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A Comparative Study in the Execution of Gypsum Coatings under an Environmental Impact Perspective

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Abstract: The gypsum slurry used in coatings is a construction material that generates many residues. Despite the proven feasibility of recycling, the reduction of waste is still the best way of minimizing the environmental impact. Different technologies have been studied in order to replace its use. However, studies have shown that the losses in construction when using gypsum plasterboard panels are approximately 5%. Although gypsum plasterboard panels seem to be environmentally more suitable, it is necessary to do a comparative study to support the advantages of using plasterboard panels. The survey of aspects and impacts was carried out directly in the monitoring of the implementation procedures in work. For the impact assessment, the methodology took into account significance criteria, scope, frequency and severity. From the score attributed to these criteria was possible to assess the severity of impacts and define which finishes would be environmentally more suitable. As a result has been that the gypsum plasterboard panels causes less environmental impacts during the construction, in this evaluation we found 33 impacts unless that the coatings with gypsum slurry and their most appropriate use under the environmental point of view.

Keywords: construction materials; gypsum plasterboard panels; gypsum slurry; environmental impacts

1. Introduction

Construction is one of the sectors of the economy that cause major environmental impacts. In addition to the degradation caused by the extraction and use of natural resources (sand, limestone, gravel, wood, water) and pollution resulting from the constructive activity, this sector is, among all the productive activities, the main waste producer. It is estimated that the volume of generated waste, Construction and Demolition Waste (CDW), is twice greater than the volume of urban solid waste. These wastes result mainly from misuse or poor quality of the materials used in the work and, in part, the low-skill labor force employed in construction.

To reduce waste generation in construction sites is both a question of cost reduction and environmental impact. New materials and/or new techniques applied to existing materials may generate less waste production and, even, potentially-recycled waste. Traditionally, the civil construction finishing's were made through sculptures and faceted rocks. With the evolution of the construction processes and the development of manual skills, it was possible to mold gypsum slurry with different shapes for use as finishing. The main advantages are the easy application and low-cost.

However, the gypsum slurry that has been used in construction generates too much residues. This residue becomes a potential problem, considering that your incorrect disposal can contaminate the soil, water and air. In addition, the appropriate disposal can cost twice the value compared to the amounts paid by the normal waste disposal. An alternative to substitute the coating of gypsum slurry is the gypsum plasterboard panel (GPP), which consists of a coated gypsum board with paper card. The panel is applied by means of screws in the location where you want to install it. The GPP has a standard size and can be cut according to the area to be

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placed. Perfect fittings are obtained once that the panel can be cut in pieces and this results in finishing's with less waste generation.

Our goal in this study is to analyze the gypsum slurry used as coating in the civil construction and evaluate alternatives that may generate the least amount possible of waste and, consequently, minimize environmental impacts. We carry out a survey and an assessment of the environmental impacts caused by the processes of coating, using both gypsum slurry and GPP in order, to compare results and support the choice by the material and the constructive method environmentally more appropriate.

1.1. The Gypsum in the Civil Construction

Gypsum is dihydrate mineral formed by calcium sulfate with chemical formula $CaSO_4.2H_2O$. It is very soft, with hardness of 2 in the Mohs scale and has been used in a number of applications, as fertilizer, plaster, orthopedic cast and for sculptures. After crushed, grinded and heated between 130° and 160°C gypsum dehydrates and converts in hemihydrate gypsum or plaster (CaSO4.½ H2O)[1]. Although moderately water-soluble, it has good properties for construction once that it forms a plastic mass widely used for finishing purposes. The plasticity of fresh paste, the fast hardening, the smoothness of the hardened surface and the low cost are advantages that are promoting a continuous growing of plaster as finishing in constructions. According to DNPM, the National Department of Mineral Production [2], the per capita consumption of plaster increased about 25% in the last years.

The main use of plaster is as coating material. This is applied directly on walls and ceilings, and as casting material, lining boards, moldings, picture frames and other pieces of finishing and decoration. In addition to these uses, the drywall is used in the internal fence (walls, ceilings and linings) of all types of buildings. Among the uses of gypsum, the gypsum slurry used as coating is the one that generates the largest volume of waste at the construction site. By the other hand, GPP is an alternative solution for reducing the amount of residue.

