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EVALUATION OF PHYSICAL MECHANICAL PROPERTIES IN CONCRETE PAVERS MADE WITH CONSTRUCTION AND DEMOLITION WASTE

Jhonatan Alexander Becerra Duitama [1], Jhonattan Andrés Echeverría Avella [2], Paula Andrea Galvis Echeverría [3]

[1] Master in mechatronics engineering, professor, Juan de Castellanos University, jalexanderbecerra@jdc.edu.co.
[2, 3] Civil engineer, Juan de Castellanos University.

ABSTRACT

In this study concrete pavers replacing natural coarse aggregate with recycled coarse aggregate were manufactured. The substitution percentages were 15%, 30% and 45%. The chief characteristics studied for coarse aggregate were particle size, bulk density and specific density. The chief characteristics studied in the pavers were water absorption, density and flexural strength. It was observed that the density of the pavers decreased by increasing percentage of recycled coarse aggregate replacement due to the due to the high porosity of the recycled aggregates. On the other hand, it was found that the pavers with a 15% substitution were the only ones that reached the average flexural tensile strength indicated in the standard. It was concluded that the manufactured pavers can be used in areas with high rainfall or high-water tables, as well as in car parks or sidewalks.

Keywords: Recycled coarse aggregate; paver; construction and demolition wastes; flexural tensile strength; water absorption.

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EVALUACIÓN DE LAS PROPIEDADES FÍSICO-MECÁNICAS EN ADOQUINES DE CONCRETO FABRICADOS CON RESIDUOS DE CONSTRUCCIÓN Y DEMOLICIÓN

RESUMEN

En este estudio se fabricaron adoquines de concreto sustituyendo el agregado grueso natural por agregado grueso reciclado. Los porcentajes de sustitución fueron del 15%, 30% y 45%. Las principales características estudiadas en los agregados gruesos fueron la granulometría, la densidad aparente y la densidad específica. Por otro lado, las principales características estudiadas en los adoquines fueron la absorción de agua, la densidad y la resistencia a la flexión. Se observó que la densidad de los adoquines disminuyó al aumentar el porcentaje de sustitución del agregado grueso reciclado debido a la alta porosidad presente en los agregados reciclados. A su vez, se encontró que los adoquines con una sustitución del 15% fueron los únicos que alcanzaron la resistencia a la flexión indicada en la norma. Se concluyó que los adoquines fabricados pueden ser utilizados en zonas de alta pluviosidad o con altos niveles freáticos, así como en parqueaderos o aceras.

Palaras clave: *Agregado grueso reciclado; adoquín; residuos de construcción y demolición; resistencia a la flexión; absorción de agua.*

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1. INTRODUCTION

One of the industrial sectors that has the greatest impact on the environment is construction. Some of the impacts generated are deforestation and soil erosion, contamination of adjacent water sources, the impact on nearby fauna and flora [1], the impact on people's health, energy consumption and the depletion of non-renewable raw materials. Among the construction materials that cause these environmental impacts are masonry bricks, asphalt and concrete, the latter being the most widely used worldwide [2].

The main component of concrete is Portland cement [3]. During 2020, 4.1 billion metric tons of cement were produced in the world. Likewise, the production of concrete worldwide is almost 25 billion tons per year; Furthermore, it is estimated that to produce concrete, around 20 billion tons of raw materials are used each year [4]. On the other hand, the cement industry contributes 10% of greenhouse gas emissions and 15% of total electricity consumption worldwide [5].

To try to reduce the aforementioned impacts, different wastes have been used as alternatives to cement or concrete aggregates, such as construction and demolition waste (CDW) [6,7]. It should be noted that CDW have several negative impacts on the environment, such as affecting the health of the nearby inhabit-ants, the direct impact on the landscape, the contamination of water sources, the impact on compaction and the use of the soils, clogging of rainwater harvesting systems, among others [8].

In order to mitigate the aforementioned impacts, construction and demolition waste has been used in some civil engineering applications. For example, as material for the bases or sub-bases in the construction of paved roads [9], to build dyke foundations [10], as alternative materials for filling pipes [11], as a cover layer for landfills [12], as a coarse aggregate for permeable pavements [13], as aggregates for concrete and to produce bricks and blocks [9].

In this study, demolition and construction waste was implemented in concrete pavers, replacing 15%, 30% and 45% of natural coarse aggregate with recycled coarse aggregate, taking into account the NTC 2017 standard. Some of the properties that were studied they were the resistance to the flexo-traction, the absorption of water and the density.

