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Construction and demolition waste as raw material in pavements layers

F.A.N. Silva[1], M.T.A. Silva[1], J.M.P.Q. Delgado*[2], A.C. Azevedo[2], G.F.C. Pereira[2]

[1] UNICAP-ICAM TECH, Curso de Engenharia Civil, Universidade Católica de Pernambuco, Recife (Brazil), fernando.nogueira@unicap.br, marcelajtavares@hotmail.com

[2] CONSTRUCT-LFC, Departamento de Engenharia Civil, Universidade do Porto, Rua Dr. Roberto Frias, Porto (Portugal), jdelgado@fe.up.pt, antonio.costaazevedo@fe.up.pt, up201911749@fe.up.pt

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Abstract: The proper management of demolition construction waste from the construction industry is an issue that has gained relevance over the last years in several research centers around the world and, in this context, researches on the potential of using construction and demolition waste to execute pavement layers have been stood out. The paper presented results of a research performed to evaluate the characteristics of the material produced by a waste treatment/beneficiation industrial plant. Tests to verify the suitability of the material as pavement subbase material were performed according Brazilian code - grain-size distribution composition, maximum characteristic dimension, shape particle index (SPI), contaminant percentage and sieving process. The results obtained indicated that the recycled aggregates investigated performed well in all the requirements of the reference standards used and only one correction, related to grain size distribution, was performed using a sieving process. It is important to highlight that the tests and analyses must be performed constantly when forming each aggregate batch, since the recycled aggregates are usually quite heterogeneous, with characteristics that may vary depending on the type of work, construction materials used or period of the year.

Keywords: sustainability, construction and demolition waste, recycling, pavement layers, laboratory tests.

1. Introduction

1.1. Brief state of the art

Sustainable development seeks to use natural resources, so that its exploitation is rationally, without causing damage to the environment in the short and/or long term. Alternative ways of replacing these resources are increasingly being explored, as is the case of recycled construction and demolition waste (RCDW) used as raw material in urban pavement bases. As a result, numerous efforts have been spent on developing recommendations, specifications and research in order to manage the application of waste in civil works, transforming them into value-added materials. In addition, the use of RCDW presents positive results from an environmental, technical and economic point of view (Awed et al., 2021; Beja et al., 2020; Arab et al., 2020; Tarbay et al., 2019). During the last years, instead of disposing of construction and demolition waste (CDW) in landfills, this material has been considered for replacing natural aggregates (Aldana & Serpell, 2016; Martinez et al., 2016). Sustainable pavements using recycled materials have become essential for maintaining natural resources, reducing potential environmental impacts, and improving the potential economic value of recycling (Dong et al., 2017). From the environmental point of view, the main problem with this type of waste is related to its irregular deposition and the large volumes produced. These irregularly deposited waste cause flooding, proliferation of harmful vectors, partial interdiction of roads and degradation of the environment. In some cases, such landfills are occupied by irregular dwellings in places where there is risk, resulting in accidents and loss of life (John & Agopyan, 2000).

At the same time, the construction and maintenance of urban roads have generated an expressive consumption of raw material which is extracted from natural deposits. However, the restrictions imposed by environmental legislation on the exploitation of natural resources have generated scarcity and high costs in the acquisition of raw materials. This impact is felt strongly by the road paving sector, which uses large volumes of natural resources, thus making it feasible to search for alternatives for replacing these materials with alternatives. From a technical point of view, numerous works have proven that the recycled aggregate has adequate performance for use in layers of floors (Mousa et al., 2017a; Azam & Cameron, 2013a; Azam & Cameron, 2013b). In most of these studies, satisfactory mechanical behaviors are presented for use on floor basis. Leite et al. (2011) identified from resilience module assays that both RCDW and a natural aggregate presented similar behaviors. Arulrajah et al. (2012) observed relatively high values of the friction angle for RCDW from tri-axial assays. Herrador et al. (2012) observed from an experimental field study that the support capacity presented with the use of RCD presented behavior similar to that observed for a structure with conventional aggregates. Such studies, among others, corroborate the performance that this alternative material presents.

