International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 1, January-2016

Effects of Recycled Concrete Aggregate on a Concrete Mix

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ABSTRACT

Basic concrete is a mix of natural resources: water, aggregate and binder cement. Thus, its production highly contributes to the depletion of scarce resources mainly limestone. In Lebanon, the crushed concrete resulting from cylinders tested in laboratories and ready mix plants, in addition to waste concrete are usually sent to landfills to be dumped whereas they can be reused in the production of several construction elements such as concrete. Minor research has been done on the topic of the use of Recycled Concrete Aggregate (RCA) in Lebanon. This experimental study highlights the effect of the use of RCA as a replacement to aggregate and its effect on the quality of the concrete throughout a testing campaign. The use of RCA in concrete was found to be a major step towards environment sustainability and can reduce the cost of concrete production.

Keywords: Compressive strength, cost management, durability, recycled concrete aggregate, slump, workability.

1. INTRODUCTION

Concrete is the most used material worldwide due to its high demand, low cost relative to other construction material (steel, wood…), its lighter density compared to steel which allows us to decrease design loads, and last but not least the ease of its production. In general, its production consumes high percentages of our natural resources in Lebanon. On the other hand, demolished and waste concrete have been used as a backfilling material with a large contribution to the offshore construction and as a gravel sub-base in roads' construction. However, no recycling measures have been performed.

The absence of governmental support and the lack of implementation of the codes and specifications for reusing concrete waste are the main reasons behind the impedance of Recycled Concrete Aggregate (RCA) in Lebanon. The use of RCA as partial replacement for concrete components has many advantages including: preservation of natural resources, which also has a direct effect on the ecosystem; saving up on the landfill space; and production of quality concrete, which in turn can benefit the economy. In this report, fresh and hardened concrete tests were performed on concrete mixtures using different percentages of RCA. The results confirmed the benefits of recycling these wastes financially and environmentally.

2. EXPERIMENTAL WORK AND RESULTS

A. Material properties of aggregate

Aggregates are significant components of concrete. The cylinders were sent to the crushing factory and 3 sizes were produced: 19.0 mm, 9.5 mm and crushed sand. The samples were then tested as per ASTM standards in order to determine their properties. The performed tests are Material Finer, Absorption, Sand Equivalent and Sieve Analysis (See Table 1, Fig.1, Fig.2 and Fig.3).

Table 1: Material Testing Results

Tests	**Aggregate size**		
	19 mm	**9.5 mm**	**4.75 mm**
Material Finer	0.8	0.7	4.3
Absorption	4.3	5.7	7.7
Sand Equivalent	69		

