INFLUENCE OF SIZE AND REPLACEMENT RATIO OF RECYCLED CONCRETE AGGREGATE ON CONCRETE PROPERTIES

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ABSTRACT

This experimental study investigates the influence of replacing certain ratios of natural aggregate by recycled concrete aggregate on properties of fresh and hardened concrete. Two maximum nominal sizes of aggregate used in this study 40 mm and 20 mm, the source of used recycled concrete aggregate comes from the demolitions of the upper skeleton of *Al-AZHAR* building in Sohag. Thirty six mixes were designed and carried out to study the effect of both aggregate size and replacement ratios on concrete properties, the replacement ratio of recycled aggregate changed from 0 to 50% using of two sizes of aggregate 20 and 40 mm. A slump and compacting factor were measured to express fresh concrete properties, hardened concrete properties were expressed by compressive strength tests after 7 and 28 days, pull out bond strength, splitting tensile strength and flexure strength. Test results shows the bad effect of replacing natural aggregate by recycled concrete aggregate on both fresh and hardened concrete properties.

Keywords: Recycled Concrete Aggregate - Natural Aggregate – slump - compressive strength - Flexural strength

1. Introduction

The amounts of construction and demolition waste have increased considerably over the last few years. Nowadays, almost all demolished concrete has been mostly dumped to landfills. From the viewpoint of environmental preservation and effective, utilization of resources, the interest in using recycled materials derived from construction and demolition waste is growing all over the world. Crushing concrete to produce coarse aggregate for the production of new concrete is one common means for achieving a more environment friendly concrete. This reduces the consumption of the natural resources, as well as the consumption of the landfills required for waste concrete,[12].

Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes, [2], [6].

During the last 10 years the needs to produce a green concrete has increased, and also to use demolition wastes from roads, bridges, buildings and other structures, as mentions and presented in many researches [1],[2],[3],[9],[10]..

"***M. Etxeberria et al***". [9], studies the influence of amount of recycled coarse aggregates on properties of recycled aggregate concrete, as four ratios of wetted coarse

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aggregate 0, 25, 50, 100 % were used to design a four concrete mixes to achieve the same compressive strength. He found decreasing in compressive strength, splitting tensile and modulus of elasticity by increasing the ratio of coarse aggregate, and recommend to use recycled aggregate concrete with low-medium compressive strength.

In 2008 "***Sami W. Tabash et al***",[10], studied the influence of recycled concrete aggregates on strength properties of concrete, and they cares with the sources of recycled aggregate, as it can be obtained through the demolition of concrete elements of roads, bridges, buildings and other structures, or it can come from the residue of fresh and hardened rejected units in precast concrete plants. And the quality of the recycled concrete aggregate will normally vary depending on the properties of the recovered concrete. Variations between concrete types result from differences in aggregate quality, by using aggregate from different places. And they conclude that aggregate toughness based on the Los Angeles degradation test, indicate that the percentage loss of the recycled concrete aggregate is within the acceptable limit. And the aggregate soundness test results, based on five cycles in saturated solution of sodium sulfate, show that the percentage loss of the recycled aggregates made from concrete with minimum strength of 30 MPa are within the acceptable limit.

Many of researchers [5],[7],[8], focused on the effect of the replacement ratio of recycled concrete aggregate on the hardened concrete properties. In 2011 " ***Wai Hoe Kwan et al***",[13], studied the influence of the amount of recycled coarse aggregate in concrete design and durability properties, by design five concrete mixes with target strength 250 kg/cm2, with different ratios of recycled concrete aggregate 0, 15, 30, 60 and 80%, and they studied compressive strength, shrinkage, water absorption and permeability. They conclude that the replacement level of the natural coarse aggregate with the recycled concrete aggregate would reduce the compressive strength of the concrete. The expansion takes place in water curing, and the highest expansion attained by specimens with 80% replacement is 64.8 % higher in compared to that of the normal concrete at 56 days. The permeability of concrete increasing by increasing the recycled concrete aggregate content.

This work studying the effect of using both of fine and coarse recycled concrete aggregate (RCA) by different ratios on the fresh and hardened concrete properties, to present a cheap, environmental and Sustainability concrete mixes by using the waste materials of demolitions (RCA) to replace the natural aggregate (NA) in concrete mixes.

2. Experimental Work

Monitoring and study the influence of replacing ***NA*** by different ratios of ***RCA*** on the different properties of fresh and hardened concrete, the effect of concrete strength, Coarse Aggregate M.N.S. and the replacement ratios of ***NA*** by ***RCA*** are studied.

