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Concrete with Aggregates from Construction and Demolition Waste in Colombia

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ABSTRACT

While in some countries very high percentages of the construction and demolition (C&D) waste are recycled as construction material, in Colombia, practically all the C&D waste is dumped. Besides, aggregate sources near Bogotá, the capital, are almost depleted, so aggregates have to be brought from far quarries. Consequently, reclaiming aggregates from C&D ruble would lead to environmental and economical benefits. Some research projects with limited scope have been done since the mid nineties and their main findings are presented here. As a more systematic and thorough approach is missing, a research project that considers the relevant variables affecting the performance of recycled concrete in Colombia has been initiated at la Escuela Colombiana de Ingeniería (ECI). The objectives, activities and expected results are depicted. A description of a pilot plant for producing recycled concrete in campus that is part of the project is also made.

INTRODUCTION

Bogotá, the capital of Colombia, is a 7 million people city, that produces around 8 million tons/year of construction and demolition (C&D) waste [Bojacá, 2008], part of which are deposited in the few authorized C&D landfills (one in Bogotá and some in small towns near Bogotá), part (10-15%) are illegally dumped in public areas such as "humedales" (disappearing wetlands around Bogotá that help controlling floods and that are home to some endangered animal species) and highway shoulders, part in the sanitary landfill and only a small part (about 8 %) are re-used. It is believed that in a few years some of the C&D landfills will be completely full as well as the sanitary landfill leading to a huge environmental problem.

On the other hand, quality aggregate sources near Bogotá are almost depleted, so at present, part of the aggregate used for concrete has to be brought from quarries quite far from the city (100-200 km) increasing the cost of concrete production [Bogotá mayor's office, 1997]. In other cities aggregate production generates problems such as landslides, destruction of habitats, and air pollution. Consequently, producing aggregates from C&D ruble, would lead to enormous environmental and economical benefits.

Although Bogotá is by far the larger city of Colombia, these problems, particularly the disposition of C&D waste, are common in most cities and towns. Due to Bogotá's size and the speed at which C&D landfills are running out of space, Bogotá officials have recently shown interest in reusing C&D waste. In general in the rest of the country people are not concerned about this issue since they still have enough room for landfills and still have aggregate sources close to urban areas. However, one of the goals of this project is to warn communities of the problem so they can begin taking care of C&D waste and making plans for using it as construction material.

Of the total C&D waste produced in Bogotá, about 80 % (6.5 million tons/year) is excavated material (clay, silt and organic material) and about 20 % (1.5 million tons/year) is concrete or brick ruble. It is estimated that 90-95 % of the total material can be re-used as filling material or as aggregate for concrete. However, in Colombia there are only a few examples of civil works where C&D waste has been used for concrete elements [Bedoya, 2003]. The fact that contractors and owners do not know that quality concrete can be made from recycled aggregates, that current Colombian standards do not consider or do not mention these aggregates as concrete material and the lack of regulations that promote the use of recycled aggregate and discourage dumping C&D ruble are some of the reasons why practically no one has made serious attempts to recycle these materials in Colombia.

Background

The former paragraph does not mean that there has not been interest on recycling C&D waste in this country. Some research projects have been done since mid nineties and some city officials have shown interest lately. The main findings of some of these projects will be presented as follows:

Reyes (1999) for his master's thesis produced recycled-concrete masonry blocks of 125 x 245 x 65 mm, paving tiles, and 100 x 200 mm cylinders with three types of recycled Portland cement concrete. Type one was composed of brick ruble as coarse aggregate and river sand. For type two, crushed brick as fine aggregate and river gravel as coarse aggregate were used. Type three was composed of crushed brick as coarse and fine aggregate. The three mixtures had different w/c ratios as shown in Table 1. Cylinders and blocks were subjected to compression tests at 28 days while paving tiles were subjected to abrasion. Table 1 shows mixtures characteristics and the corresponding compressive strength of cylinders (f'c) and blocks (f'm).