Figure 1: Sieve analysis curve for aggregate size 19 mm

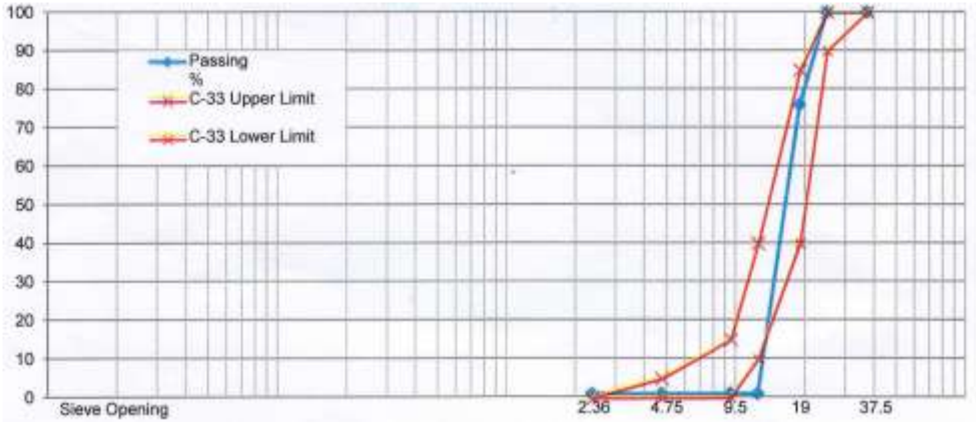


Figure 2: Sieve analysis curve for aggregate size 9.5 mm

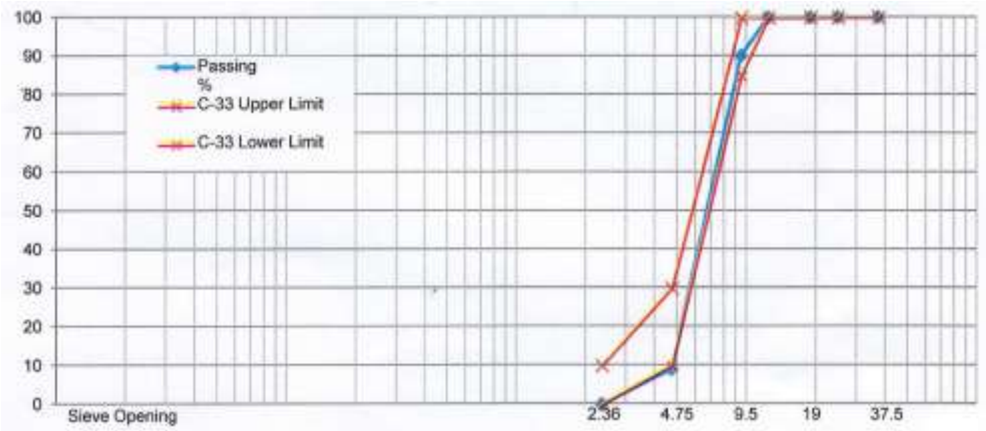
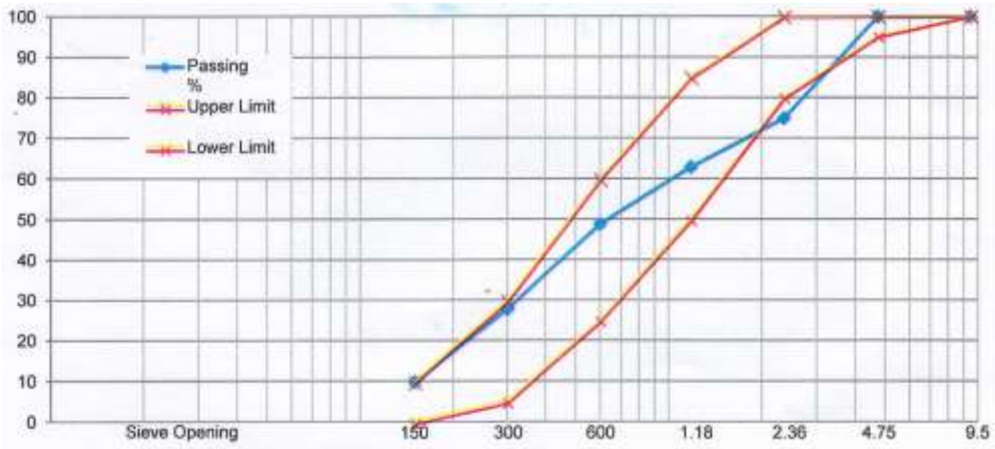


Figure 3: Sieve analysis curve for aggregate size 4.75 mm



B. Preparation of RCA mix design

In order to confirm the benefits of recycled concrete aggregate, different percentages of RCA mix samples were prepared as follows [1]:

a Mix 1: 50% RCA (coarse aggregate: 19.0mm, 9.5mm), 50% normal coarse aggregate and 100% normal fine aggregates (crushed and natural sand)

b Mix 2: 100% RCA (coarse aggregate: 19.0mm, 9.5mm) and 100% normal fine aggregates (crushed and natural sand)
c Mix 3: 100% RCA (coarse aggregate: 19.0mm, 9.5mm), 100% RCA crushed sand and 100% natural sand
d Mix 4: 100% RCA (coarse aggregate: 19.0mm, 9.5mm), 100% RCA crushed sand and 0% natural sand
e Mix 5: 100% RCA (coarse aggregate: 19.0mm, 9.5mm), 100% RCA crushed sand and 0% natural sand and air entrainer is induced.

C. Tests on fresh and hardened concrete

Concrete is a manufactured product; it should attain high quality before it is delivered to the job site. After mixing different percentages of RCA, the performance of the RCA mix should be compared to that of the normal mix. Various tests were conducted on freshly mixed and hardened concrete. These tests are Slump test (See table 2), unit weight, yield and air content (See table 3) and compressive strength (See table 4).

Table 2: Slump Test Results for each mix regarding different trials

Slump	Mixes	Trials
180 mm	**Normal concrete mix**	**Trial 1**
210 mm	**Mix 1**	**Trial 1**
245 mm	**Mix 2**	**Trial 1**
225 mm	**Mix 2**	**Trial 2**
200 mm	**Mix 2**	**Trial 3**
160 mm	**Mix 3**	**Trial 1**
184 mm	**Mix 4**	**Trial 1**
220 mm	**Mix 4**	**Trial 2**
225 mm	**Mix 4**	**Trial 3**
235 mm	**Mix 5**	**Trial 1**

Table 3: Yield of all mixes equals to one and the results of Air Content

Mix	Density	Yield	Air content
Normal Mix	2314	0.996 ≅ 1	5.80%
Mix 1	2314	0.996 ≅ 1	5.80%
Mix 2	2261	0.99≅ 1	3.40%
Mix 3	2315	0.989≅ 1	3.50%
Mix 4	2220	1.01	4.50%