In order to investigate the effect of the previous parameters, *thirty-six* concrete mixes were designed and cast. Details of all concrete mixes are presented in Table (1). All of these mixes were designed to achieve the target strength without using any admixtures, and surface area of combined aggregate equal to the optimum value ranges from 24 to 26 cm^2/gm.

The fresh properties of the casted mixes were determined by measuring both of slump and compacting factor, according to Egyptian code (ECP 203-2010), [4]. Also cubes, cylinders and prisms were cast to measure the hardened concrete properties.

Table 1.
Details of concrete mixes

Group \ Variables		Target Strength Kg /cm^2	Aggregate		M.N.S. In mm
			NA %	RCA %	
A	mix 1	175	100	0	20
	mix 2	175	100	0	40
	mix 3	250	100	0	20
	mix 4	250	100	0	40
	mix 5	350	100	0	20
	mix 6	350	100	0	40
B	mix 7	175	90	10	20
	mix 8	175	80	20	20
	mix 9	175	70	30	20
	mix 10	175	60	40	20
	mix 11	175	50	50	20
C	mix 12	175	90	10	40
	mix 13	175	80	20	40
	mix 14	175	70	30	40
	mix 15	175	60	40	40
	mix 16	175	50	50	40
D	mix 17	250	90	10	20
	mix 18	250	80	20	20
	mix 19	250	70	30	20
	mix 20	250	60	40	20
	mix 21	250	50	50	20
E	mix 22	250	90	10	40
	mix 23	250	80	20	40
	mix 24	250	70	30	40
	mix 25	250	60	40	40
	mix 26	250	50	50	40

Group \ Variables		Target Strength Kg /cm^2	Aggregate		M.N.S. In mm
			NA %	RCA %	
F	mix 27	350	90	10	20
	mix 28	350	80	20	20
	mix 29	350	70	30	20
	mix 30	350	60	40	20
	mix 31	350	50	50	20
G	mix 32	350	90	10	40
	mix 33	350	80	20	40
	mix 34	350	70	30	40
	mix 35	350	60	40	40
	mix 36	350	50	50	40

3. Materials

- ***Cement:*** Ordinary Portland cement (***CEM I 42.5 N***) was used. Mechanical, physical and chemical properties of the used cement agree with the requirements of the Egyptian code (ECP 203-2010), [4].
- ***Aggregate:***
- ✓ ***Natural Aggregate:*** the used natural aggregate used from Assuit quarries, and its physical, chemical and mechanical properties are shown in table 2, and grading of aggregate shown in figures 1.

Table 2.
Properties of Natural Aggregate.

Property	Sand	Gravel 40 mm.	Gravel 20 mm.
Specific Weight	2.58	2.53	2.56
Bulk Density (t/m^3)	1.68	1.63	1.66
Water Absorption %	0.53	0.93	0.65
Clay and Fine Dust Content %	1.125	0.56	0.625
Crushing Value %	--------	10.13	17.25
Fineness modulus	3.58	--------	--------
chloride content CL- %	0.034	0.025	0.005
Sulfates content SO_3 %	0.093	0.0116	0.0235
Degree of alkaline (PH)	7.5	8	7.7

% Passing % Passing % Passing

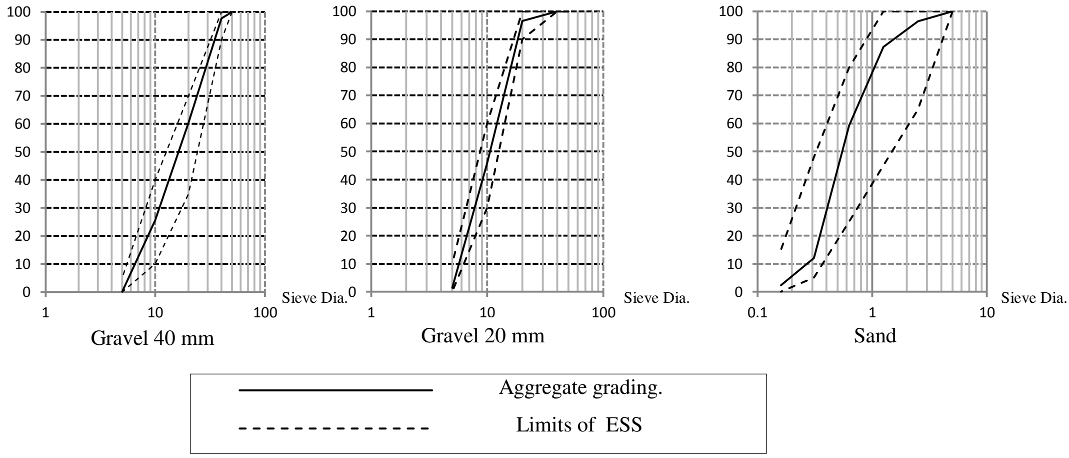


Fig. 1. Grading of Natural Aggregate.

