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EVALUATION OF THE POTENTIAL OF THE USE OF CONSTRUCTION AND DEMOLITION WASTE (CDW) IN THE PRODUCTION OF SOILS FOR THE RECOVERY OF DEGRADED AREAS BY MINING

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Palavras-chave: soil recovery; mining; degraded areas; construction and demolition waste.

Abstract

O The evolution of modern civilization brings with it a series of challenges regarding the management of its waste. Proper disposal of construction and demolition waste (CDW) has become a challenge across the planet. Parallel to this challenge, another one emerges: recovering areas degraded by mining. The objective of this paper was to characterize, through X-ray Fluorescence (XRF) and X-ray diffraction (XRD), CDW samples collected during the period from October 2018 to October 2019 in a recycling centre and determine its potential as an element in production of recovering soils of areas degraded by mining. Calcite and quartz were found, in addition to trace elements such as Fe, Mg, Mn, Cu, Zn, Ni, essential elements for plant nutrition, capable of restoring the chemical and physical conditions of soils. The results obtained showed that the elements Chromium (Cr) and Barium (Ba) were above the limits established by CONAMA Resolution 420/2009 (Brazil), whereas according to Order AAA / 661/2013 (Spain), all elements found were above the limits allowed for that country. The presence of heavy metals is considered normal in Brazilian soils, some of which are considered essential micronutrients. The results provide data to affirm that the CDW are suitable for use in soil production for the purpose of recovering areas degraded by mining, by applying tests on a larger scale and with a soil-water-plant interface.

Introduction

Brazilian National Solid Waste Policy - Federal Law No. 12,305 / 2010 (BRASIL, 2010) establishes the appropriate hierarchy in the integrated management of solid waste: non-generation, reuse, recycling, treatment and proper final disposal. Similarly, Resolution 307/2002 (BRASIL, 2002) of the National Environment Council (CONAMA) establishes guidelines, classification criteria and procedures for the management of construction waste in the country.

In Brazil, 7,192,372.71 tonnes of construction waste are generated annually by the public sector and 7,365,566.51 tonnes by the private sector (IPEA, 2012), which can cause numerous environmental impacts negative, if not properly managed.

In more developed countries, CDW also generates problems, making management and final disposal difficult, given the associated environmental liabilities (CALVO, 2017; SUÁREZ-SILGADO et al, 2018; MENEGAKI & DAMIGOS, 2018). For example in Spain, which in 2012 generated 26 million tons of CDW, considering that they represented 20% of the total waste generated by that country, being the sixth in the ranking of generators in the European Union (FERNANDEZ-NARANJO et al, 2016).

In Brazil, the generation of CDW reaches 50% of the total waste generated in large urban centres (LASSO, 2011).

Thus, there is a need to seek technical and viable solutions, from an economic point of view, for adequate integrated management of construction waste, with the least possible environmental impact. In Brazil, generators are legally responsible for the correct handling and management.

In parallel, in another production chain, the mining one, there is a need to recover degraded areas, especially in the open air, such as clay mining for ceramics and extraction of coal. What happens is that it is necessary to consider that the use of produced soils, in the recovery of degraded areas, favours environmental conservation by reducing the use of loan areas associated with the recycling of CDW, reducing the negative environmental impacts of their disposal in landfills.

It is noteworthy that although the CDW classified as “class A” by CONAMA is considered as inert waste, Oliveira (2002) concluded that concrete waste is “non-inert”, when subjected to acid rainwater. The author concluded that ions from the decomposition of these residues can contribute to the contamination of water courses, changing their natural conditions.

In the same vein, several researchers warn that in the disposal or use of CDW in soil, there is a prior need for study and analysis of the toxic potential of these residues, because while characterizing them, the authors found toxic elements (SCHAEFER et al, 2007; TOWNSEND et al , 2004; RAMALHO & PIRES, 2009; FILIZOLA et al, 2006, FERNADEZ-NARANJO et al, 2016). Thus, it is necessary to test the toxicity of residues by means of physical-chemical techniques and using bioindicators.

