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BEHAVIOR OF REINFORCED SELF-COMPACTING CONCRETE BEAMS CONTAINING STEEL FIBERS AND RECYCLED COARSE AGGREGATES

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Abstract: Concrete wastes are generally delivered to the landfill sites for disposal. Due to increase charges of landfill and shortage of natural coarse aggregate (NCA), recycled coarse aggregate (RCA) (resulting from concrete wastes) is growing interest in building engineering. It is sustainable to use recycled construction materials to preserve the natural resources and maintain the environmental of cities. In the present study, RCA was used as a full replacement of NCA in some specimens of beams to produce self-compacting concrete (SCC). The experimental work consists of casting and testing eight rectangular simply supported reinforced concrete beams of (1200*180*250) mm for length, width, and height respectively with concentric point load as well as tests for control specimens to determine the mechanical properties of SCC. Four of these eight beams were tested for flexural and the other four beams for shear behavior. The present research includes the following main variables: transverse reinforcement (stirrups spacing, 50 mm and 100 mm), coarse aggregate (RCA and NCA) and steel fibers of (V_f = 0.5%). All beams have constant longitudinal steel reinforcement ratio=0.008. Experimental results have generally showed that ultimate loads (Pu) of beams made with RCA were approximately close to the results of beams made with NCA by percentages (1.08% and 1.11%) for flexural and shear behavior respectively. RCA can be used as a full replacement in the future construction industry. The presence of steel fibers increases the maximum deflection of beams by 1.55% for flexural and 1.02% for shear behavior.

Keywords*:* *Self-compacting concrete, Recycled coarse aggregate, Steel fibers*

سلوك العتبات المسلحة الذاتية الرص المحتوية على الياف الحديد والركام الخشن المعاد

الخلاصة: غالبا مايتم التخلص من الخرسانة القديمة (انقاض خرسانية) في مواقع ذات أرض مفتوحة. ونظرا لزيادة وثقل التحميل لهذه المواقع وندرة (قلة) المصادر الطبيعية لانتاج الركام الخشن الطبيعي، يتم استخدام الركام المعاد تدويره (المشتق من الخرسانة القديمة). وهذا الركام زاد الاهتمام به في الصناعات الانشائية. لذلك في الهندسة المستدامة يتم استخدام الركام المعاد تدويره من اجل المحافظة على الموارد الطبيعية واصلاح بيئة المدن. في هذا البحث، استخدم الركام المعاد (RCA) كبديل كلي عن الركام الطبيعي (NCA) وذلك لانتاج خرسانة ذاتية الرص. تضمن العمل المختبري طريقة الصب والفحص (تحت تأثير الانثناء والقص) لثمان عتبات خرسانية مستطيلة المقطع وبسيطة الاسناد بأبعاد (1200*180*250) ملم طول، عرض، وارتفاع على التوالي ذات تحميل مركزي احادي، بالاضافة الى فحوص للنماذج الخرسانية في مرحلة الخرسانة المتصلبة لتحديد الخواص الميكانيكية للخرسانة ذاتية الرص. تم اختيار اربع عتبات من اصل ثمانية لدراسة سلوك الانثناء والاربعة الاخرى لدراسة سلوك القص. تضمن البحث المتغيرات الرئيسية التالية: تسليح القص (المسافة بين الاطواق50 ملم و 100 ملم)، الركام الخشن (RCA و NCA) والياف التسليح ذات النسبة الحجمية الثابتة (0,5 %). علما ان نسبة حديد التسليح الطولي ثابته 0,008 =ρ. اظهرت النتائج العملية عموما ان الاحمال القصوى للعتبات المصبوبة بأستخدام الركام المعاد تدويره مقاربة جدا الى الاحمال القصوى للعتبات المصبوبة

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بأستخدام الركام الطبيعي وبنسبة تغاير بسيطة لذلك من الممكن استخدامه كبديل عن الركام الطبيعي في الصناعة الانشائية المستقبلية حيث ان نسبة الزيادة (1,08% و 1,11%) لسلوكي الانثناء والقص على التوالي . ان وجود الياف الحديد زاد من قيمة الهطول للعتبات الخرسانية بنسبة زيادة (1,55%) لسلوك الانثناء و (1,02%) لسلوك القص.

1. Introduction

Concrete is the main construction material that is widely used in all types of civil engineering works such as infrastructure, low and high-rise buildings, and installations of defense work, environs defense and local-domestic improvements. However, recently the perception of the continued extensive abstraction and use of natural resources aggregates is questioned at a wide-reaching level (Lawson et al, 2001). This is chiefly because of natural aggregates quality depletion and the greater awareness of protection of environmental. Considering this, the obtainability of natural resources to the future had also been recognized (CSIR, 2000).

Today, there are severe shortages of natural resources in current situation. Concrete production and utilization are rapidly increased, which result in increased natural aggregate consumption as they are the largest component of concrete (Wai et al, 2012). Building materials are progressively featured by their sustainable features; a solution of these problems is recycling damaged concrete and producing a substitute aggregate for concrete structures (Valeria et al, 2009).

Recycled coarse aggregate (RCA) reduces impact on landfills, reduces energy depletion and provides cost reserves (Huang et al, 2002). On the other hand, there is the beneficial use of RCA in concrete building (Eguchi et al, 2006). RCA is made of crumpled, arranged, inorganic subdivisions treated from material that is used in structure and destruction rubbles (Ravi, et. al, 2013). RCA is defined in (BS 8500-1, 2006) as the general word for aggregate result from the reusing of inorganic material before used in building.

1.1. Self-Compacting Concrete

Self-compacting concrete (SCC) has been described as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labour, it has proved beneficial economically because of a number of factors, including: (EFNARC, 2002)

- faster construction.
- reduction in site manpower.
- better surface finishes.
- easier placing.
- improved durability.
- greater freedom in design.
- thinner concrete sections.
- reduced noise levels, absence of vibration.
- safer working environment.

