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PHYSICAL AND MECHANICAL PROPERTIES OF RECYCLED GYPSUM AND POTENTIAL APPLICATION FOR PRECAST PANELS

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Keywords: gypsum panels, mixed pastes, sustainability, gypsum pastes.

Abstract

This study reveals the physical properties of recycled gypsum and mechanical performance of precast gypsum panels made of recycled gypsum. In addition, the comparative analysis of the physical properties and mechanical behavior of the precast panels of recycled gypsum with those of the commercial gypsum has been made. After collection of recycling and grinding gypsum residues, the quality of the powder produced was evaluated in terms of units of mass and fineness modulus. Additional tests of the dry paste were conducted for assessment of hardness, water absorption, and compressive strength of recycled gypsum. The commercial potential of the material was evaluated by the bending strength test of precast panels. The results demonstrate that recycled gypsum is sustainable, ecologically correct and a feasible material for the production of precast elements with great potential of use in civil construction.

PROPRIEDADES FÍSICAS E MECÂNICAS DO GESSO RECICLADO E A POTENCIAL APLICAÇÃO EM PAINÉIS PRÉ-MOLDADOS

Palavras-chave: painéis de gesso, mistura de pastas, pastas de gesso e sustentabilidade.

Resumo

Este estudo analisa as propriedades físicas do gesso reciclado e o desempenho mecânico de painéis de gesso pré-moldados feitos de gesso reciclado. É também realizada uma comparação com as propriedades físicas do gesso comercial e o comportamento mecânico dos painéis de gesso comerciais pré-moldados. Após a coleta, reciclagem e moagem de resíduos de gesso, a qualidade do pó produzido foi avaliada em unidades de massa e módulo de finura. Testes adicionais da pasta endurecida foram realizados para avaliar a dureza, a absorção de água e a resistência à compressão do gesso reciclado. O potencial comercial do material foi avaliado pela resistência à flexão dos painéis pré-moldados. Os resultados demonstram que a reciclagem de gesso é sustentável, ecologicamente correta e viável para a produção de elementos pré-moldados com grande potencial de uso na construção civil.

INTRODUCTION

For a very long time the economic development of the nations has been associated with the continual exploitation of natural resources without great concern for nature preservation. Natural resources were thought to be unlimited and little attention was paid to environment pollution.

Over the years, this reckless behavior towards nature and a series of associated environmental impacts have led to a great awareness about the use of natural resources and the need of environmental conservation.

Currently, an almost worldwide effort to implement sustainable and ecologically correct development is observed. Recycling is an attractive alternative for the preservation of the remaining natural resources and the reutilization of the resources already in use.

A production sector that deserves attention due to the waste that is produced is the gypsum industry. In Brazil, most of the companies in this sector have difficulty to dispose their waste because of lack of either financial resources or knowledge of recycling methods.

Recently, the administration of various Brazilian states, through their environmental agencies, have passed laws that prohibit the disposal of gypsum waste into erosion holes or garbage dumps. Now, this environmental agencies requires the use of industrial waste dumps, which usually are located far away from gypsum production regions.

According to Bezerra (2009), the world annual consumption of gypsum is about 125 million tonnes, with 2 million tonnes in Brazil alone. Brazil is 16th in the world production of gypsum and its production basically supplies the internal market. According to John & Cincotto (2003), about 5% of the total gypsum produced in Brazil is lost in the manufacture and application processes.

Carneiro et al. (2001) showed that Europeans, Japanese and Americans have sufficient recycling knowledge for the recovery of the agglomerating power of selected gypsum waste. The objective of the present work is to investigate the physical and mechanical properties of recycled gypsum in Brazil through experimental tests. The characteristics of the recycled powder (units of mass and fineness modulus), set pastes (compressive strength, water absorption and hardness) and of a commercial product (evaluation of the bending strength of recycled gypsum panels) have been studied.

The results show that recycled gypsum is both sustainable and ecologically correct and the production of precast elements using this material presents great potential of using in civil construction, such as ceiling panels and partitions. The potentiality of this material is demonstrated by comparison between experimental data obtained from specimens of precast elements produced with recycled gypsum and specimens made of commercial gypsum normally used in commercial production.