Table 4: Compressive strength at 7 days for each mix

	RCA	Natural Aggregate	With Natural Sand	Without Natural Sand	Natural Crushed Sand	Recycled Crushed Sand	Air Entrainment	7 Day Compressive Strength (MPa)
Mix 1	50 %	50 %	X		X			**32.2**
Mix 2	100 %	0	X		X			**28.0**
Mix 3	100 %	0	X			X		**31.7**
Mix 4	100 %	0		X		X		**34.3**
Mix 5	100%	0		X		X	X	**26.6**

D. Production of recycled concrete aggregate masonry block

Concrete can be poured as hollow or solid, normal or light weight, precast masonry units of different sizes suitable to be used for load and non-load bearing wall unit partitions. The mixes are designed with the available materials in order to economize and reach the required properties of the products. The hollow load bearing concrete blocks of the standard size 400 x 200 x 200 mm will weigh between 17 and 26 kg (1063 to 1625 kg/m^3) when made with normal weight aggregates. Trials of RCA masonry block mixes were performed and the results were as follows:

- The minimum compressive strength based on net area for non-load bearing is 3.5MPa according to ASTM C90 and C129.
- Compressive strength (f‘c) of the RCA block = 12.12 >3.5 MPa, the compressive strength of RCA block exceeds the minimum compressive strength.
- RCA block can be produced and used in partitions. And for structural blocks, which can be produced and used in partitions, consultants in Lebanon demand a minimum f‘c = 10 MPa.
- f‘c (RCA block) = 12.12 >10 MPa so it can be used for structural block.

3. ANALYSIS

A. Compressive strength

In all the trials, the compressive strength of concrete at 28 days of the RCA mixes was small compared to the compressive strength of the control normal mix at 28 days. As the percentage of the recycled concrete aggregate increased, a partial decrease of the compressive strength was detected. The low durability of the RCA compared to that of the normal aggregate affects such decrease in strength. The mix of 100% RCA with natural sand and the mix without natural sand but with high amount of cement showed approximately same strength. The mix regarding the 100% RCA without natural sand (mix 4) indicates that all fines are of RCA nature. In this mix a high amount of cement has been used in order to provide workability. In fact RCA are highly absorptive, therefore small size particles can be added to achieve workability. In addition to that, in all the mixes a non-angular shape of RCA was used to enhance workability. However, addition of cement is not a good economic factor and causes environmental issues. As a result, the mix was repeated, where same amount of cement used in all mixes was preserved and air entrainment (mix 5) was used in order to induce workability. This trial showed a relative decrease in the compressive strength compared to the previous mixes, whereas workability was totally reached using the air entrainment. A well significant notice is that the 30 MPa compressive strength target was accomplished in all the trials of different RCA percentages. As a conclusion, it is difficult but not impossible to achieve a certain compressive strength using different amounts of RCA, unless inappropriate testing materials were used.

B. Slump Analysis

The amount of water in a certain concrete volume has a great influence on the workability. The higher water content leads to higher workability of concrete. But water cannot be added arbitrarily because an excess of water in concrete will lead to a more workable concrete with a lower compressive strength. A high aggregate/ cement ratio leads to a lean concrete, where a less quantity of cement paste is provided to lubricate surface area of aggregate which produces a fresh concrete with low fluidity. On the other hand, a concrete with low aggregate/cement ratio and more paste exists to make a cohesive mix in order to improve the workability. Moreover, Aggregates with high absorption tend to decrease the slump especially if they are not pre-wetted properly. If aggregates are not in their SSD phase they absorb some of the water required for the concrete mix. An important factor is the graded aggregate in the mix; a well-graded aggregate has all sizes of aggregates, which leads to a small amount of voids in a given volume. Holding other factors constant, for a smaller amount of voids, more quantity of paste must be available to better lubricate the aggregate particles. Rounded aggregate contributes to better workability than flaky, elongated or angular aggregate; in fact, for a given volume, rounded aggregate has less contact area and less voids than angular aggregate.

In all the mixes, well-graded aggregate and a flaky rough aggregate were used, so the gradation of aggregate, shape and surface texture were considered as constants in the analysis of slump test. The only variable in the mixes is the aggregate/cement ratio. In all the mixes, when having a yield less than one, the quantity of coarse aggregate was reduced to achieve a yield equals to 1. Therefore, a constant value of cement and a decrease in the amount of aggregate lead to a decrease in aggregate/cement ratio and therefore increase the workability as explained above. The table 5 below indicates the degree of workability according to the slump value. All the obtained mixes have slump greater than 150 mm so a very high workability.