The workability of SCC can be characterized by the following properties: (EFNARC, 2002)

- Filling ability
- Passing ability
- Segregation resistance
- Filling ability (unconfined flow ability): the ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight.
- Passing ability (confined flowability): the ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without compaction.
- Segregation resistance (stability): the ability of SCC to remain homogeneous in composition during transport and placing.

2. Objective of This Paper

The main objective of this research is to investigate both flexural and shear behavior of reinforced self-compacting concrete beams by using (RCA) of (10 mm) maximum size which is recycled coarse aggregate taken from an old concrete barrier.

3. Research Significance

Self-compacting concrete (SCC) offers several economic and technical benefits; the use of steel fibers extends its possibilities. Steel fibers acts as a bridge to retard their cracks propagation, and improve several characteristics and properties of the concrete. Fibers are known to significantly affect the workability of concrete (B. Krishna and V. Ravindra, 2010).

3.1 The Effect of Fibers On Workability

Fibers affect the characteristics of SCC in the fresh state. They are needle-like particles that increase the resistance to flow and contribute to an internal structure in the fresh state. Steel fiber reinforced concrete is stiffer than conventional concrete. In order to optimize the performance of the single fibers, fibers need to be homogeneously distributed; clustering of fibers has to be avoided. The effect of fibers on workability is mainly due to four reasons:

First, the shape of the fibers is more elongated than the aggregates; the surface area at the same volume is higher.

Second, stiff fibers change the structure of the granular skeleton, whereas flexible fibers fill the space between them. Stiff fibers push apart particles that are relatively large compared to the fiber length, which increases the porosity of the granular skeleton.

Third, the surface characteristics of fibers differ from that of cement and aggregates, e.g. plastic fibers might be hydrophilic or hydrophobic.

Finally, steel fibers often are deformed (i.e. have hooked ends or are wave-shaped) to improve the anchorage between them and the surrounding matrix. The size of the fibers relative to the aggregates determines their distribution. To be effective in the hardened state it is recommended to choose fibers not shorter than the maximum aggregate size. Usually, the fiber length is 2-4 times that of the maximum aggregate size (Steffen and Joost, 2009).

3.2 The Use of Silica Fume

Silica fume or *microsilica* (very fine amorphous silica particles < 1 μm) is studied as concrete mineral admixture in the early 1950's at the Norwegian Institute of Technology. However, only in the mid 1970's, after the advent of superplasticizers, silica fume both in practice and in laboratory started in several Scandinavian countries: Norway, Sweden, Denmark and Iceland. After then, research work and practical use of silica fume in concrete started in many countries outside Europe. Silica fume and superplasticizer are complementary materials to manufacture self-compacting concretes with great cohesion of the fresh mix. Due to this special behavior, silica fume in the presence of superplasticizer can compensate the absence of fine materials, such as fly ash or ground limestone in relatively lean cement mixtures (M. Collepardi, et.al, 1981).

3.3 Recycled Coarse Aggregates

Recycling of demolition rubble is not a new idea and some reported cases of recycling demolition waste date back to the 2nd world war. In several countries, practicularly in Europe, it is an important process which is used to produce a useful sources of aggregate for the construction industry. The increasing price of land in recent years has led to high dumping costs at landfill sites, particularly in london. Demolition contractors, wishing it dispose of rubble, have found that it is now more expensive to dump demolition waste than to recycle it. Some demolition contractors unfortunatly resort to fly-tipping i.e. tip rubble illegally on private or public land, to dispose of what is a potentially valuable material. To promote recycling, incentives shoud be given to demolition contractors by installing recycling plants in urban locations and allowing the use of recycled aggregate instead of natural aggregate for some purposes (Margaret Mary, 1990), as shown in figure1.

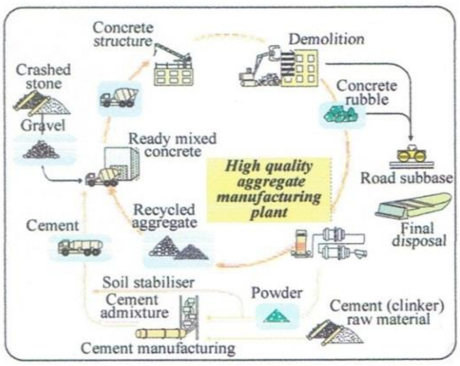


Figure 1: Schematic flow of concrete recycling system (Hirokazu, et.al, 2005)

3.3.1 Advantages of Recycled Coarse Aggregates

1- Cost saving.
2- Environmental saving.
3- Time saving.
4- Reduce impact of landfill.
5- decrease energy consumption.

4. Materials and Experimental Work

Self-Compacting concrete eight beams of (1200*180*250) mm has been made using confident proportions of cement, fine aggregate, coarse aggregate (natural and recycled), superplasticizer, silica fume and water. In the program of testing, the compressive strength of concrete was kept constant which it is 60 MPa. The mix proportion was (1:1.5:1.74) by weight of cement, sand and gravel respectively with 0.35 water to powder ratio (w/p). Ordinary Portland cement (OPC) type I was used of 500 kg/m^3content. AL-Ukhaider natural sand of 750 kg/m^3 with fineness modulus (2.6) and specific gravity 2.63 was used. Natural and recycled coarse aggregate of 870 kg/m^3 with maximum size (10mm) and specific gravity 2.62 and 2.58 respectively was used. Superplasticizer content (Glenium 51) was 14 L/m^3. Silica fume content was 56 kg/m^3. Hooked steel fibers with aspect ratio (80) were used. All beams and control specimens have no need to vibrate because they are flow under their own weight. For each concrete mix, three cube specimens (150*150*150) mm, three cylinders (150*300) mm and one prism (100*100*500) mm have been taken and tested at 28 days.

