Physical and mechanical characterization of recycled aggregates obtained from construction debris[1]

Caracterización física y mecánica de agregados reciclados obtenidos a partir de escombros de la construcción[1]

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Abstract

The saturation of disposal points for solid residues is one of the largest problems that Latin-American countries, including Colombia are facing now, and it can be attributed to inefficient processing and the lack of adequate policies for the handling and management of solid residues from construction waste and debris. In the city of Santiago de Cali, Colombia, for example, 2,480 cubic meters of this waste is produced on a daily basis, from which only 40% is reutilized. An alternative that rises is to use the construction residues for the production of prefabricated elements. In this study, it was transform a punctual, representative sample of construction waste in different aggregate size, with the purpose of characterizing its potential utilization in conventional concretes and studying the viability of its usage in the production of construction materials.

Keywords: Demolition and construction residues; aggregates; concrete; mechanical and physical properties.

Introduction

It is evident the global need for increasing the efficiency in terms of material and energy consumption, that is why there is a priority to study materials for their recycling capabilities, especially in the specific case of concrete, which is today the most fabricated construction material in the world and it has one of the highest environmental impacts. Numbers around 10 billion metric tons a year, meaning more than a ton per capita per year. In Colombia, although the index is lower, the construction industry is one of the most dynamic and of higher incidence in the economic development of the country. One of the consequences that are derived of the construction business is the generation of considerable volumes of waste. The construction and demolition residues (RCD) or "escombros" as they are called in some Latin-American countries, are waste material generated during the different stages of civil construction, which includes structures and refused materials; materials that have been used and deteriorated, and including those that are produced by excavation and cleaning of the site after completion of the project. This kind of residue is generated by natural events such as earthquakes, floods, landslides, etc. (Torgal and Jalali, 2011; Oikonomou, 2005; Poon and Chang, 2007) The concrete residues stand over the rest for their volume. One of the alternatives to add value to these residues, is to use these as feedstock for the production of gravel and recycled sands, that are apt for usage as aggregates in traditional concrete mixes (Eguchi et al., 2007; Malesev, 2012; Deshpande, 2011; Matar y Dalati, 2011; Poon et al., 2002; (Rao et al., 2007).

It is estimated that the aggregate demand for concrete preparation is of 18 million cubic meters per year, according to the National Statistics Management Department, *DANE*, for the amount of Portland cement that is dispatched nationwide, that amount reaches 9 million tons per year, it permits the inference of a concrete consumption that sorrounds 35 million metric tons per year. Even further, it is calculated that the Valle del Cauca is responsible for 10% of this demand, which generates the question of when are the stone quarries going to be unable to provide this material demand of non-renewable resources.

The usage of recycled materials (RCA) in the concrete mix, is a tendency that is increasing from a few decades ago, and has been proven that certain type of construction waste upgrade the mechanical performance, durability and workability of concrete when being used as fine or coarse aggregate (González et al., 2012; Braga et al., 2014).

The mechanical and physical properties were analyzed in a comparative manner, in contrast to the natural aggregates that are normally used in the construction industry, with the purpose of proving the viability of its use in the fabrication of Portland cement concrete. All the RCD conditioning activities were conducted in the facilities at Universidad Del Valle (Cali, Colombia) in the framework of the Composite Materials Group (GMC).

Methodology

In the figure 1, the methodology applied to the development and execution of the research is shown.