Internationally, CDW also represents a problem for integrated waste management because they are formed in high volumes, a problem that is worsened in countries where the reduced territorial extension and, consequently, the production of natural resources, aggravates the need for reuse and recycling.

The generation of CDW in the European Union (EU) presents significant differences between its member states. The total waste generated for the year 2014 was 2.5 million tons, with the percentage of CDW being high (Luxembourg: 85%, Malta: 75%, Holland, Germany, Denmark and the United Kingdom: 68, 53, and 48% respectively). The recycling rate for this waste in 2014 was 88%, considering 28 EU countries. In the rest of the countries on the European continent it was 12%, with the CDW destined to landfills (SÚAREZ-SILGADO et al, 2018).

According to Súarez-Silgado et al (2018), the most developed countries had a very high rate of recycling of CDW: Malta (100%), Holland (99%), Germany (94%), Denmark (92%), United Kingdom (95%). There was an increase compared to 2012, proving a trend of improvement in CDW management in Europe.

In the United States (USA), for the year 2003, 170 million tons of CDW were generated, with a recycling rate of 48%. However, the remaining 52% were destined for landfills, with the generation rate increasing in recent years (MENEGAKI & DAMIGOS, 2018).

In Asia, there is a wide variation between countries. With the exception of South Korea and Japan, in the other countries on the continent, CDW management is deficient, with around 40% of the total waste generated being CDW and practically without recycling (SÚAREZ-SILGADO et al, 2018).

The generation of CDW varies a lot between countries, which can be explained by the temporal variation, when economic conditions are more favourable to civil construction, due to the climate, in addition to the degree of incentive to civil construction.

In Latin America, there are still many difficulties, due to economic, social and cultural factors. Brazil is the first country to adopt CDW management legislation (SUAREZ-SILGADO et al, 2018).

In Ecuador, environmental protection is provided for in the 2008 Constitution, which is therefore recent. Waste management specifically is provided for in the Environmental Management Law, enacted in 2012 (VEINTIMILLA, 2017).

In Costa Rica, Law no. 8,839 / 2010 (Integrated Waste Management) was created in 2010 (CALVO, 2017). Integrated waste management in Costa Rica proposes a model similar to that of

Brazil, favouring non-generation and culminating in reuse and recycling, to subsequently appropriately dispose of waste (CALVO, 2017).

Colombia presents different municipal legislation for integrated management of CDW, with emphasis on the cities of Medellín, Bogotá, Cali and Ibagué (SUÁREZ-SILGADO et al, 2018).

In an attempt to improve the relationship between generation and proper destination, in Europe, specifically in the Netherlands, since 1997 there have been restrictions and prohibitions on CDW landfills, as well as in Flanders, since 1998. In Germany CDW cannot be sent to landfills and in Austria there is an obligation to separate and recycle CDW since 1993. In Sweden, there is a ban on landfill of hazardous and combustible waste since 2002 and solid waste since 2005, including CDW (SUÁREZ-SILGADO et al, 2018).

According to Suárez-Silgado et al. (2018), in some countries there is the imposition of taxes for the disposal of CDW, such as Hong Kong, since 2005. In France, Denmark, the Netherlands, Sweden, Finland, Belgium, Austria, Italy and France there is also a levy of taxes for disposal of CDW as a measure of restriction to the disposal at the expense of recycling, in an attempt to discourage the generation and disposal of waste, prioritizing material recovery. The authors also highlight countries such as Denmark and Great Britain where natural resource tax plans were enacted in order to reduce the cost difference between recycling and extracting raw materials from nature. As stated by the authors, the granting of benefits and subsidies can also reward recycling activities. It was adopted in some countries such as the Netherlands.

Despite advances in terms of legislation, the use of CDW in the recovery of degraded areas is rarely reported in the specialized literature.