Table 1. Recycled Concrete Properties of Reyes' Study

Name	Coarse Aggregate	Fine Aggregate	a/c	f'c (MPa)	f'm (MPa)
1	Crushed brick	River sand	0.7	13	20
2	River gravel	Crushed brick	0.8	11	20
3	Crushed brick	Crushed brick	0.9	7	12

Reyes also run abrasion tests in recycled concrete paving tiles and brick tiles. Mass loss of recycled concrete tiles was 3 % significantly higher than that of brick tiles that was 0.8 %. Although compressive strength of recycled concrete cylinders was quite low, material complied with the Colombian Standard NTC 4026 (and ASTM C 90) for concrete masonry units.

Torres (2000) as part of his master's thesis made a series of concrete mixtures with a fixed w/c ratio of 0.50 using recycled aggregates from concrete columns and beams, masonry walls, ceramic tiles and different amounts of Portland cement. The composition and the mean 28-day compressive and flexural strengths of the two recycled-aggregate mixes and the control mix are presented in Table 2. One of the recycled-concrete mixtures had a lower compressive strength while the mixture with ceramic tiles had higher strength than the control mix. As for flexural strength the recycled concrete mix had a modulus of rupture a little bit higher than that of the control mix. Torres also measured the absorption of E2 samples and obtained 5.8 %. These results show that mechanical strength of recycled concrete might be close to or even higher than natural aggregate concrete.

Table 2. Recycled concrete properties of Torres' study

Name	Coarse Aggregate	Fine Aggregate	a/c	f'c (MPa)	MR (MPa)
Control	Natural	Natural	0.50	25	5.2
E1	Crushed concrete and brick	Crushed concrete and brick	0.50	22	5.8
E2	Crushed concrete, brick and ceramic tile	Crushed concrete, brick and ceramic tile	0.50	29	n/a

Lately Bogotá officials have shown interest in recycling C&D waste due to the lack of landfills and the depletion of aggregate sources. As a result, in 2001 a cooperative research project between ECI and the Public Services Executive Unit (PSEU) of Bogotá leaded to an experimental program designed to evaluate the potential for reuse of C & D debris obtained from 17 building sites most related to construction or rehabilitation of highways or pedestrian ways. Material was classified in three groups: fine material composed of clay, silt and organic matter; material coming from excavation and demolition composed of contaminated aggregate, pieces of concrete; and material coming from demolition and construction sites composed of concrete and brick not contaminated with soil, dust or organic matter.

Material type 1 was tested for its ability as filling material. Consequently, material was subject to different levels of compaction. Unconfined compressive strength, q_u, and tangent modulus at 50 % strength, E_t were determined. It was found that in general q_u and E_t increased with the level of compaction leading to the conclusion that this material has to be compacted to be used for sub-bases and back filling.

Material type 2 was stabilized with different amounts (4 and 7 %) of Portland cement. Samples were made by mixing the recycled material with cement and water. Samples were compacted to a high density and cured in a humidity chamber for 7 days. Compression tests were performed on half of the samples in dry state. The rest of the samples were subjected to the compression test after have been immersed in water for 4 hours to determine the residual compressive strength. I high variability was found but in general, it was found that the higher the fine content the lower the residual compressive strength, and the higher the cement content the higher the compressive and residual compressive strengths.

Concrete was made out of material type 3. Two sources were used. One was a demolished old house; consequently the ruble was composed by brick and concrete. The other source was a pedestrian path, so recycled material was mainly composed by weak concrete.

Material from both sources was crushed, sieved and characterized. Sieved material was re-combined using Fuller size distribution. Seven low-slump concrete mixtures were made with the w/c ratio varying from 0.68 to 0.94. Table 3 shows the characteristics of these mixtures as well as the 28-day compressive strength. In general, compressive strengths are slightly lower than those expected for conventional concrete.

