Use of recycled concrete rubbles as coarse aggregate in concrete

Hisham Qasrawi[1], Iqbal Marie[2] & Hasan Tantawi[3]

[1] Senior lecturer, Civil Engineering, Faculty of Engineering, The Hashemite University

[2] Senior lecturer, Civil Engineering, Faculty of Engineering, The Hashemite University

[3] Associate Professor, Civil Engineering, Dean of Faculty of Engineering, The Hashemite University

ABSTRACT: The use of concrete in structures consumes millions of tons of aggregates. Since earth is the source of the aggregates (either natural or crushed), then obtaining these amounts would have an adverse effect on the environment. Furthermore, demolishing concrete structures and dumping the concrete rubbles would aggravate the problem. Therefore, it becomes necessary to recycle the crushed concrete and use it as course aggregate in new concrete mixes.

The effect of using recycled aggregates concrete (RCA) on the basic properties of normal concrete is studied. First, recycled aggregate properties have been determined and compared to those of normal aggregates. Except for absorption, there was not a significant difference between the two. Later, recycled aggregates were introduced in concrete mixes. In these mixes, natural coarse aggregate was partly or totally replaced by recycled aggregates. Results showed that the use of recycled aggregates has an adverse effect on the workability of concrete. Such an effect can be easily retained by using plasticizers. Also, concrete strength has been reduced by 5% to 25% depending on the percent of the normal aggregate replaced by recycled aggregate and the water-cement ratio. With respect to the tensile strength, recycled aggregate concrete was slightly lower.

1. INTRODUCTION

In this rapid industrialized world, recycling construction material plays an important role to preserve the natural resources. Recycling of concrete is important because it helps to promote sustainable development in the protection of natural resources, and reduces the disposal of demolition waste from old concrete (Yong et al 2009).

Recycling concrete wastes is important in getting rid of demolished concrete, which increases with time and use. For example, the amounts of demolished buildings in Europe amount to around 180 million tons per year (Limbachiya et al 2004).

Old concrete and masonry that have "reached the end of the road" can be recycled and used not only as aggregate for new concrete, but also for a number of other applications in construction (ECCO 1999). For example, since 1982 the ASTM definition of coarse aggregate has included crushed hydraulic cement concrete, and the definition of manufactured sand includes crushed concrete fines (ECCO 1999). Similarly, the U.S. Army Corps of Engineers and the Federal Highway Administration encourage the use of recycled concrete as aggregate in their specifications and guides (FHWA 1985). Several references (Limbachiya et al 2004, ECCO 1999, FHA 1985, Anderson et al 2009, CCA 2008, ACI 555 2001, PCA 2008, Nelson et al 2004) have presented literature survey and research results in the field of the use of recycled aggregate,

[1] Corresponding author, Senior lecturer, Civil Engineering, Faculty of Engineering, The Hashemite University, Zarqa 13115, JORDAN
Email: qasrawi2@yahoo.com
[2] Senior lecturer, Civil Engineering, Faculty of Engineering, The Hashemite University, Zarqa 13115, JORDAN
[3] Associate Professor, Dean of the Faculty of Engineering, The Hashemite University, Zarqa 13115, JORDAN

concrete and masonry. Hence, the advantages of using recycled aggregate in concrete can be summarized as follows:

1. Environmental considerations.

In this time of increasing attention to the environmental impact of construction and sustainable development, Portland cement concrete has much to offer: (1) it is resource efficient-minimizing depletion of our natural resources; (2) it is inert, making it an ideal medium in which to recycle waste or industrial byproducts; (3) it is energy efficient, it is superior to wood and steel; (4) it is durable, continuing to gain strength with time; and finally (5) it is recyclable, fresh concrete is used on an as-needed basis (whatever is left over can be reused or reclaimed as aggregate), and old hardened concrete can be recycled and used as aggregate in new concrete or as fill and pavement base material.

2. Economic factors.

Recycling concrete is an attractive option for governmental agencies and contractors alike. Most municipalities impose tight environmental controls over opening of new aggregate sources. In many areas, increase of the cost of starting new quarries is increased. For demolition contractors, landfill space is limited and can be far away, especially in urban areas. Hence, the disposal of old concrete and masonry is costly. Also, dumping fees will most likely rise as construction debris increases and the number of accessible landfills decreases. Furthermore, the cost and transport distances of conventional aggregates could continue to increase as sources grow scarce.