From the economic and sustainable point of view, the use of RCD presents aspects of great relevance, and it is not necessary to explore new deposits. Carneiro et. al. (2001) mentions that the evaluation of economic aspects is of fundamental importance to promote the acceptance of this form of RCDWs. The recycling of CDWs also contributes to quality and safety of urban roads reducing costs in maintenance, rehabilitation and reconstruction actions. Ricci (2007) points out that a road in bad conditions causes a 57% increase in fuel consumption, 37% in operating costs and 50% in accidents. On the other hand, it has been increasingly common to use sustainability practices such as 3R (recycle, reuse and reduce) in the construction of civil works. Works such as the one developed by Calvo et al. (2014) highlight the main positive points of construction and demolition waste management practices. However, the considerations presented above are rarely discussed together, in order to weigh the environmental, technical and economic aspects related to the application of RCDW as part of the flexible pavement structure. In fact, an integrated discussion allows us to analyze which aspects are most important for the feasibility of an enterprise with the use of the technique.

In Brazil, civil construction occupies a prominent place in the economy, urban development, industrial and service provision. In recent years, the sector has shown remarkable growth, and with this, the need to expand the necessary infrastructure for the development of its activities. However, this growth results in the generation of waste, which does not always have a correct destination. Thus, it is observed that this residue in many cases acts as an environmental liability, resulting in several problems due to the lack of adequate management. According to the Brazilian Association of Public Cleaning and Special Waste (ABRELPE, 2013) it is estimated that Brazil generates more than 50 million tons per year of waste from civil construction. The execution of urban roads requires a considerable amount of material for their execution. In a brief estimate, considering a typical structure of an urban road with 7.5 meters wide where it is necessary a consumption greater than 2250 m^3/km of virgin material for the execution of 30 cm of compacted graduated gravel base. Thus, the use of waste in the execution of road works also depends on the volume offered by it. The RCDW collected, in this case, present satisfactory volumes to enable practical use in urban paving works. Thus, verifying the large volume of waste that has the potential to be recycled, it is essential to analyze a policy of reuse and recycling of RCDW.

The overall objective of this research was to evaluate the feasibility of using recycled construction and demolition waste originating from a waste treatment/benefit plant to execute pavement layers to verify its conformity with standard demands of codes of design and construction. In order to obtain a material that presents good workability and allows laboratory tests for control, it is essential to compose the mixtures in the grain-size distribution ranges defined by NBR 15116 (2004). In the construction of bases and sub-bases of pavements it was verified that the recycled aggregates from RCDW are an excellent material and it was observed the technical feasibility of using the recycled aggregate in the construction of urban paving works, since they presented low expansion values (Silva et al., 2010). It is important to highlight that the results obtained with the RCDW used depends on the type of aggregates produced and tests and analyses must be performed constantly when forming each aggregate batch, since the recycled aggregates are usually quite heterogeneous, with characteristics that may vary depending on the type of work, construction materials used or period of the year.

2. Materials and methods

2.1. *Materials*

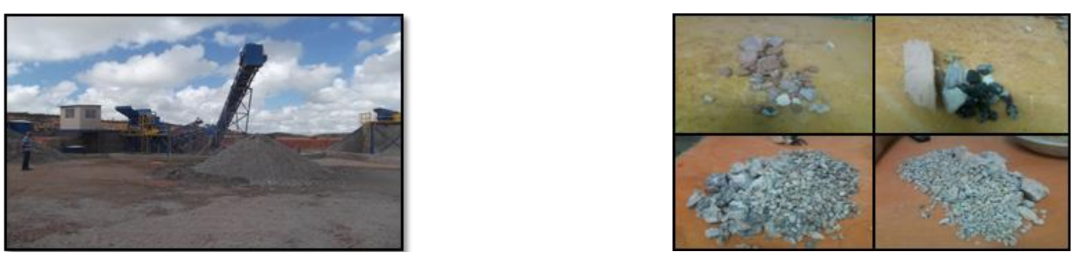
The general requirements that a recycled aggregate must present for use in paving, according to NBR 15116 (2004), are illustrated in Table 1.