Lasso (2011) developed an experiment involving CDW “Class A” as a soil corrective and conditioner for agricultural purposes with good results. Fernandez-Naranjo et al. (2016) evaluated the future use, in Spain, of CDW for the recovery of areas degraded by mining according to European Union standards, due to a new Spanish guideline for the disposal of this kind of waste in mining areas. They found technical and environmental feasibility, with only the exception of high sulphate content in that country's CDW. The adoption of geotechnical waterproofing techniques in order to prevent percolation is recommended. Restrepo, Bedoya & Vega (2016) characterized and evaluated the CDW as an option for the recovery of urban soils in Colombia. The authors concluded that there is technical and environmental viability by deepening the techniques of characterization and recycling of these residues. Restrepo, Bedoya & Vega (2016) tested the use of CDW in Colombia for the purpose of recovering degraded soils. They concluded that it is viable as a soil conditioner.

However, all experts reaffirm the need to deepen concerns about environmental issues, especially the potential for contamination provided by the CDW, given its great heterogeneity and composition, in order to avoid the risk of bioaccumulation in the associated ecosystems. Due to the great variation in the generation and the heterogeneity of CDW, there is a concern with the concentration of possible contaminants (SCHAEFER et al, 2007; TOWNSEND et al, 2004; RAMALHO & PIRES, 2009; FILIZOLA et al, 2006, FERNADEZ-NARANJO et al, 2016).

Townsend et al (2004) reported a high level of heavy metals in CDW. Likewise, Ramalho & Pires (2009) identified dangerous elements in recycled CDW in São Carlos, SP, Brazil. Still, according to Schaefer et al (2007), heavy metals leached from CDW composed of mortars. The elements Cu, Zn and Cd were found in greater concentration and the values found were higher than the recommended by the European directive 98/83 / EC.

Thus, the objective of the present paper is to carry out the previous chemical characterization by using X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) of CDW “class A” samples, according to CONAMA Resolution 307/2002. The purpose is to verify chemical elements with potential for contamination and bioaccumulation, aiming at the environmental viability of using it for soil production in projects for the recovery of areas degraded by mining.

Materials and methods

For this paper, civil construction and demolition waste “class A” was chemically and mineralogically characterized by XRF and XRD. It was collected in a recycling centre of CDW during 12 months (October 2018 to October 2019) in order to provide a more representative sampling in a temporal space, with the purpose of evaluating its potential use in the recovery of soils degraded by mining.

Collection and sampling of construction waste

Three samples of 20 kg of solid construction waste were collected, according to NBR 10.007 / 2004 standards (ABNT, 2004), at *3R'S Reciclagem* construction and demolition waste recycling plant, in Criciúma, SC, Brazil (Figure 1). It is a city of 215,186 inhabitants (IBGE, 2020), an industrial and mineral centre of the State of Santa Catarina (SC), in the southern region of Brazil. The collection was made during a period of one year (every four months) with the purpose to obtain a final sample with greater representation in the sampling period. It should be noted that the recycling plant operates by producing recycled CDW from “class A” waste, according to CONAMA Resolution 307/2002, in a mixed way, that is, material called “grey” (consisting of concrete and mortar) and material called “red” (ceramics, ceramic blocks, bricks), which translates into a greater advantage in the present work, since both residues result in a single product already homogenized.

After the collection and drying in an oven at 100˚C for 24 hours, the samples were quartered (separated 30 g). Then, they were processed in an orbital mill, sieved in a 200-mesh sieve and sent, after further quartering (5 g), to the Laboratory of Geotechnics at the Federal University of Rio Grande do Sul (UFRGS) to define minerals in the form of oxides by using X-ray diffraction (XRD) techniques and mineralogical characterization by X-ray fluorescence (XRF). The remaining samples were reserved for carrying on the research.

Figure 1: Detail of the production process at *3R'S Reciclagem* waste recycling plant in Criciúma, SC, Brazil.

Through X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques. The presence and quantity of minerals was determined through X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques.