2. THE USE OF GYPSUM IN CIVIL CONSTRUCTION

Bauer (2001) defines gypsum as a broad term for a family of simple binders basically constituted of more or less hydrated sulfates and calcium anhydrides. Brazilian code NBR 13207 (1994) defines gypsum as the powder obtained from the calcination of the gypsite. Bezerra (2009) reported that gypsum is little used in Brazil, with a relatively low internal consumption in relation to more developed countries.

The gypsum production cycle has two steps: in the first step, the material is prepared for consumption and gypsite powder is produced; in the second, the consumption step, powder gypsum is turned into a paste. After setting, the product acquires the original shape (gypsite) and is sold in the form of wall and ceiling panels, cornices, statuettes and others molded pieces.

The use of recycled gypsum in block making with 30% recycled gypsum paste is technically viable, giving a final product that is very similar to blocks made of commercial gypsum paste (Abreu et al., 2009). According to Carvalho et al. (2008), recycled gypsum can be used in the production of different materials, including ceiling panels and cornices, without loss of the required properties and visual aspects.

Based on production losses determined by John & Cincotto (2003), the estimated amount of gypsum waste produced in Brazil in 2008 was 137,500 tonnes/year, which is equivalent to 5% of the total produced in Brazil. For this reason, Lima & Camarini (2011), highlight the gypsum recycling as a major factor for sustainable development.

The use of recycled gypsum in the production of gypsum panels by the industry has the advantage of using manufacture waste, which is significantly advantageous from the environmental viewpoint, and the cutting of expenditures on the transportation of waste from the plant to industrial dumps or recycling sites.

On-site recycling also reduces the risks of environment contamination during waste transport. Although the environmental gains are important, for Alencar et al. (2011), the economic gains, as well as the social gains, may be extremely important. In the case of industrial waste, on-site recycling ensures the quality of the waste as a raw material, as it is free of impurities and other contaminants.

Zhao et al. (2010) understand that economic viability is directly related to cost reduction, which may be achieved by the increase in the number of recycling plants and their location close to the waste generation points. The increase in waste disposal cost may be a favorable economic factor for the implementation of recycling processes (Klein & Robison, 2012).

3. PHYSICAL AND MECHANICAL CHARACTERISTICS OF GYPSUM PASTES

Gypsum paste is formed by the dilution of gypsum powder in water. It is used in lining, panel molding, mold repair, and the fabrication of decorative elements. According to Munhoz & Renófio (2006), gypsum paste sets when gypsum reacts with water in an exothermic process. The amount of water used in mixing influences the workability of the paste and the initial and final time of solidification and setting.

Studies developed by Iwasaki & Camarini (2011) on gypsum pastes with water/gypsum ratios of 0.70 and 0.80 showed that recycled gypsum has lower plasticity, shorter setting time, greater porosity and permeability and a smaller capacity of densification than fresh commercial gypsum. However, they have greater bending and compressive strength and surface hardness.

A way of improving paste workability is by increasing the amount of water used in mixing. Petrucci (1998) recommends using from 50 to 70% water in gypsum paste production and avoiding amounts greater than 80%. However, small businesses use up to 100%.

According to Ribeiro (2006), water absorption is another important characteristic in the panel molding process, as it may interfere with the material hardness and surface finish. The Brazilian codes do not refer to gypsum water absorption.

Compressive strength and bending strength are hardened gypsum paste characteristics that are also important, since they indicate the maximum forces to which the manufactured product can be subjected. Cincotto et al. (1988) evaluated 15 Brazilian brands of gypsum and found compressive strength values ranging from 9.93 to 27.29 MPa, while the bending strength ranged from 4.40 to 10.50 MPa and the hardness values, between 13.55 and 53.08 MPa.

MATERIALS AND METHODS

The method used in this study involved the separation and collection of gypsum waste, grinding, milling, powdering, calcination and homogenization, powder and paste characterization in the fresh and hardened states, panel preparation and testing. The powder was characterized by the fineness modulus and units of mass. Hardened paste was characterized by compressive strength, hardness and water absorption. Finally, the panels were submitted to bending strength tests.

Both commercial and recycled gypsum were evaluated for comparative analysis. Basically, 0.69 kg of gypsum waste, composed of 40% residues from the precast production process, 45% from waste from the application and 15% from demolition services was selected. This composition was defined in order to establish a composition as close as possible to that verified in the sector.