Table 1. General requirements for recycled aggregate for paving (Source: NBR 15116, 2004).

Properties		Recycled aggregate class A		Standards and tests (aggregate)	
		Coarse	Fine	Coarse	Fine
Grain-size distribution composition		Non-uniform and well-graduated with uniformity coefficients $C_U > 10$		NBR 7181 (2016)	
Maximum characteristic dimension		≤ 63		NBR NM 248 (2016)	
Shape particle index (SPI)		≤ 3	-	NBR 7809 (2006)	-
Passing material content in the 0.42 mm sieve		Between 10% and 40%		NBR 7181 (2016)	
Contaminants (%) - maximum levels in relation to the mass of the recycled aggregate	Non-mineral materials of the same characteristics[1]	2		Annex A	Annex B
	Non-mineral materials of different characteristics[1]	3		Annex A	Annex B
	Sulphates	2		NBR 9917 (2009)	

[1)] For the purposes of this standard, they are examples of non-mineral materials: wood, plastic, bitumen, charred materials, glass and ceramic glazing.

Considering the early works presented in literature, this work aimed to evaluate the application of RCDW aggregate, coming from the Recife Metropolitan Region (Brazil), as pavement subbase material. Laboratory tests were performed to determine the physical characteristics of RCDW and mechanical properties. The RCDW material used in this study came from the company CTR Candeias, which is installed in the landfill in the Muribeca neighborhood, in the city of Jaboatão dos Guararapes, Pernambuco. Figure 1 illustrates the facilities of the recycling plant. The methodology used for the physical characterization and performance evaluation strictly followed the recommendations of the following Brazilian standards: NBR 15115 (2004) and NBR 15116 (2004). Following the recommendations of NBR 15116 (2004) to achieve a quality control regarding the material characterization, the samples were the most representative possible, in accordance with the procedures detailed in NBR NM 26 (2001) and NBR NM 27 (2001). The lot was formed by receiving the material during a period of one month, from which the partial samples were taken, which corresponds to random collections twice a day of 10 kg each. Finally, the field sample was reduced to the test sample, following the recommendations of NBR NM 27 (2001) by the quartering process.



(a) (b)

Figure 1. (a) Solid waste recycling plant of civil construction, city of Jaboatão dos Guararapes, Pernambuco (Brazil) and (b) RCDW composition.

2.2. Materials characterization

The RCDW material used in this work contained 38.8% of crushed stones, 59.4% of recycled mortar/concrete aggregates, 1.2% of recycled ceramic aggregates and 0.6% of other materials (contaminants), such as wood, glass, plastic, paper, etc. According to the result of the composition, it is observed that the recycled aggregate is framed as concrete waste aggregate (CWA), that is, it presents the sum of the percentages of mortar/concrete paste and crushed stones greater than 90%, according to 15116 (2004), and can thus be used in pavement layers. Another criterion to be analyzed is the percentage of contaminant materials. In this case, this percentage was 0.6% and was therefore approved, since it meets the requirements listed in Table 1. Figure 1(b) represents the composition of the sample for determining the percentages. The physical characterization of RCDW aggregate was performed by the following laboratorial tests: analysis of grain size distribution, uniformity coefficient and particle shape index. Finally, for the mechanical characterization, the compaction and the Californian Bearing Ratio (CBR) tests were also performed.

In addition to these general requirements, the recycled aggregate must meet specific requirements. These requirements vary in terms of the type of use in the execution of floor layers, according to parameters of support capacity and swelling, according to Table 2. These tests were performed according to NBR 9895 (2017) that is equivalent to AASHTO T193 (2013) and ASTM D1883 (2016), for example.

Table 2. Specific requirements for recycled aggregates for paving (Source: NBR 15116, 2004).