2. MATERIALS AND METHODS

2.1 Selection of raw materials

The recycled material was obtained from a soil laboratory located in the city of Tunja, Colombia. This is made up of concrete cylinders that have been subjected to compression resistance tests. In order to implement this residue, it was subjected to a mechanical crushing process in order to obtain a granular material similar to the natural aggregate used for the production of concrete. The crushing was carried out in a plant located near the city of Tunja, dedicated to the production of aggregates for construction. Four nominal maximum sizes were obtained from the crushing process: 1 inch, 3/4-inch, 1/2 inch and 3/8 inch, in addition to fine material. For the elaboration of the concrete pavers, the aggregate with a nominal maximum size of 1/2 inch was chosen. These aggregates were characterized by physical techniques, such as fineness modulus, absorption percentage and bulk density.

2.2 Mix Design

For the mix design, the provisions of the American Concrete Institute (ACI) were taken into account. The calculations carried out were established to obtain absolute volumes and find the necessary dosages to produce 1 m^3 of concrete.

2.3 Tests of resistance to bending-traction, water absorption and density

Pavers in the shape of a rectangular parallelepiped were manufactured with the dimensions shown in Figure 1. Five specimens were made for each percentage of substitution (15%, 30% and 45%). To elaborate the paving stones, the Colombian Technical Standard NTC 2017 was taken as a reference [14], which establishes the requirements and characteristics for the construction of concrete paving stones implemented in pedestrian and vehicular traffic and distributed static loads. To corroborate compliance with the characteristics of the elaborated specimens, the absorption, density and flexo-traction tests were carried out. The pavers were faulted 28 days after curing.

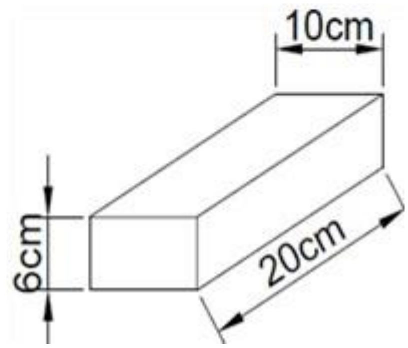

Figure 1. Dimensions of the manufactured pavers.

3. RESULTS

In order to obtain the results, it was necessary to make tests on the aggregates, to choose the best combination of materials for the mix conformation and to make tests on the manufactured pavers. The procedure developed to obtain the results is explained below.

3.1 Obtaining the aggregates

Through the granulometric analysis of the recycled coarse aggregate and the natural aggregate, the values of maximum natural size were obtained. The recycled aggregate presented a classification by size of 93.47% gravel, 0.57% corresponding to sand and 5.96% to fine material. On the other hand, Figure 2 shows the granulometric curve obtained by the sieving analysis test carried out on these materials

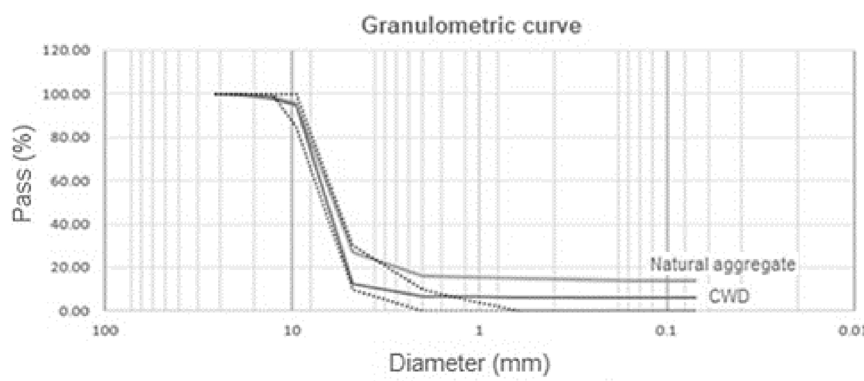

Figure 2. Granulometric curve for coarse aggregates.

As a preventive measure, the natural aggregate was washed to reduce the amounts of fine material, so that it complies with the required gradation and thus reduce the possible negative effects that it can generate on the results. On the other hand, the fineness modulus obtained was 2.39, this classifies the material as fine sand and is acceptable as required by the standard. Likewise, Figure 3 shows the data of the bulk density for the natural coarse aggregate and for the recycled coarse aggregate.

