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Recycled construction and demolition waste in mining rehabilitation

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Abstract

Currently, the main destination for non-valuable recycled construction and demolition waste (CDW) consists of its disposal in landfills. Because of the high volume of non-valuable recycled CDW generated, and due to the disposal it is usually developed in low-controlled or even non-controlled conditions, this kind of management may derive in safety and environmental issues. Therefore, it is necessary to find an alternative management system that allows, firstly, the recovery of this kind of waste and, secondly, enables the rehabilitation of areas affected by mining activities.

The Geological Survey of Spain (IGME) is carrying out a management commission for the Ministry of Agriculture, Food and Environment which aims to produce a methodological guideline for the rehabilitation of mining pits and quarries with non-valuable recycled CDW in open-pit facilities.

The main target is the implementation of the basic legislation applicable on this matter (Royal Decree 1481/2001; Royal Decree 105/2008; Royal Decree 975/2009; Law 22/2011), with the ultimate objective of reaching a framework that allows the mining rehabilitation with non-valuable recycled CDW in safety and healthy conditions for population and environment.

The abovementioned guideline will be based on the physicochemical characterization of waste, the environmental constraints, and the rehabilitation objectives.

Keywords: recycled aggregates, CDW, mining, mining areas, inert waste, concrete, ceramics, environmental rehabilitation, waste management, leachability.

1 Introduction

Construction and demolition waste (CDW) represents more than 20% of the total generated waste in Spain during 2012 (data from Eurostat, 2012) surpassed only in percentage by industrial waste.

Furthermore, Spain was the sixth European Union country with the greater production of CDW, with around 26 million tonnes during this period (data from Eurostat, 2012). This high quantity of CDW represents a major environmental issue. The recovery of this kind of waste is essential to reduce its negative impact on the environment and human health, and to ensure a rational use of natural resources.

According to the Waste Framework Directive and the Government Waste Management Framework Plan (2016–2022), 70% (by weight) of non-hazardous CDW, excluding excavation waste, should be subjected to some sort of recovery operation (re-use, recycling, backfilling operation using waste to substitute other materials, etc.) by 2020. Although the level of recovery of CDW in Spain has been significantly increased in recent years according to the Spanish Federation of CDW Management Companies (data from FERD, 2015), the recovery ratio was about 38% in 2013, far below the objective established by the European Union (EU). The remainder of CDW production (non-valuable recycled CDW) was disposed of in inert landfills (26%) or dumped in unsupervised landfills (36%). In recent years, the declining demand for recycled CDW due to the crisis in the construction sector has contributed to strengthening this situation.

Royal Decree 975/2009, about management of extractive industries waste and protection and rehabilitation of areas affected by mining activities, contemplates the possibility of filling mining pits with inert waste of non-mining origin. In addition, for landscaping purposes, Royal Decree 105/2008, (which regulates the production and management of CDW in Spain), considers the use of inert CDW in the restoration of degraded areas or in refurbishment works as a recovery operation.

In this context, the Ministry of Agriculture, Food and Environment orders the elaboration of a management commission to the Geological Survey of Spain (IGME) which aims to produce a methodological guideline for the rehabilitation mining pits with non-valuable recycled CDW. Additionally, this use could be a new path to increase the percentage of recovery of CDW in our country, in order to reach the recovery ratio established by the European Union for 2020.

2 Potential use of non-valuable recycled CDW in mining rehabilitation

There are no official statistics at a national level about the use of CDW in mining rehabilitation. Anyway it is possible, as the first approach to the issue, to estimate the potential of recovery of the non-valuable recycled CDW that is feasible to use for mining rehabilitation purposes. To do this, the minimum annual volume of mining pits generated as well as the annual volume of CDW intended to landfill operations have been determined.

The year 2012 has been selected because it is the most recent year with available data for both subjects: mining and waste.