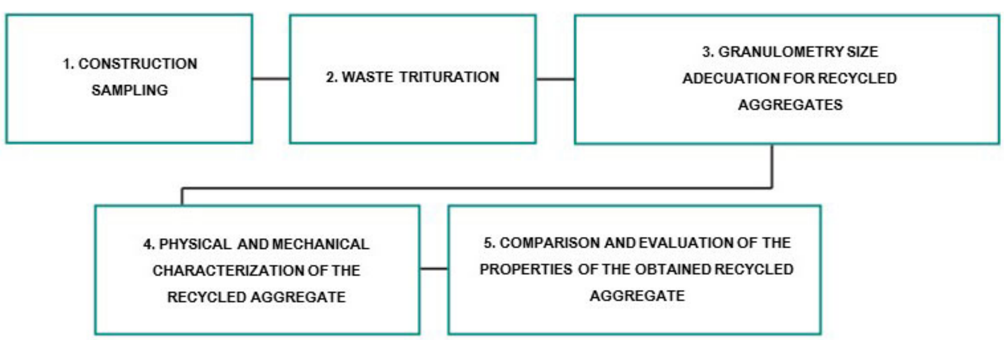

Figure 1. Research Project Methodology

The waste sampling was done inside Universidad Del Valle. These samples corresponded to reinforced concrete pieces, 40 cm in average diameter, which were submitted to a primary milling process with a jaw crusher and then with a hammer mill with the purpose of reducing its initial size until obtaining fine and coarse aggregates apt for use in concrete mixes. The separation of grain size was guaranteed by the means of manual sifting, passing the aggregates through a 1/2" grid wire mesh (figure 2).

Figure 2. Waste Trituration Process

For the characterization of the obtained aggregates the following technical regulations that were applied are shown in table 1.

Table 1. Technical norms used in the aggregate characterization

Test	Regulation or code applied
Aggregate sifting	NTC 77
Aggregate unitary mass	NTC 92
Organic impurities	NTC 127
Gravel density, absorption, porosity	NTC 176
Sand density, absorption, porosity	NTC 237
Humidity content of aggregates	NTC 1776
Angels coefficient	ASTM C131
Shape coefficient	UNE-EN 933

Source. Authors

Results and analysis

The conditioning that was conducted for the production of RCD, allowed to reduce the size of the original material fragments to a comparable one necessary for this kind of materials to be used as commercial aggregates for concrete mix production as observed in figure 3.

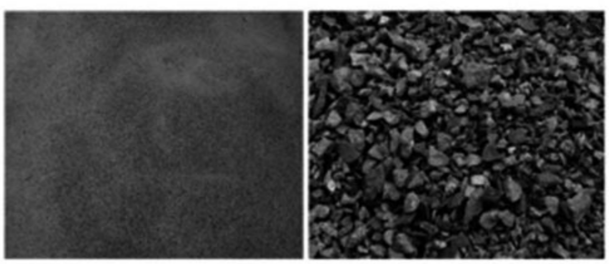

Figure 3. Recycled aggregates, Fine (on the left) Coarse (on the right)

From the macroscopic view, the aggregates obtained from the waste milling reached the grain size similar to those present in natural aggregates. However, it is important to study its granulometric distribution to evaluate if this parameter is within the standards or presents a similar behavior. For this reason, it was necessary to analyze granulometrically each of the recycled samples obtained and compare them to the ASTM C33 code for granulometric grading which stipulates the ideal conditions for the production of concrete (figures 4 and 5).

In the figure 4, it is observed how the fine recycled aggregate shows the same behavior that natural sand in general lines; even though it seems a bit coarser than the same, for which the granulometric curve reveals a slight deviation in the 2.36 mm and 1.18 mm mesh sizes in comparison to the curve generated by the natural sands. However, since the deviation is small, it can be affirmed that the recycled sands present an adequate granulometric behavior for the use in the fabrication of concrete mix.

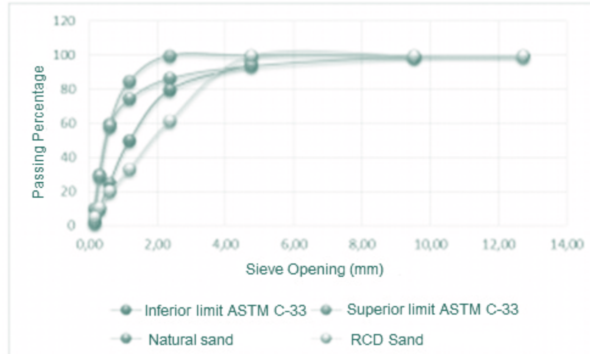

Figure 4. Fine aggregates granulometric distribution curves.