5. Test Results

As mentioned before, the main aim of this research is to study the flexural and shear behavior for the properties of self-compacting concrete beams containing recycled coarse aggregate (RCA) as a full replacement of natural coarse aggregate (NCA) in some specimens in addition to the specimens of (SCC).

According to the test program of this study, the investigation involves eight beam specimens tested under incrementally increasing load until failure. Cracking moment, ultimate moment, deflection at the center and quadrant of the beams were recorded. Also this research presents and discusses crack patterns and modes of failure for all beams.

5.1 Results of SCC in Fresh State

SCC is defined by its behavior in the fresh state, to verify whether concrete meets certain requirements which are explained in specifications and guidelines such as (EFNARC, 2002). The slump flow, L-box and V-funnel tests used for all mixes of SCC are illustrated. Table 1 is based on the results of these three tests and the limitation of (EFNARC, 2002).

Table 1 tests results of fresh properties for SCC

Mixture	Slump flow test		L-box test			V-funnel test
	D (mm)	T_{500} (sec)	H_1 (mm)	H_2 (mm)	(H_2/H_1)	T(sec)
SCC50/1	680	2.5	88	72	0.82	4
SCC50/2	720	2	85	82	0.96	3
SCC50/3	650	3.5	87	71	0.82	6.5
SCC50/4	680	3	80	75	0.93	5
SCC100/1	682	3	90	78	0.87	4.5
SCC100/2	732	2	88	84	0.95	3
SCC100/3	662	4.5	86	68	0.80	5.5
SCC100/4	676	3	83	74	0.90	5
EFNARC, 2002	650-800	2-5	-	-	0.8-1	10

where:

SCC50/1	Specimen of beam with (SCC) self-compacting concrete/ (50) stirrups spacing/ (1) natural aggregate with steel fiber
SCC 50/2	Specimen of beam with (SCC) self-compacting concrete/ (50) stirrups spacing/ (2) natural aggregate without steel fiber
SCC 50/3	Specimen of beam with (SCC) self-compacting concrete/ (50) stirrups spacing/ (3) recycled aggregate with steel fiber
SCC 50/4	Specimen of beam with (SCC) self-compacting concrete/ (50) stirrups spacing/ (4) recycled aggregate without steel fiber
SCC 100/1	Specimen of beam with (SCC) self-compacting concrete/ (100) stirrups spacing/ (1) natural aggregate with steel fiber
SCC 100/2	Specimen of beam with (SCC) self-compacting concrete/ (100) stirrups spacing/ (2) natural aggregate without steel fiber
SCC 100/3	Specimen of beam with (SCC) self-compacting concrete/ (100) stirrups spacing/ (3) recycled aggregate with steel fiber
SCC 100/4	Specimen of beam with (SCC) self-compacting concrete/ (100) stirrups spacing/ (4) recycled aggregate without steel fiber

From table 1 it can be noted that all mixes tests satisfy the requirements of (EFNARC, 2002) specification and also indicated excellent deformability without blocking. It indicates the following results:

1- The mixes which have recycled coarse aggregate (RCA) have time for both slump flow and V-funnel tests greater than the mixes with natural coarse aggregate (NCA), but they have diameter smaller than the mixes with (NCA).

2- The mixes with 0.5% steel fibers addition have time greater than the mixes without steel fibers (non-fibrous mixes), but they have smaller diameter than the non-fibrous mixes.

3- The mixes with 0.5% steel fibers addition have (H_2/H_1) nearest to the minimum value of requirements, because the presence of steel fibers in the mix that make the mix more dense.

4- The mixes which have (RCA) have (H_2/H_1) smaller than the mixes with (NCA) because the crushed texture of (RCA).

The causes of the above mentioned points is the presence of RCA and steel fibers make the horizontal flow slower because the mixture become thicker and less fluidity.

5.2 Mechanical properties results of SCC

The properties of SCC in the hardened state are important to understand the behavior of reinforced concrete beams. The mechanical properties that were studied in this investigation are as follows:

5.2.1 Compressive strength (f'_c)

The most important properties of all tests is the compressive strength test because it describes the concrete features that are associated with the strength and the essential importance of the compressive strength of concrete in structural design. Table 2 shows the measured values of compressive strength.

Table 2 Measured values of compressive strength

Mix	$f'c$ (cube), MPa	$f'c$ (cylinder), MPa	$f'c_{\text{cylinder}} / f'c_{\text{cube}}$
SCC50/1	61.8	49.5	0.8
SCC50/2	60.5	48.2	0.8
SCC50/3	61	49.1	0.8
SCC50/4	60.2	47.9	0.79
SCC100/1	61.3	48.1	0.78
SCC100/2	60.2	47.05	0.78
SCC100/3	61	47.7	0.78
SCC100/4	60	47	0.78

The table above shows that the results of compressive strength of mixes made with natural coarse aggregate (NCA) have slight increase than the mixes made with recycled coarse aggregate (RCA) by (1.0%) because the recycled aggregate was reacted previously. Also, "Figure 2" shows the relationship between compressive strength and volumetric ratio of steel fibers. It is obvious from this figure that there are only marginal improvements in compressive strength due to addition of steel fibers because the fibers act as aggregate of special shape in view of their small percentages in practical material (Aliewi, 2006). The mixes made with steel fiber of V_f (0.5%) have slight increase than the mixes of non-fibrous concrete by percentages of (1.0%) for flexural behavior and (1.2%) for shear behavior.