Based on the National Mining Statistics (http://www.minetur.gob.es/ENERGIA/MINERIA/ESTADISTICA/Paginas/Consulta.aspx), it was possible to obtain the total mass of mining minerals extracted in 2012. Only those mine sites considered to have favourable conditions for the rehabilitation with non-valuable recycled CDW (evaporitic lithologies, sedimentary minerals, fine-grained rocks, etc.) were selected.

Furthermore, the density of these minerals was determined through searching in several web sites. The simply division of the total mass produced and the density gives, as result, the total volume of mineral extracted (table 1).

It is necessary to consider that volumetric data obtained are referred to a minimum mining void, due to it being probable that the holes generated during the extractive operations are higher (the non-productive material are also removed and occasionally remains stored in mining heaps or tailings dams).

Table 1: Estimated minimum pit volume generated due to mining activities in 2012.

	Annual production (kg)	Density[a] (kg/m^3)	Volume (m^3)
REFRACTORY CLAY	78,000,000	1,362	57,269
BENTONITE	97,000,000	593	163,575
KAOLIN	247,000,000	2,510	98,406
POTASSIUM CHLORIDE	632,000,000	1,996	316,633
GLAUBERITE	1,050,000,000	2,785	377,020
SEPIOLITE	622,000,000	2,000	311,000
THENARDITE	175,000,000	2,690	65,056
CLAY	8,289,000,000	2,638	3,142,749
MARLSTONE	5,581,000,000	2,243	2,488,185
GYPSUM	6,360,000,000	2,550	2,494,118

[a]www.csgnetwork.com/specificgravmettable.html
www.engineeringtoolbox.com
webmineral.com
www.edumine.com/xtoolkit/tables/sgtables.htm
rocscience.com/help/rocfall/webhelp/baggage/Rock_Density_Table.htm

This way, the estimated total (minimum) pit volume generated due to mining activities was 9 514 011 m^3.

In addition, data about the use of non-hazardous CDW, excluding excavated soils were obtained from the Spanish National Institute of Statistics (data from INE, 2012). The volume of non-hazardous CDW, based on the treatment received, was calculated (table 2) applying a conservative density value of 2.3 t/m^3 (http://www.cedexmateriales.vsf.es/view/archivos/residuos/447.pdf).

The results obtained show that the volume of non-valuables recycled CDW is similar to the volume generated by mining activities in 2012. These data permitted to assess the estimated increase in the percentage of CDW recovery that the use of non-valuable recycled CDW in mining rehabilitation would imply. According to

Table 2: Data related to CDW management (extracted from the INE databases for the year 2012).

Non-hazardous CDW (excluding excavated soils)	Recovery	Backfilling Operations	Disposal	Total
Weight	18,705,743 t	4,328,999 t	4,292,972 t	27,327,714 t
Volume	8,132,932 m^3	1,882,173 m^3	1,866,510 m^3	11,881,615 m^3

INE data, if CDW disposed in landfills (4,292,972 t) had been destined to rehabilitate mining pits, the quantity of non-hazardous CDW used in backfilling operations (table 3) would be double. These actions are recognised as recovery operations by the Waste Framework Directive and the Royal Decree 105/2008.

Therefore, the use of non-valuable recycled CDW in mining rehabilitation would help to achieve the minimum recycling target of 70% (by weight) for CDW by 2020 and would reduce the environmental impact in areas affected by mining activities.

Table 3: Potential of RCD recovery when mining rehabilitation activities are included.

	Recovery	Backfilling operations	CDW recovery
Current recovery non-hazardous CDW*	18,705,743 t	4,328,999 t	23,034,742 t
Potential recovery non-hazardous CDW*	18,705,743 t	8,621,971	27,327,714 t

*Excluding excavated soils

Calculating a better estimation of the increase of the CDW recovery percentage due to the use on mining rehabilitation works is not an objective of this document. Moreover, INE data may not reflect the current situation of the CDW management in Spain, when compared with data provided by the Spanish Federation of CDW Management Companies. Despite these limitations, is important to highlight the great potential of the use of non-valuable recycled CDW in mining rehabilitation activities.

