Main mechanical properties of concrete mixed with construction and demolition wastes for reuse

Principales propiedades mecánicas de concreto mezclado con residuos de construcción y demolición para su reuso

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Abstract

In general, the increase in civil constructions has led to an increase in the production of construction and demolition waste (CDW), a fact that stands out in the city of Bogotá. This situation results in a negative environmental impact, making it necessary to develop strategies for creating management programs in construction sites for the reuse, recycling, and final disposal of the waste they produce. These strategies should be aimed at processing CDW for their later reincorporation and reuse, where concrete stands out as CDW due to being a composite material with a high percentage of use in civil construction works in Bogotá. Therefore, it was determined that there was a need to analyze some of its mechanical properties such as compressive strength, tensile strength, flexural

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strength, and its particle size distribution, to assess the possibility of recycling it and using it in the production of new concrete for reuse in construction, proposing an alternative to decrease the exploitation of natural resources and conservation strategy for the environment by reducing the C&D waste that goes to landfills. For this research, tests were conducted using concrete specimens with 100% recycled aggregates and an age of 28 days. The results show that the mechanical properties of recycled concrete are diminished, but as future work it is evident that there is a possible improvement by reducing the amount of recycled coarse aggregates to produce such concrete.
Keywords: concrete, construction and demolition waste, mechanical properties, stress.

Resumen

A nivel general el aumento de construcciones civiles ha generado un incremento en la producción de residuos de construcción y demolición (RCD), aspecto que resalta en la cuidad de Bogotá. Este aspecto da lugar a un impacto ambiental negativo, por lo que es necesario generar estrategias para que en las obras se creen programas de gestión para la reutilización, reciclaje y disposición final de los desechos que producen. Estas estrategias deben estar encaminados a procesar los RCD, para su posterior reincorporación y reúso, donde el concreto se destaca como RCD por ser un material compuesto con un alto porcentaje de uso en las construcciones de obras civiles en Bogotá. Por ello se determinó la necesidad de analizar algunas de sus propiedades mecánicas como su resistencia a la compresión, resistencia a la tracción, resistencia a la flexión y su granulometría, para determinar la posibilidad de su reciclado y uso en la fabricación de nuevos concretos para reúso en construcciones, planteando una alternativa para disminuir la explotación de los recursos naturales y estrategia de conservación del medio ambiente reduciendo los RCD que van al relleno. Para esta investigación los ensayos se realizaron usando probetas de concreto con 100% de agregados reciclados y con una edad de 28 días. Los resultados muestran las propiedades mecánicas del concreto reciclado se ven disminuidas, pero como trabajo futuro se evidencia una posible mejorar disminuyendo la cantidad de agregados gruesos reciclados para la elaboración de dicho concreto.

Palabras clave: concreto, esfuerzo, propiedades mecánicas, residuos de construcción y demolición.

1. Introduction

The execution of construction projects, renovation and demolition requires different processes such as excavations, cutting of materials, joining and assembling of different structures, have increased the extraction of natural resources, negative environmental impacts [1] and thus the generation of waste materials or CDW [2], these CDW are also produced by demolition of civil constructions, repairs or improvements; creating environmental problems [3].

It is impossible to completely eliminate such waste, which makes it necessary to manage it appropriately, considering in the first instance its reuse before its final disposal, such as the production of concrete for reuse taking into account properties such as compressive strength, modulus of elasticity [4] and microstructural characteristics [5], or the reduction of the generation of these wastes with the use of digital tools such as the one mentioned in [6] who developed a model for the characterization of asphalt mixtures for road construction, in which digital image processing algorithms, discrete Fourier transform and Kohonen organizational maps are implemented, in this way optimizing the construction process and the quality of pavements. Several authors have studied the subject with favorable results, such as the reduction of the carbon footprint [7], saving of natural resources, energy reduction, greenhouse gas emissions [8], or the one mentioned in [9] which consists of developing and implementing a solid waste management plan for buildings with environmental indicators or as mentioned in [10] which indicates that CDW recycling reduces environmental impacts and environmental degradation because mismanagement of this waste contributes 60% to freshwater pollution. Also in [11] they recommend building CDW recycling plants at a distance of 70 km from the construction site, this recycling facility being an advantage for environmental impact.

The reuse of demolition waste is a frontier research area [12] that requires significant attention for the environment, its conservation and the promotion of recycling as a reengineering technique [13]. Current trends in construction and demolition of recycled waste guide these efforts for a sustainable future [14] with current and future impacts in both controlled and uncontrolled demolition projects due to natural disasters [15], which in turn impact sustainable production and consumption in the entire construction field [16]. Where decision making in the analysis of reuse materials and current construction projects a potential that guides what is now defined as intelligent construction [17] which also covers road infrastructure from materials in pavements [18] and metallurgical processing techniques, covering all that is involved in civil engineering in waste and resource management [19], also in the production of alkaline activated materials with mixtures of processed concrete, ceramics and making full use of CDW as binder and aggregates to reduce waste storage [20].