3. Other uses

Unprocessed RCA is useful to be applied as many types of general bulk fill, bank protection, sub-basement, road construction, noise barriers and embankments. Processed RCA can be applied to new concrete for pavements, shoulders, median barriers, sidewalks, curbs and gutters, and bridge foundations. It also can be applied to structural grade concrete, soil-cement pavement bases, lean concrete and bituminous concrete (PCA 2008). Also, it has been used to produce high strength concrete (Nelson et al 2004).

4. Recycling steel reinforcement

Steel reinforcement is taken off from concrete before crushing to the required sizes. This steel can be sent for recycling in the steel industry.

The use of RCA for the production of concrete involves breaking demolished concrete into materials with specified size and quality. These materials can then be combined to produce aggregate of a pre-determined grading and hence can be used in concrete. Moreover, the steel reinforcement can be recycled.

In this research, the authors try to use the recycled concrete rubbles in normal concrete mixes and study the possible effects on some of concrete properties.

2. MATERIALS

The cement used in all mixes is ordinary Portland cement (Type I) conforming to ASTM C 150-92 specifications

Natural coarse aggregate is crushed limestone from local sources. Gradation of the normal aggregates from local sources was obtained using ASTM C136. Sieve analysis results are shown in Figure 1. Natural coarse aggregate was obtained by combining various aggregates of different single-sized aggregates in order to arrive at a grading accepted by BS and ASTM standards. Concrete rubbles were obtained by (a) crushing the previously tested samples in the lab into smaller particles, (b) these particles were sieved using the standard sieves for course aggregates, and (c) the sieved particles were combined in order to obtain a gradation similar to that of the natural aggregates. By this, the possible effect of the change of gradation on the properties of concrete is minimized. It is clear from Figure 1 that both aggregates are within BS

882 and ASTM C33 grading requirements for coarse aggregate of nominal maximum size 20 mm (ASTM 1.5”) to 5 mm (ASTM #4).

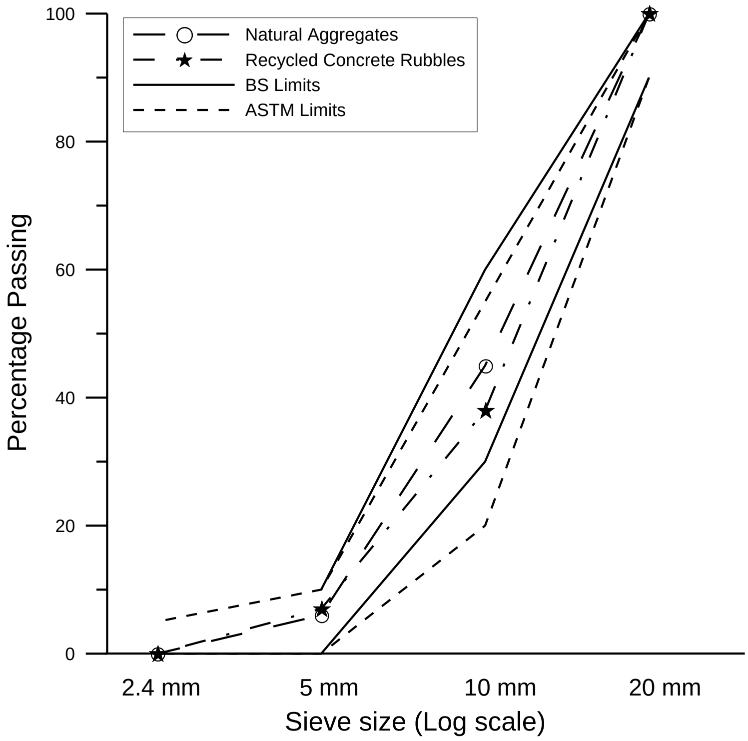

Fig. 1: Grading of both normal aggregate and concrete rubbles

Natural sand, *known locally as desert sand*, is used in all mixes. The results of the sieve analysis of fine aggregate are shown in Table 1. ASTM C33 and BS 882 grading limits are also shown. Although this sand is relatively fine, it has good properties and is commonly used in concrete mixes. The fineness modulus of sand is 1.56. The sand can be classified as fine, and is not within the ASTM C 33-92 standard limits. However, the sand is within the limits of BS 882: 1992 standards and is classified as “F” (fine sand).