Table 5: Slump classification according to IS:7320, BS:1881, ASTM C143, AASHTO T 119 specifications

Slump (mm)	Degree of workability
0-25	Very Low
25-50	Low
50-100	Medium
100-150	**High**
>150	**Very High**

C. Air Content and Yield Analysis

According to ACI 211.1, the air content in a non-air-entrained concrete with a nominal maximum size of 1 inch (25 mm) is 1%. The results obtained are all above the limit for example: mix 1: 3.4%, mix 2: 3.5%, and mix 3:4.5%. In an air-entrained concrete, for a nominal maximum size of 1 inch (25 mm) and mild exposure, the air content should be 3%. In the mix in which the air entrainment admixture was used, the air content is 7 % which exceeds the limit specified by ACI 211.1. The excess air content is due to entrapped air in the air-entrained and non-air-entrained concrete mixes, this amount can be reduced using mechanical vibrator.

Yield is used to determine the real volume of concrete produced in a ready mix plant. Producers of concrete and contractors that order concrete might be worried about the quantity of concrete sent to the jobsite. Over-yield occurs when the amount of delivered concrete is greater than the amount ordered. Under-yield occurs when the quantity delivered is less than the quantity ordered [16].
In order to prevent over-yield and under-yield several mixes were done, on each mix the unit weight was measured following the steps described by ASTM C 138. After several trials, an ideal one was reached for each mix with a yield equals to 1. Therefore using the ideal trial for each mix prevents problems caused by over-yield and under-yield of concrete.

4. MANAGEMENT OF THE MATERIAL

In addition to the environmental benefits of the usage of RCA, the benefits also include financial rewards. A survey was performed among the Ready Mix firms and Testing Laboratories in Lebanon in order to evaluate the effect of concrete waste on the finances of a company. The results of this survey show that a considerable amount of money is spent on the disposal of the waste resulting from their day-to-day operations.

Table 6: A survey of estimated quantities of concrete laboratory wastes and concrete residue

Ready Mix & Labs	Number of Waste Cylinder (Per day)	Concrete Residue (m^3)	Transportation Cost (\$ Per m^3)
Mega Béton	20 to 30	3 to 7	4
SakerBéton	24	4 to 5	4
King Béton	15	4 to 6	4
Redland	70	10 to 15	4
TQP Lab	200	----	6
3PE Lab	250	----	6
ACTS Lab	250	----	6
GEMALAB	185	----	6

According to a study done by Mega Béton ready mix, it is noticed that the cost of the concrete mix using RCA is much cheaper than the normal control mix. The reason behind this decrease in the cost is the low aggregate's cost. In general, the production of normal concrete aggregate requires more equipment, manpower, and geotechnical tests.. The process of obtaining aggregates in Lebanon starts from carrying out many soil tests in order to get familiar with the present soil type. The second step is digging into mountains using caterpillars; sometimes this requires explosions for extracting hard rocks. These rocks are then transported to the quarries, where they will be transformed into different sizes of aggregates. At this time, consuming process, which involves high costs regarding transportation, equipment, manpower is fully absent in the production of RCA.

Furthermore, the trials constructed with RCA gave a higher strength from 30 MPa (desired). According to ACI 318 (table 5.3.2.2), the required average strength for 30 MPa mix is 38.3 MPa. All the mixes using RCA produce a higher strength than 38.3 MPa using the same water-to-cement ratio in both RCA and normal mix, so no need to increase the cement content, which will not affect the cost. The only variable in the total cost is the aggregate's cost, which was previously discussed.

5. CONCLUSIONS AND RECOMMENDATIONS

This paper elaborates the usage of different percentages of RCA in concrete. It also includes the test results carried out in 3rd Party Engineering Lab and Mega Béton performed on fresh and hardened concrete, especially compressive strength test, which confirms the advantages of the usage of RCA. The use of recycled concrete aggregates is a major step towards environmental sustainability and cost reduction of concrete production.

Despite the fact that RCA concrete mixes have the ability of reaching high compressive strength standards, low cost and wide availability, RCA must be taken with precaution and wider research should be implemented. Further studies shall include a wider range of tests for fresh concrete properties/durability properties and effects on other mix types and more range of usage. Tests should be done on RCA concrete at its weakest point "shrinkage", which may occur due to its highly absorptive nature. Consequently, wider research should be implemented concerning feasibility studies.

6. ACKNOWLEDGMENT

Special thanks to Rafik Hariri University that supported our work throughout every performed step. We are also thankful to the managers of 3rd Party Engineering, Mr. Abdulkader Kairouz and Eng. Suha Saleh's guidance while performing all the laboratory work. Full appreciation goes to Engineer Ibrahim Saab and the quality manager of Mega Béton for providing us access to their lab, materials and equipment.

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