Table 3. Cooperative Project ECI-Bogotá PSEU Recycled Concrete Properties

Name	Coarse Aggregate	Fine Aggregate	a/c	f'c (MPa)
A-08	Crushed concrete, brick and ceramic tile	Crushed concrete, brick and ceramic tile	0.94	10
B-09	Crushed concrete ($f'_C \geq 21$ MPa)*	River sand	0.75	16
C-010	Crushed concrete ($f'_C \leq 17.5$ MPa)	River sand	0.79	14
D-011	Crushed concrete ($f'_C \geq 21$ MPa)	Crushed brick	0.85	13
E-012	Crushed brick (50%) + crushed concrete ($f'_C \geq 21$ MPa) (50%)	River sand	0.70	15
F-013	Crushed brick (50%) + river gravel (50%)	River sand	0.68	16
G-014	Crushed concrete ($f'_C \geq 21$ MPa)	Crushed concrete ($f'_C \geq 21$ MPa)	0.74	11

* *Compressive strength of original concrete*

Bedoya [2003] claims in his master's thesis that there is a cultural issue regarding the use of recycled concrete that has to be considered in the future. People, including owners, contractors and designers, are not willing to use concrete with recycled aggregates since for them recycled means useless or bad quality. He mentions that as result of a former experimental project conducted by himself [Bedoya, 1999], a concrete block manufacturer produced prefabricated concrete pieces [Figure 1] such as masonry blocks and curbs using recycled aggregates. The mean compressive strength over the gross area of the samples tested was 4.8 MPa that is higher than the required by the Colombian Standard for masonry blocks.

Fig. 1. Recycled Concrete Blocks Made with Recycled Aggregate

Bojacá [2008] searched the worldwide state-of-the-art and found that some countries recycle very high percentages (more than 80 %) of the C&D ruble, that other countries have done research and important efforts to use increasing amounts of C&D waste, that some countries recycle not very high percentages of C&D ruble and that many others like Colombia do not recycle C&D ruble at all. He found that it is necessary government intervention in the process by for example providing facilities where ruble can be classified, processed and stored. However, he also found, that this is not enough and that successful recycling programs require a legal framework that ensures that contractors re-use construction and demolition waste, for example by fining the use of concrete without recycled aggregates or by fining dumping of concrete or brick ruble in landfills.

Bojacá also performed an experimental work in which he made two series of recycled concrete with crushed 100 x 200 mm concrete cylinders already tested as aggregate. The resulting crushed material was classified in two categories, depending on f'c of the original concrete. One corresponded to concrete with f'c between 18 and 25 MPa and the other to f'c between 25 and 32 MPa. Using these two types of recycled aggregate and natural aggregate four concrete mixes were made as shown in Table 4. The first two mixtures had a w/c ratio of 0.60 while the last two had a w/c ratio of 0.40. Cylinders and beams were subjected to compression and flexural tests respectively. The absorption of concrete made of recycled aggregate was also determined. The compressive and flexural (rupture modulus,RM) strengths of all mixtures as well as the absorption of the recycled concrete samples are shown in Table 4. Strengths of the recycled concrete mixes with high w/c ratio were significantly lower than the control mix, while strengths of the recycled concrete mixes with low w/c ratio were slightly higher than the corresponding control mix. Absorption of recycled concrete was quite high as expected for these materials.

Table 4. Bojacá,s Project Recycled Concrete Properties

Series	Coarse Aggregate	Fine Aggregate	a/c	f'c (MPa)	RM (MPa)	Absorption (%)
A-1 control	Natural	Natural	0.60	26	4.7	
A-2	Crushed concrete (f´c = 18-25 MPa)	Natural	0.60	13	3.9	12.4
B-1 control	Natural	Natural	0.40	37	6.0	
B-2	Crushed concrete (f´c = 25-32 MPa)	Natural	0.40	43	5.4	9.7

As can be seen a number of limited experimental campaigns regarding recycled concrete have been conducted at some universities in Colombia. These projects have focused on compressive and flexural strength but not a single one has looked into durability issues. Besides, as a small number of samples was tested in each project, results do not let draw solid conclusions nor make quantitative recommendations and guidelines. These results are not enough to convince society of the advantages of recycled concrete and officials to develop the legal framework required to implement a successful C&D waste recycling program. Despite the above, results do show that it is possible to produce recycled concrete with acceptable mechanical strength.