Gypsum waste blocks were initially fragmented with a civil construction debris grinder. Next, the resulting material was milled in a roller mill to a granulometry smaller than 1 mm. Finally, the granulated mass of 13.14 kg of gypsum was powdered in a bar-mill with bars a 21.8 kg load for 4 h 15 min.

The resulting powder (1 kg) was placed in two 27 cm x 39 cm trays and calcined in an oven at 170 ºC for 2 h. The calcined material was homogenized by the stacking method, in a Jones-type double-quartering quarter, following Oliveira & Aquino (2007).

The fineness modulus and the units of mass, were determined following code NBR 12127 (1991). Compressive strength tests following code NBR 12129 (1991) were performed using four series of 18 test samples with water/gypsum ratios of 0.70, 0.80, 0.90 and 1.00 (recycled and commercial gypsum) and two series of six mixed paste samples with 25% and 50% recycled gypsum and a water/gypsum ratio of 1.00.

The hardness tests were performed according to code NBR 12129 (1991) using pastes produced with water/gypsum ratios of 0.70 and 1.00. The bending strength tests, following NBR 12775 (1992) were performed by using the three-point method, as proposed by Gram & Gut (1994), with a span length of 100 mm.

The 60 cm x 60 cm panels used in the bending strength tests were molded by a small business center (manufactory). Four panels (recycled gypsum, commercial gypsum, 25% recycled gypsum mixed paste, and 50% recycled gypsum mixed paste) were made using manually mixed pastes.

EXPERIMENTAL RESULTS

5.1. Gypsum powder and fresh paste

After grinding, a maximum gypsum granulometry of 12.5 mm with a fineness modulus of 4.73 were obtained. Once this was done, another treatment was performed and the maximum particle size and fineness modulus were reduced to 2.4 mm and 2.69, respectively. The gypsum powder resulted in 53 kg.

The gypsum powder was calcined at 170 °C (170 to 172 °C), producing 32.55 kg of recycled gypsum. The homogenized recycled gypsum and the commercial gypsum were submitted to granulometry test, providing a fineness modulus of 0.3 and 0.1, respectively.

The units of mass per volume values evaluated for recycled and commercial gypsum were 328.95 and 646.18 kg/m^3, respectively. These values are lower than the NBR 13207 (1994) specification (700 kg/m3); however, the result of commercial gypsum is compatible with those reported by Hincampié Henao & Cincotto (1997) (596 and 606 kg/m3), and Bernhoeft (2010) (686 and 688 kg/m^3).

5.2. Hardened gypsum paste

Test specimens were produced using the aluminum and glass molds as shown in Figure 1A, following the size recommendations specified by NBR 12129 (1991). Compressive strength tests were performed with 156 specimens divided as follows: 72 specimens of commercial gypsum pastes, 18 of which were gypsum water (0.7, 0.8, 0.9 and 1.0); 72 specimens of recycled gypsum pastes, 18 of which were water plaster (0.7, 0.8, 0.9 and 1.0); 6 mixed sample proofs with 25% recycled gypsum and 75% commercial gypsum with w/g (water/gypsum) factor of 1.0; 6 mixed samples with 50% recycled gypsum and 50% commercial gypsum with w/g factor of 1.0. The tests with the commercial and recycled gypsum mixed together were obtained with 7, 14 and 28 days. For commercial composite and recycled composite materials alone, the tests were performed at 28 days. Figure 1B. Shows the specimens produced.

A) B)

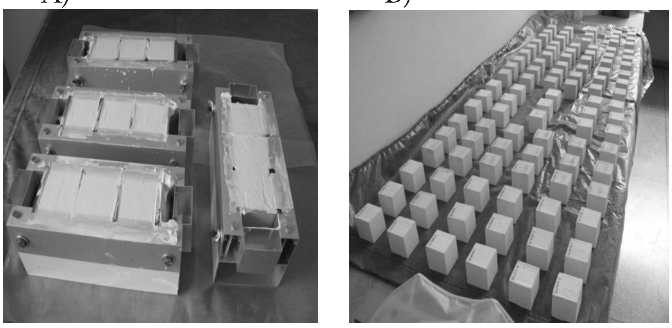

Figure 1. (A) Molding and (B) specimens for compressive strength and water absorption tests

