Characterization of recycled gypsum

Ana Jiménez-Rivero*, Justo García-Navarro
[a] Research Group Sustainability in Construction and Industry giSCI - UPM, Universidad Politécnica de Madrid. Ciudad Universitaria s/n, 28040 Madrid, Spain.

* Corresponding author. Tel.: +34 91 336 58 65; fax: +34 91 336 36 88
E-mail address: ana.jimenez@upm.es

Abstract

Quality secondary materials are imperative to promote the recycling of post-consumer waste. Existing specifications for recycled gypsum are country-specific and even company-specific. In order to improve the way in which gypsum waste is treated, European guidelines on recycled gypsum quality criteria have been outlined in the framework of the European Life+ Gypsum to Gypsum project "From Production to Recycling: a Circular Economy for the European Gypsum Industry with the Demolition and Recycling Industry". Such guidelines provide the basis for this study. During the GtoG project, deconstruction, gypsum recycling and plasterboard manufacturing processes were monitored in distinct European contexts. Business-as-usual gypsum feedstock and recycled gypsum were tested. The aim of the present study is to analyse the results obtained on relevant parameters that characterize gypsum as a raw material (e.g. particle size, free moisture, purity). Recycled gypsum samples are compared to business-as-usual gypsum samples, while at the same time outlining the implications of parameters that differ from the GtoG guidelines.

Keywords: gypsum plasterboard; secondary raw material; quality criteria; technical; toxicological; parameters.

1. Introduction

At present, it is feasible to recycle gypsum sourced from urban mining (known as end-of-life (EoL) gypsum or post-consumer gypsum waste). However, the use of post-consumer RG is still very low in the European Union. For example, the weight percentage of post-consumer RG in a reference plasterboard in the year 2013 in the European Union was estimated to be 1% [1]. Worth noting is that, in the European Union, a market for post-consumer RG has only emerged in Benelux, Scandinavia, France, the Netherlands and the UK [2].

Landfilling therefore becomes the common destination of EoL gypsum in countries where a market for post-consumer RG has not yet emerged. Gypsum landfilling typically contributes to primary resource depletion, hydrogen sulphide and methane emissions from landfills [1].. Different measures currently aim to mitigate such emissions, such as gypsum landfilling in specific monocells [3] or the examination of alternative landfill cover soils [4]. But recycling, apart from avoiding the above mentioned harmful effects, is a mechanism to achieve resource efficiency and contribute to sustainable development [5].

In order to be usable by the gypsum industry, RG should comply with the quality criteria threshold agreed between the final costumer and the recycler. Little was published about the diverse RG quality criteria before the beginning of the European Life+ Gypsum to Gypsum project “From production to recycling: a circular economy for the European gypsum Industry with the demolition and recycling Industry” [6]. Knowledge on such existing quality criteria (see [2] for extended information) can guide new costumers of RG (i.e. manufacturers aiming to reincorporate RG in their process) towards preparing the most suitable agreements according to the nature of the manufacturing process (e.g. use of natural of synthetic feedstock, equipment).

Moreover, the GtoG project has produced a set of European voluntary guidelines on the RG quality criteria for the gypsum industry, as a result of three years of collaborative works between agents’ part of the value chain. The works included pilot projects (deconstruction, recycling and manufacturing processes) in distinct European locations (France, the UK, Germany, Belgium and the Netherlands). Producers, recyclers and laboratory Loemco (Official Laboratory for Testing Materials of Construction, third party laboratory, partner of the GtoG project) discussed the test results and agreed on initial values [7]. These are the first harmonised guidelines at EU level covering technical and toxicological parameters (hereinafter GtoG guidelines on RG quality criteria).

The present study focuses on test results from five European pilot projects, which included 21 gypsum feedstock samples. The aim is to analyse relevant parameters that characterize gypsum as a raw material (business-as-usual gypsum and RG feedstock). The paper discusses the quality of the gypsum feedstock against the GtoG guidelines on RG quality criteria (See Section 3). The samples were collected by Loemco during the GtoG project, between February 2014 and January 2015. Most of the tests were carried out by this laboratory, except those related to radioactivity, mercury testing and total organic carbon, which were conduced by Laboratory for Gamma-ray Spectrometry in Belgium (SCK- CEN), Institut Frenesius in Germany (SGS) and Instituto Técnico de Materiales y Construccciones in Spain (Intemac), respectively.