The presence and quantity of minerals was determined. These minerals when applied to degraded soils can improve their physical properties (aeration, infiltration) and provide essential nutrients (Ca, Mg, Fe, Mn, Cu, Zn, Ni) or that can be beneficial to plants: Na, Si, Cu (RESTREPO; BEDOYA & VEGA, 2015).

XRD Analysis

For the chemical characterization through X-ray diffraction analysis (XRD) the powder method was used. In the powder sample, the pulverized or disaggregated material is deposited in a specific sample holder for powder, seeking to preserve the disorientation of the particles where all minerals or crystalline structures are analysed.

Minerals and / or crystalline phases were identified by measuring the interplanar spacing ("d" values) and the relative intensities of the diffractogram peaks.

The XRD was performed on a Siemens X-ray diffractometer (BRUKER AXS), model D-5000 (θ-2θ) equipped with a fixed Cu anode tube ($\lambda = 1.5406$ Å), operating at 40 kV and 25 mA at primary beam and curved graphite monochromator in the secondary beam.

XRF Analysis

Regarding the X-Ray Fluorescence (XRF), the powder samples were analysed in the angular range of 15 to 75° 2θ in steps of 0.05 ° / 1s using divergence and anti-scattering slits of 2 mm and 0.2 mm in the detector.

For larger elements, sample preparation was performed by using the melted sample technique. As for the smaller elements, the sample was prepared by using the pressed pellet method. The presence of volatiles was evaluated by using gravimetric techniques and is represented by LOI (Loss on Ignition). The X-ray fluorescence spectrometer (XRF) used was the RIX 2000 model by Rigaku.

Data processing

The statistical processing of the data was performed with the Microsoft Excel® Solver tool. It consisted of calculating the means, standard deviation (SD) and coefficient of variation (CV).

Results and discussion

The chemical characterization of CDW makes it possible to evaluate the potential of these residues, when properly recycled after separation, and recovery of areas degraded by mining, especially in open-sky mining processes. I can avoid possible generations of new contaminated sites and degraded soils.

The XRD analysis aimed to corroborate the crystalline phases present in the CDW. Figures 2, 3 and 4 show very similar crystalline phases, which are made of quartz (SiO_2) and calcite ($Ca(CO_3)$), present in the samples collected during the period of twelve months, in a CDW recycling centre in the municipality of Criciúma, SC. It confirms that the origin of these materials is basically concrete, mortar and ceramics, as expected for this type of waste, with peaks of quartz (SiO_2) and Ca (CO_3), without silicates Al and Fe, which is justified, in the case of quartz, by the fact that all SiO_2 is linked to quartz. These results are in line with that described by Lasso (2011); Restrepo, Bedoya and Vega (2015).