ONGOING PROJECT

In view of the limited information available in Colombia, researchers at the Escuela Colombiana de Ingeniería (ECI) Materials Laboratory initiated in 2009 a more systematic approach to study the effect of variables such as type and percentages of C&D waste (brick, concrete, glass and ceramic tile), water-to-cement ratio, supplementary cementing materials, and paste content on compressive and flexural strength, elastic modulus and durability properties (permeability, resistance to carbonation, chlorides penetration, and absorption) of recycled concrete.

As research results are not enough to promote the use of C&D ruble as construction material, it was decided to install a pilot plant (Figure 2) in order to use C&D waste produced inside ECI facilities as a result of construction and demolition of activities, testing activities at the materials laboratory or research projects (Figures 3,4,5) to produce recycle concrete for use in construction works inside the university. The purpose of this demonstration project is to reduce the on-campus C&D waste sent to landfills and to show community, contractors, officials and legislators that it is technically and economically feasible to produce quality concrete from C&D waste.

The pilot plant is composed of a small crusher shown in Figure 2, a cylindrical tromel for separating material in various sizes and a small concrete mixer. The crusher is capable of producing recycled aggregate with maximum size varying from 5 mm to 25 mm by adjusting the jaw.

Fig 2. Crusher and Detail of the Jaw

Fig 3. Material Resulting from Concrete Testing

Fig 4. Material Resulting from Research Projects

Fig 5. Material Resulting from Testing at the Materials Laboratory

The main objectives of the project are:

- Evaluate the effect of mechanical and durability properties of concrete with recycled aggregates.
- Produce concrete using recycled aggregates produced with the pilot plant for in campus applications
- Develop a guide for producing recycled concrete in Colombia
- Show results to officials and community in general in order demonstrate the technical and economic advantages of using recycled aggregates
- Propose the implementation of a legal framework that promotes the use of recycled concrete and discourage dumping C&D waste

Testing Plan

The following tests will be performed on natural and recycled aggregates in order to characterize their behavior.

- Los Angeles abrasion loss test
- Micro Deval
- Absorption

- Sieve analysis
- Shape

The following tests will be performed on control and recycled concrete to get information on mechanical and durability properties:

- Compressive strength
- Flexural strength
- Elastic modulus
- Drying shrinkage
- Initial surface absorption test (ISAT)
- Rapid chloride permeability
- Carbonation in an accelerated chamber
- Ultrasonic Pulse Velocity
- Sulfate resistance

To evaluate the effect of the following relevant variables a series of concrete mixtures with different amounts and types of aggregates will be made:

- Recycled aggregate: crushed concrete and brick
- Percentages of replacement of recycled concrete: 25, 50, 75, 100 % of coarse aggregate and 25, 50 % of fine aggregate. There will be control mixtures with 100 % natural aggregate
- Water-to-cement ratio: variable between 0.4 and 0.7
- Supplementary cementing materials: fly ash and metakaolin

The study will be divided in various phases. In phase I, that began in August 2009, two series of concrete mixtures have been made. In both series recycled aggregate was used to replace 25 % coarse natural aggregate. In one series recycled aggregate is crushed concrete; in the other series it is crushed brick.

SUMMARY AND CONCLUSIONS

Practically no C&D waste is recycled in Colombia, despite that millions of tons are dumped each year, particularly in big cities and that aggregate production generates a big environmental impact or that aggregates sources are almost depleted in some cities like Bogotá.

Some research has been conducted at Colombian universities in the last 15 years. However, these projects have had limited scope, the number of samples tested in each project is not enough to draw valid conclusions and durability issues have not be considered.

Based in worldwide experience, results from previous research in Colombia and taking advantage of the recent interest of Bogotá officials in recycling C&D ruble, researches at la Escuela Colombiana de Ingeniería Materials laboratory have initiated a research project which objectives include study the effect of a number of relevant variables on the performance of recycled concrete; implement a pilot plant to produce aggregates from the C&D waste generated inside the institution and produce recycled concrete for in campus use; and to show community and officials the advantages of using recycle concrete and induce the development of a legal framework to promote its use.

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