3 Applicable legislation

The legislative framework for the use of CDW in the rehabilitation of lands degraded by mining activities is very complex. It includes regulations regarding: waste management, specific legislation for CDW management, mining sites rehabilitation and landfills. Furthermore, European, national, regional, and even municipal (for minor works and house repairs) legislation are applicable. In table 4 the applicable national legislation is summarized.

Table 4: Summary of the applicable Spanish legislation.

CDW and waste management legislation	
Law 22/2011	About waste and contaminated soils.
R.D. 105/2008	About regulation of CDW production and management.
R.D. 1481/2001	About regulation of waste removal through disposal in landfills.
Tech. Development of R.D. 1481/2001	About waste landfill facilities.
Order AAA/661/2013	Amendment of R.D. 1481/2001.
Mining and mines restoration legislation	
Law 22/1973	About mines.
R.D. 975/2009	About management of extractive industries waste and protection and rehabilitation of areas affected by mining activities.
R.D. 777/2012	Amendment of R.D. 975/2009.
Correction of errors in R.D. 777/2012	Corrections in R.D. 777/2012.

Some interest considerations resulted from the legal framework are pointed out below. Pursuant to Royal Decree 105/2008, to be mining restoration by using CDW considered as a recovery operation, it must comply with these items: a) the competent regional environmental authority must previously declare the environmental restoration plan as a recovery operation; b) the operation must be carried out by a waste manager authorized by the regional administration; c) the operation results in the substitution of the natural resources needed for this restoration.

Moreover, the Royal Decree 975/2009 allows the use of inert non-valuable recycled CDW whenever both backfilling and rehabilitation of the pit comply with all requirements established in the Royal Decree 1481/2001, which regulates the disposal of waste in landfills. Therefore, the conditions imposed to inert waste landfills are applicable in this case. The rule establishes that inert waste landfills must be fitted with a natural geological barrier characterized by having, at least, one-meter thick and a permeability of 10^{-7} m/s. If the natural terrain does not comply with these parameters, it must be necessary to install an artificially established geological barrier, requiring a mineral layer of 0.5 meters thick, thus ensuring the waterproofing of the mining pit. In addition, the construction of an efficient drainage system is mandatory. However, due to its inert character, the rule allows the regional environmental authority, when the risk is considered as acceptable, to decide not to require the installation of a geological barrier and/or a drainage system.

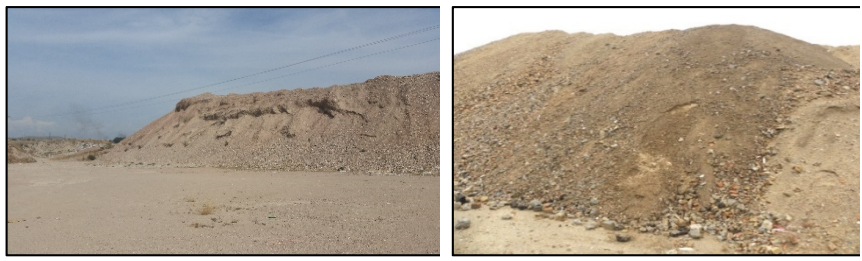
4 Characterization of CDW for mining restoration

Most of the recycling plants are equipped with two separate recycled aggregate production lines: concrete line and ceramic line (figure 1).

Ceramic waste usually come from building demolitions or domiciliary maintenance minor works. It is not unusual that this kind of waste arrives at the recycling plant without selective separation at the source.

