GYPSUM TO GYPSUM: FROM PRODUCTION TO RECYCLING

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ABSTRACT

The feasibility of incorporation of recycled gypsum derived from post-consumer (construction and demolition) gypsum-based waste into the plasterboard manufacturing process up to a maximum target of 30% w/w in feedstock is investigated and the resulting impact on variable plasterboard manufacturing costs is techno-economically assessed, based on data collected from pilot projects in five European plasterboard plants and according to a generic process model. ASPEN Plus 2006 Simulation Software is used for the calculations. The functional unit is 1 m^2 of standard type plasterboard (12,5 mm thickness).

The rate of incorporation achieved ranges between 20-30% (average 25,2%), which results in an average 0,6% reduction of the total variable cost per m^2 of plasterboard. According to the cost analysis, this impact is caused by the considerable decrease of raw materials' cost, which compensates for cost increases in other process parameters (additives, water demand and electrical energy).

Keywords: gypsum-based waste, recycled gypsum, post-consumer recycled gypsum, plasterboard manufacturing

1. Introduction

Gypsum is a rock-like mineral predominantly consisting of calcium sulphate dihydrate ($CaSO_4.2H_2O$), used in construction in different applications such as plasterboard, building plaster and gypsum blocks, among others. Plasterboards and gypsum-based products found increased application in the post-second world war era and the sector is one of the few fully integrated industries within the construction products field; the European Gypsum Industry covers the whole life-cycle of the product since the companies which extract the mineral "Gypsum" also process it and manufacture the value-added construction products and systems (UPM, 2013).

Until the mid 1980s, most of the gypsum used in the EU building and construction was naturally mined. Now-a-days, synthetic gypsum produced by the Flue Gas Desulphurization (FGD) process of fossil fuel-fired power stations (FGD gypsum) is widely used as an alternative feedstock in the gypsum industry. Moreover, most plasterboard manufacturing plants traditionally recycle their own production waste. This results in up to ~5% inclusion of re-processed secondary gypsum as raw material in the board. Since gypsum is known to be indefinitely and 100% recyclable as it always keeps its natural properties during use (UPM, 2013), post-consumer recycled gypsum (i.e. derived from construction and/or demolition gypsum-based waste) can be also reincorporated in the production chain, thus serving natural resources preservation policies and promoting a circular economy, as well as complying with current EU legislation.

Specifically, according to Directive 2008/98/EC on Waste (Waste Framework Directive, WFD) the waste hierarchy that should be applied as a priority in all the EU Member States was drafted as: waste prevention → reuse → recycling → recovery → disposal. In that final case, according to Council Decision 2003/33/EC non-hazardous gypsum-based material should be disposed of only in landfills for non-hazardous waste in cells where no biodegradable waste is accepted. WFD establishes that, by 2020, the preparing for reuse, recycling and other material recovery of most of the categories defined in the European List of Waste (ELW) shall be increased to a minimum of 70% by weight. However, plasterboard recycling yet appears far away from the 70% target, while 2003/33/EC is not correctly implemented in many EU countries, due to the inexistence of specific monocells for the disposal of gypsum waste in landfills (UPM, 2013).

On the other hand, post-consumer gypsum-based waste volumes are becoming increasingly larger and are expected to further increase in the future, given the widespread usage of plasterboard in modern constructions. Some plants have recently started to introduce the usage of post-consumer recycled gypsum, raising the incorporation rate of recycled material in feedstock up to ~10-15% w/w. However, while "clean" waste from construction sites, being free of contaminants (except for the residual paper originating from plasterboard waste) and having the same properties as production waste, can be easily reincorporated in the manufacturing process, the reincorporation of demolition waste presents a real challenge, given its various impurities (e.g. wood pieces, metal parts, non-water based paints, adhesives etc.).

Once gypsum-based waste from construction and demolition is separated on site, it can be received by a recycler company that will process it to produce recycled gypsum. Given that the final product must have specific quality parameters, independently of the feedstock used for its fabrication, the challenge is clear; to deal with more complex waste material of variable quality without relying on landfill, by re-incorporating more into the manufacturing process of plaster-based products.

This contribution presents the results of Action B3 of the "GtoG" ("Gypsum to Gypsum") Life+ project. The area of study concerns 8 European countries (Belgium, France, Germany, Greece, Poland, Spain, the Netherlands and the UK). The project's 17 partners include companies that cover the entire value chain; demolition companies, gypsum recyclers and the European Gypsum Industry. Action B3 focuses on the technical issues of the reincorporation of recycled gypsum into plasterboard manufacturing.