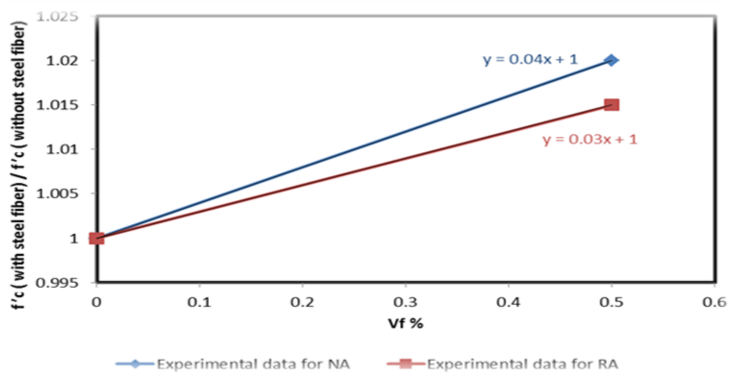


Figure 2: Effect of steel fibers content on the compressive strength for SCC mixes.

5.2.2 Splitting tensile strength (f_t)

It is a significant property of hardened concrete which the cracking of concretes is almost commonly refers to tension stress that accrued. Table 3 and "Figure 3" below show the measured values of splitting tensile strength test of all mixes and the predicated values calculated from the equations 1 and 2.

(ACI 363R-1992), $f_t(\text{predicated}) = 0.59(f'c)^{0.55}$ (1)

(ACI 318M-2011), $f_t(\text{predicated}) = 0.56\sqrt{f'c}$ (2)

where : $f'c$ and f_t in MPa.

Table 3: Measured values of splitting tensile strength

Mix	f_t (experimental), MPa	f_t (predicated), MPa ACI 363R-1992	f_t (predicated), MPa ACI 318M-2011
SCC50/1	4.11	5.04	3.94
SCC50/2	2.72	4.97	3.88
SCC50/3	3.98	5.02	3.92
SCC50/4	2.65	4.95	3.87
SCC100/1	3.97	4.96	3.88
SCC100/2	2.83	4.90	3.84
SCC100/3	3.94	4.94	3.86
SCC100/4	2.62	4.90	3.85

Table 3 shows the following:

- The values of experimental and predicated (f_t) of the mixes with steel fibers are greater than the same mixes but without steel fibers because the presence of steel fibers will increase the ductility of concrete.
- Both (RCA) and (NCA) have the same effect on the values of (f_t).
- The values of experimental (f_t) are approximately close to equation 2.

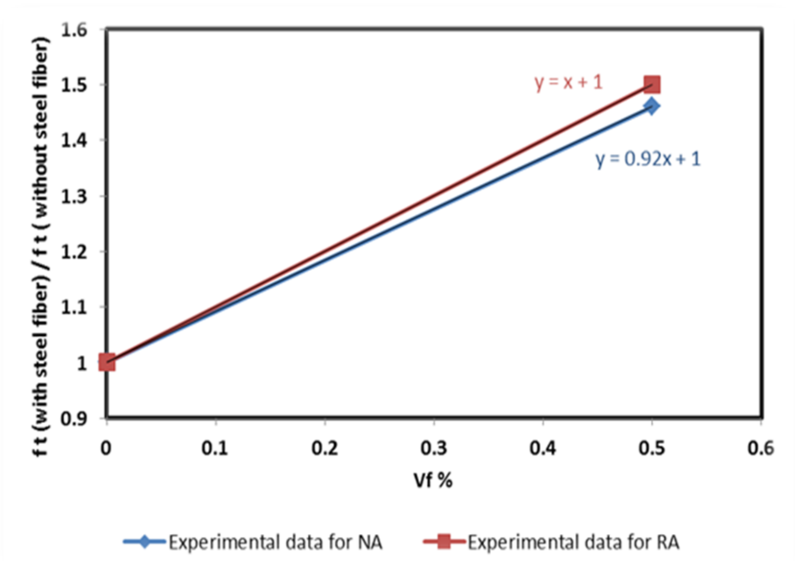


Figure 3: Effect of steel fibers content on the splitting tensile strength for SCC mixes

5.2.2 Flexural strength (f_r)

Flexural strength (modulus of rupture) is the maximum tensile stress of concrete tested in flexural, and can be calculated from the formula used for elastic materials, (f_r = MC/I), (where M is bending moment, C is the distance from the neutral axis to the outermost fiber of concrete and I is the moment of inertia) by testing a plain concrete beam. Experimental results of this work were compared with the equation adopted by (ACI 318M-2011) code as shown in Table 4 and "Figure 4" and the equation is as below:

$$f_r = 0.62\sqrt{f'c} \qquad (3)$$

where: $f'c$ and f_r in MPa.

Table 4: Measured values of flexural strength

Mix	fr (experimental), MPa	fr (predicated), MPa ACI 318 M-2011
SCC50/1	5.45	4.36
SCC50/2	4.35	4.3
SCC50/3	4.42	4.34
SCC50/4	4.31	4.29
SCC100/1	5.62	4.3
SCC100/2	4.43	4.25
SCC100/3	4.55	4.28
SCC100/4	4.40	4.26

Table 4 shows that the mixes with steel fibers give values of (f_r) greater than the mixes without steel fibers because the presence of steel fibers will increase the ductility of concrete.

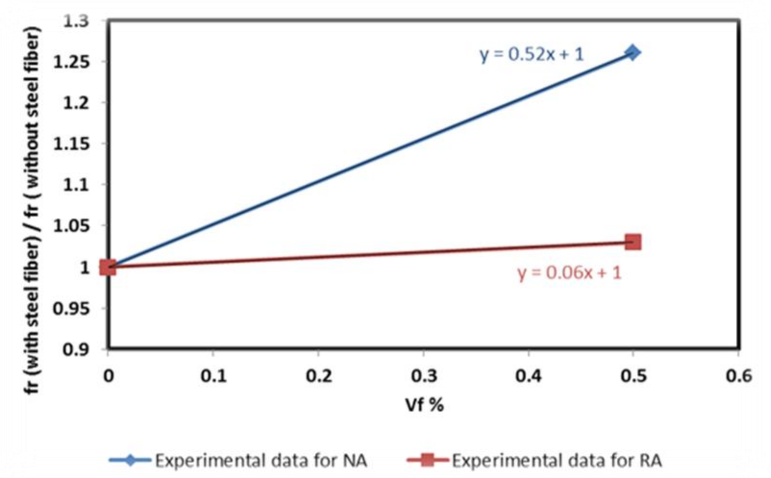


Figure 4 : Effect of steel fibers content on the flexural strength for SCC mixes

5.2.4 Elastic Modulus (E_C)

It is the most significant elastic property of concrete. It can be obtained by carrying a compressive test on concrete cylinders. Table 5 and "Figure 5" explain values of elastic modulus for various strength and the theoretical values adopted the following equations:

$$\text{(ACI 363R-1992)}, \quad Ec = 3320\sqrt{f'c} + 6900 \qquad (4)$$

(ACI 318M-2011), $E_c = 4700\sqrt{f'c}$ (5)

where: $f'c$ and E_c in MPa.

Table 5 Measured values of modulus of elasticity

Mix	E_C (experimental), MPa	E_C (predicated), MPa ACI 363R-1992	E_C (predicated), MPa ACI 318M-2011
SCC50/1	36498.27	30258.27	33067.43
SCC50/2	34607.70	29949.50	32630.32
SCC50/3	29867.35	30163.70	32933.55
SCC50/4	28978.64	29877.66	32528.62
SCC100/1	35200.81	29925.60	32596.46
SCC100/2	34231.50	29672.88	32238.71
SCC100/3	25410.80	29829.64	32460.64
SCC100/4	24257.73	29660.77	32290.06

Table 5 shows that the mixes with steel fibers give values of (E_c) greater than the mixes without steel fibers because the presence of steel fibers will increase the ductility of concrete.

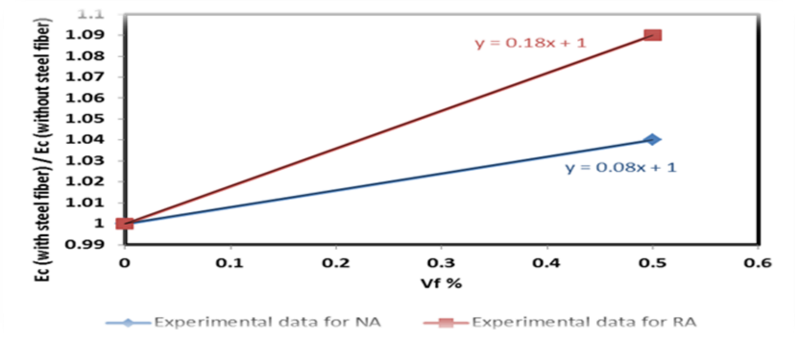


Figure 5 Effect of steel fibers content on the elastic modulus for SCC mixes

5.3 Cracking moment (M_{cr})

Cracking moment is defined as the moment at which the first visible surface cracks on the surfaces of the member appears. Table 6 and "Figure 6" show the results of cracking load and ultimate load. It is clearly shown that the cracking load increases when the ultimate load increased. The cracking load to the final load ratio (P_{cr} / P_u) was generally between (9 – 14) %.

Table 6 Cracking loads of the tested beams

Beam	P_{cr} (kN)	P_u (kN)	P_{cr} / P_u (%)	M_{cr}* (kN.m)
SCC50/1	30	217.5	13.79	7.88
SCC50/2	25	192.5	12.98	6.56
SCC50/3	24	201	11.94	6.30
SCC50/4	20	180	11.11	5.25
SCC100/1	20	168.5	11.86	5.25
SCC100/2	18	154	11.68	4.73
SCC100/3	16	155.5	10.28	4.20
SCC100/4	13	135	9.63	3.41

*$M_{cr} = P_{cr} . L /4$

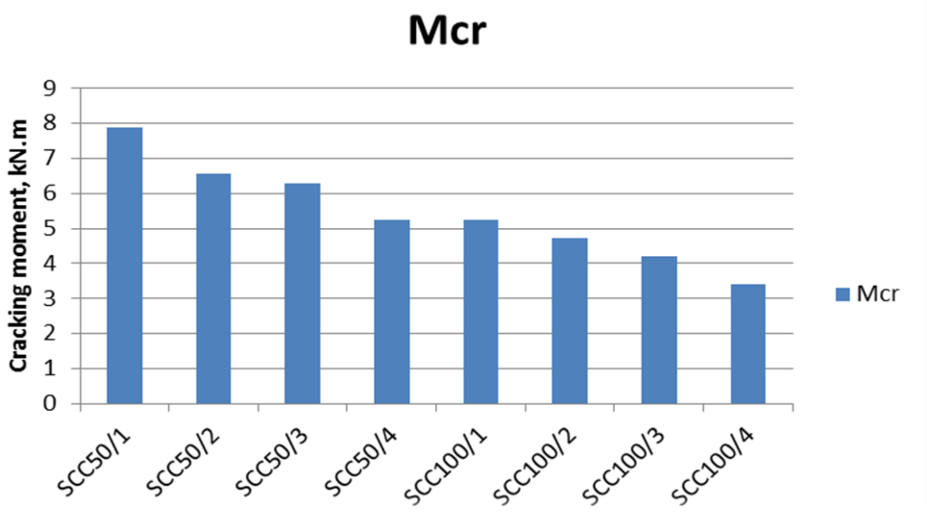


Figure 6 Cracking moment for the tested beams

Table 6 and "Figure 6" show the following results:

The effect of coarse aggregate: the cracking moment values of the beams mixed with (NCA) were larger than the beams mixed with (RCA) when the other parameters are kept fixed because the shape of recycled aggregate is angular.

It was already reacting and exposed to tensile stress, so the bonding with the rest of concrete component would be little so the cracking moment (M_{cr}) would be lesser. The percentage of these increments is about (24-25)% for both flexural and shear behavior.