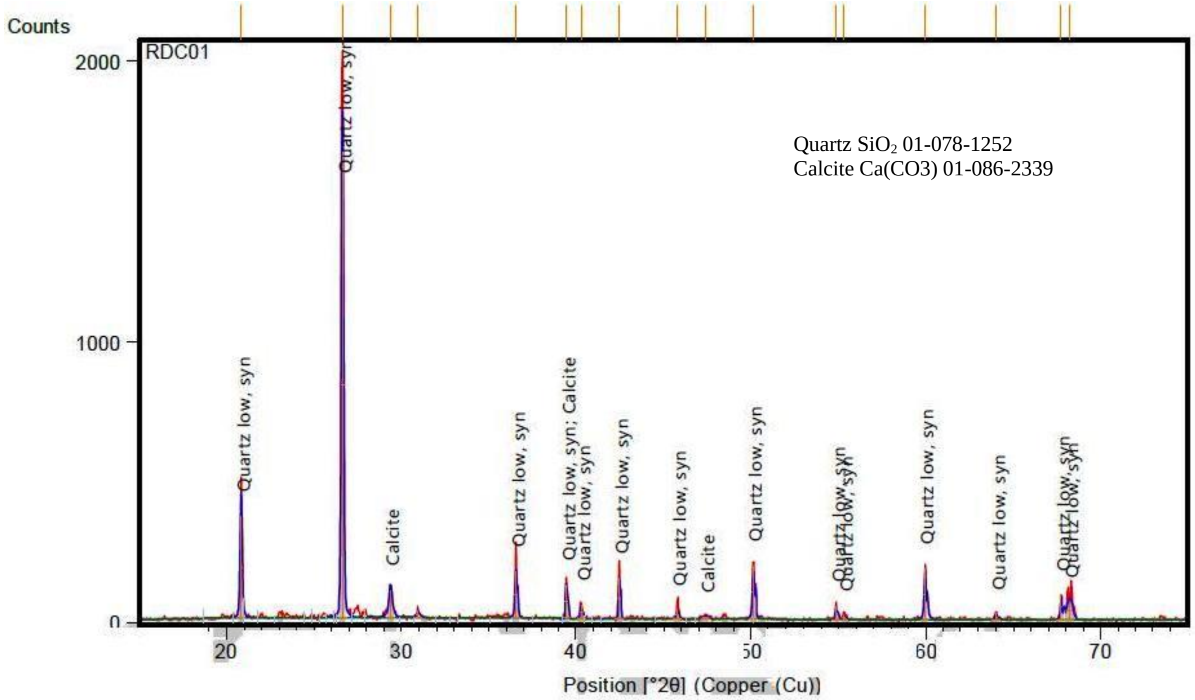

Figure 2: X-ray diffractogram of CDW sample 1.

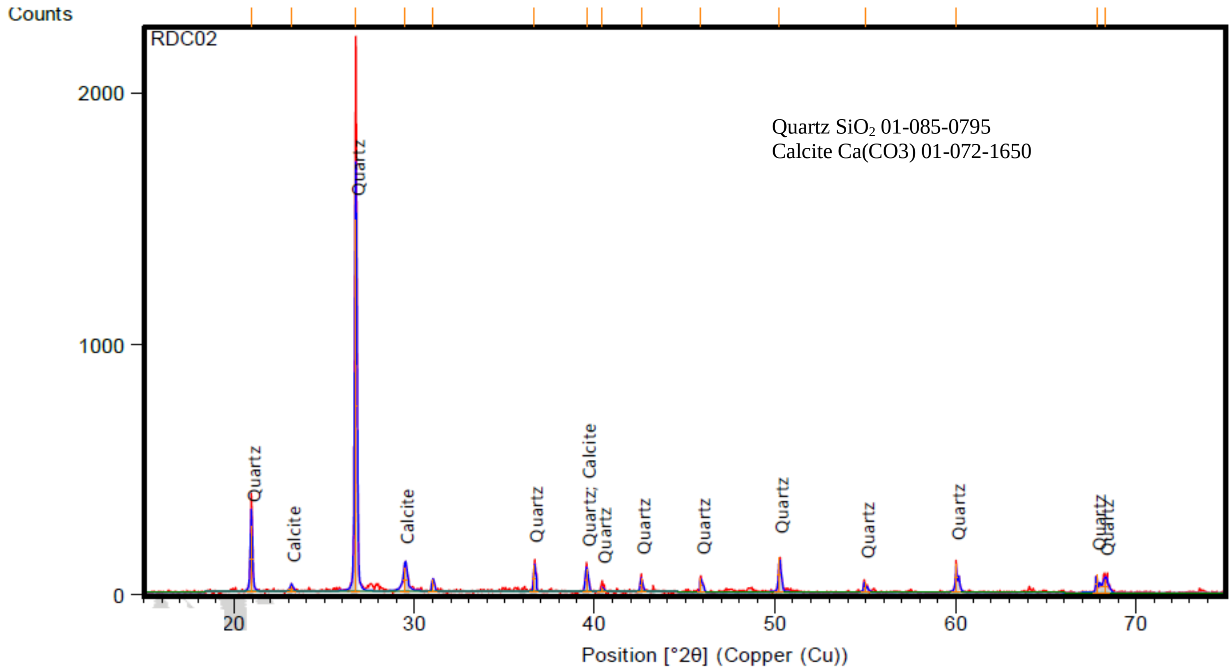

Figure 3: X-ray diffractogram of CDW sample 2.