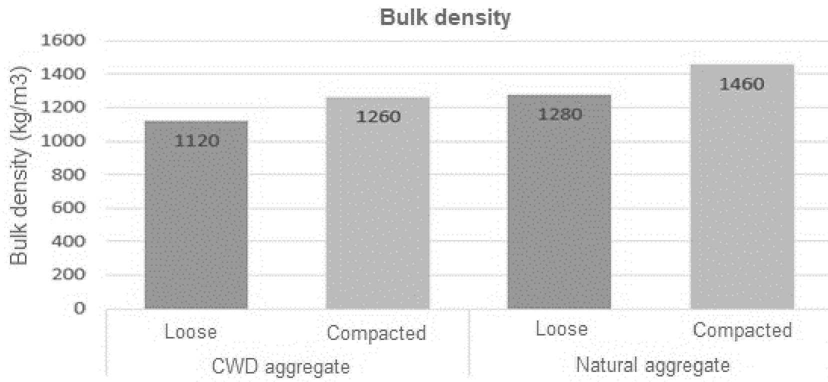

Figure 3. Bulk density for coarse aggregates.

Figure 4 presents the specific gravity for coarse aggregates, in which the reduction of 17.2% is observed, reflecting the greater presence of pores in the recycled aggregate grains.

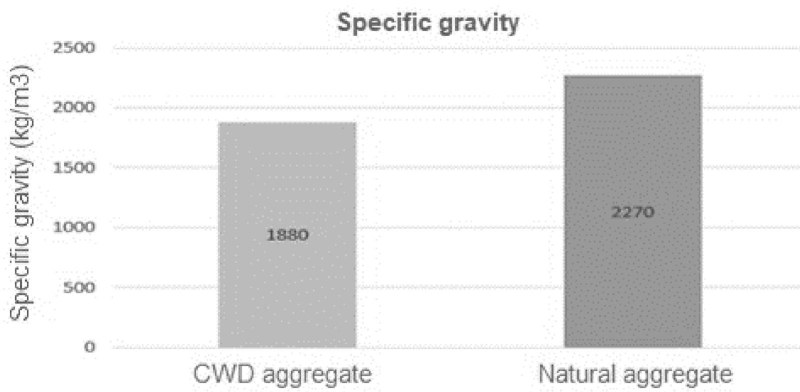

Figure 4. Specific gravity for coarse aggregate.

3.2 Conformation of the mixture

Table 1 shows quantity and dosage of materials for 1 m^3 of concrete. It can be observed that, as the amount of replacement percentage increases, the amount of water in the mixture increases; It can be observed that, as the amount of replacement percentage increases, the amount of water in the mixture increases.

Table 1. Quantity and dosage of materials for 1 m^3 of concrete.

Replacement percentage	15	30	45
Proportion	1:1.72:0.27:1.39	1:1.42:0.54:1.38	1:1.11:0.81:1.36
Compressive strength f'c (psi)	3500	3500	3500
Cement (kg)	424	424	424
Natural coarse aggregate (kg)	729.14	600.47	471.79
Recycled coarse aggregate (kg)	113.84	227.68	341.52
Fine aggregate (kg)	588.24	582.66	577.08
Water (L)	258.47	264.09	269.71

3.3 Carrying out the tests on paving stones

Figure 5 shows the absorption values for paving stone specimens with substitution percentages of 15% (AD15), 30% (AD30) and 45% (AD45).

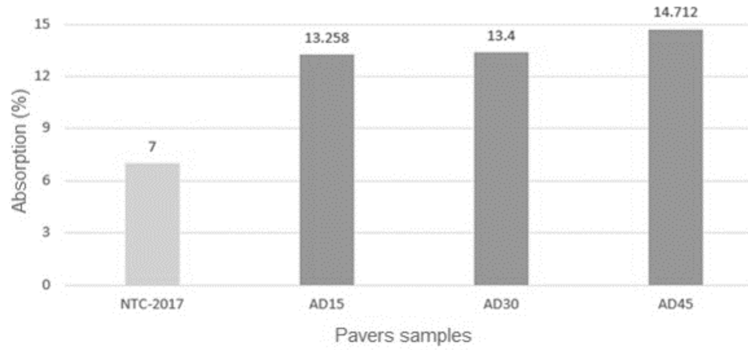

Figure 5. Absorption obtained for modified pavers specimens.