1.1.1. Gypsum Slurry and Recycling Aspects

The gypsum slurry coating paste is applied manually or by pneumatic projection directly on the masonry walls of ceramic or concrete blocks. It is a low-cost material since it can replace the layer of roughcast and in step of preparation for painting, the base mass [3]. The high capacity of hydration of the gypsum shortens the time between the application and the painting increasing the speed of work [4]. Another advantage of the gypsum slurry as a coating is its simple preparation, just mixing with water [5].

After mixing the plaster powder in water, the hardening time of the paste ranges from 15 to 20 minutes. The application of the coating must occur before the beginning of the chemical reactions of hardening. Once solid, the paste cannot be smoothed again with addition of water because it is an irreversible exothermic reaction. The rapid hardening of the gypsum slurry together with a low-skill manpower is the main cause of huge amount of waste in the construction site [6].

In the case of direct coating on masonry, layers of 5 to 10 mm thick have a consumption average of 5.9 kg/m² with about 45% of waste [7]. Part of the losses is caused to the excess of coating thickness on the wall, which will become residue after demolition or removal of the coating. However, most of the waste is generated during the process of finishing and this represents a high cost for the gypsum industry [6].

A survey of the costs for disposal of construction and demolition waste, in southern Brazil, in the year 2012, showed that residues as wood, concrete, ceramic, metal and others cost about US$ 7.00/m³ and the destinations are deposits which transform the materials into aggregates. In the case of the gypsum slurry, the cost is US$ 17.00/m³ for collect and US$ 55.00/m³ for deposit at licensed sites. Before 2011, the gypsum slurry was classified as a Class "C" residue, waste for which were not developed economically viable technologies or applications for recycling/reuse [8] in accordance with the Brazilian resolution n° 307 of the National Council for the Environment (CONAMA). According to the CONAMA's resolution No. 431 of 2011, the gypsum was reclassified as class "B", being now a recyclable product [9].

Gypsum recycling methods have already been surveyed since the late 1990's and there have been a significant advance on three fronts of reuse: cement industry, agriculture and the gypsum industry. Studies have shown that after grinding and calcination, the material back to its commercial state and maintain the same physical and mechanical properties. However, recycling is only possible if the gypsum residues are not contaminated with any other material. This requires a waste management in the construction site involving its correct specification, training of the workers, and compliance with rules of use since the phase of collection, segregation and transport until the final disposal of the gypsum waste [10]. Other limitations to the recycling of gypsum slurry are presented below, as mentioned by [6]:

- Gypsum is abundant and cheap in the region of production, *i.e.*, Chapada do Araripe, northeastern Brazil. However, the cost of transport to the gypsum industry comes to be too expensive due to the large distance (over hundred to thousand kilometers) from the main consumption cities. Consequently,

transportation of the waste to be reprocessed is economically unviable;

- The recycling process is more complex than the production from the virgin material. More energy is required for recycling it than for producing it. The cost of collection, separation, transport and the necessary equipment makes the recycling process more expensive than the natural raw material processing. In addition, the recycled gypsum has variability in performance;

- In some regions, the amount of gypsum waste generated is not enough to support an industrial recycling process;
- The segregation of the residue of gypsum and the control of contamination at the time of generation does not occur in the most companies.

1.2. Alternatives to the Replacement Gypsum Slurry

Despite the proven possibility of recycling the gypsum slurry, the reduction of waste is still the best possibility to minimize the environmental impact. Some alternatives such as gypsum slurry and gypsum plasterboard panels can replace the use of gypsum plasterboard coating paste more efficiently.

1.2.1. Gypsum Slurry Modified

The gypsum slurry modified with addition of hydrated lime or thickeners, additives like those derived from cellulose, HEC (hydroxyethyl cellulose) and HEMC (hydroxy ethyl methyl cellulose) has a larger hardening time, *i.e.*, hardens more slowly and can be applied in a greater span of time, which significantly reduces the losses. In the standard gypsum slurry, the hydration reaction begin to occur more quickly, reducing the waiting time for the begin of the application. This form has a standby time of about 20 minutes. On the other hand, the gypsum slurry with partial replacement of 23% (m/m) of hydrated lime has the stand by time to 5 minutes. This represents an increase of productive time of 15 minutes, *i.e.*, a time span of 78 to 100% greater [11].