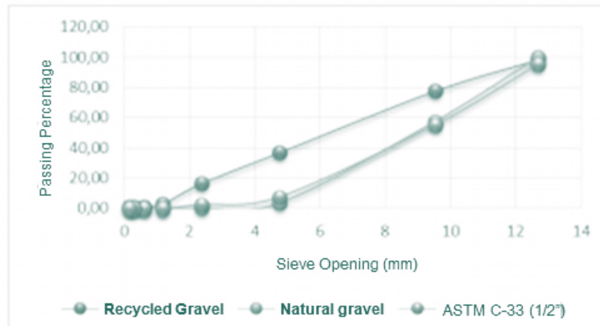

Figure 5. Coarse aggregates granulometric distribution curves

In figure 5, the coarse recyclable waste aggregates also show a similar behavior to the natural aggregate of similar size, but the 4.75 mm and 9.52 mm wire meshes have a slight deviation that shows that the recycled aggregates are slightly finer than the milled aggregates it was compared to. In spite of the previous, the granulometric distribution that can be observed is good and resembles those of the parameters proposed by ASTM C33.

The morphology is another important aspect to be analyzed, since the physical influence of the aggregate in the fresh and hardened states that contain them, can be evaluated, because the more angular the particle is, its accommodation abilities within the concrete will be less, even though they have better adherence with the matrix. The coarse recycled aggregate and the natural, presented an average shape factor of 0.49, which indicates that their morphology is similar, as it can be observed in figure 6.

One of the main characteristics that these recycled aggregates exhibit is the adhered mortar, to which various important properties are attributed to this kind of aggregates in concrete. In figure 7, the presence of the adhered mortar on a natural aggregate particle, can be observed.

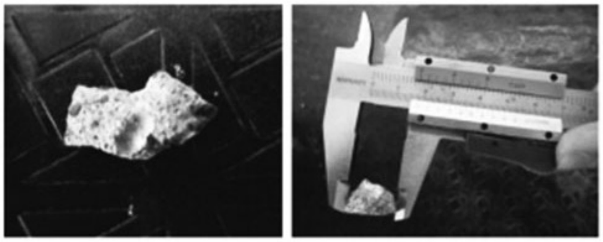

Figure 6. Coarse recycled aggregate particle morphology.

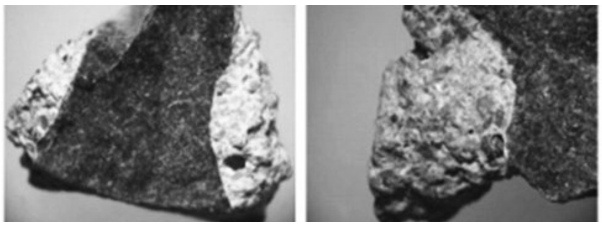

Figure 7. Coarse recycled aggregate particle morphology.

This aspect can be corroborated through electronic scanning microscopy (MEB) which reflects the presence of this mortar in the small particles of natural gravel.

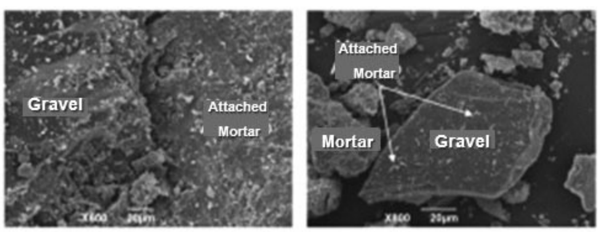

Figure 8. Electronic scan microscopy of the recycled aggregates. Coarse (left), fine (right)