5.4 Ultimate Moment (M_u)

It is the maximum moment which can be carried out by the beams that are tested. Table 7 and "Figure 7" show the results of experimental and theoretical ultimate moments as follows:

Table 7 Ultimate moment of the tested beams

Beam	P_u (kN)	M_u *(experimental) kN.m	M_u **(predicated) kN.m
SCC50/1	217.5	57.10	53.89
SCC50/2	192.5	50.53	34.79
SCC50/3	201	52.76	52.12
SCC50/4	180	47.25	32.42
SCC100/1	168.5	50.23	52.79
SCC100/2	154	45.43	30.37
SCC100/3	155.5	48.82	52.19
SCC100/4	135	40.44	28.17

*$M_u = P_u \cdot L/4$, ** $M_u = \varphi \{A_s f_y (d - \frac{a}{2})\}$, $a=\frac{As\, fy}{0.85 f'c\, b}$

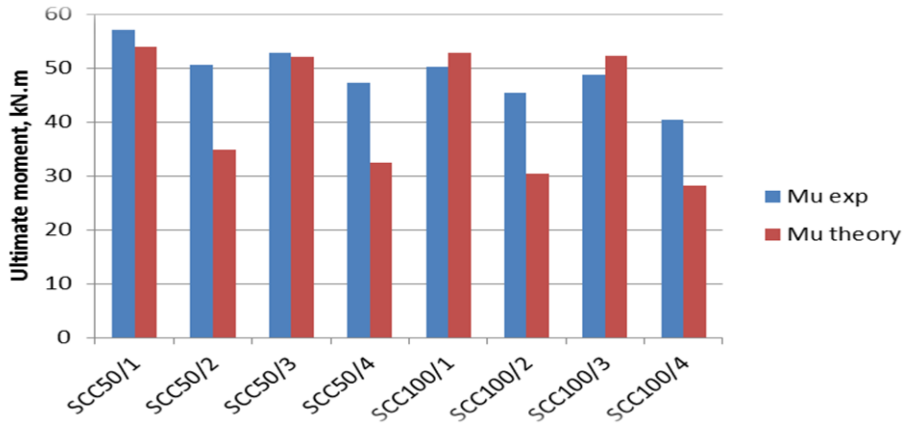


Figure 7 : Theoretical and experimental Ultimate moments (M_u) for the tested beams

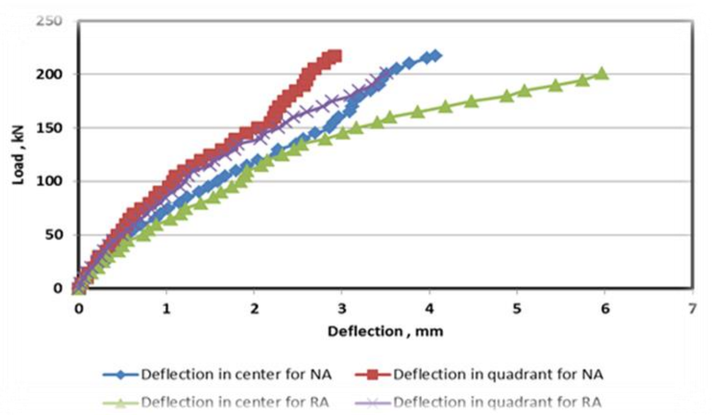
It is obvious that the predicated moment values vary between (32.42-53.89) kN.m for flexural behavior and between (28.17-52.79) kN.m for shear behavior, while the experimental moment results vary between (47.25-57.10) kN.m for flexural behavior and between (40.44-50.23) kN.m for shear behavior.

5.5 Load Deflection Behavior

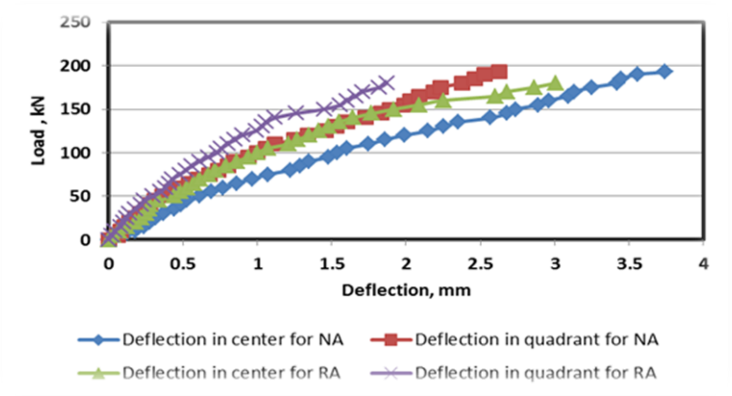
The structural behavior is normally explained using load versus deflection curves. The load-deflection curves in this work are taken at mid-span and quadrant of all the tested beams. Table 8 illustrates the maximum deflection in mid-span and quadrant of the beam with maximum load, and "Figure 8" shows the load-deflection curves of self-compacting concrete.