The disadvantage found in partial replacement of gypsum slurry by lime, maintaining constant the water content, is the reduction of mechanical resistance to compression and dynamic elasticity module. However, the problem can be solved with the incorporation of filler, properly dosed, in the gypsum slurry and lime [4].

1.2.2. Gypsum Plasterboard Panels

The gypsum plasterboard panels consist predominantly of a mixing of gypsum (calcium sulfate dihydrate), water, 4 to 12% of paper card and impurities like glass fibers, clays and starch, among others. There are no data available on the composition of brazilian products, once these additives are part of the industrial secret of each manufacturer [6].
In fact, the gypsum plasterboard panels are not just an alternative for coating, but also a constructive method that replaces the internal seals of ceramic blocks of masonry or concrete. With the commercial name drywall, the system is based on the assembly of a skeleton of galvanized steel wire or wood, where the gypsum panels are supported. The possibility of combining plates with different dimensions has proven an efficient solution to reduce residues. On the other hand, the use of double panels in order to get a cavity to be filled with absorbent lining and insulation materials provides a better acoustic performance than the conventional masonry [4].

In so far environmental impacts are concerned, waste generation occurs in two ways: in the production of gypsum plasterboard panels and during execution of the sealing system on the construction site. Production residues are recycled through the reinsertion of the same in the process of production of the plates, since they have known composition. In the jobsite, residues are produced after cutting and related activities of modulation [12].

According to previous researches, the losses with gypsum slurry in brazilian constructions are estimated at 5% [6]; other studies found higher loss, of about 7 to 8% [13]. The generation of waste with the use of GPP is less than the gypsum slurry and all system components drywall (galvanized steel profiles, brackets, screws, tapes, acoustic band, cardboard plaster plates and mass treatment of the joints) are 100% recyclable.

1.3. Environmental Impacts and Aspects: Definition, Survey and Evaluation

When studying a process or material under the environmental point of view, it is necessary to consider about its impacts. According to ISO 14001 of 2004, the environmental aspect of the activity must consider its interference in the air, water, soil, natural resources, flora, fauna, human beings and their interrelationships. Environmental impact is already set to "changes in the environment, harmful or beneficial, wholly or partially resulting from environmental aspects". Therefore, the relationship between environmental aspect and impact is of cause and effect [14]. The survey and evaluation of environmental aspects and impacts is one of the primary tools for the implementation of an environmental management system, in addition to guidelines for the establishment of corrective actions and control measures of environmental impacts.

The norm ISO 14004 of 2007 does not determine which methodology should to be used for the survey and evaluation of environmental aspects and impacts, only recommends that criteria must be established to

define what would be considered significant. The norm suggests that the establishment of significant criteria must observe the following items: scale of impact; severity of the impact; duration of impact; type and size of the aspect and frequency of aspect [15].

2. Methodological approach

The first approach involved a literature review in order to search alternatives for gypsum slurry coating that could be environmentally more sustainable. The literature indicated gypsum plasterboard panels as a potential alternative but information available were not sufficient to support any decision in this respect. So, the second methodological approach was observe and collect data on the mode of finishing using gypsum slurry and gypsum plasterboard panel directly into a construction site of residential buildings. From these observations, we conducted the survey of environmental aspects and impacts generated.

The data collection for the survey was carried directly in the construction site during the execution of the coating. The methodology for the identification and evaluation of environmental aspects and impacts was created from the recommendations of the ISO 14004 [15]. As suggested by this standard, the criteria used for assessing the significance of aspects and impacts were: comprehensiveness and severity of impact and the frequency of the aspect. For scoring the classification criteria of gravity and the significance level, we use as reference the procedures for the identification and evaluation of environmental aspects and impacts of the Environmental Management System (EMS) of the University of Vale do Rio dos Sinos (UNISINOS), which was adapted for the specific purposes of this research [16].

The valuation criteria and the sum of the final scores were carried out inductively, method that part of particular facts to then achieve a general conclusion. From the comparison of the results, we concluded which one of the techniques of gypsum usage can cause less environmental impact.