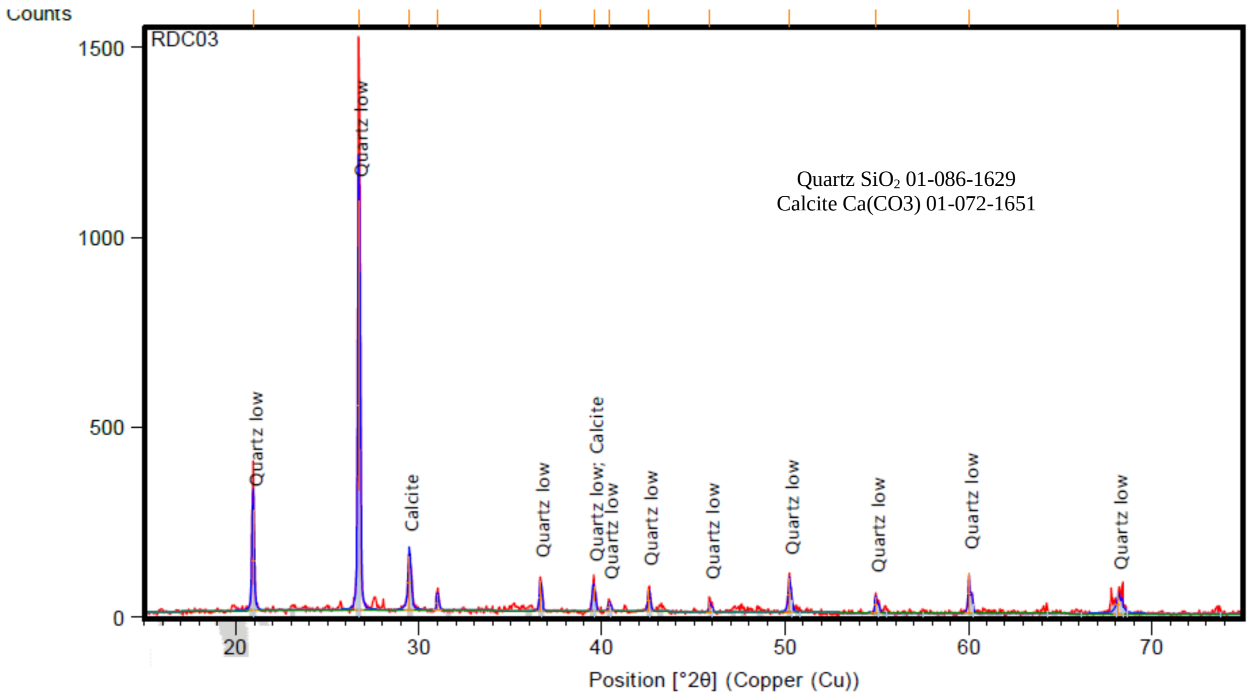

Figure 4: X-ray diffractogram of CDW sample 3.

Table 1 shows the results of the XRF which are in accordance with the results of the assessment of XRD, where the values are presented in percentage (%) of the sample's weight; in Table 2, where the trace elements are shown, the values are presented in mg.Kg^{-1}.