The growth of civil works is evident worldwide, which brings with it the generation of CDW, which has become a global problem, so in the European Union there is the directive on construction waste where measures were established so that at least 70% of the CDW is reused, recycled or recovered, developing sorting technologies in order to improve the quality of the aggregate derived from CDW [21], Similarly, in several provinces of China, a study was carried out to calculate the generation of CDW using the area estimation method where the spatial correlation of waste generation was studied, showing the increase in waste generation [22]. In Mexico City 25% of CDW goes to landfills, however the country's environmental standard NADF-007RNAT-2013 that establishes the classification and management specifications for construction and demolition waste, in the federal district recommends recycling through a process of selection, crushing, sieving and storage for reuse [23] and in Brazil there is Resolution 307 of the National Environmental Council with criteria, procedures and management of CDW to develop and implement municipal plans to prevent these wastes from ending up in landfills; however, only a small amount of these wastes are reused in the construction industry [24].

The application of CDW, creating materials and being used in construction projects, has gained popularity, being also used in the development of aerated foamed concrete [25], mortars [26], geotechnical applications [27], pavements and roads [28] [29], geopolymers [30] [31], among others.

2. Methodology

A series of tests are carried out for the characterization of recycled concrete with CDW by means of specimens made with recycled material to determine mechanical properties of compression and granulometry with a casting age of 28 days, which is the stipulated period for carrying out the tests [32], then several authors who have worked with this material are consulted to finally compare the values obtained for the properties and thus reach the relevant conclusions.

3. Results

When the samples are taken into account, the results obtained are used to analyze two properties in particular that correspond to the granulometry and the compressive strength that characterize the concrete.

3.1 Granulometry

The granulometry allows to determine the size of the particles which is a physical property of the sediment particle samples [33] that compose the concrete and is performed by means of sieves that vary by mesh number, allowing to define the fineness and distribution of the grain depending on the percentage that passes and the percentage that remains retained [34].

To determine the granulometry, the sieves recommended by the Colombian technical standard NTC 174 [35] are shown in Table 1.

Table 1. Granulometry values for concrete [35].

Sieve NTC 32 (ASTM E 11)	Percentage passing
9,5 mm	100
4,75 mm	95 a 100
2,36 mm	80 a 100
1,18 mm	50 a 85
600 μm	25 a 60
300 μm	10 a 30
150 μm	2 a 10

These data are used to perform the granulometry tests and are taken as standard values.

With this information, the tests were carried out, for which 4 test tubes were made with 100% recycled coarse aggregates, adding sand, water and gravel and with an age of 28 days. The granulometry test was performed with a final sieve of 0.15 mm, corresponding to the number 100. The percentage retained was 0.1%, the percentage that passed was 3%, and the accumulated percentage was 99.4%.

The study conducted by [36] used recycled concrete coarse aggregate with a shade number 100 obtaining a retained percentage of 0.0; percentage passing is 3.4% and the cumulative of 96.6%.

For [37] the granulometry results obtained are retained percentage of 1.5; percentage passing 1% and accumulated 99.38%.

The work done in [38] uses concrete from CDW obtaining a retained percentage of 13.57, accumulated 95.48% and passed 4.52%.

3.2 Compressive strength

This is a main property of concrete [39] used in structural design and quality control of concrete [40] because building products made of this material are subjected to compressive stress, which is the intensity of force per unit area, thus generating the resistance which is measured in units of effort.

The compressive strength test is performed in a universal testing machine where loads are applied gradually, to determine the characteristics of the material such as its yield stress, elasticity and compressive strength [41], where the value for the compressive strength of concrete with natural aggregates is on average 35.6 MPa [42].

With the 4 specimens manufactured with 100% CDW aggregates and a 28-day casting, they were placed one by one in the universal testing machine until they broke and then the values were taken, obtaining a compressive strength of 23.8 MPa.

In [43] they make their laboratories in two phases where they use a pattern concrete and concretes with aggregate substitution with CDW, and the value obtained with a specimen 100% substitution and age 28 days 33.25 Mpa compressive strength.

The compressive strength value obtained by [44] from concrete made with 100% recycled aggregates and 28 days of casting is 36.7 MPa.

The compressive strength obtained in [37] for concrete with CDW aggregate is 33 MPa, while the result for the compressive strength of recycled concrete in [45] is

25.5 MPa and with the 100% recycled concrete analyzed in [46] the compressive strength is 32.04 MPa.

4. Analysis of results

The results obtained experimentally are compared with those found by various authors in scientific databases.