Table 8 Maximum deflection in mid-span and quadrant of the beams

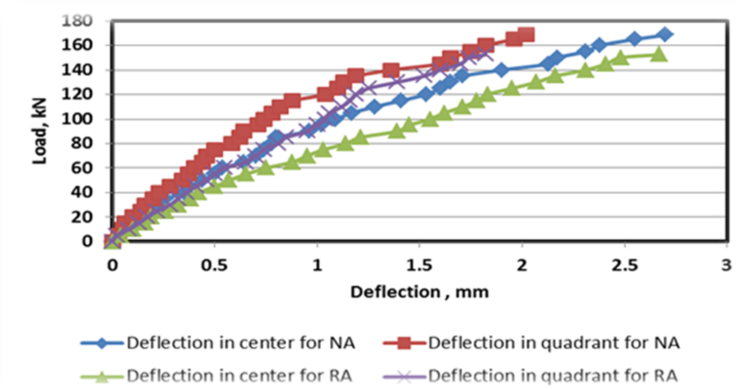
Beam	Ultimate load, kN	Maximum deflection at mid-span, mm	Maximum deflection at quadrant, mm
SCC50/1	217.5	4.07	2.92
SCC50/2	192.5	3.74	2.63
SCC50/3	201	5.97	3.51
SCC50/4	180	3.01	1.87
SCC100/1	168.5	3.19	2.25
SCC100/2	154	2.7	2.02
SCC100/3	155.5	2.67	1.82
SCC100/4	135	3.07	2.21



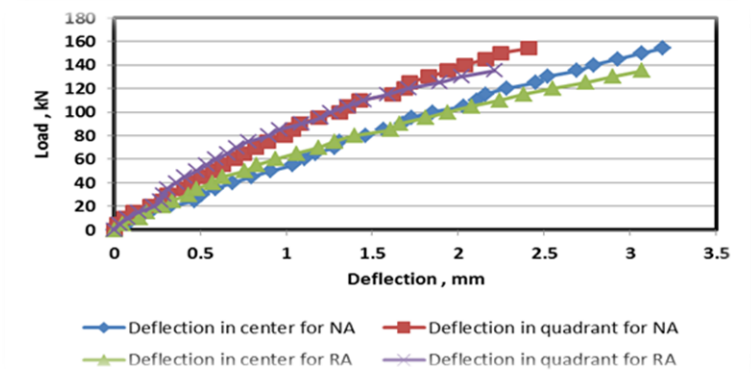
A) Comparison between (NCA) and (RCA) with steel fibers addition for self-compacting concrete (flexural failure)



B) Comparison between (NCA) and (RCA) without steel fibers addition for self-compacting concrete (flexural failure)



C) Comparison between (NCA) and (RCA) with steel fibers addition for self-compacting concrete (shear failure)



D) Comparison between (NCA) and (RCA) without steel fibers addition for self-compacting concrete (shear failure)

Figure 8 (A,B,C and D) Load - deflection curves for specimens containing natural coarse aggregate (NCA) and recycled coarse aggregate (RCA)

5.6 Crack Patterns and Modes of Failure

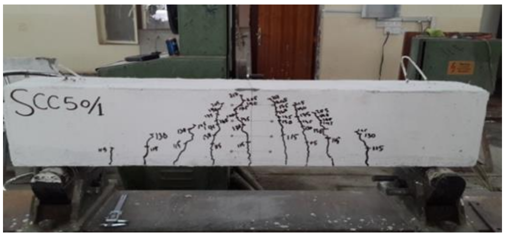
In this study, four of eight beams are designed with Φ6@50 mm spacing for stirrups. This group of beams fails in flexure by yielding of tension steel bars. The other four beams are designed with Φ6@100 mm spacing for stirrups and fail in shear by diagonal tension cracking. Longitudinal steel bars (3Φ12 mm) for the 8 beams were hooked at their ends by about 90° to ensure that no bond failure between steel bars and surrounding concrete can take place. Table 9 and "Figure 11 and 12" show maximum crack width and modes of failure of the tested beams**.** Crack width is measured by a simple gauge (knives) as shown in "Figure 9"which is used to give an approximate crack size during visual surveys, this simple gauge has been designed to provide inspectors with a low cost alternative for determining the width of cracks in a concrete. While the measuring of crack depth by a Digital Caliper,8" (200mm) as shown in "Figure 10", this instrument (provide an accurate depth of cracks) is easy to read LCD digits, rolling thump wheel, plus control buttons for zero, on/off and inch/mm functions. Range 0-8" (200mm) with accuracy 0.001mm.

Table 9 Maximum crack width and modes of failure of the tested beams

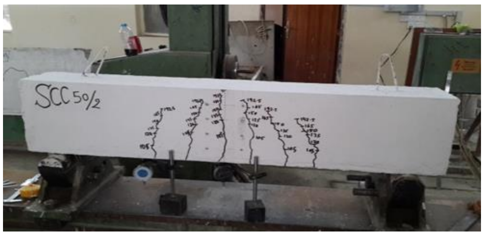
Beam	P_u , kN	Crack width, mm	Crack depth, mm	No. of cracks	Mode of failure
SCC50/1	217.5	0.35	1.9	9	Flexure
SCC50/2	192.5	0.4	2.1	6	Flexure
SCC50/3	201	0.4	1.7	9	Flexure
SCC50/4	180	0.65	1.95	9	Flexure
SCC100/1	168.5	0.15	1.44	4	Shear
SCC100/2	154	0.25	1.73	4	Shear
SCC100/3	155.5	0.3	1.61	4	Shear
SCC100/4	135	0.45	2.4	4	Shear

Figure 9 Crack width measurement

Figure 10 Digital Caliper

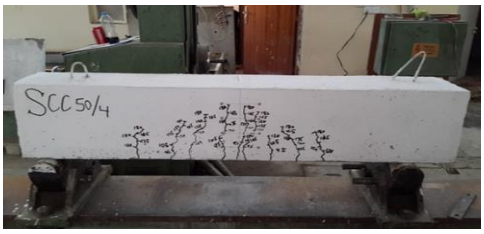


(a) Natural aggregate with steel fiber



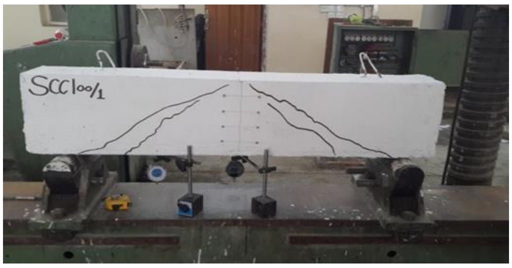
(b) Natural aggregate without steel fiber