Table 1: X-ray fluorescence spectrometry: result in % by weight

Element	SiO_2	Al2O3	TiO_2	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
Sample/S^1	0.09	0.04	0	0.03	0	0.02	0.01	0.07	0.02	0.01	-
CDW 1	64.88	8.72	0.65	3.74	0.05	1.7	9.86	nd	1.4	0.06	8.94
CDW 2	48.59	10.97	0.87	4.35	0.06	3.29	16.23	nd	1.28	0.08	14.28
CDW 3	52.43	10.91	0.84	4.28	0.06	2.56	14.7	nd	1.36	0.09	12.79
Average	55.3	10.2	0.78	4.12	0.05	2.51	13.59	nd	1.34	0.07	12.0
SD	8.52	1.28	0.12	0.33	0.006	0.79	3.25	-	0.06	0.02	2.75
CV	15.41	12.55	15.19	8	10	31.35	23.9	-	4.45	25.97	22.9

LOI: Loss on ignition; SD: Standard Deviation; CV Coefficient of variation; S^1: Standard deviation of the methodology for the Standard Granite AC-E adopted by Geostandards; nd: Not detected.

Table 2: X-ray fluorescence spectrometry: result of trace elements in mg.Kg^{-1}

Element	S^1	Limit mg.Kg^{-1} of dry weight: Order AAA/661/2013*	Limit mg.Kg^{-1} of dry weight: CONAMA Resolution 420/2009 **	CDW 1	CDW 2	CDW 3	Average	SD	CV
Y	0.78	n/a	n/a	9.7	15.7	15.8	13.7	3.4	25.4
Pb	1.56	0.5	72	50.5	37.0	41.2	42.9	6.9	16.0
Ni	1.45	0.4	30	22.3	19.5	18.7	20.1	1.8	9.37
Cu	0	2	60	32.7	24.7	20.2	25.8	6.3	24.47
Sr	0.87	n/a	n/a	243.6	325.3	331.1	300	48.9	16.3
Zr	0.68	n/a	n/a	239.3	144.6	247.8	210.5	57.2	27.21
Zn	0.65	4	300	121.1	114.7	121.1	118.9	3.69	3.10
Nb	0.3	n/a	n/a	5.9	5.8	5.6	6.1	0.43	7.13
Rb	1.11	n/a	n/a	73.8	71.4	72.8	72.6	1.2	1.65
Cr	4.62	0.5	75	244.1	141	145.7	176.9	58.2	32.9
Ba	29.63	20	150	225.6	196.1	186.3	202.6	20.4	10.09

S1: Standard deviation of the methodology for the JG1A Granite Standard, adopted by Geostandards; DP: Standard deviation CV: Coefficient of variation; n/a: not applicable; * Reference for inert waste landfills; ** Reference for the prevention of soil quality.

As for the trace elements, or smaller elements, it can be seen that they are naturally present in Brazilian soils in different proportions, depending on the original rock. These variations are attributed to the chemical and physical properties of each soil profile (HUGEN et al., 2013). Also, it is observed in Table 2 that the trace elements are below the values determined by CONAMA Resolution 420/2009, which determines the Soil Quality Reference Values (QRV) in Brazil, with the exception of the elements Cr and Ba.

The elements Cr and Ba are widely used in the production of construction materials, such as cement and ceramics. Ba is used in the composition of ceramics and Cr in the production of cement, which, when undergoing a manufacturing process, can oxidise chromium to its most toxic form, Cr (VI). In the EU, since 2005, soluble Cr (VI) is limited to 2 mg.Kg^{-1}. In Brazil, the contents of Cr (VI) and Cr (III) in cements and derivatives are above the limits allowed by European regulations, which even becomes an impediment to the export of these products (MATOS & NÓBREGA, 2009).

Barium in high soil conditions can be absorbed by plants and inhibit photosynthetic activity affecting plant development and consequently productivity. It becomes evident the toxic effect of this chemical element (LIMA et al, 2012).

It is noteworthy, however, that as for the European regulation Order AAA / 661/2013 (SPAIN, 2013), all trace elements are above the limit allowed by the regulation (Table 2). It confirms the results obtained by Schaefer et al (2007).