✓ ***Recycled Aggregate:*** The recycled coarse aggregates used in this work were produced by crushing the demolitions of Al-AZHAR Institute in "***Awlad Yehia village – sohag***". The crushed concrete was from the upper skeleton (*Slabs and beams*) has been screened using the sieve analysis method. The produced ***RCA*** having M.N.S. of 40 mm and 20 mm, testing of ***RCA*** was carried out according to the Egyptian code (ECP 203-2010), [4]. The physical, mechanical and chemical properties of the ***RCA*** are determined according to the Egyptian code (ECP 203-2010), [4]. It was observed that the density, water absorption ratio were the properties having the highest differences in comparison with natural aggregate. The differences observed in these properties are mainly due to the adhered mortar as reported by many other researchers [2, 8 and 11], and the physical, chemical and mechanical properties are presented in table 3, grading of aggregate shown in figures 2.

Table 3.
Properties of Recycled Aggregate.

Property	Sand	Gravel 40 mm.	Gravel 20 mm.
Specific Weight	2.5	2.44	2.44
Bulk Density (t/m^3)	1.58	1.46	1.39
Water Absorption %	4.8	3.8	4.3
Clay and Fine Dust Content %	0.42	0.05	0.05
Crushing Value %	--------	29	35
Fineness modulus	3.55	-------	-------
chloride content CL- %	0.07	0.062	0.065
Sulfates content SO_3 %	0.226	0.223	0.224
Degree of alkaline (PH)	9.5	9	9.5

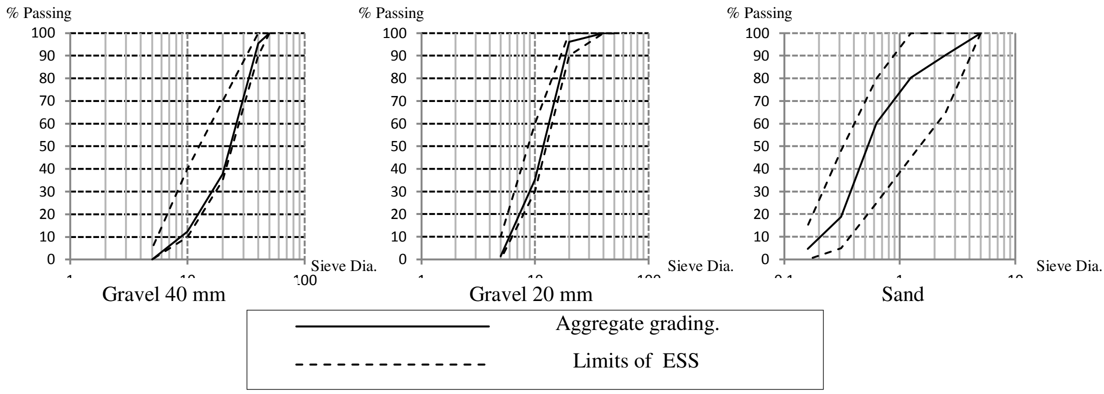


Fig. 2. Grading of Recycled Aggregate.

4. Concrete mixes

All of the concrete mixes were designed to achieve its target strength (175, 250 and 350), without using any admixtures, surface area of combined aggregate ranges from 24 to 26 cm^2 / gm. Only ***NA*** used on the control mixes (*from mix 1 to mix 6*), and in the other mixes the ***NA*** were replaced by ***RCA*** as presented in table 1. The concrete mixes proportions by weight shown in tables 6 and 7.

