11
6	440	659	11

3.7 Limestone Powder:

Al-Gubra is the local name for this powder, which has been taken from local market and utilized to rise the quantity of powder (filler + cement). The limestone powder (L.S.P) according to EFNARC 2005 [7] should be less than 0.125 mm to be most helpful. The cost of grinding is very small. The cement in SCC mixtures is generally partially substituted by fillers like limestone powder. Specific surface of the LSP utilized was 310 kg/ m2. Specific gravity of the LSP was 2.4.

4. Proportioning of Concrete Mixture

Mixture proportioning is more critical for SCC than for NC. Several trials are carried out on mixture incorporating superplasticizer (SP) by raising the dosage of the admixture slowly and adjusting the w/c ratio for ensuring the self-compacting. After these trials one concrete mixture has been chosen which satisfy SCC and with compressive strength of around 38 MPa. Table (3) demonstrates the quantity of utilized mix materials. The mixing method may be summarized as:

1- Powder (lime stone powder and cement) and aggregate were blended for one minute.
2- The first part 80% of blending water was added gradually and blended for another 1 minute.
3- The second part 20% of blending water with superplasticizer dissolved in it was added gradually whereas blending for another one minute.
4- blending was continuous for additional 3 minutes.
5- The blend was allowed to break for 3.5 minutes.
6. The blend was remixed for thirty seconds and discharged for casting.

Table (3) Concrete mix materials

Material	Content
Cement kg / m^3	413
Limestone Powder kg / m^3	179
Coarse Aggregate kg / m^3	786
Fine Aggregate kg / m^3	827
Water kg / m^3	183
SP kg / m^3	4

5. Tests on Fresh Self Compacting Concrete

In this work, consideration of concrete mix as a self compacting concrete is verified by three standard tests: Slump flow, L-box and V-funnel as shown in **Figures (1),(2) and (3).**

Fig. (1): Slump flow test

Fig. (2): L-box test

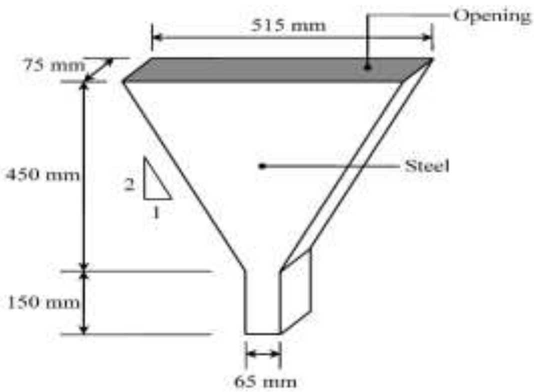

Fig. (3): V-funnel test for SCC

6. Tests and Measurements of SCC Beams

Universal testing device of capacity 2000 kN was utilized for testing the beams. Through the test, the deflection at mid-span and applied load was recorded by utilizing dial gauges of 0.01 mm/div. The outputs from each test sample were collected and utilized in plotting the load-deflection curves. All tests were carried out initially under the condition of load control of 10 kN increments, which was then decreased to 5kN near to the ultimate load.

Fig. (4): beam inside testing Machine

7. Fresh and Hardened SCC Properties

The fresh and hardened properties of this mixture are demonstrated in Tables (4) and (5) respectively, obtained for two mixes with and without RCA.

Table (4): Properties of fresh SCC

SCC	Slump flow (mm)	T 500 (sec)	V-funnel (sec)	BR
0% RCA	700	2.76	8.55	0.93
50% RCA	703	2.74	8.50	0.94

Table (5): Properties of hardened SCC at 28 days

SCC Type	Compressive strength(MPa)		Splitting strength (MPa)	Static modulus of elasticity (GPa)
	Cube 150x150 Fcu	Cylinder 150x300 f_c'		
0% RCA	48.04	38.43	3.99	31.56
50% RCA	44.36	35.49	3.93	31.02

8. Behavior of SCC Beams

Figures (5) to (7) demonstrate the crack patterns for SCC beams after testing. At low load levels, all the tested beams behaved in an elastic style where no defects in their structures and the cracks did not appear at any location and the deflections are small at mid-span and proportional to the applied loads, consequently the stresses were slight and full cross section was active in carrying the loads. At failure, length and number of flexural cracks increased with increasing the shear span to effective depth ratio because of the greater bending moment. With raising the load the numbers of cracks increased and main diagonal cracks were looked between the point loads and each reactions, at the ends, the cracks became more extensive and expanded in the directions of the loads and reactions, Also the flexural cracks were increased at failure with increasing the amount of web reinforcement because of the greater shear resistant from web reinforcement.