2.1. Survey and Evaluation of Environmental Aspects and Impacts

For the identification of the aspects and evaluation of environmental impacts associated with the use of plaster in construction, we decided to examine only the execution process coating. From the follow up directly on construction site, we seek to identify every aspect of activities and your relationship with the largest possible number of environmental impacts generated.

We attribute weights to the evaluation taking into account the degree of comprehensiveness, the severity and frequency of each impact. The values were classified of 1 to 3, according to Table 1.

Table 1. Weights of criteria

Weights	Comprehensiveness of the impact	Severity of the impact	Frequency of the aspect
1	Isolated to workplace	Cause light damage	Every six months or longer
2	Restricted to workplace and other environments of the construction site	Causes moderate damage	Monthly
3	Covers area outside of the construction site	Cause severe and irreversible damage	Weekly or daily

Adding up the score assigned to the criteria of comprehensiveness, severity and frequency of each impact, we obtained the severity of the impact on the environment, which may be insignificant, moderate or critical of according with the Table 2. Based on the impact assessment, we attribute the significance to the associated aspect. Thus, aspects that generate moderate or critics impacts (score up to 5) were considered as significant.

Table 2. Gravity of impact

Sum of points	Gravity of impact	Degree of significance
To score 4 points	Insignificant	Without significance (no)
Score of 5 to 7 points	Moderate	Significance (yes)
Score of 8 to 12 points	Critical	Significance (yes)

3. Results and Discussion

3.1. Description and Monitoring of the Execution of Coatings

The application of coating with the gypsum slurry starts with the preparation of the dough when the gypsum powder is sprinkled over the water, giving off large amounts of fine particles that blend into the atmosphere in the workplace. After the timeout, which varies from 20 to 30 minutes, the gypsum slurry is applied on the wall in thin layers until reaching the desired thickness. In this application, that occurs in the vertical direction, from the bottom to the top, there is loss of the material that flows through the wall. The service also generates a certain level of noise caused by friction of the tool with the wall.

After dry, the coating has to be sanded to eliminate imperfections. The sanding, which can be either manual or mechanical, is the step that generates most dust. In the manual sanding, the worker has a greater contact with the gypsum dust, in addition to the physical exertion, which can cause repetitive strain. Mechanical sanding increases productivity and reduces the direct contact with dust, however, the noise generated by such equipment is intense and continuous. Both dust and noise can cause diseases. Researches have proved the relationship between environmental pollution by exposure to dust and respiratory health issues [17].

In terms of waste generation, we observe that it occurs at all stages of the coating service, because drying of gypsum slurry is very fast. Huge quantities of gypsum residue are scattered around the desktop and end up being mixed with other materials that makes impossible their recycling. This waste ends up contaminating the soil and water when disposed in inappropriate sites. If the gypsum residues are separated properly, they will be collected for transshipment and disposed in specific areas. However, costs are higher than the construction and demolition common wastes.

The execution of wall combines steel structure with gypsum plasterboard panels. Firstly, the markings of walls, doorways and windows are made. After, the metal profiles are cut with cutting pliers and, is made and then coating the profiles with the tape for sound insulation. As the project is modulated, the loss by cutting the profiles is minimal, only in cases where docking problem occurs. The fixing of the metal tabs on the floor, walls and top slab is made with electric screwdriver, which generates heavy noise during the process of screws fixing. The gypsum plasterboard panels are fixed in the metal frame with electric screwdriver, which also generates noise. Among the gypsum plasterboard panels can be placed mineral wool that assists in thermo acoustic comfort. Then, the gypsum plasterboard panels are cut to the fit exact and also are cut the doorways. The waste generated in the cutting process is packed by the company that executes the coating and return to the gypsum plasterboard panels company. There, it is reincorporated into the production process. The generation of waste and dust during the execution of the coating is almost inexistent. The installation of metal structures and the plasterboard panels does not require great physical effort of the workers, because the materials are light, however, the workforce must be specialized.