Application	CBR (%)	Swelling (%)	Compaction energy
Material for reinforcing subgrade	≥12	≤1.0	Normal
Material for pavement primary surface course and subbase	≥20	≤1.0	Intermediate
Material for pavement base[1]	≥60	≤0.5	Intermediate or modified

[1)] For use as a base material only for traffic routes with $N \leq 10^6$ repetitions of the standard axis of 8.2tf (80KN) in the design period

3. Experimental results and analysis

All the results analysis of the tests carried out in the RCDW material was based on the requirements of the Brazilian standard NBR 15116 (2004) which defines the general and specific requirements for use in pavement layers.

3.1. Physical characterization

The three requirements required by NBR 15116 (2004) were analyzed in detail: (a) the uniformity coefficient, Cu; (b) the maximum aggregate diameter; and (c) the percent passing material content in the 0.42 mm sieve. The grain-size distribution composition test was performed according to the determinations of NBR 7181 (2016). Should be noted that all the material collected was sieved in a sieve of 6.3 mm (maximum aggregate diameter) and discarded the retained material.

Grain-size distribution was obtained through a sieve analysis and the results are presented in Figure 2 and Table 3.

Table 3. Grain-size distribution of the RCDW tested (Source: self-elaboration).

Sieves (mm)	50.8	38.1	31.5	25.4	19.1	12.5	9.52	6.30	4.75	2.36	1.18	0.60	0.42	0.30	0.15
Accumulated (%)	92.4	86.9	84.1	68.9	57.6	38.1	28.1	15	9.8	5.9	4.1	2.9	2.1	1.5	0.5

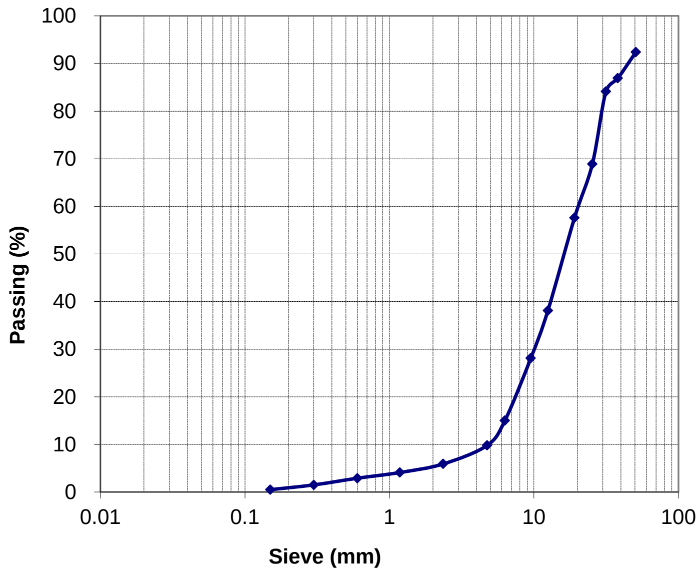


Figure 2. Grain-size distribution curve of the RCDW tested (Source: Self-elaboration).

The uniformity coefficient (Cu) is determined by the ratio of the diameters of the aggregates corresponding to 60% and 10% passing, as described by Eq. (1),

$$C_u = \frac{d_{60\%}}{d_{10\%}} \quad (1)$$

where $d_{60\%}$ is the diameter where 60% of the material passes and d10% is the diameter where 10% of the material passes. The result obtained was C_u=4.3, a value significantly lower than that specified by the standard. Thus, it is concluded that the material did not meet this requirement. For uniformity coefficient less than 5 the material is considered with uniform grain-size distribution. Moreover, as presented in Table 3 and Figure 2, the percent passing 0.42 mm sieve was approximately 2.1%, a value lower than the range established by the standard, which is in the range between 10% and 40%.

As the material under analysis did not meet two items, described by the standard, all correlated with grain-size distribution, its grain-size distribution stabilization was performed. The grain-size distribution correction process can be carried out in three ways: crushing of the material, mixing with other material, and sieving. In this research, it was opted for the process with low-cost which is the correction by the sieve. As the material presented an excess of coarse aggregates, the correction was performed in the 0.42mm sieve, which was the one that presented the non-conformity, and rejected a percentage of the material retained in this sieve. As the passing percentage in the 0.42 mm sieve is 2.1%, the correction by sieving was fixed that this percentage would be 25%, which would be within the range allowed by the standard. From this parameter, the new percentages were obtained in the other sieves, with a simple three-way rule and the percentage of rejected material in the part retained in the 0.42 mm sieve was 91.8%.