Table 1: Sieve analysis of fine aggregates compared with ASTM and BS

Sieve size (mm)	ASTM Designation	Sand	ASTM limits	BS Grading Requirements		
				BS - C	BS - M	BS - F
10	3/8”	100	100	100	100	100
5	# 4	99.9	100	89 - 100	89 - 100	89 - 100
2.40	# 8	99.6	95 - 100	60 - 100	65 - 100	80 - 100
1.20	# 16	98.9	80 - 100	30 - 90	45 - 100	70 - 100
0.600	# 30	91.3	50 - 85	15 - 54	25 - 80	55 - 100
0.300	# 50	45.1	25 - 60	5 - 40	5 - 48	5 - 70
0.150	# 100	8.6	10 -30	0 – 15* 0 – 20^	0 – 15* 0 – 20^	0 – 15* 0 – 20^
0.075	# 200	1	NA	NA	NA	NA

* Natural aggregate ^ Crushed aggregate

The Specific gravity and absorption of the aggregates were measured using ASTM C 127and ASTM C 128. In each case, representative samples were taken and tested according to the corresponding ASTM standard. For natural aggregate, the average of three values was calculated and presented in Table 2. Because of the higher variability in concrete rubbles, the average of six values (taken from different crushed lots) was calculated and presented in Table 2. The hardness of the aggregates was obtained using ASTM C131. The Los Angeles abrasion values of both aggregates are shown in the table. The compacted density (dry-rodded unit weight) of the aggregates was obtained using ASTM C 29.

Table 2: Physical and mechanical properties of graded aggregate

Property	**Coarse Aggregate**	**Fine Aggregate**	**Concrete Rubbles**
Specific gravity (SSD)	2.57	2.59	2.28
Water absorption	1.67	1.9	5.8
Rodded bulk density	1502 kg/m^3	-	1310 kg/m^3
LA abrasion (%)	25	-	31

3. EXPERIMENTAL PROGRAM:

In order to study the effect of the use of concrete rubbles as coarse aggregates, several concrete mixes have been prepared and tested in the laboratory. The following steps summarize the program that has been followed:

1. Conventional concrete mixes of water/cement ratio of 0.45, 0.55 and 0.65 were designed and tested in the laboratory. All mixes were prepared and adjusted to obtain concrete of medium workability (slump 8 to 12 cm). Guidance of the ACI 211.1 was introduced in the preliminary design of these mixes. Then, the mixture proportions were practically adjusted in the lab. Table 3 summarizes the mixture proportions of natural aggregate mixes. Mixes containing slag aggregate have the same proportions shown in Table 3 but the coarse aggregate content only change according to the replacement ratio.
2. All mixes were tested for workability using the slump test described in ASTM C 143.
3. Several cubes of 100 mm side length were prepared and cured in the laboratory in a water bath under a temperature of 20º ± 2º C; then tested at the age of 28 days for compressive strength. The average of three values was recorded as the strength of concrete.
4. Several standard prisms of 100 x 100 x 500 mm were prepared and cured in the laboratory in a water bath under a temperature of 20º ± 2º, then tested at the age of 28 days for flexural tensile strength. The average of three values was recorded as the strength of concrete.
5. Concrete-containing rubble mixes were prepared by replacing a certain amount of the coarse aggregate by rubbles, while keeping all other variables constant. The ratio of rubbles used was 25, 50, 75 and 100 percent by weight of coarse aggregate.
6. Concrete-containing rubble cubes and prisms were prepared and tested as in steps 2, 3 and 4.

4. RESULTS

Figure 2 shows the relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the percentage of the original slump for all mixes. The workability of concrete reduces by the increase in the ruble content. This can be attributed to the increase in water demand which is difficult to predict ((Buck, 1977; Hansen and Narud, 1983, Park 1999).

Yong et al 2009 solved this problem by soaking aggregates in water and then using in saturated surface dry condition.