3.2. Evaluation of Aspects and Impacts in the Execution of Coating with Gypsum Slurry and with Gypsum Plasterboard Panels

From the monitoring of coating services in the construction site were created the Tables 2 and 3, by assigning values to the criteria, as previously explained in the methodology. During the execution of coating with gypsum slurry, the impacts more significant occurred due the use of water in the process of preparation of gypsum slurry, consumption of material and use of additional materials, as sandpapers, tow and personal protective equipment's. From the fourteen identified impacts, six were considered critic, seven considered moderate, and only one considered insignificant.

In the execution of the coating with gypsum plasterboard panels, two impacts related to noise generation were considered critical; it is quite intense in the stages of drilling and cutting of metal profiles and gypsum plasterboard panels. Three impacts are considered moderate and nine of them insignificant. Three aspects are classified as Significant and the other five as Insignificants.

The final score of the impacts on the performance of coating gypsum slurry reached 92 points whereas use of gypsum plasterboard panels sums 59 points. This represents an important difference in the assessment of impacts between the two materials. Table 3 shows the results.

Table 3. Evaluation of aspects and impacts in the execution of coating with gypsum slurry and with GPP

Aspect	Impact	()[1]	()[2]	()[3]	()[4]	()[5]	()[6]
Execution of coating with gypsum slurry							
Use of labor	Possible diseases	1	2	1	4	Insignificant	no
Dust generation	Air contamination	2	2	3	7	Moderate	yes
	Lung diseases	1	2	3	6	Moderate	
Noise generation	Noise pollution	3	1	3	7	Moderate	
	Discomfort to workers	3	1	3	7	Moderate	yes
	Nuisance to neighbors	3	1	3	7	Moderate	
Energy consumption	Use of natural resources	1	2	3	6	Moderate	yes
Use of water	Use of natural resources	2	3	3	8	Critical	yes
Materials consumption	Use of natural resources	3	3	2	8	Critical	yes
Waste generation	Contamination of soil, water and air	3	2	3	8	Critical	
	Spending on destination	2	1	3	6	Moderate	yes
	Occupation of transhipment and transport areas	3	3	3	9	Critical	
Disposal of waste	Contamination of soil, water and air	3	3	3	9	Critical	yes
		Sum total of points:			92		
Execution of coating with GPP							
Use of labor	Possible diseases	1	2	1	4	Insignificant	no
Dust generation	Air contamination	1	2	1	4	Insignificant	no
	Lung diseases	1	1	1	3	Insignificant	
Noise generation	Noise pollution	3	2	3	8	Critical	
	Discomfort to workers	2	3	3	8	Critical	yes
	Nuisance to neighbors	3	1	3	7	Moderate	
Energy consumption	Use of natural resources	1	1	3	5	Moderate	yes
Use of water	Use of natural resources	1	1	1	3	Insignificant	no
Materials consumption	Use of natural resources	3	1	1	5	Moderate	yes
Waste generation	Contamination of soil, water and air	1	1	1	3	Insignificant	
	Spending on destination	1	1	1	3	Insignificant	no
	Occupation of transhipment and transport areas	1	1	1	3	Insignificant	
Disposal of waste	Contamination of soil, water and air	1	1	1	3	Insignificant	no
		Sum total of points:			59		

()[1] Comprehensiveness of the impact ()[2] Severity of the impact ()[3] Frequency of the aspect ()[4] Sum of points ()[5] Gravity of impact ()[6] Degree of significance

4. Conclusions

The gypsum slurry used for cladding is one of the materials that generate the most waste in the construction sites. The studies show that it it's occurring mainly by the great speed of hardening after the mixture with water. This high percentage of waste represents a overspending for the construction sector. If deemed since the collection until the deposit in the licensed sites, the costs can reaches three times more than the destination of common building materials. Even with the evolution of the research for the reuse/recycling of the gypsum, there are some limitations, such as the difficulty of segregation of the residues at the construction site and avoid its contamination with other materials.

This study shows that the best alternative to the large amount of waste generated by gypsum slurry is the use of similar materials that generate fewer residues if compared with standard coatings. In fact, GPP are the best option once that it is well known and accepted in the construction market. The survey and the evaluation of environmental aspects and impacts carried out in this study reinforce GPP as an option to reduce environmental impacts as well as cost in a construction project.

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Conflict of Interest

The authors declare no conflict of interest.

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