Table 6.
mixes proportions using aggregate M.N.S. 40mm

Mix NO.	Target strength (Kg / cm^2)	Cement (Kg)	Aggregate (Kg)		Water (liter)
			gravel	sand	
Mix 2	175	250	1237.5	688	165
Mix 4	250	350	1153	640.5	185
Mix 6	350	450	1083	602	196

Table 7.
mixes proportions using aggregate M.N.S. 20mm

Mix NO.	Target strength (Kg / cm^2)	Cement (Kg)	Aggregate (Kg)		Water (liter)
			gravel	sand	
Mix 1	175	250	1235.5	686.25	172
Mix 3	250	350	1153.5	640.6	190
Mix 5	350	450	1082	600	202

5. Tests and Specimens

Properties of fresh and hardened concrete mixes determined in this study according to the Egyptian code. ***Slump and compacting factor*** were used to measuring the properties of fresh concrete. Other wise hardened concrete properties were determined by measuring:

- ***Compressive Strength:*** The compressive strength test was carried out according to the ESS 1658/2010 [4]. Cube specimens of (150 × 150 × 150 mm) were tested to evaluate concrete compressive strength at ages of 7 and 28 days.
- ***Splitting Tensile Strength:*** The splitting tensile strength test was carried out according to the ESS 1658/2010 [4]. Standard cylinders of 150 mm diameter and 300 mm height were tested to determine the splitting tensile strength after 28 days, as shown in figure (3).

Fig. 3. Splitting tensile test.

- ***Pullout bond strength:*** The pull out bond strength test was carried out according to the ESS 1658/2010 [4]. Measuring by casting and testing of three ribbed steel bars with 16 mm. diameter were empted in three standard cylinders with 150 mm diameter and 300 mm height, as shown in figure (4).

Fig. 4. Pull out bond strength test.

- ***flexural strength:*** measuring by casting and testing of three standard prisms with dimension 10 x 10 x 60 for mixes contains 20 mm M.N.S. aggregates, and prisms 15 x 15 x 75 for mixes contains 40 mm M.N.S. aggregates, according to the ESS 1658/2010 [4], tested under one-half point load. as shown in figure (5).

Fig. 5. flexural strength test.

6. Result

Results of tested concrete mixes are presented in table 8.

Table 8.
Results of fresh and hardened concrete properties.

Mix No.	Fresh Concrete Properties		Hardened Concrete Properties (Kg/cm2)				
	Slump (mm)	C.F. %	Fc 7	Fc 28	Ft	Fb	Fcr
1	42	91	153	200	17.4	20.5	31.6
2	45	90	147	198	18.1	21.2	31.5
3	40	92	207	272	20.5	27.3	45
4	42	92	215	282	23.1	29.1	45.9
5	42	92	268	355	27.4	41.85	60.25
6	45	91	278	365	30.2	44.1	64
7	38	91	140	184	14.6	18.8	28.65
8	38	90	131	172	13.4	17.25	26.3
9	37	90	127	169	12.75	16.5	25.1
10	34	88	123	160	12	15.2	23.5
11	30	88	112	150	10.75	14	21.25
12	45	90	141	185	16.8	19.3	29.2
13	40	90	135	175	15.2	18.1	27.1
14	40	87	131	172	14	17.6	26
15	35	87	126	166	13.1	16.6	24.6
16	35	85	115	152	11.5	15	22.25
17	38	92	189	251	18	24.9	40.75
18	35	90	180	240	16.8	23.5	38.5
19	35	90	173	232	16.2	22.2	36.6
20	32	88	161	216	14.9	20.3	33.2

Mix No.	Fresh Concrete Properties		Hardened Concrete Properties (Kg/cm2)				
	Slump (mm)	C.F. %	Fc 7	Fc 28	Ft	Fb	Fcr
21	30	88	155	209	14.5	19.5	31.5
22	40	91	197	265	21	27	42.3
23	37	90	187	241	18.3	24.2	38.2
24	37	90	179	235	17.2	23.5	37
25	35	88	172	223	16.5	22.1	34.75
26	35	88	164	217	15.8	21.1	33.2
27	40	91	263	345	25.3	40.2	57.75
28	40	91	249	325	23.8	37	53.5
29	37	91	241	318	22.6	34.9	51.2
30	35	90	234	304	21.2	31.2	48.2
31	35	90	222	290	18.7	29.4	45.3
32	42	91	264	345	27.5	41.2	59.2
33	42	90	256	338	25.5	39.6	56.3
34	40	90	251	332	23	37.2	53.4
35	38	89	242	325	21.5	35.9	51.1
36	38	88	225	295	19.3	32.25	46