Table 4. New grain-size distribution of the RCDW tested, corrected by continuous sieving (Source: self-elaboration).

Sieves (mm)	50.8	38.1	31.5	25.4	19.1	12.5	9.52	6.30	4.75	2.36	1.18	0.60	0.42	0.30	0.15
Accumulated (%)	94.2	90.0	87.8	76.2	67.5	52.6	44.9	34.9	30.9	27.9	26.6	25.6	25.0	18.2	6.1

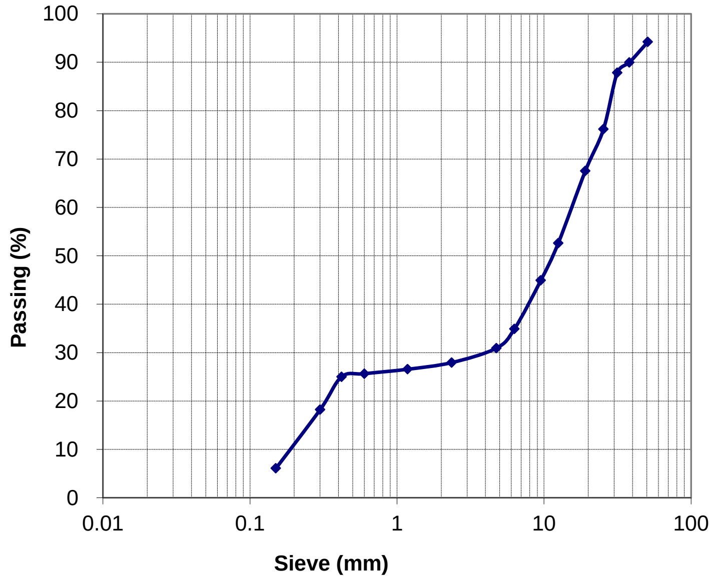


Figure 3. New grain-size distribution curve of the RCDW aggregate (Source: self-elaboration).

Table 4 and Figure 3 present the new grain-size distribution of the material after sieving correction. After the grain-size distribution correction, the two items that were in non-compliance with the standard were met. First, the percentage of passing material in the 0.42 mm sieve went from 2.1% to 25.0% and the uniformity coefficient (Cu) was also changed to 15.8. So, with this simple and low-cost procedure, these two parameters began to be within the values required by the standard and the RCDW material can thus be used in the manufacture of pavement layers. Finally, the standard NBR 15116 (2004) suggested that the shape particle index (SPI) must be less than or equal to 3. In order to verify how lamellar the grains were, the test was performed according to NBR 7809 (2006) and the value found for the recycled aggregate used in the research was 1.96, therefore, within the established limit.

3.2. Mechanical characterization

In order to analyze the specific requirements, the tests that determined the California Bearing Ratio (CBR) and the Swelling of the recycled aggregate were performed. In the compaction test, the standard establishes that the energy applied is intermediate. Thus, the test was performed and the compaction curve was obtained, and thus the parameters for the California Support Index were removed, and the value of the optimum moisture content of 10.28% and the maximum dry density of 1509 kg/m³ was obtained, which can be observed in Figure 4.

A specimen was molded with intermediate energy to perform the California Support Index test. This test also provides the swelling of the material. Figure 5 exposes the information in this assay. The results showed that the material tested can only be used in a pavement subbase, since its CBR was 29.8% and the swelling of 0.1% is made within the limit established by the standard. Finally, it is possible to find in literature several resilient modulus models to predicted (M_r) values depending on material properties, such as CBR (Mousa et al., 2017b). For materials with CBR > 10%, the following equation is suggested,

$$M_r = 2555 \times CBR^{0.65} \quad (2)$$

where M_r is the resilient modulus (psi). For that case, with a CBR equal to 29.8% it was obtained a resilient modulus of 23207.7 psi.