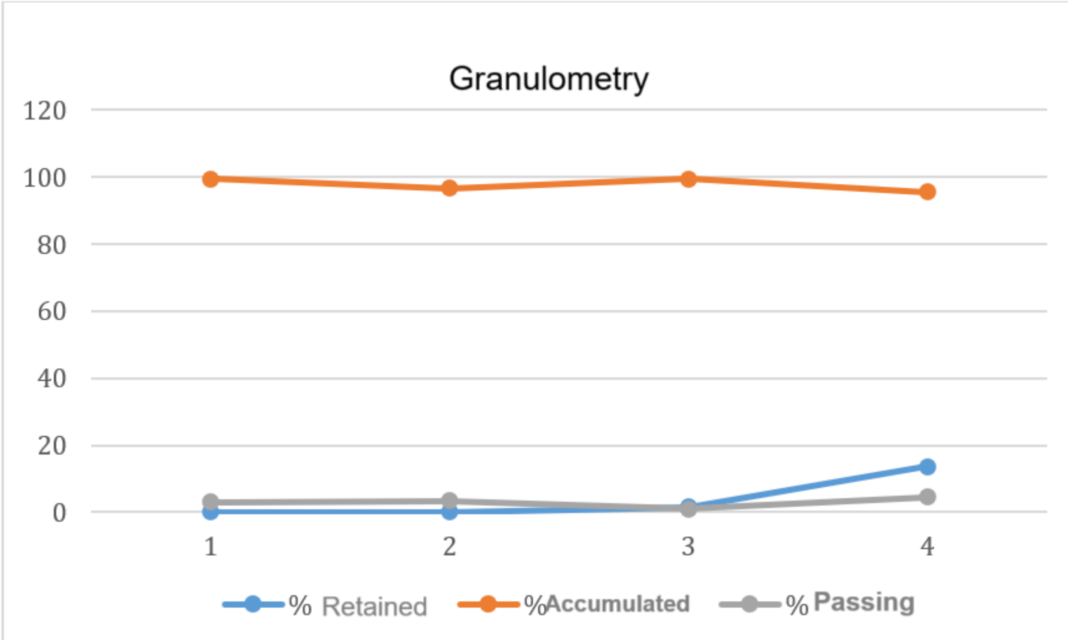
Table 2 presents the granulometry in a test performed with a 0.15mm sieve (No. 100) and with an age of 28 days.

Table 2. Tabulation of granulometry

GRANULOMETRY			
	% Retained	% Accumulated	% Passing
Authors	0.1	99.4	3
[36]	0.0	96.6	3.4
[37]	1.5	99.38	1
[38]	13.57	95.48	4.52

The graph of the granulometry percentages is shown in Figure 1.

Figure 1. Granulometric distribution



The statistical analysis of granulometry is found in Table 3.

Table 3. Statistical analysis of granulometry

% Retained		% Accumulated		% Passing	
Mean	3,7925	Mean	97,715	Mean	2,98
Standard error	3,2771	Standard error	0,9937	Standard error	0,7342
Median	0,8	Median	97,99	Median	3,2
Standard deviation	6,5542	Standard deviation	1,9874	Standard deviation	1,4684
Sample variance	42,9575	Sample variance	3,9499	Sample variance	2,1562
Kurtosis	3,7679	Kurtosis	-4,4747	Kurtosis	1,5734
Skewness	1,9363	Skewness	-0,2675	Skewness	-0,8497
Coefficient of variation	48,2992	Coefficient of variation	50,7003	Coefficient of variation	41,7165

Analyzing the kurtosis, it is evident that the percentage retained and the percentage that passes have a leptokurtic distribution, indicating that the highest concentration of data is close to the mean, while the accumulated percentage is a flat distribution tending to the tails of the distribution having a platykurtic kurtosis and having atypical data.

The coefficient of variation indicates that the data have a heterogeneous behavior and for this reason it is concluded that they are dispersed with respect to the values of central tendency.

The data in Table 4 shows the compressive strength of various authors taken in concrete with CDW and age of 28 days.

Table 4. Compressive strength tabulation

COMPRESSIVE STRENGTH	
Authors	23.8 MPa
[43]	33.25 MPa
[44]	36.7 MPa
[37]	33 MPa
[45]	25.5 MPa
[46]	32.04 Mpa

The distribution of the data is shown in Figure 2 and the respective statistical analysis can be found in Table 5.