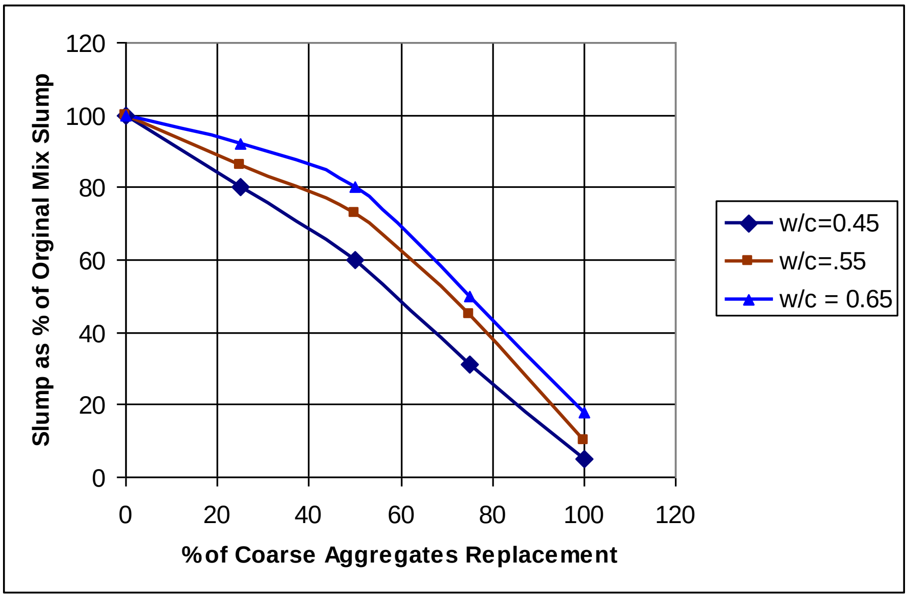

Fig. 2: Relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the percentage of the original slump

Figure 3 shows the relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the 28-day compressive strength. The use of the rubbles resulted in reduction of the compressive strength. This reduction increases by the increase in the amount of rubbles. Similar results are shown by Limbachiya et al 2004. However, Limbachiya, et al observed approximately no change in strength for replacement values below 25%. From Fig. 3, it can be also concluded that higher strength concretes suffered more reduction in strength.

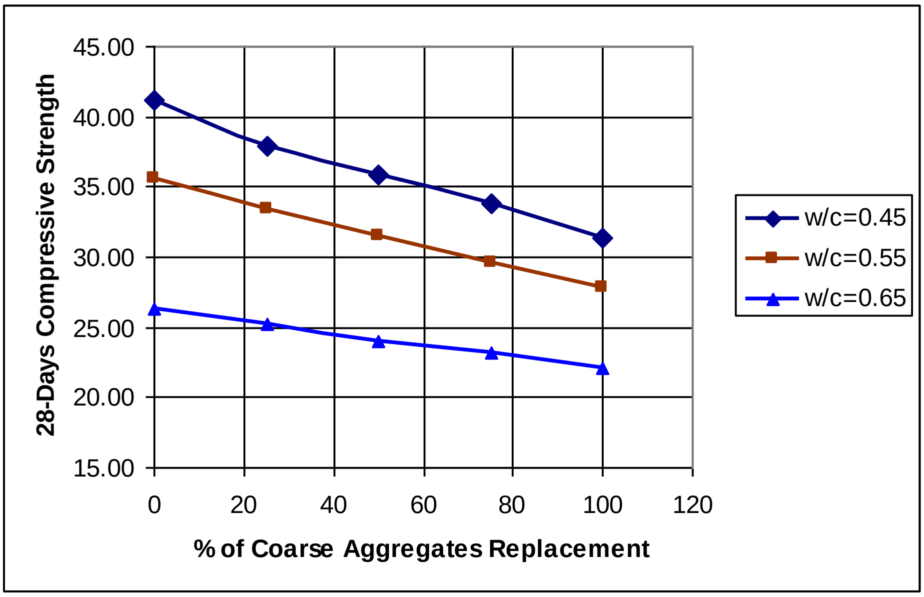

Fig. 3: Relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the 28-day compressive strength.

Figure 4 shows the relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the 28-day tensile strength. The use of the rubbles resulted in reduction of the tensile strength. This reduction increases by the increase in the amount of rubbles. Also the higher strength concretes suffered more strength reduction. However, the reduction in tensile strength was less than the reduction in compressive strength. For example, the use of 100% replacement reduced the compressive strength of the mixes by 25% for w/c ratio 0.45, while in the case of tensile strength this value is 14%.