(c) Recycled aggregate with steel fiber

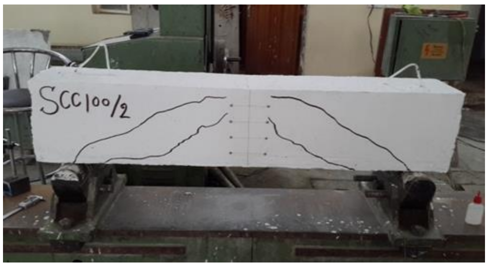


(d) Recycled aggregate without steel fiber

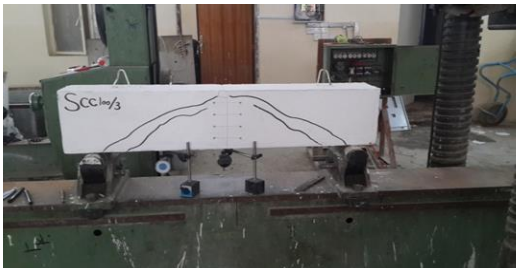
Figure 11 Crack patterns and Modes of failure for SCC/ flexural behavior



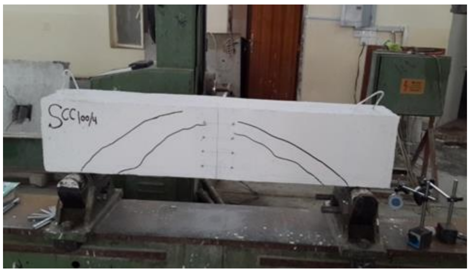
(e) Natural aggregate with steel fiber



(f) Natural aggregate without steel fiber



(g) Recycled aggregate with steel fiber



(h) Recycled aggregate without steel fiber

Figure 12 Crack patterns and Modes of failure for SCC/ shear behavior

6. Conclusions

Based on the results obtained from experimental work for eight rectangular reinforced concrete beams which are made from self-compacted concrete with (NCA) and (RCA), besides to their corresponding cubes, cylinders and prisms specimens, the conclusions can be illustrated below:

6.1 Fresh Properties of Self-Compacting Concrete SCC

1. The effect of RCA on the fresh properties of SCC: the specimens of RCA gives results of fresh properties of SCC approximately close to the other specimens of NCA with time increase by percentages of (44.5%, 50.5%) for flexural and shear behavior respectively and also with diameter decrease by percentages of (42.5%, 53.5%) for flexural and shear behavior respectively.
2. The effect of steel fiber on the fresh properties of SCC: the use of steel fibers of V_f (0.5%) gives time to flow horizontally more than the non-fibrous concrete specimens by (20%, 45.5%) for flexural and shear behavior respectively.

6.2 Mechanical properties of self-compacting concrete SCC

1. The results of mechanical properties of SCC with NCA mixes have slight increase than RCA mixes by (1.0%, 1.0%, 1.23% and 1.2%) for compressive strength, tensile strength, flexural strength and elastic modulus respectively.
2. The effect of steel fibers on mechanical properties of concrete gives larger values than the non-fibrous concrete by (1.02%, 1.5%, 1.1% and 1.03%) for compressive strength, tensile strength, flexural strength and elastic modulus respectively.

6.3 Cracking Moment (M_{cr})

1. The mixes of RCA give cracking moment values smaller than NCA mixes by 1.25% for both flexural and shear behavior.
2. The cracking moment of steel fiber mixes is greater than mixes without steel fiber by 1.2% for both flexural and shears behavior.

6.4 Ultimate Moment (Mu

1. The mixes of RCA give ultimate moment values smaller than NCA mixes by 1.1% and 1.08% for flexural and shear behavior.
2. The ultimate moment of steel fiber mixes is greater than mixes without steel fiber by 1.13% and 1.2% for flexural and shear behavior.

6.4 Load-Deflection Curves

1. The maximum deflection of RCA mixes is the same as NCA mixes for the same parameters.
2. The maximum deflection of steel fiber mixes has values greater than the non-fibrous mixes.

6.5 Crack Patterns and Modes of Failure

1. The presence of RCA in the mixes gives the first crack loads and ultimate loads come earlier than the other mixes that used NCA.
2. The presence of steel fiber in the mixes made the concrete more ductile to resist first crack and ultimate loads.

7. Brief Conclusion

It can be used this type of coarse aggregate (recycled coarse aggregate) in the future projects as a substitute of natural coarse aggregate because the recycling process services to decrease energy usages, reduces raw aggregate depletion, reduces water and air pollution by reducing requirements for conventional waste discarding, reduces emissions of greenhouse gases, protects and saves environment. It is sustainable using of resources so it can preserve the natural resources.

This can be obtained by some reservations as follows:

1. Some researches must be made as it mentioned in the recommendations below in order to contain all the branches of this subject which include increase safety factor for applied load and decrease factors for strength for bending and shear.
2. The reaching and obtaining the above advantages of the recycling program need support and help from the government and companies in order to preserve the environment and save money by giving contribution for this project to construct a mass crushing planets for breaking the concrete barriers to produce the substitute raw materials in future which is acceptable and high quality from one side and economic from the other side. And that entire conclusion had done in this work to have a good

quality control in order to let this project to success and to be accepted by constructed companies and engineers.

8. Recommendations

1. This work can be further extended with other different types of concrete beams such as (high strength concrete, reactive powder concrete and hybrid concrete beams of normal concrete and Self-compacting concrete).
2. The use of other types of fibers such as plastic fibers instead of steel fibers.
3. The effect of using other members such as columns or other variables such as (with or without stirrups, shear span to depth ratio and beam size) can be studies.
4. Studies of self-compacting concrete in flexural and shear behavior by using metakaoline instead of silica fume; this is an economic advantage in this country.
5. The theoretical work by using finite element method can be used in this study of normal and self-compacting concrete with recycling aggregate.

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