Figure 2. Compressive strength distribution

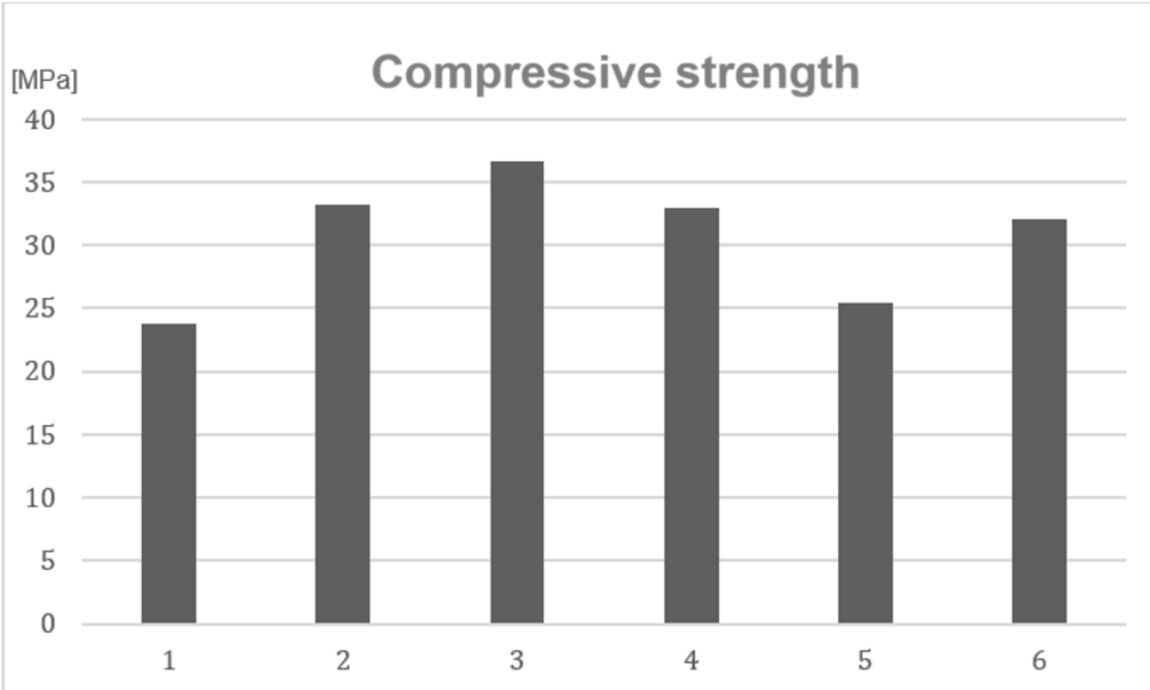


Table 5. Statistical analysis of compressive strength

Compressive strength	
Mean	30,715
Standard error	2,035
Median	32,52
Standard deviation	4,9847
Sample variance	24,8473
Kurtosis	-1,2829
Skewness	-0,5511
Coefficient of variation	16,2289

It is evident that the resistance values found in the different tests are close because the coefficient of variation is less than 25%, it can also be observed that the standard deviation is low, which indicates that there is homogeneity in the data and that they are close to the mean, so they do not present great dispersion.

Although a platykurtic distribution is evident because the kurtosis has a negative value so its trend is flat, indicating that there are outliers that make them move away from the mean. The percentage error using the compressive strength standard value given in [42] is used.

$$\%Error = \frac{|30{,}71 - 35{,}6|}{35{,}6} * 100 = 13{,}73\% \quad (1)$$

This analysis leads us to improve the preparation of the samples by changing the percentage of recycled aggregates, and also possible to change the number of tests performed by having an adequate number of specimens that allows for more consistent data.

5. Conclusions

The total replacement of natural aggregates by CDW in concrete is not convenient because its mechanical properties are affected, hat is to say, there are negative effects on mechanical properties compared to fresh concrete [47] [48] observing that the higher the percentage of replacement, the more its properties will be affected [49], which allows to deduce that recycled concretes with CDW can be used in construction applications but it depends on the percentage of recycled coarse aggregates it contains [44].

The recycling and reuse of these materials contribute to environmental conservation and to the natural sources of materials, so it is necessary to adapt sites that serve as collection centers where this type of waste can be taken as final disposal [50].

It can be determined that CDW can be used as aggregates to be reused in construction processes, thus avoiding the exploitation of natural resources and contributing to the environmental impact.

Finally, economic benefits can also be obtained with the use of this concrete by making the respective balance of natural aggregates and aggregates from CDW [49].

As future research, the economic impact of the use and reuse of these materials obtained from CDW can be studied by controlling the production of these wastes using manuals or policies for their reduction, recycling and use, becoming a collaborative work between the different users of the construction industry.

Similarly, the environmental impact obtained with the use and effective control of CDW in areas of the country where construction projects are currently being carried out, including leachates, carbon footprint and natural resources, can be emphasized.

It is also possible to work with the elaboration of concrete with different ratios of CDW, water and aggregates, determining the different properties, durability and appropriate applications having a relevant and reliable characterization of this concrete elaborated with CDW.

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