Waste of a lower quality than recycled aggregate and size from 0 to 20 mm or 0 to 40 mm, are produced in both production lines, during the pre-sieved (previously to grinding and classification) phase. This kind of waste does not have commercial opportunities (GERD [1]). About 50% of CDW entering the recycling plants are ceramic waste. These non-valuable recycled CDW are disposed in inert landfills or stockpiled in recycling plants. This project focuses on non-valuable recycled CDW. Inert nature is the main precondition for using this kind of material in mining rehabilitation.

In order to characterize and determine their inert nature, essays and criteria set out in the Order AAA/661/2013 were applied to CDW samples. A total of 10 samples of non-valuable recycled CDW were obtained from 7 recycling plants in the Autonomous Community of Madrid. Samples were separated in three groups according to the origin of the CDW: CDW from concrete residues, CDW from ceramic residues and CDW from mixtures of concrete and ceramic residues.



Non-valuable recycled CDW (concrete line) Non-valuable recycled CDW (ceramic line)

Figure 1: Non-valuable recycled CDW from both concrete and ceramic lines.

Leachability of CDW samples was assessed by carrying out the leaching test UNE-EN 12457-4:2003 "*Characterization of waste. Leaching. Compliance test for leaching of granular waste materials and sludge. Part 4: one stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction)*". As, Ba, Cd, total Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn, chloride, fluoride, sulphate, phenol index, dissolved organic carbon (DOC) and total dissolved solids (TDS) contents were determined and compared with the limits set by the Order AAA/661/2013. The results of the leaching tests and the limit values are shown in table 5. Non-compliances with the limit values are highlighted.

Furthermore, the total content of TOC (total organic carbon), BTEX (benzene, toluene, ethylbenzene and xylenes), PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls) and mineral oils (C10-C40) were determined. The results of the analyses and the limit values are shown in table 6. Non-compliances with the Order AAA/661/2013 are highlighted.

Table 5: Results of the leaching tests. Comparison with limits set by the Order AAA/661/2013. Non-compliances with the limit values are highlighted in bold print.

LEACHING TEST UNE-EN 12457-4 Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**		
		CONCRETE (mg/kg)		**MIXTURE (mg/kg)**
Parameter	**Limit value mg/kg dry matter**	**1**	**2**	**10**
As	**0.5**	0.028	0.063	0.197
Ba	**20**	0.725	0.0429	0.402
Cd	**0.04**	<0.02	<0.02	<0.02
Total Cr	**0.5**	0.067	0.0571	0.0848
Cu	**2**	0.12	0.0517	0.0575
Hg	**0.01**	<0.05	<0.05	<0.05
Mo	**0.5**	0.043	0.0334	0.0255
Ni	**0.4**	0.058	<0.05	0.119
Pb	**0.5**	<0.02	<0.02	<0.02
Sb	**0.06**	0.023	0.0125	0.0311
Se	**0.1**	<0.05	<0.05	0.0547
Zn	**4**	0.14	0.182	0.263
Chloride	**800**	50	1	2
Fluoride	**10**	<5	<5	<5
Sulphate	**1000**	**8840**	280	**13696**

LEACHING TEST UNE-EN 12457-4 Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**						
		CERAMIC (mg/kg)						
Parameter	**Limit value mg/kg dry matter**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
As	**0.5**	0.091	0.035	0.0793	0.1	0.103	0.183	0.042
Ba	**20**	0.403	0.504	0.449	0.442	0.112	0.198	0.45
Cd	**0.04**	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Cr	**0.5**	0.043	0.244	0.0393	0.064	0.054	0.0417	0.04
Cu	**2**	0.039	0.146	0.0447	0.19	0.05	0.873	0.05
Hg	**0.01**	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mo	**0.5**	0.112	0.0695	0.0265	0.022	0.023	0.0241	0.039
Ni	**0.4**	<0.05	0.234	<0.05	<0.05	0.072	0.063	0.176
Pb	**0.5**	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sb	**0.06**	0.029	**0.0632**	0.0176	0.019	0.008	0.0167	0.015
Se	**0.1**	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zn	**4**	0.425	0.249	0.712	0.269	0.264	0.644	0.721
Chloride	**800**	140	90	1	31	1	1	4
Fluoride	**10**	<5	<5	<5	<5	<5	<5	<5
Sulphate	**1000**	**18700**	**15100**	**6079**	**7520**	**2796**	**1169**	**13793**

Table 6: Total organic parameters contents. Comparison with limits set by the Order AAA/661/2013. Non-compliances with the limit values are highlighted in bold print.