On the other hand, in Figure 6, the density values obtained for each of the percentages of substitution of coarse aggregates by CDW in paving stones are observed.

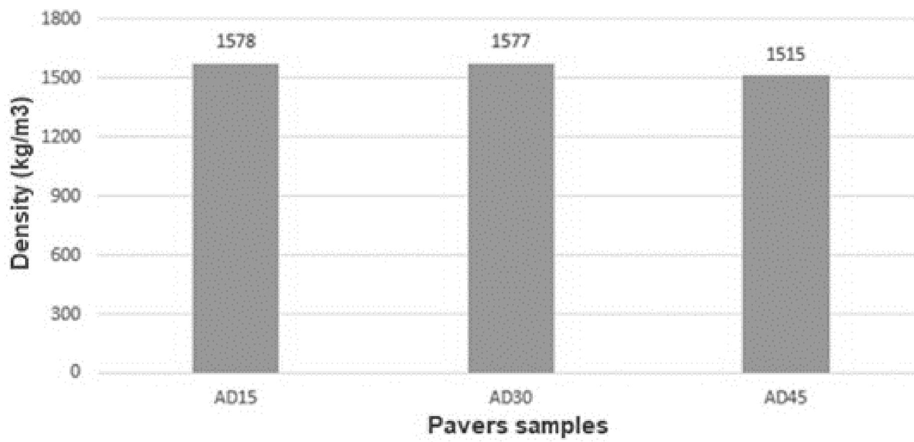

Figure 6. Density obtained for modified pavers specimens.

Figure 7 shows the results obtained for the modulus of rupture of the paving stones in saturated condition, which indicated that only the 15% substitution percentage managed to comply with the flexural-tensile strength required by the NTC 2017 standard.

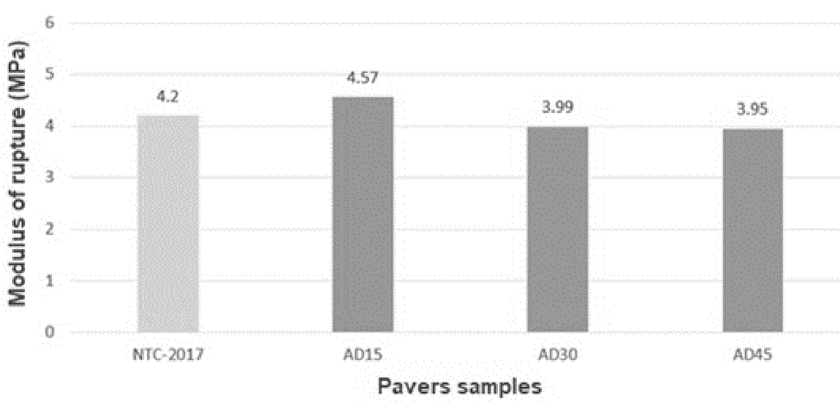

Figure 7. Values of modulus of rupture in saturated condition for paving stone specimens.

In turn, Figure 8 shows the internal structure of three paving stones with different substitution percent-ages after carrying out the flexo-traction test.

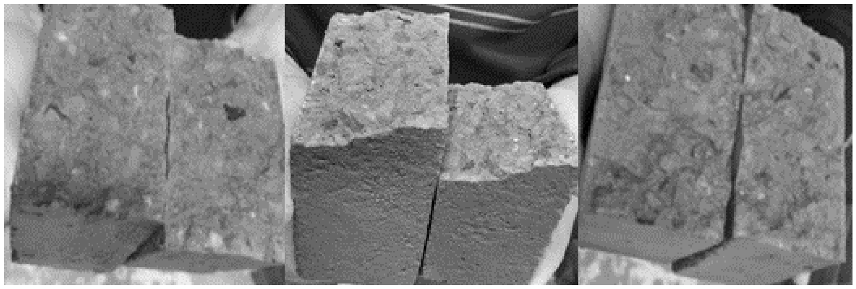

Figure 8. Internal parts of pavers.

4. DISCUSSION

It was observed that there was no considerable discontinuous gradation and that the fines present are the product of the separation of the particles that make up the mortar from the recycled cylinders. For the fineness modulus obtained, the concrete will have a representative fluidity, which can facilitate the process of mixing and placing it in the previously designed molds, generating a homogeneity of the concrete.