7. Discussion of Results

7.1. Effect of replacing ratios of recycled concrete aggregate on fresh concrete properties:

The investigation of the fresh concrete properties indicates that, the replacing ratio of RCA has a negative effect on both of workability, and compact-ability. Increasing the percentage of RCA from 0% to 50%, slump decreasing by 15%, 16% and 22% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 40 mm aggregate M.N.S., also its decreasing by 16%, 25% and 30% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 20 mm aggregate M.N.S. Also by increasing the percentage of RCA from 0 to 50% compacting factor decreasing by 3.3%, 4.3% and 5.5% for grades 350, 250 and 175 kg/cm2 respectively for mixes made from 40mm aggregate M.N.S., and also its decreasing by 2.1%, 4.3% and 3.3% for grades 350, 250 and 175 kg/cm2 respectively for mixes made from 20 mm aggregate M.N.S.

7.2. Effect of replacing ratios of recycled concrete aggregate on compressive strengths for different grades of concrete:

The examination of the tested cubes after 7 and 28 days indicates that, the replacing ratio RCA % has a bad effect on the compressive strength. By increasing the percentage of RCA from 0 to 50%, Fc7 decreases by 19%, 23.7% and 22% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 40 mm aggregate M.N.S. Also its decreases by 17.1%, 25.1% and 26.8% for grades 350, 250 and 175 kg/cm2 respectively. For mixes made from 20mm aggregate M.N.S. By increasing the percentage of RCA from 0% to 50% Fc28 decreases by 19.2%, 23% and 23.2% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 40 mm aggregate M.N.S., also its decreases by 18.3%, 23.1% and 25% for grades 350, 250 and 175 kg/cm2 respectively. For mixes made from 20mm aggregate M.N.S., as shown in figure 6.

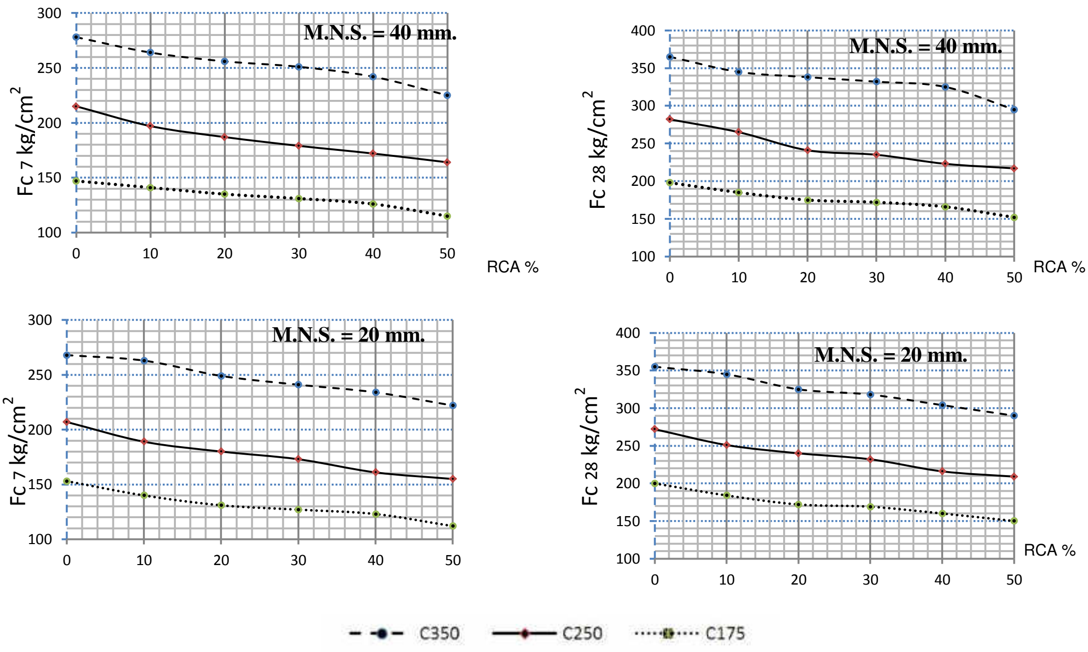


Fig. 6. Effect of RCA% on compressive strengths.

The investigation of the results of the Brazilian tensile test indicates that, the replacing ratio RCA% has a bad effect on splitting tensile strength. As by increasing the percentage of RCA from 0% to 50% tensile strength decreasing by 36.1%, 31.6% and 36.4% for grades 350, 250 and 175 kg/cm2 respectively. For mixes made from 40 mm aggregate M.N.S. Also its decreasing by 31.75%, 29.2% and 38.2% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 20 mm aggregate M.N.S., as shown in figure 7.