Order AAA/661/2013		NON-VALUABLE RECYCLED CDW		
		CONCRETE (mg/kg)		MIXTURE (mg/kg)
Parameter	**Limit value mg/kg dry matter**	**1**	**2**	**10**
TOC	**30000**	6300	n.a.	5676
BTEX	**6**	< 0.05	< 0.05	< 0.05
PCB	**1**	< 0.025	< 0.025	< 0.025
Min. oil	**500**	< 40	93	145.4
PAH	**55**	< 0.05	< 0.279	< 0.08

n.a.: Result not available.

Order AAA/661/2013		NON-VALUABLE RECYCLED CDW						
		CERAMIC (mg/kg)						
Parameter	**Limit value mg/kg dry matter**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TOC	**30000**	-	3700	5100	n.a.	n.a.	7272	8145
BTEX	**6**	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
PCB	**1**	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Min. oil	**500**	**648.3**	< 40	< 40	99.9	41.7	64.8	243.2
PAH	**55**	17.4	1.32	0.38	0.381	0.259	< 0.08	< 0.08

n.a.: Result not available.

5 Results and conclusions

Based on the results of the leaching tests, and their comparison with the limits values set by the Order AAA/661/2013, it can be concluded that the non-valuable recycled CDW cannot be considered as inert waste, mainly due to the high contents of sulphates. There are also punctual nonconformities with regard to Sb and mineral oil contents. Therefore, the sulphate content appears to be a limiting factor.

This fact implies that, in conformity with the Royal Decree 1481/2001, it would be necessary to establish a geological barrier previously to the operations of rehabilitation with non-valuable recycled CDW. Additionally, it could preclude the use of this kind of waste in the rehabilitation of mining pits according to the Royal Decree 975/2009.

It should be noted that in mining areas whose geochemical background is rich in sulphates, the environmental impact due to sulphates is limited. In these mining areas, it is possible to renounce the installation of a geological barrier with the specifications established in Royal Decree 1481/2001. Flores *et al*. [2] suggest that, it would not be necessary to establish constrains regarding sulphates contents when non-valuable recycled CDW are destined for its disposal in mining pits located in massive gypsiferous terrains.

The sulphate content will depend on the origin of the waste and the lithological features of the aggregates or construction materials employed, according to the geological and mineral existing resources in each region (Romero [3]). The non-valuable recycled CDW samples obtained in the recycling plants located in the southeast of Madrid (gypsiferous terrains) show the highest sulphate contents (samples 3, 4, 9, and 10), while the lowest sulphate concentrations are recorded in the samples from the plants located in the north of the region (samples 7 and 8) with granitic substrate type.

Therefore, based on the results, it is not possible to predict categorically if the sulphate content of a particular non-valuable recycling CDW sample will exceed the limit values established for inert waste. In any case, the number of samples analysed is still low, and it is considered necessary to take at least 30 samples from different CDW management companies from different regions with diverse regional geochemical background.

There are many examples of restoration with CDW in gravel pits and quarries located in the proximities of large cities (Rubio *et al*. [4]). Excavation soils were employed in many of the cases.

Some specialists are in favour of the use of non-valuable recycle CDW in mining rehabilitation due to its low cost and because the use of these waste allow to perform a landscape restoration under (geotechnically) safe conditions, promoting revegetation and landscape integration. In addition, the recovery of non-valuable recycled CWD, also allows reducing the need for new landfills (Flores *et al*. [2]).

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