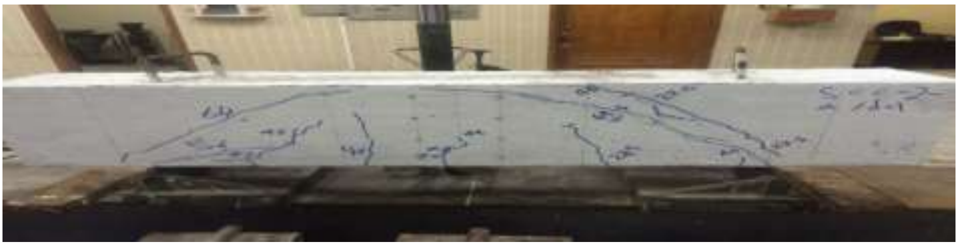

Fig. (5): Crack Pattern for Beam A-1

Fig. (6): Crack Pattern for Beam B-1

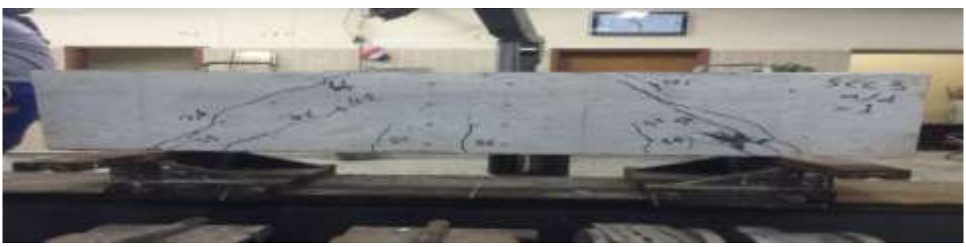

Fig. (7): Crack Pattern for Beam C-1

9. Effect of using RCA on SCC beams

9.1 Cracking and Ultimate Load

Effect of utilizing RCA on cracking and ultimate loads and the ratio between them for beams in groups (A) and (B) are detailed in Table (5). SCC beams with 50% recycled coarse concrete aggregate exhibited a lesser cracking load and shear strength compared with SCC beams cast with normal coarse aggregates. This decrease is attributed to the lower compressive strength in beams with RCA. The reduction in cracking load due to using the RCA in group (B) as compared with group (A) which made with NCA value ranges from 2.78 % to 10.53 % (average is 6.04 %). This reduction in cracking load becomes lesser as the (a/d) ratio increases. The reduction in ultimate load due to using the RCA in group (B) as compared with group (A) value ranges from 12.23 % to 21.88 % (average is 17.58 %). This reduction is larger as (a/d) ratio increases. The ratio between the, cracking and ultimate loads ranges from 0.41 to 0.56 (average is 50.1 %) for SCC beams made with NCA in group (A) while it ranges from 0.42 to 0.70 (average is 58 %) for SCC beams made with RCA in group (B), i.e., this ratio is smaller in group (A) as compared with beams in group(B).

Table (5) Effect of (RCA) on cracking and ultimate loads

(a/d)	Group (A)			Group (B)			% Variation due to use RCA	
	Pcr Kn	Pu Kn	Pcr /Pu	Pcr kN	Pu kN	Pcr /Pu	Δpcr %	Δpu %
1	285	695	0.41	255	610	0.42	-10.53	-12.23
1.5	245	495	0.49	230	420	0.55	-06.12	-15.15
2	210	380	0.55	200	300	0.67	-04.76	-21.05
2.5	180	320	0.56	175	250	0.70	-02.78	-21.88

9.2 Deflection

Deflection was measured at mid span of the beams at different loading stages. The maximum deflections at failure were not obtained to avoid dial gauge damage. Figures (8) to (9) present comparison between deflection in beams of group (A) cast with normal aggregate and group (B) with recycled aggregate. It can be noticed that, at the same load, the deflections of group (A) were lesser than similar beams of Group (B) cast with recycled aggregate. This is because beams (B) have lower modulus of elasticity than beams(A) then result in lesser flexural rigidity (EI). The increase in deflection due to using the RCA in group (B) as compared with group (A) which made with NCA are 21 % for a/d ratio of 1, 21 % for a/d ratio of 1.5, 19 % for a/d ratio of 2 and 42 % for a/d ratio of 2.5 with an average of 26 %.