2. Materials and methods

The experimental methods for the assessment of the RG quality criteria parameters are based on four European documents as follows. The Instruction Sheet VGB-M 701 [8] for the case of free moisture, purity, salts and pH; the European Standard EN 933-1 for the particle size results (maximum size measured in Table 1 and particles below 4 mm in Fig. 1); EN 13137 for assessing the total organic carbon (TOC) and EN ISO 11885 for analysing the toxicological parameters. Additionally, the radioactivity index was calculated according to the RP 112 document (EC) and the asbestos content was analysed according to the Rietveld method [9].

The limit values of the technical parameters (see column “GtoG project guidelines” in Table 1) are based on previous criteria developed by the quality protocol in the UK [10] and BV Gips in Germany [11], being the later used as a benchmark. The guidelines for the toxicological parameters (see column "GtoG project guidelines" in Table 3) are also based on the criteria developed by BV Gips in Germany [11], which in turn is based on the study conducted by Beckert on natural and FGD gypsum [12].

The raw materials object of study (natural, FGD and RG) were collected from the GtoG pilot projects (N=21). These included business-as-usual and RG feedstock as detailed below.

– Business-as-usual gypsum feedstock (GY_{BAU}) for plasterboard manufacturing (N=8). Four samples come from plants using mined gypsum. One sample corresponded to pre-consumer RG.
– RG feedstock (GY_{RG}) for plasterboard manufacturing (N=13), including pre-consumer (from plasterboard production) and post-consumer RG samples (gypsum-based systems were dismantled from renovation works, segregated on-site and transported to the recycler. Further details on the pilot projects can be found in section "Monitoring of European Pilot Projects" in Jiménez-Rivero and García-Navarro (2016)).

3. Gypsum as feedstock: business-as-usual versus recycled gypsum feedstock

Table 1 shows information on the average results obtained for the technical parameters. These parameters, along with the toxicological ones (detailed in Table 3) are part of the quality criteria for the use of RG into new gypsum products.

Table 1. Technical parameters analysis

Parameter	Unit	GtoG project guidelines[a]	GY_{BAU}				GY_{RG}			
			M	SD	Min	Max	M	SD	Min	Max
Maximum size	mm	15.00	7.38	9.89	0.10	20.00	8.00	4.00	2.00	14.00
Free moisture	% w/w	<10	3.02	3.01	0.05	6.85	6.91	5.05	0.27	17.14
Purity	% w/w	>80	91.78	2.57	89.01	96.41	87.41	3.36	79.83	90.64
Total organic carbon	% w/w	<1.5	0.17	0.28	0.01	0.83	0.85	0.72	0.19	3.13
Magnesium salts	% w/w	<0.1	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.04
Sodium salts	% w/w	<0.06	0.01	0.01	0.00	0.02	0.02	0.01	0.02	0.07
Potassium salts	% w/w	<0.05	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.04
Soluble chloride	% w/w	<0.02	0.00	0.00	0.00	0.01	0.02	0.03	0.01	0.12
pH	-	6-9	7.54	0.65	6.50	8.51	8.13	0.47	7.53	8.91

[a] In accordance with [7].
Total organic carbon (TOC), magnesium salts (MgO), sodium salts (Na_2O), potassium salts (K_2O), soluble chloride (Cl).
M: mean value; SD: standard deviation; Min: minimum; Max: maximum.

3.1. Particle size

The particle size was analysed in terms of the maximum size measured. In average, GY_{BAU} and GY_{RG} had similar maximum size. However, the deviation was higher for the case of GY_{BAU} (7.38 ± 9.89) compared to GY_{RG} (8.00 ± 4.00). Moreover, the minimum size varied greatly between samples (0.10 mm in the GY_{BAU}, compared to 2.00 mm in GY_{RG}). This is mainly due to plant specifics., as plants that use natural gypsum typically accept higher particle sizes while FGD plants have more strict requirements [9].

Variations in the particle size distribution of feedstock may affect the calcination rate (i.e. higher times for coarser compared to finer particle sizes) and thereby the calcination efficiency. Thus, the particle size of RG should be in line with the conventional feedstock used by the manufacturer.