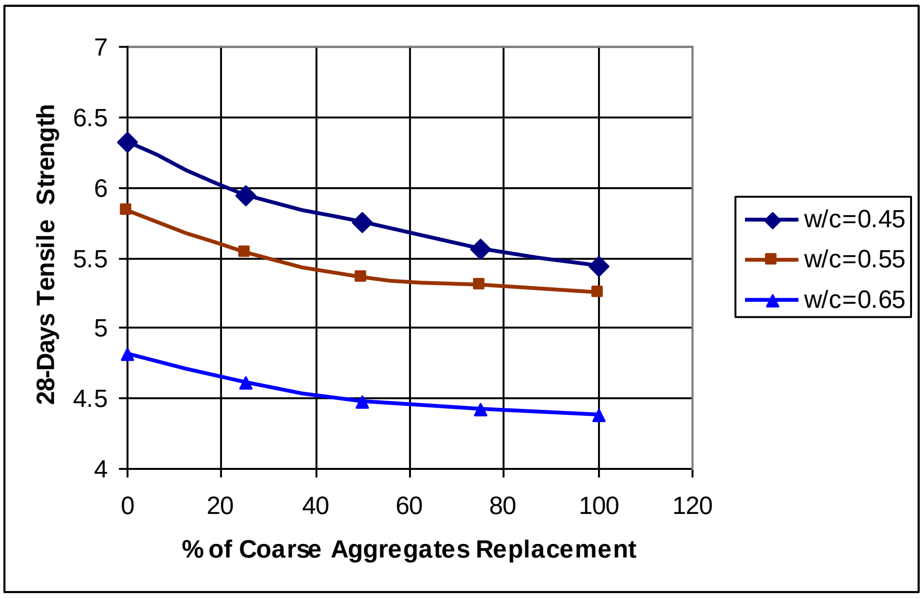

Fig. 4: Relationship between the percentage of the coarse aggregate replaced by concrete rubbles and the 28-day tensile strength

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the study presented in this paper, the following are drawn:

1. The use of concrete rubbles as coarse aggregate is possible in normal concrete mixes. This is useful in reducing the environmental problems created by dumping these materials.
2. The use of concrete rubbles as coarse aggregate in concrete mixes resulted in a decrease in the strength depending on the replacement ratio and the grade of concrete. Such an effect can be cared for by reducing the w/c ratio
3. The effect on compressive strength is more than that on tensile strength.
4. The use of concrete rubbles results in severe effect on the workability of concrete. However, as it is well-known, the use of plasticizers and superplasticizers will be beneficial in solving this problem.
5. It is important to conduct further research concerning the use of these materials before applications. Properties such as shrinkage, durability, ..etc, needs to be extensively and carefully studied.

6. REFERENCES

ACI Committee 555 (2001)
Removal and Reuse of Hardened Concrete, ACI 555R-01, ACI Committee 555 Report, American Concrete Institute, Farmington Hills, Michigan, 26 pp.

Anderson K**.** Uhlmeyer W., Russell M. (2009)
Use of Recycled Concrete Aggregate in PCCP: Literature Search**,** WA-RD 726.1**.** State Department of Transportation, Washington, 37 pp.

Buck, A. D. (1977)
Recycled aggregate as a source of aggregate. ACI Journal. May, pp 212-219.

CCA Australia (2008)
Use of Recycled Aggregates in Construction, Cement Concrete & Aggregates, Australia, 25 pp.

ECCO (1999)
Recycling Concrete and Masonry, Information bulletin EV 22, Environmental Council of Concrete Organizations, 12 pp.

FHWA (1985)
Recycling Portland Cement Concrete, DP 47-85, Federal Highway Administration, Washington DC, 6 pp.

Hansen T.C. and Narud H. 1983. Strength of recycled concrete made from crushed concrete coarse aggregate. Concrete International. January 1983: 79-83.

Limbachiya M, Koulouris A., Roberts J. and Fried.A., Performance of Recycled Aggregate Concrete, RILEM International Symposium on Environment-Conscious Materials and Systems for Sustainable Development, 127 – 136, 2004.

Nelson, Shing Chai NGO, High-Strength Structural Concrete with Recycled Aggregates, Dissertation, University of Southern Queensland, 2004, 112 pp.

OSSGA (2010)
The ABCs of Recycled Aggregate, Issue No. 1, Ontario Stone and Gravel Association, 4 pp.

PCA (2008)
Concrete Technology -Concrete Design and Production-Materials: Recycled Aggregates. Retrieved, August 26, 2008, from http://www.cement.org/tech/cct_aggregates_recycled.asp.

Park S. G. (1999)
Recycled Concrete Construction Rubble as Aggregate for New Concrete, Study report No. 86, BRANZ, 16 pp.

Yong, P.C. and Teo D.C.L., (2009)
Utilization of Recycled Aggregate as Coarse Aggregate in Concrete, UNIMAS E-Journal of Civil Engineering, Vol. 1: issue 1, August, pp 1-6.