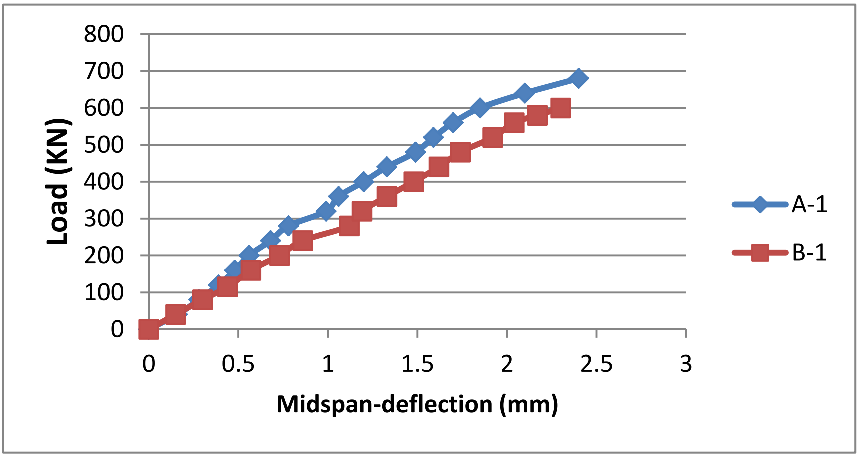

Fig. (8): Comparison of load - midspan deflection curves for beams A-1 and B-1

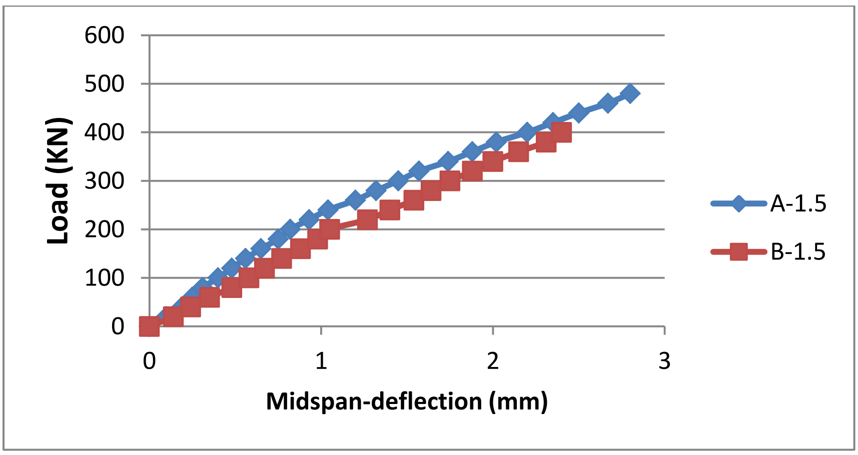

Fig. (9): Comparison of load - midspan deflection curves for beams A-1.5 and B-1.5

10. Effect of Shear Span to Effective Depth Ratio (a/d)

10.1 Cracking and Ultimate Load

Effect of (a/d) on cracking and ultimate loads and the ratio between them for beams with all a/d ratios are detailed in Table (6 a, b and c). The increase in (a/d) ratio leads to reduce in cracking and ultimate shear capacities. The reduction in cracking load due to increasing (a/d) ratio from 1 to 1.5 for all groups ranges from 9.8 % to 14.04 % (average reduction is 11.24 % and standard deviation is 1.92) and due to increasing (a/d) ratio from 1.5 to 2 ranges from 13.04 % to 14.29% (average reduction is 13.64 % and standard deviation is 0.60). Also this reduction ranges from 4.08 % to 14.29 % (average reduction is 10.10 % and standard deviation is 4.60) due to increasing (a/d) ratio from 2 to 2.5 . The reduction occurring in SCC beams with NCA in group (A) is larger than that occurring in SCC beams with RCA in group (B). The reduction becomes larger with the increase in shear reinforcement.