3.2. Free moisture

The average free moisture obtained for GY_{BAU} (3.02 ± 3.01) compares well with data from Venta (1997), in which values between 1 and 3% free moisture content in natural gypsum are reported. This parameter was above the threshold (10 %w/w) in three of the 13 post-consumer RG samples object of study (RG-08, RG-09, RG-10, see Fig. 1), being the maximum value measured 17.14%w/w. This moisture in post-consumer RG can be limited with the use of covered skips for EoL gypsum from deconstruction to recycling, the duration and conditions of storage [15].

Reincorporation of RG with high free moisture content may pose a technical problem since the material would need additional drying operations. Such extra processes would require higher primary energy and costs. As a consequence, the Eurogypsum Recycling Working Group recommends to limit free moisture of RG to 5% [7], [9].

3.3. Purity

This parameter refers to the content of calcium sulphate dehydrate ($CaSO_4 \cdot 2H_2O$) in the material. Differences are especially evident between gypsum products manufactured in plants using FGD gypsum (i.e. high purity, above 95% according to [16]) compared to plants using natural gypsum (i.e. purity commonly ranges from 80% to 96% according to Henkels & Gaynor (1996); values in line with 91.28% purity measured by Chandara et al. (2009)). In this study, purity of GY_{BAU} was 4.37 % w/w higher compared to GY_{RG}. GtoG guidelines on RG quality criteria establish minimum 80% purity, and the Eurogypsum Recycling Working Group recommends a value of at least 85% [7]. In any case, these guidelines should be adapted to each particular context.

Purity affects the primary energy use of the calcination stage during the manufacturing process, due to the content of chemically bound water (i.e. higher purity requires higher energy demand) [9]. On the other hand, the higher the purity, the lower the weight of the gypsum product and the effects of potential impurities, which makes hither purity a desired parameter [17].

3.4. Total organic carbon (TOC)

The existing technology for processing EoL gypsum is designed to separate the paper from the gypsum core. However, traces of paper waste may remain in the recycled material. Such traces should be limited in order to warrant low levels of TOC. In this study, one sample exceeded the TOC threshold in the GtoG guidelines on RG quality criteria (RG-01, TOC=3.13), which was attributed to the nature of this sample (RG-01 corresponded to only pre-consumer RG). Pre-consumer gypsum waste is often processed by using equipment that may not separate the lining paper from the gypsum core [19].

High TOC values affect the fluidity of the slurry and increases the excess of water demand. The residual paper should therefore be kept at the minimum possible level. The Eurogypsum Recycling Working Group recommends TOC below 1.0% w/w [7].

3.5. Water soluble salts and pH

Water soluble salts include magnesium, sodium, potassium and chloride. These salts can be found in all types of gypsum, and therefore they are not particularly linked to the use of RG. However, a high content of salts can be due to high amounts of residual paper [9]. The only sample that presented a high TOC content (RG-01), also showed a high sodium (0.066% w/w) and chloride (0.124% w/w) content. On the other hand, the pH value complied in all cases.

The presence of soluble salts affects the paper bonding in plasterboard production. This is due to the migration of salts to the interface between the paper and the gypsum core, during the drying of plasterboard in drying kilns. These potential deposits of salts could cause the detachment of paper from the gypsum core during installation, particularly when plasterboard is exposed to high moisture [17].

3.6. Toxicological parameters

Toxicological parameters are related to potential heavy metal trace elements in the gypsum feedstock. Table 3 shows the relevant parameters part of the GtoG guidelines on RG quality criteria. It is worthwhile mentioning that these threshold values are considered by the gypsum industry as a starting point, to be redefined for the case of RG [7].

In this study, 88% of GY_{BAU} and 77% of GY_{RG} samples complied with the GtoG guidelines. One sample (RG-04) had a high content of lead, nickel and zinc, of unknown origin. Three samples (GY-M-03, RG-05 and RG-11) exceeded the nickel content. In order to further investigate these results, Institut Frenesius (SGS) conducted a second analysis on eight samples of feedstock, which resulted on values of nickel below the threshold (in samples which nickel content varied between <0.01 and >10.00 in the GtoG analysis). Discrepancy between the results suggests that further investigation is needed on the procedures and testing methods for trace elements [9].