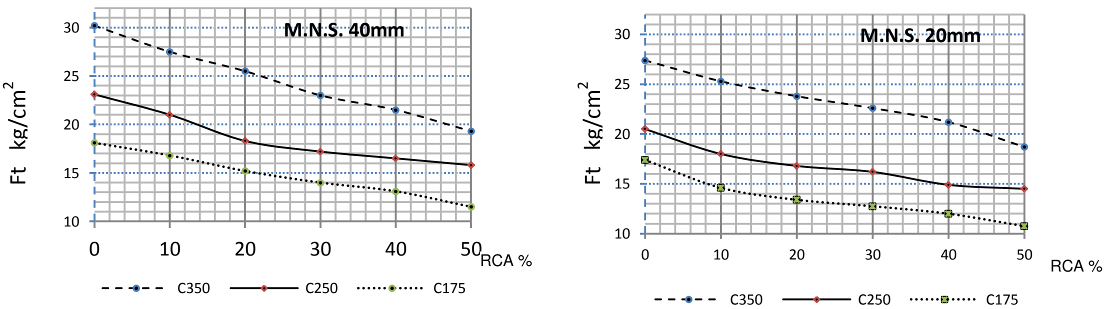


Fig. 7. Effect of RCA% on splitting tensile strength.

7.4.Effect of replacing ratios of recycled concrete aggregate on Bond strength for different grades of concrete:

The examination of the tested cylinders that having empted steel bars with 16 mm diameter, under pull-out bond test its indicates that, the replacing ratio of RCA has a bad effect on splitting tensile strength. As by increasing the percentage of RCA from 0% to 50% the bond strength decreasing by 26.9%, 27.5% and 29.2% for grades 350, 250 and 175 kg/cm2 respectively. For mixes made from 40 mm aggregate M.N.S. Also it's decreasing by 29.7%, 28.6% and 32.1% for grades 350, 250 and 175 kg/cm2 respectively, for mixes made from 20mm aggregate M.N.S., as shown in figure 8.

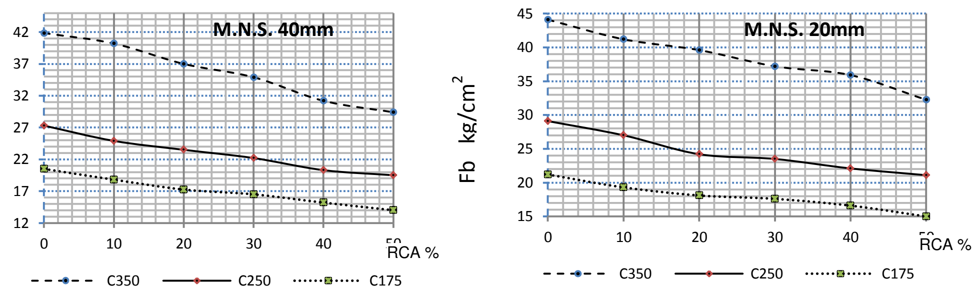
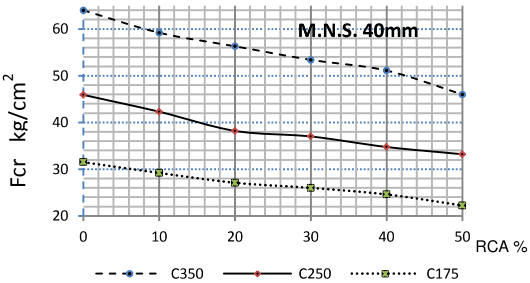


Fig. 8. Effect of replacing ratios (RCA %) on Bond strength.

7.5. Effect of replacing ratios of recycled concrete aggregate on flexural strength for different grades of concrete:

The examination of the tested prisms under 3-points of loading test indicates that, the replacing ratio RCA % has a bad effect on flexural strength, as by increasing the RCA% from 0% to 50% the flexural strength decreasing by 28.4%, 27.7% and 29.3% for grades 350, 250 and 175 kg/cm2 respectively. For mixes made from 40 mm aggregate M.N.S., also flexural strength decreasing by 24.8%, 30% and 32.75%, for grades 350, 250 and 175 kg/cm2, respectively. For mixes made from 20mm aggregate M.N.S., see figure 10.