The reduction in the ultimate load due to increasing the (a/d) ratio from 1 to 1.5 ranges from 17.24 % to 28.78 % (average reduction is 24.42 % and standard deviation is 6.6) and due to increasing (a/d) ratio from 1.5 to 2 ranges from 19.44 % to 28.57 % (average reduction is 23.26 % and standard deviation is 3.87). Also this reduction ranges from 13.04 % to 16.67 % (average reduction is 15.34 % and standard deviation is 1.38) due to increasing (a/d) ratio from 2 to 2.5. the decrease in the ultimate load is attributed to the lower contribution of arch action of shear transfer in beams with higher a/d ratio. The reduction occurring in SCC beams with NCA in group (A) is lesser than that occurring in SCC beams with RCA in group (B). Also, the reduction becomes smaller as shear steel increase. This reduction decreases with increases (a/d) ratios for beams without shear steel in groups (A) and (B). This reduction in group (A) ranges from (28.78 % to 15.79 %) and in group (B) (31.51% to 16.67 %). The ratio between cracking and ultimate loads ranges from 0.37 to 0.41 (the average is 0.40) for a/d =1and it ranges from 0.40 to 0.55 (the average is 0.47) for a/d = 1.5.Also it ranges from 0.42 to 0.67 (the average is 0.53) for a/d =2 while (0.48 to 0.70 with average 0.55) for a/d =2.5 , i.e., generally this ratio increases as the (a/d) ratio increases.

Table (6) effect of shear span to effective depth ratio (a/d)

a- a/d=1 and 1.5

group	a / d = 1			a / d = 1.5			% Variation due to increasing (a/d)	
	Pcr kN	Pu kN	Pcr /Pu	Pcr kN	Pu kN	Pcr /Pu	Δpcr %	Δpu %
A	285	695	0.41	245	495	0.49	-14.04	-28.78
B	255	610	0.42	230	420	0.55	-09.80	-31.15
C	295	780	0.38	265	620	0.43	-10.17	-20.51
D	320	870	0.37	285	720	0.40	-10.94	-17.24

b- a/d= 1.5 and 2

group	a / d = 1.5			a / d = 2			% Variation due to increasing (a/d)	
	Pcr kN	Pu kN	Pcr /Pu	Pcr kN	Pu kN	Pcr /Pu	Δpcr %	Δpu %
A	245	495	0.49	210	380	0.55	-14.29	-23.23
B	230	420	0.55	200	300	0.67	-13.04	-28.57
C	265	620	0.43	230	485	*0.47*	-13.21	-21.77
D	285	720	0.40	245	580	0.42	-14.04	-19.44

c- a/d= 1.5 and 2

Group	a / d = 2	a / d = 2.5	% Variation due to increasing (a/d)

	Pcr kN	Pu kN	Pcr /Pu	Pcr kN	Pu kN	Pcr /Pu	Δpcr %	Δpu %
A	210	380	0.55	180	320	0.56	-14.29	-15.79
B	200	300	0.67	175	250	0.70	-12.50	-16.67
C	230	485	*0.47*	200	420	0.48	-13.04	-13.40
D	245	580	0.42	235	490	0.48	-4.08	-15.52

10.2 Deflection

From Figures (10) to (11), it is clear that the increase in the (a/d) ratio significantly increases the deflection value for all load stages in all groups. This increase becomes larger as the applied load increases.