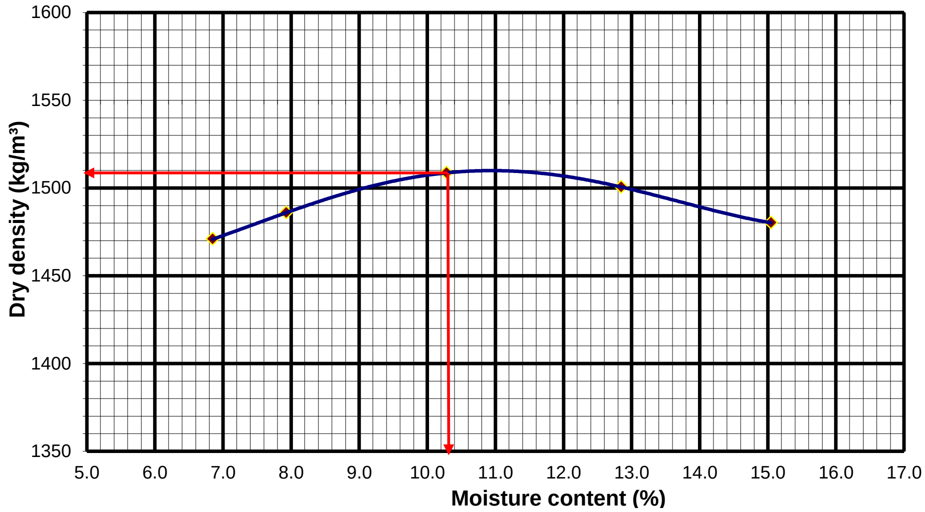


Figure 4. Compaction curve of the RCDW tested.

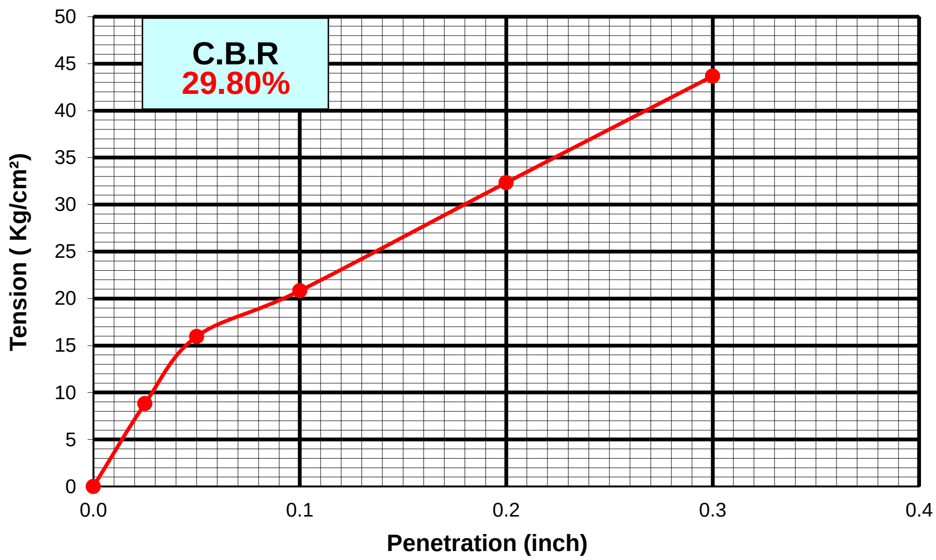


Figure 5. CBR test.