The interface that is generated between the adhered mortar and the gravel particle is a relatively weak zone and presents certain brittleness, which brings as a consequence that the largest recycled particles, having a larger fraction of this mortar, have lower mechanical properties than the fine, due to the molturation process that occurs in the finest aggregates, this interface is eliminated in great volume when the mortar detaches from the gravel particle (Tam, 2009; Shayan, 2003; Cheng, 2005; Zhou, 2010), as it can be observed in the figure 8 (right). Based on the previous, the resistance to wear that the recycled aggregate particles exhibit is lower (33.65%) than the presented by the natural particles (16.39%); according to the specifications of the ASTM C131, which indicate that the coefficient values for the angels superior to 50% which correspond to lowest quality arid, not apt for construction , while in the contrary, values under 20% correspond to good quality aggregates with resistance to wear, meeting any application standards(McNail, K y Kang, 2013).

Other of the possible consequences that the adhered mortar has on recycled aggregate can be reflected in the density, porosity and absorption of the particle values, as it can be observed in the tables 2 and 3, in which other characteristics of interest that recycled aggregates have, are presented.

It can be observed that the density of the recycled aggregates is lower than the natural; this slight decrease is due to that fraction of the mortar that keeps adhered and whose porosity is higher than the natural aggregate which affects density slightly (Safiuddin, 2011, McNail, K y Kang, 2013; Wardeh et al., 2014).

One of the aspects that has the most relevance or impact in the characterization of recycled aggregates is their high water absorption, since it is the variable that most differs when comparing different aggregate types. It was observed that the water absorption percentage for the recycled aggregates is much higher than the natural, phenomena that is also due to the porous structure of the adhered mortar that these aggregates have and their higher water absorption capacity (Leite, 2012; Etxeberria, 2007; McNail, K y Kang; Bendimerad et al., 2014).

Table 2. Mechanical and physical characteristics of coarse aggregates

Characteristic	Code	Natural	Recycled
Bulk apparent density	NTC 176	2.54 g/cm^3	2.26 g/cm^3
Absorption	NTC 176	2.01 %	7.28 %
Unitary loose mass	NTC 92	1.47 g/cm^3	1.26 g/cm^3
Unitary compact mass	NTC 92	1.59 g/cm^3	1.46 g/cm^3
Thinness module	NTC 77	6.38	5.64
Nominal maximum size	NTC 77	12.5 mm (1/2°)	12.5 mm (1/2°)
Maximum size	NTC 77	12.5 mm (1/2°)	12.5 mm (1/2°)
Di/Di ratio (morphology)	UNE 933-4	0.493	0.499
Angels´Coefficient	ASTM C-131	16.39 %	33.65 %

Source: Authors

Table 3. Mechanical and physical characteristics of fine aggregates

Characteristic	Code	Natural	Recycled
Bulk apparent density	NTC 176	2.58 g/cm^3	2.28 g/cm^3
Absorption	NTC 176	1.89 %	6.44 %
Unitary loose mass	NTC 92	1.63 g/cm^3	1.51 g/cm^3
Unitary compact mass	NTC 92	1.74 g/cm^3	1.80 g/cm^3
Thinness module	NTC 77	2.61	2.34
Nominal maximum size	NTC 77	2.36 mm (1/2")	4.75 mm (1/2")
Maximum size	NTC 77	12.55 mm (1/2")	11.55 mm (1/2")
Organic matter	NTC 127	#2	#2
Organic matter	NTC 127	#2	#2

Source: Authors

Conclusions

The use of concrete residues as aggregates for concrete shows an important feasibility from the mechanical and physical point of view, asides from the positive impact that using these materials. The porosity and adhered mortar quantities can be managed with a grain size that reduces the adhered mortar presence to a minimum, so that they become finer aggregates apt for concrete mix production. However, spite these characteristics that could be counterproductive for this kind of materials, they must have the same meet or exceed the regulations that the construction grade aggregates.

Acknowledments

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