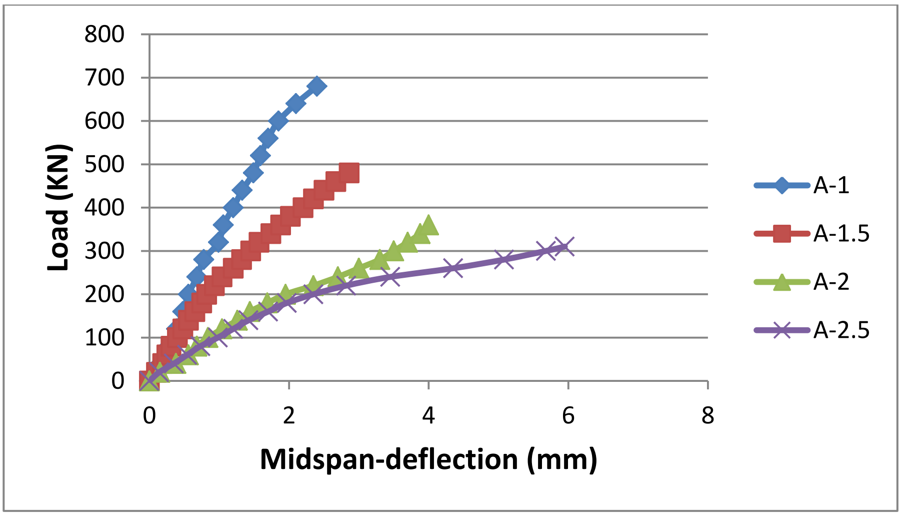

Figure (10): Comparison of load - midspan deflection curves for beams in group (A)

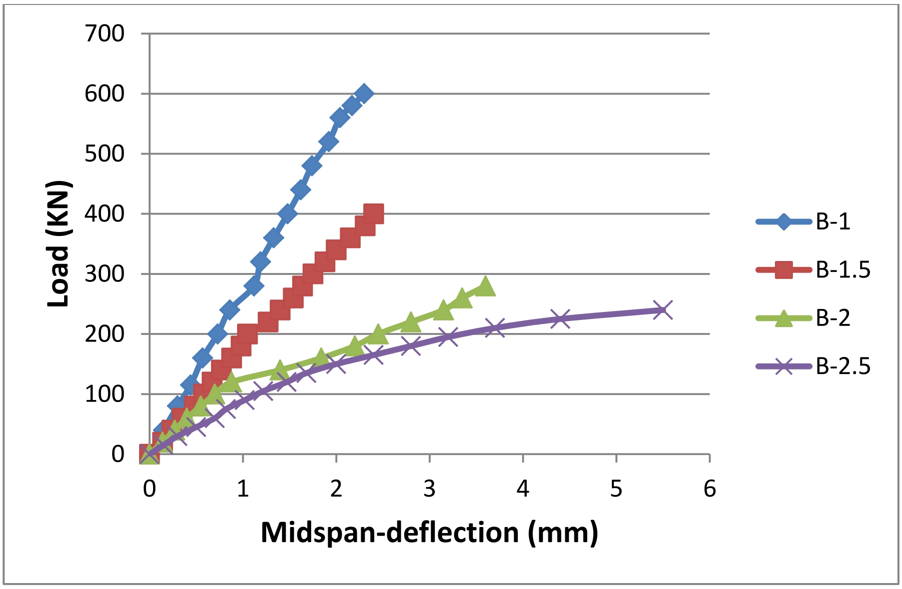

Figure (11): Comparison of load - midspan deflection curves for beams in group (B)

11. Comparison between Measured and Predicted Shear Strengths of SCC Beams

The shear strengths of SCC beams made with NCA and RCA were calculated in accordance with Zsutty,s equation (8), Arabzad et al. equation (9), ACI 318M-14 Code (10). The predicted value were compared with the present experimental results. As listed in Table (7). Zsutty,s equation and ACI 318M-14 Code demonstrated better agreement with the experimental results as compared with the other used methods.

Table (7) Measured and Calculated Shear Strength for Beams

Beam name	a/d	vu (N/mm^2)				(1/2)	(1/3)	(1/4)
		(1) Exp.	(2) ACI 318M-14	(3) Zsutty	(4) Arabzad			
Group (A)								
A-1	1	5.641	4.851	5.027	3.786	1.163	1.122	1.490
A-1.5	1.5	4.018	3.534	2.928	2.438	1.137	1.372	1.648