4. Conclusions and comments

This work analysis the possibility of using the RCDW collected in the Metropolitan Region of Recife for the execution of pavement layers. All tests were performed according the Brazilian standardization and the results obtained show that the residue used reached the parameters required by the standard with the realization of small corrections of low cost. The main conclusions arising from the research carried out are:

1. The recycled aggregate (RCDW) collected at the recycling plant located in the city of Jaboatão dos Guararapes presents good technical conditions for application in layers of pavements, being approved only for use in subbase, due to the value of the CBR found to be lower than is specified for use on pavement basis;
2. The recycled aggregate used met most of the required requirements: CBR value, maximum aggregate size, shape particle index and limit in the percentage of the composition of contaminant materials;
3. Its particle size composition had to be corrected because in its original composition it did not meet two requirements: the uniformity coefficient and the passing material content in the 0.42 mm sieve;

4. The grain-size distribution correction was performed by sieving the material, performed in the 0.42mm sieve and the rejection of 91.76% of the material retained in this sieve, which resulted in a new particle size distribution that will meet the specifications for the passing material content in the 0.42 mm sieve and in the uniformity index;
5. It is also important to emphasize that these tests and analyses must be carried out constantly in the formation of each batch, since the recycled aggregates are quite heterogeneous, with characteristics that may vary depending on the type of work, construction materials used or period of the year. Based on the results obtained here, it is recommended to use recycled aggregate in layers of pavements in the city of Jaboatão dos Guararapes, due to its technical characteristics, lower cost than the conventional aggregate and, mainly, by reducing environmental impacts.

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References

AASHTO T193 (2013). Standard method of test for the California bearing ratio, American Association of State Highway and Transportation Officials (AASHTO), USA.

ABRELPE-Brazilian Association of Public Cleaning and Special Waste (2013). Overview of solid waste in Brazil, editing in 2013. <http://www.abrelpe.org.br/Panorama. Acessed at June 2020.

Aldana, J.C. & Serpell, A. (2016). Methodology for the preparation of construction project waste management plans based on innovation and productive thinking processes: A case study in Chile, Revista de la Construccion 15(1), 32-41. doi.org/10.4067/S0718-915X2016000100003.

Arab, M,, Alzara, M., Zeiada, W. & Omar, M. (2020).. Combined effect of compaction level and matric suction conditions on flexible pavement performance using construction and demolition waste, Constr. Build. Mater. 261(11), 119792. doi.org/10.1016/j.conbuildmat.2020.119792

Arulrajah, A., Piratheepan, J., Disfani, M.M., & Bo, M.W. (2012). Resilient moduli response of recycled construction and demolition materials in pavement subbase applications, J. Mater. Civ. Eng. 25, 1920–1928. doi.org/10.1061/(asce)mt.1943-5533.0000766

ASTM D1883 (2016). Standard test method for California bearing ratio (CBR) of laboratory-compacted soils, ASTM International, West Conshohocken, PA, USA.

Azam, A.M., & Cameron, D.A. (2013a). Laboratory evaluation of recycled concrete aggregate and recycled clay masonry blends in pavement applications, J. Adv. Civil Eng. Mater. (ASTM) 2, 328-346. doi.org/ 10.1520/ACEM20120016

Azam, A.M., & Cameron, D.A. (2013b). Geotechnical properties of recycled clay masonry and recycled concrete aggregate blends in pavement, J. Mater. Civil Eng. (ASCE) 25, 788-798. doi.org/10.1061/%28ASCE%29MT.1943-5533.0000634

Awed, A.M., Tarbay, E.W., El-Badawy, S.M. & Azam, A.M. (2020). Performance characteristics of asphalt mixtures with industrial waste/by-product materials as mineral fillers under static and dynamic loading, Road Mater. Pavement, in press. doi.org/10.1080/14680629.2020.1826347

Beja, I.A., Motta, R. & Bernucci, L.B. (2020). Application of recycled aggregates from construction and demolition waste with Portland cement and hydrated lime as pavement subbase in Brazil, Constr. Build. Mater. 258, 119520. doi.org/10.1016/j.conbuildmat.2020.119520

Calvo, N., Varela-Candamio, L. & Novo-Corti, I. (2014). A Dynamic Model for Construction and Demolition (C&D) Waste Management in Spain: Driving Policies Based on Economic Incentives and Tax Penalties. Sustainability 6, 416-435. doi:10.3390/su6010416.