5. Conclusions

The present work has analysed data from testing gypsum feedstock (business-as-usual and recycled gypsum). The results have been discussed according to the existing voluntary guidelines on recycled gypsum quality criteria for the gypsum industry (GtoG guidelines on quality criteria), which were fulfilled by the majority of the RG samples. Most of these parameters can be typically managed by the deconstruction-recycling value chain (e.g. free moisture, total organic carbon), by applying effective deconstruction processes (i.e. dismantling, separate collection), and adequate recycling procedures and equipment. In any case, technical parameters should be adapted to the specifics of each plant and values should be periodically monitored.

Acknowledgement

This study has been performed under the framework of the GtoG project, supported by the European Commission – DG Environment through the Life + programme; under contract number LIFE11 ENV/BE/001039. The article has been prepared during the research stay of Ana Jiménez at TU Delft, from February to April 2016, granted by the “XVI Convocatoria de ayudas del Consejo Social para el Fomento de la Internacionalización de Doctorados”, Universidad Politécnica de Madrid.

Table 2. Toxicological parameters

Parameter	Unit	GtoG project guidelines[a]	GY-F-01	GY-F-02	GY-M-01	GY-M-02	GY-F-03	GY-M-03	GY-M-04	GY-R-01	RG-01	RG-02	RG-03	RG-04	RG-05	RG-06	RG-07	RG-08	RG-09	RG-10	RG-11	RG-12	RG-13
As	mg/kg	<4.0	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21
Be	mg/kg	<0.7	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pb	mg/kg	<22.0	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	130.40	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18	< 0.18
Cd	mg/kg	<0.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cr	mg/kg	<25.0	< 0.01	1.42	< 0.01	0.85	1.39	< 0.02	5.97	1.37	< 0.01	< 0.01	0.78	4.85	3.47	2.06	1.10	2.03	1.79	2.34	5.94	1.22	< 0.02
Co	mg/kg	<4.0	< 0.01	< 0.01	< 0.01	< 0.01	< 0.02	< 0.02	< 0.01	< 0.02	< 0.01	< 0.02	< 0.01	< 0.02	2.61	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cu	mg/kg	<14.0	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.02	< 0.02	< 0.01	< 0.01	< 0.01	< 0.01	4.59	< 0.01	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	4.13	< 0.02
Mn	mg/kg	<200.0	16.10	53.40	18.80	43.80	25.23	52.83	33.90	14.82	52.80	17.40	62.20	56.10	50.60	26.20	21.10	25.40	24.00	26.08	52.80	10.24	20.40
Ni	mg/kg	<13.0	< 0.01	< 0.01	< 0.01	< 0.01	7.52	40.50	12.30	7.64	< 0.01	< 0.01	< 0.01	30.70	31.40	7.91	8.51	10.40	8.60	2.88	31.60	11.30	11.10
Hg	mg/kg	<1.3	0.20	0.43	<0.05	<0.05	0.30	0.08	0.23	<0.05	0.39	<0.05	<0.05	0.21	0.21	0.28	0.29	0.29	0.31	0.29	0.21	<0.05	<0.05
Se	mg/kg	<16.0	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37
Te	mg/kg	<0.3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	mg/kg	<0.4	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12	< 0.12
V	mg/kg	<26.0	4.11	2.74	2.96	3.11	4.37	5.99	7.36	6.07	1.03	4.03	5.44	4.58	4.61	4.50	3.54	3.99	4.32	5.09	7.42	3.70	5.29
Zn	mg/kg	<50.0	4.30	15.30	4.19	4.31	15.50	6.39	29.54	39.52	16.90	3.94	5.32	52.90	31.29	18.41	18.31	13.96	17.24	16.67	43.11	16.02	13.68
Asbestos	yes/no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
R index	< 0.5	< 0.5	-	-	-	-	-	-	-	-	< 0.02	< 0.05	< 0.07	< 0.14	< 0.17	< 0.04	< 0.04	< 0.05	< 0.05	< 0.04	< 0.08	< 0.06	< 0.07

[a] In accordance with [7].

References

[1] A. Jiménez Rivero, R. Sathre, and J. García Navarro, ‘Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union’, Resources, Conservation and Recycling, vol. 108, pp. 171–181, Mar. 2016.