With respect to bulk density, it can be seen that there is not a considerable difference between the two materials. This is due to the crushing process used, since, in both cases, it was carried out in the same plant, generating a similarity in the shape and size of the grains. This allows the voids between particles to be simi-lar and the changes that occur are only governed by the internal porosity of each material.

On the other hand, the absorption percentage of the recycled aggregate is higher than that of the nat-ural coarse aggregate. This characteristic may vary depending on the origin of the CDW; Furthermore, the aggregates considered light weight have absorption values higher than those obtained in this test, but their implementation in concrete has presented characteristics that approve their use.

In addition, when designing the mix, it is observed that the substitution by CDW means a higher volume and less weight of coarse aggregates in the mix. Likewise, these values indicate that the variation in the absolute volume of the fine aggregate will decrease as the percentage of substitution increases. On the other hand, the amount of water will vary because humidity corrections must be made for each of the substitution cases.

Table 1 shows that, by including CDW, the amount of coarse and fine aggregate is decreased, this is because the method used is based on the absolute volume of the materials. It can be noted that the density decreases as the implementation of CDW in the mix increases [15]. On the other hand, the amount of water increases as indicated by some studies carried out [16-18]. In these it was shown that the absorption and porosity that the recycled aggregate presents in its natural state, is the reason why the quantity must be in-creased to make the mixture.

The results obtained for the absorption percentages exceed the ranges required by the NTC 2017 stand-ard. Similarly, it is verified that the low density attributed to the high porosity and the poor gradation of the recycled aggregate, generated in the concrete the condition of permeability and greater water ab-sorption. Therefore, the possibility of implementing these paving stones should be evaluated in places where saturated environments are present, and to avoid the accumulation of water on the surface of the roads or platforms, thus taking advantage of the permeability and absorption that these present.

As mentioned above, the water absorption exceeds the required ranges, directly influencing the de-crease in resistance. Also, it was observed that, in the paving stones with a percentage greater than 15% of substitution, a similar average resistance was presented, in contrast to the other percentage of substitution.

In the failure of the specimens there was no detachment of particles, the fracture was presented in a clean and direct way. In turn, the natural coarse aggregate differs by its orange colour and it can be seen that the paving stone on the left side has a greater quantity of these, since the substitution was 15% compared to the one on the right, which was 45%.

On the other hand, the recycled aggregate stands out for its dark grey and pale grey grains, which come from the mortar contained in the recycled concrete cylinders. It is noted that these grains were not fractured tangentially to the fracture line of the paving stone, this indicates that the paving stone had a joint response between all the components against the stress to which it was subjected.

Additionally, it is observed in the figures, that the material was distributed efficiently, there were no concentrations of CDW in specific places. Demonstrating that the integration of this material with the rest was efficient, and achieves a homogeneous structure, which reduces adverse effects on the performance of the concrete.

5. CONCLUSIONS

Concrete pavers were manufactured replacing the natural coarse aggregate with recycled coarse concrete aggregate (CDW), in percentages of 15%, 30% and 45%. The density of the recycled pavers decreased as the percentage of substitution increased, because the recycled coarse aggregate has a higher porosity caused by the amount of recycled mortar particles present in the mix. For this reason, the absorption percentage of the pavers reached high values, which exceed the ranges of the norm. However, these paving stones can be implemented in adverse environments, such as areas with high rainfall or high-water tables.

On the other hand, the flexo-traction for the replacement of 15% in the paving stones, met the aver-age resistance indicated in the NTC 2017. For the rest of the evaluated percentages, the result did not reach the required range, but the values at being so close to this, they can be evaluated for the use of paving stones intended for the construction of structures, where the loads are less demanding such as parking lots and platforms.

Given the aforementioned results, it is recommended to look for an aggregate or material, which can complement and improve the characteristics of the recycled aggregate, so as not to restrict the use of this CDW in paving stone concrete. It is recommended to carry out the following tests, which were not carried out in this investigation, but are important to give a better characterization of the materials and paving stones studied: resistance to abrasion for paving stones and resistance of the coarse aggregate to degradation by abrasion.