Carneiro, A.P., Burgos, P.C. & Alberte, E.P.V. (2001). Use of recycled aggregate in base layers and pavement subbase. Recycling of rubble for the production of building materials. Salvador: EDUFBA; Caixa Econômica Federal.

Dong, B., Wang, J., Wu, H., Song, Q., Zheng, L., Jiang, W., Zuo, J., Liu, G., Duan, H. & Zhang, H. (2017). Characterizing the generation and flows of construction and demolition waste in China, Constr. Build. Mater. 136, 405–413. doi.org/10.1016/j.conbuildmat.2017.01.055.

Herrador, R., Pérez, P., Garach, L. & Ordóñez, J. (2012) Use of recycled construction and demolition waste aggregate for road course surfacing, J. Transp. Eng. 138 182–190. doi.org/10.1061/(ASCE)TE.1943-5436.0000320.

John, V.M. & Agopyan, V. (2000). Construction waste recycling. In: Solid and Household Waste Seminar, 2000, São Paulo-SP: CETESB, 2000. <http://www.reciclagem.pcc.usp.br/ftp/CETESB.pdf>. Access at November 2019.

Leite, F.D.C., Motta, R.D.S., Vasconcelos, K.L. & Bernucci, L. (2011). Laboratory evaluation of recycled construction and demolition waste for pavements, Constr. Build. Mater. 25, 2972–2979, doi.org/10.1016/j.conbuildmat.2010.11.105.

Martínez, I., Etxeberria, M., Pavón, E. & Díaz, N. (2016). Analysis of the properties of masonry mortars made with recycled fine aggregates for use as a new building material in Cuba, Revista de la Construccion 15(1), 9-21. doi.org/10.4067/S0718-915X2016000100001.

Mousa, E., Azam, A.M., El-Shabrawy, M & El-Badawy, S.M. (2017a). Laboratory characterization of reclaimed asphalt pavement for road construction in Egypt, Can. J. Civil Eng. 44, 417-425. doi.org/10.1139/cjce-2016-0435

Mousa, E., Gabr, A., Arab, M.G., Azam, A.M. & El-Badawy, S.M. (2017b). Resilient modulus for unbound granular materials and subgrade soils in Egypt, Proceedings of the International Conference on Advances in Sustainable Construction Materials & Civil Engineering Systems (ASCMCES-17), Sharjah, United Arab Emirates, April 18-20.

NBR 15116 (2004). Recycled aggregate of solid residue of building constructions - Requirements and methodologies. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR 7181 (2016). Soil - Grain size analysis. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR NM 248 (2016) Aggregates - Sieve analysis of fine and coarse aggregates. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR 7809 (2006). Coarse aggregate - Determination of shape index by the caliper - Method of test. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR 9917 (2009). Concrete aggregates - Determination of soluble salts, chlorides and sulphates. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR 15115 (2004). Recycled aggregates of construction and demolition wastes - Construction of pavement layers – Procedures. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR NM 26 (2001). Aggregate – Sampling. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR NM 27 (2001). Aggregates - Reducing field samples to laboratory testing size. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

NBR 9895 (2017). Soil - California bearing ratio (CBR) - Testing method. ABNT - Brazilian Association of Technical Standards, Rio de Janeiro, Brazil.

Ricci, G. (2007). Study of mechanical characteristics of compacted concrete with roller and recycled aggregates of construction and demolition for paving. MSc. Thesis, Department of Transportation Engineering, Polytechnic School of the University of São Paulo, Brazil.

Silva, T.O., Carvalho, C.A.B., Lima, D.C., Calijuri, M.L., Lani, J.L. & Oliveira, T.M. (2010). Soil geotechnical classification systems: case study applied to unpaved highway. R. Árvore 34(2), 313-321. https://www.scielo.br/pdf/rarv/v34n2/v34n2a14.pdf

Tarbay, E.W.; Azam, A.M. & El-Badawy, S.M. (2019). Waste materials and by-products as mineral fillers in asphalt mixtures, Innov. Infrastruct. Solut. 4, 5-. doi.org/10.1007/s41062-018-0190-z