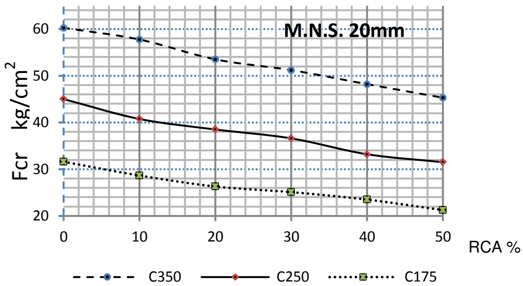


Fig. 10. Effect of replacing ratios (RCA%) on flexural strength.

8. Conclusions

Based on experimental tests results drawn on *thirty-six* concrete mixes, using recycled concrete aggregate. Within the scope of the present study and range of investigated parameters the following conclusions can be:

1 - Bulk density and specific gravity of recycled concrete aggregate is slightly lower than natural aggregate, otherwise the water absorption is much higher than the natural aggregate, due to the adhered mortar. These properties may cause quality control problems if not take in to consideration in the design of the concrete mixes.

2 - The recycled concrete aggregate in this case of study, have a noticeable salts content as Chloride (CL-) and Sulfates (SO_3) content.

3 - The recycled concrete aggregate has a bad effect on slump and compact-ability of fresh concrete properties. So it is important to take this in the design of concrete mixes.

4 - The ratios of recycled concrete aggregate have a significant effect on the compressive strength of concrete at the different ages. This effect is clearly on the mixes have low cement content.

5 - The splitting tensile strength, Bond strength and Flexural strength, are decreasing by increasing the RCA ratio more over than the loss founded in compressive strength.

6 - Using of recycled concrete aggregate has a worse effect on concrete properties, especially tensile strength, due to the weakness of cohesion between new cement paste and recycled concrete aggregate.

7 - Using of recycled concrete aggregate in concrete mixes with M.N.S. 40 mm is more efficient than using with concrete mixes with M.N.S. 20 mm.

9. Notations:

RCA	: Recycled Concrete Aggregate.
NA	: Natural Aggregate.
M.N.S	: Maximum Nominal Size.

Fc_7 & Fc_{28}	: Cube compressive strength after 7 and 28 days respectively.
Ft	: Splitting tensile strength (*Brazilian tensile test*).
Fb	: Pull-out bond strength.
Fcr	: Flexural strength.

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تأثير حجم ونسبة استبدال الركام المعاد تدويره على خواص الخرسانة

الملخص العربى:

نتيجة للزيادة المطردة في كمية المخلفات الناتجة من هدم المباني والتى تشكل الخرسانات المكونة للهيكل النسبة العظمى فيها من هذه المخلفات، وخاصة في بيئتنا المحيطة حيث يتم التخلص من هذه المخلفات بطرق عشوائية مما يتسبب عنه ضررا بيئيا بالغا و إهدار للموارد الطبيعية المتمثلة في الركام الطبيعي. جاءت هذه الدراسة للوقوف على مدي تأثير استبدال نسبه محدده من الركام الطبيعي (الزلط والرمل) بركام خرسانة معاد تدويره على خواص الخرسانة الطازجة والمتصلده، وتم استخدام ناتج هدم الهيكل الخرساني لمعهد أولاد يحي الأزهري بمركز دار السلام بسوهاج كمصدر لركام الخرسانة القديم لإعادة تدويره. وتم الأخذ في الاعتبار في هذه الدراسة تأثير كلا من المقاس الاعتباري الأكبر للركام المستخدم وكمية الاسمنت المستخدمة في الخلط التصميمية لإنتاج مقاومات مختلفة وكذلك نسب الاستبدال للركام الطبيعي بركام معاد تدويره، وتستعرض نتائج هذه الدراسة خواص الخرسانة الطازجة المتمثلة في اختبار الهبوط ومعامل الدمك، وخواص الخرسانة المتصلدة المتمثلة في مقاومة الضغط ومقاومة الشد بالانحناء ومقاومة الشد بالانفلاق ومقاومة التماسك للخرسانة، *ومن نتائج* هذه الاختبارات يتضح التأثير السيئ لاستخدام ركام خرسانة قديم معاد تدويره على خواص الخرسانة المنتجة، و الذي يجب أخذه في الاعتبار عند تصميم الخلطات الخرسانية باستخدام ركام خرسانه معاد تدويرة.