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REFERENCES

[1] Sani, R., & Nzihou, A. (2017). Production of clay ceramic using agricultural wastes: Study of properties, energy savings and environmental indicators. Applied Clay Science, 146, 106-114. https://doi.org/10.1016/j.jclepro.2013.11.005

[2] Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews, *29*, 394-416. https://doi.org/10.1016/j.rser.2013.08.037

[3] Scrivener, K. L., & Nonat, A. (2011). Cement and Concrete Research Hydration of cementitious materials, present and future. Cement and Concrete Research, 41(7), 651-665. https://doi.org/10.1016/j.cemconres.2011.03.026

[4] Kisku, N., Joshi, H., Ansari, M., Panda, S. K., Navak, S., & Dutta, S. C. (2017). A critical review and assessment for usage of recycled aggregate as sustainable construction material. Construction and Building Materials, 131, 721-740. https://doi.org/10.1016/j.conbuildmat.2016.11.029

[5] Hossain, U., Sun, C., Hong, Y., & Xuan, D. (2018). Evaluation of environmental impact distribution methods for supplementary cementitious materials. Renewable and Sustainable Energy Reviews, 82, 597-608. https://doi.org/10.1016/j.rser.2017.09.048

[6] Shi, C., Li, Y., Zhang, J., Li, W., Chong, L., & Xie, Z. (2016). Performance enhancement of recycled concrete aggregate - A review. Journal of Cleaner Production, 112, 466-472. https://doi.org/10.1016/j.cemconres.2011.03.026

[7] Becerra-Duitama, J. A., & Rojas-Avellaneda, D. (2022). Pozzolans: A review. Engineering and Applied Science Research, 49(4), 495-504. https://doi.org/10.14456/easr.2022

[8] Wu, H., Zuo, J., Zillante, G., Wang, J., & Duan, H. (2021). Environmental impacts of cross-regional mobility of construction and demolition waste: An Australia Study. Resources, Conservation and Recycling, 174, 105805. https://doi.org/10.1016/j.resconrec.2021.105805

[9] Zhang, J., Ding, L., Li, F., & Peng, J. (2020). Recycled aggregates from construction and demolition wastes as alternative filling materials for highway subgrades in China. Journal of Cleaner Production, 255, 120223. https://doi.org/10.1016/j.jclepro.2020.120223

[10] Vieira, C. S., & Pereira, P. M. (2015). Use of recycled construction and demolition materials in geotechnical applications: A review. Resources, Conservation and Recycling, 103, 192-204. https://doi.org/10.1016/j.resconrec.2015.07.023.

[11] Rahman, M., Imteaz, M., Arulrajah, A., & Disfani, M. M. (2014). Suitability of recycled construction and demolition aggregates as alternative pipe backfilling materials. Journal of Cleaner Production, 66, 75-84. https://doi.org/10.1016/j.jclepro.2013.11.005

[12] Rahman, M. A., Arulrajah, A., Piratheepan, J., Bo, M. W., & Imteaz, M. A. (2014). Resilient Modulus and Permanent Deformation Responses of Geogrid-Reinforced Construction and Demolition Materials. Journal of Materials in Civil Engineering, 26(3), 512-519. https://doi.org/10.1061/(asce)mt.1943-5533.0000824

[13] Monrose J., Tota-Maharaj, K., & Mwasha, A. (2019). Assessment of the physical characteristics and stormwater effluent quality of permeable pavement systems containing recycled materials. *Road Materials and Pavement Design*, *22*(4), 1-33. https://doi.org/10.1080/14680629.2019.1643397

[14] ICONTEC (2018). NTC 2017 Adoquines de concreto para pavimentos. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC)

[15] Kumar, G., Shrivastava, S., & Gupta, R. C. (2020). Paver blocks manufactured from construction & demolition waste. Materials Today: Proceedings, 27, 311-317. https://doi.org/10.1016/j.matpr.2019.11.039

[16] Evangelista, L., Guedes, M., De Brito, J., Ferro, A. C., & Pereira, M. F. (2015). Physical, chemical and mineralogical properties of fine recycled aggregates made from concrete waste. Construction and Building Materials, 86, 178-188. https://doi.org/10.1016/j.conbuildmat.2015.03.112

[17] Lovato, P. S., Possan, E., Molin, D. C. C. D., Masuero, Â. B., & Ribeiro, J. L. D. (2012). Modelling of mechanical properties and durability of recycled aggregate concretes. Construction and Building Materials, 26(1), 437-444. https://doi.org/10.1016/j.conbuildmat.2011.06.043

[18] Pepe, M., Toledo Filho, R. D., Koenders, E. A. B., & Martinelli, E. (2014). Alternative processing procedures for recycled aggregates in structural concrete. Construction and Building Materials, 69, 124-132. https://doi.org/10.1016/j.conbuildmat.2014.06.084