[2] A. Jiménez Rivero, A. De Guzmán Báez, and J. García Navarro, ‘Gypsum Waste: Differences across Ten European Countries’, International Journal of Sustainability Policy and Practice, vol. 11, no. 4, pp. 1–9, 2015.

[3] The Council of the European Union, ‘Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex to Directive 1999/31/EC (2003/33/EC)’, Official Journal of the European Communities, p. L 11/27 – 11/49, 2003.

[4] C. Plaza, Q. Xu, T. Townsend, G. Bitton, and M. Booth, ‘Evaluation of alternative landfill cover soils for attenuating hydrogen sulfide from construction and demolition (C&D) debris landfills’, Journal of Environmental Management, vol. 84, no. 3, pp. 314–322, 2007.

[5] G. K. C. Ding, ‘Sustainable construction-The role of environmental assessment tools’, Journal of Environmental Management, vol. 86, no. 3, pp. 451–464, 2008.

[6] GtoG Project, ‘Life+ Gypsum to Gypsum (GtoG) project “From production to recycling: a circular economy for the European Gypsum Industry with the Demolition and Recycling Industry”, 2013. http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4191. [Accessed: 17-Jan-2016].

[7] GtoG project LIFE11 ENV/BE/001039, ‘DC2: Protocol of action B2.2: Quality criteria for recycled gypsum, technical and toxicological parameters’, 2015. http://gypsumtogypsum.org/documents/quality-criteria-for-recycled-gypsum-technical-and-toxicological-parameters.pdf. [Accessed: 13-Nov-2015].

[8] VGB, VGB-M 701e. Instruction Sheet Analysis of Analysis of FGD Gypsum FGD gypsum. 2008.

[9] GtoG project LIFE11 ENV/BE/001039, ‘DB4: Report of Production Process Parameters’, 2015. http://gypsumtogypsum.org/documents/report-on-production-process-parameters.pdf. [Accessed: 09-Nov-2015].

[10] WRAP and Environment Agency, ‘Quality Protocol. Gypsum. End of waste criteria for the production and use of recycled gypsum from waste plasterboard’. 2013.

[11] Bundesverband der Gipsindustrie e.V., ‘Recycled gypsum (RC-gypsum). Initial test for recycling plants, quality management, quality requirements and analysis methods’, 2013.

[12] J. Beckert, Comparison of natural gypsum and FGD gypsum: studies for a comparative assessment of the health impact of natural gypsum and FGD gypsum from coal-fired power plants with a view to their use in the manufacture of building. materials. 1990.

[13] A. Jiménez-Rivero and J. García-Navarro, ‘Indicators to Measure the Management Performance of End-of-Life Gypsum: From Deconstruction to Production of Recycled Gypsum’, Waste and Biomass Valorization, pp. 1–15, 2016.

[14] G. J. Venta, ‘Life cycle analysis of gypsum board and associated finishing products’, 1997.

[15] GtoG project LIFE11 ENV/BE/001039, ‘DA2: Inventory of best practices. Gypsum to Gypsum project LIFE11 ENV/BE/001039’, 2015. http://gypsumtogypsum.org/documents/da2-inventory-of-best-practices.pdf. [Accessed: 17-Jan-2016].

[16] WRAP and Environmental Resources Management Ltd (ERM), ‘Technical Report: Life Cycle Assessment of Plasterboard’, 2008.

[17] P. J. Henkels and J. C. Gaynor, ‘Characterizing synthetic gypsum for wallboard manufacture’, ACS Division of Fuel Chemistry, Preprints, vol. 41, no. 2, pp. 569–574, 1996.

[18] C. Chandara, K. A. M. Azizli, Z. A. Ahmad, and E. Sakai, ‘Use of waste gypsum to replace natural gypsum as set retarders in portland cement.’, Waste management (New York, N.Y.), vol. 29, no. 5, pp. 1675–9, May 2009.

[19] GtoG project LIFE11 ENV/BE/001039, ‘DA1: Inventory of current practices’, 2013. http://gypsumtogypsum.org/documents/deliverable-a1-report-on-current-practices.pdf. [Accessed: 17-Jan-2016].