A-2	2	3.084	2.682	1.997	1.559	1.151	1.545	1.979
A-2.5	2.5	2.597	2.096	1.477	------	1.239	1.759	------
Group (B)								
B-1	1	4.951	4.428	4.877	3.552	1.118	1.015	1.394
B-1.5	1.5	3.409	3.251	2.848	2.299	1.049	1.197	1.483
B-2	2	2.435	2.438	1.934	1.458	0.999	1.259	1.670
B-2.5	2.5	2.029	1.900	1.429	------	1.068	1.420	------
Group (C)								
C-1	1	6.331	4.430	5.982	3.981	1.429	1.058	1.590
C-1.5	1.5	5.032	3.238	3.950	3.124	1.554	1.274	1.611
C-2	2	3.937	2.415	3.033	2.525	1.630	1.298	1.559
C-2.5	2.5	3.409	1.905	2.536	------	1.789	1.344	------
Group (D)								
D-1	1	7.062	5.567	7.096	4.239	1.266	0.995	1.666
D-1.5	1.5	5.844	4.046	5.054	3.596	1.445	1.156	1.625
D-2	2	4.708	3.069	4.149	3.154	1.534	1.135	1.492
D-2.5	2.5	3.977	2.408	3.646	------	1.652	1.091	------

12. Conclusions

From test results obtained, in this investigation the following conclusions can be drawn.

1. SCC beams with 50 % recycled coarse concrete aggregate in group (B) showed a lesser cracking load about 2.78 % to 10.53 % (the average is 6.04 %) compared with beams cast with normal coarse aggregates in group (A). This reduction in cracking load becomes smaller as the (a/d) ratio increases.
2. SCC beams with 50 % recycled coarse concrete aggregate in group (B) show a lesser shear strength about 12.33 % to 21.88 % (the average is 17.58 %) compared with beams cast with normal coarse aggregates. This reduction is larger as (a/d) ratio increases.
3. In beams without web reinforcement shear failure occurs suddenly without noticeable rise in crack width.
4. The increase in the shear span to effective depth ratio (a/d) from (1 to 1.5), (1.5 to 2) and (2 to 2.5) decreases the cracking load by average of

11.24 %, 13.64 % and 13.28 %, respectively. This reduction becomes bigger in SCC beams with NCA in group (A) when compared with the SCC beams with NCA in group (B) and this reduction becomes greater with shear steel increases.

5. The increase in the (a/d) ratio from (1 to 1.5), (1.5 to 2) and (2 to 2.5) decreases the ultimate load with average of 24.42 %, 23.26 % and 15.23 % respectively. The reduction occurring in SCC beams with NCA is lesser than that occurring in SCC beams with RCA in group (B). Also, the reduction becomes smaller as shear steel increase.

6. Values of cracking to ultimate load ratio range from 0.37 to 0.7 for all beams. This ratio is decreased with increasing (a/d) ratio in each group. Also, this ratio is lesser in SCC beams with 50% recycled coarse concrete aggregate in group (B) as compared with beams cast with normal coarse aggregates in group (A) and decreases with increasing (pv).

7. The load-deflection response of SCC beams is significantly influenced by (a/d) ratio. The response becomes appreciably non-linear as the (a/d) ratio increases.

8. Beams with 50 % recycled concrete aggregate in group (B) show larger mid-span deflection (average is 25.65 %) than beams with normal concrete aggregate in group (A) at the same load.

9. The increase in shear reinforcement from (pv=0.26 %) to (pv=0.51 %) causes small variations in the deflection values as compared with variations in the deflection values between group (B) (pv=0 %) and (C) (pv=0.26 %) for all beams.

10- The ACI code underestimate the shear capacity at members with web reinforcement in groups (C) and (D) and it predicted very close to measured values at members without web reinforcement in groups (A) and (B). The ratios of measured to predicted shear capacity of beams in groups (A, B, C and D) have average values 1.172, 1.058, 1.601 and 1.475 respectively.

11. Zsutt,y's equations have given predicted, values of shear capacity near to the measured values. The ratioss of measured to predicted shear capacity of beams in groups (A, B, C and D) have average values 1.449, 1.223, 1.244 and 1.094 respectively. This ratio is increased with increasing (a/d).

12. Arabzadeh et al. equations underestimated shear strength of SCC beams. The ratio experimental / predicted shear strength for beams in (A, B, C and D) have average values of 1.706, 1.516 and 1.587 and 1.595 respectively.

13. References

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