2. Plasterboard manufacturing process

Gypsum plasterboards are manufactured in a two-step process. The first step's generic stages include pre-processing of the gypsum feedstock (size reduction and pre-drying depending on feedstock type and properties), followed by the thermal process of calcination, where the contained $CaSO_4.2H_2O$ in gypsum converts to hemihydrate according to the equation:

$$CaSO_4.2H_2O + \text{energy} \rightarrow CaSO_4.1/2H_2O + 3/2H_2O$$

This partly dehydrated form of gypsum is the intermediate product "stucco". The stucco production step may involve a series of equipment units (i.e. crushers, dryers, mills, heated mills, calcination kettles or rotary kilns etc.) or modern heated calcination mills, an increasingly popular option in which the raw feed is dried, ground and calcined to stucco in a single stage. Moreover, depending on the equipment employed, calcination may take place by direct or indirect contact of gypsum with hot gases.

In the second step stucco is mixed with water and a series of solid and liquid additives in specific ratios which constitute the "recipe" to form the plaster slurry. The slurry is fed to the board line where it is encased between two layers of special strong paper and, as $CaSO_4.1/2H_2O$ rehydrates and converts back to $CaSO_4.2H_2O$ according to the reverse chemical reaction, it gradually sets while it is conveyed along the line at an appropriate speed. When set, the continuous length of plasterboard is cut to individual uniformly sized boards, which proceed to a large multi-zone drier to remove the excess free water and exit as the finished product. (ATHENA, 1997; Henkels, 2006; WRAP, 2008)

3. Methodology

Pilot production trials took place in five plasterboard manufacturing plants located in Germany, France (2 plants), the UK and Belgium. All plants use typical production lines, but the processes are not identical; differences exist in the feedstock/feedstock mix used and consequently in the raw material pre-processing stages, as well as in the types of industrial equipment employed.

This is considered positive for the study's purposes as it provides a broader range of sample cases.

The production trials were carried out in two parts from January 2014 until March 2015. The 1st round of trials refers to a series of runs *of the standard production* in each plant and serves as base scenario*.* The 2nd round of trials involves repeated test productions with gradual increase of the amount of post-consumer recycled gypsum above the current standard (if any) amount used and up to the set target of 30% recycled gypsum in total (production and post-consumer) or up to a technically feasible maximum, given either by product quality and/or process efficiency. The impact on variable financial costs of plasterboard manufacturing is assessed based on systematically recorded data from the trials and according to a generic process model. ASPEN Plus 2006 Simulation Software is used for the calculations. The functional unit is 1 m^2 of standard type plasterboard (12,5 mm thickness).

3.1. System boundaries - A generic process model

The system boundaries for the techno-economic impact assessment (Figure 1), are defined to include all processes from the entrance of the manufacturing plant to the production of the finished plasterboard. Further upstream and downstream operations (e.g. raw material production, product packaging etc.) do not fall into the scope of study, since their respective energy demands and costs remain unaffected by the introduction of recycled gypsum in the process. A generic process model is thus formulated, limited within the manufacturing unit borders.

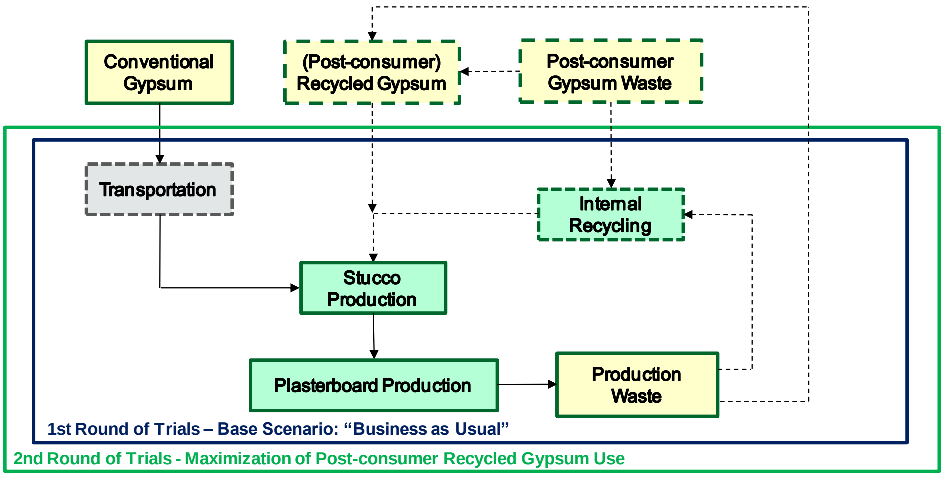

Figure 1: Generic process model for plasterboard manufacturing - Standard practices followed by all 5 pilot plants shown in solid lines, case-specific practices in dashed lines