Heavy metals are relatively stable, non-degradable chemical elements with a density greater than four and which have a high toxic character. In soil, the risk of contamination by metals is increased by industrial, agricultural and urbanization activities (HUGEN et al., 2013). They present highly differentiated forms of environmental and toxicological behaviour according to different chemical forms. This characteristic is due to its atomic structure, which is characterized by free *d* orbitals, reacting with electron acceptors (TAVARES, 2009).

After being released from their original rocks by weathering, due to their electronegativity, ionic rays and different oxidation states, heavy metals can be precipitated or co-precipitated with secondary minerals, adsorbed on the surfaces of secondary minerals (clay or oxides of Fe, Al and Mn) or organic matter present in the soil or, furthermore, complexed and leached by the soil solution (ALLEONI, et al., 2005).

Thus, considering the precautionary principle, it is worth noting that there is a need to limit the application of CDW in the soil, in order to avoid the accumulation of heavy metals over time (HUGEN et al., 2013).

In a process of recovery of degraded area by mining, the application of CDW in produced soils may become viable. Once the area is recovered, it will be destined for a purpose according to the environmental licensing process, different from an agricultural area, for instance, where soil recovery aims to increase fertility, requiring corrections and applications of fertilizers and soil conditioners with greater consistency.

Through XRF analysis, as shown in Table 1, it can be seen that a large part of the constituent material of the sampled CDW is quartz, considered inert, however, it has a structuring function in the soil, and can contribute to its physical properties, in the increased capacity for water retention, aeration, infiltration and soil texture (LASSO, 2011; RESTREPO, BEDOYA & VEGA, 2015).

In an experiment, Silva & Silva (2018) used CDW for the purpose of forming a hydraulic barrier in coal mining, aiming at successfully recovering areas degraded by mining and preventing the formation of acid mine drainage, in the proportion of 75/25. The mixture showed similar results to natural soil, indicating the previous feasibility of using CDW in the recovery of areas degraded by coal mining.

It is worth mentioning the average percentage of 13.59% of Calcite (Ca (CO_3)) in the analysed samples, which can contribute to improving the chemical quality of the soil and raising the pH (LASSO, et al., 2013). It becomes an interesting material for the recovery of soils with less high pH. This percentage is above the one found by LASSO (2011). The reason for that is the way the recycling centre where the samples of the present work were collected operated the CDW when processing and producing mixed material: grey and red together. The grey material has higher carbonate content, due to the higher concentrations of cement and mortar, associated with that found in the "red" CDW, which consists basically of ceramics, blocks and bricks. However, part of these with added "grey" material, mainly mortar.

CDW is also a source of Ca, Mg, Mn and micronutrients essential to plant organisms, as well as aluminium (Al) present in the form of oxides in ceramics and clay, and Iron (Fe) in the case of the presence of feldspars from the ceramic material, cement and limestone used in the manufacture of civil construction inputs and materials.

It is noteworthy that the coefficient of variation was below 20% in most of the elements analysed, which corroborates with Lasso et al (2013). It can be concluded that there is a degree of standardization in the production of construction materials, as well as in the production process of recycled CDW.

Furthermore, studies on soil-plant and soil-water interactions should be carried out in order to verify possible contamination and bioaccumulation due to the solubility and biological acidification of the materials present and the great degree of heterogeneity of the residues.

Concluding remarks

CDW presents desirable characteristics for the production of soils for the purpose of recovering areas degraded by mining because they contain elements necessary for the good development of the soil, they can provide improvement in physical and chemical aspects, improving the structure and texture of the soil, its capacity for sandblasting and infiltration. They also can enhance the cation exchange capacity (CEC), due to the presence of minerals, in addition to trace elements that are essential for the development of living plant organisms.

Furthermore, the presence of carbonates can result in an increase in pH, contributing to a more effective recovery in acidic soils.

Thus, the correct use of CDW properly separated, recycled and after careful analysis of its chemical composition, in the recovery of sites degraded by mining, can pave the way for the closure of the waste cycle of two large production chains: mining and construction civil society, favouring full sustainable development.

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