4. Results

The use of recycled gypsum in the base scenario (1st round of trials) ranges between 5-18% (average 10,87%) and it is increased up to 20-30% (average 25,2%) in the 2nd trials. One out of the five pilot plants managed to achieve the maximum target of 30%. Figure 2 presents the impact on variable plasterboard manufacturing costs.

The re-incorporation of recycled gypsum into the process up to a feasible maximum of ~30% results in an average 0,6% reduction of the total variable cost per m^2 of plasterboard. The cost analysis shows that this is mainly caused by the considerable decrease of raw materials' cost, which compensates for the cost increases in other process parameters (additives, water demand and electrical energy). The decrease of raw materials' cost is due to the significantly lower prices of recycled gypsum (0-7 €/t) compared to conventional gypsum market prices (9-36 €/t including shipping), whereas the fluctuations in the remaining variable process costs relate to the quality and properties of recycled gypsum.

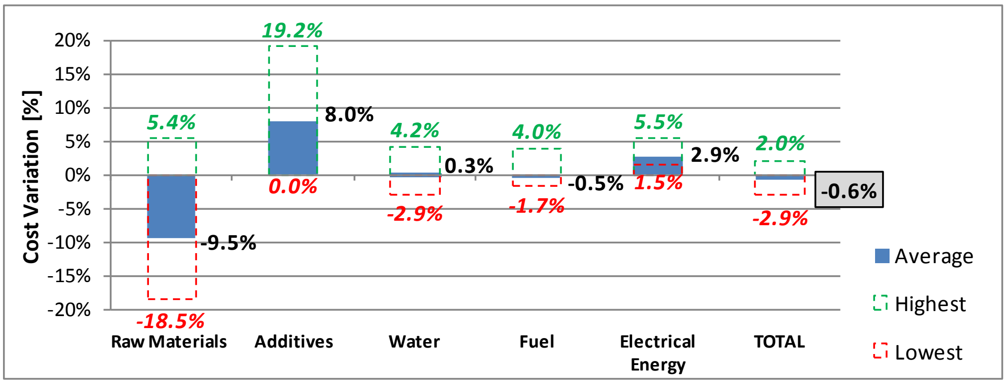

Figure 2: Impact of recycled gypsum % use maximization (Trial 1 vs Trial 2) on variable costs of plasterboard manufacturing

More specifically, the introduction or increase of recycled gypsum usage in the process alters a series of properties of the so far standard used feedstock/feedstock mix such as particle size distribution, moisture content, purity (the % w/w $CaSO_4.2H_2O$ content of gypsum on a dry basis), TOC (residual paper and fibre content), water soluble salts content, silicon content and presence of other impurities/contaminants. These key parameters are major determinant factors of the technical process characteristics that must be adapted accordingly in order to efficiently achieve the desirable product quality and thus directly or indirectly affect process costs. For example, moisture content and purity affect fuel consumption for drying and calcination respectively. Particle size, TOC and other impurities have an impact on stucco quality, which relates to its dosage in the recipe and to the fluidity of the stucco slurry when mixed with water, thus affecting water demand and, in turn, fuel consumption in the plasterboard dryer. Stucco quality and water demand relate to both the composition and the quantity of the additives mix used in the recipe, which are particularly costly. Finally, electrical energy consumption relates to changes in the mass balance (i.e. changes in the feedstock/stucco ratio and the bulk density of stucco due to different feedstock properties) and to adjustments to the load and speed of the machinery in order to maintain the desirable production rate.

The large range of impact on plasterboard costs, shown in Figure 2, (highest and lowest % cost variation) is due to the individual process characteristics of each pilot plant and reflects the different technical adjustments made to each process in the 2nd round of trials. In any case, the results clearly show that all manufacturers managed to minimize the impact on total plasterboard cost by appropriately adapting their processes.

5. Conclusions

The use of recycled gypsum up to 30% in plasterboard manufacturing is practically proved feasible and appears to have no negative impact on variable cost, as long as its market price and quality are maintained close to current levels, while further financial benefits can be achieved if the quality of the recycled material is further improved to being as similar as possible to the conventional feedstock used.

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