The compressive strength mean values are shown in Table 1. The recycled gypsum values were compatible or higher than those of commercial gypsum for water/gypsum ratios higher than 0.70. The mixed gypsum paste with a water/gypsum ratio of 0.70 and the recycled gypsum paste with a water/gypsum ratio of 0.80 follows the specifications of NBR 13207 (1994). The other sample values were lower than the standard minimum values. With the exception of the pastes with a water/gypsum ratio of 0.70, the recycled gypsum paste with a water/gypsum ratio of 0.80 follows the specifications of NBR 13207 (1994). The other sample values were lower than the standard minimum values. With the exception of the pastes with a water/gypsum ratio of 0.70, the recycled gypsum pastes presented higher values than those of commercial gypsum for the same amount of mixing water.

Table 1 - Gypsum compressive strength (MPa)

Water/gypsum ratio - Paste Type	Test age 7 days min	mean	max	14 days	mean	max	28 days min	mean	max
0.70 - Commercial (CG07) [1]	2.8	3.1	3.3	10.7	11.4	12.1	9.7	11.2	12.5
0.70 - Recycled (RG07)[2]	4.5	4.7	5.0	9.6	10.4	11.0	9.6	10.9	12.3
0.80 - Commercial (CG08) [1]	2.7	2.8	2.9	6.7	6.9	7.2	7.3	7.6	7.7
0.80 - Recycled (RG08) [2]	3.9	4.5	4.9	8.7	9.3	10.2	8.4	9.2	10.1
0.90 - Commercial (CG09) [1]	4.2	4.7	5.0	4.9	5.3	5.6	5.7	6.1	6.4
0.90 - Recycled (RG09) [2]	5.4	5.5	5.7	6.6	7.2	7.8	6.9	7.8	8.3
1.00 - Commercial (CG10) [1]	4.0	4.4	4.9	4.0	4.4	4.9	4.1	4.7	5.2
1.00 - Recycled (RG10) [2]	4.8	5.1	5.7	5.7	6.0	6.7	5.4	6.0	6.3
1.00 - Mixed 25%[3]	-	-	-	-	-	-	5.3	5.9	6.1
1.00 - Mixed 50%[3]	-	-	-	-	-	-	5.6	5.9	6.2

NOTES: Commercial[1]: Gypsum totally commercial;

Recycled[2]: Gypsum totally recycled;

Mixed[3]: Percentage of recycled gypsum in mixed pastes.

The compressive strength of mixed pastes with 25 to 50% recycled gypsum and a water/gypsum ratio of 1.00 was compatible or higher than those of commercial gypsum. In general, recycled and mixed gypsum pastes presented better results than the commercial gypsum paste in the same production and testing conditions.

Although authors like Petrucci (1998) attribute the final gypsum compressive strength to paste drying, the statistical analysis of the obtained results indicates the gypsum age as being responsible for 8.5% of its strength.

From the hardness tests performed according to NBR 12129 (1991), the obtained values of recycled gypsum with a water/gypsum ratio of 0.70 ranged from 29.44 to 32.80 MPa, with a mean value of 31.20, and for commercial gypsum, from 29.64 to 33.70 MPa, with a mean value of 30.99 MPa. For recycled gypsum, pastes with a water/gypsum ratio of 1.00, mean and range values were 11.08 MPa and 10.95-11.29 MPa, and for commercial gypsum, 11.97 MPa and 11.70-12.12 MPa. These results demonstrated the compatibility of recycled gypsum with this characteristic (compression resistance).

The specimens produced with recycled and commercial gypsum pastes with a water/gypsum ratio of 1.00 and subjected to immersion for 24 h had water absorption coefficients of 56.02 and 56.00%, respectively. These results demonstrated that considering the water absorptions, the behaviors of commercial and recycled gypsum were alike.

5.3. Gypsum ceiling panels

Ceiling panels can be manufactured as flat panels or as gypsum boards. Flat panels are usually made in commercial sizes of 60 x 60 and 60 x 65 cm, with panel center and edge thickness values of 15.0 and 30.0 mm, respectively.

The panels are made by small business (manufactory) by mixing water and gypsum (about 5 liters) in a mixer for about 2 min. The paste is poured into previously prepared molds and the corrugated mold top that shapes the panel surface is lowered down. After 10 min for the chemical reaction to occur, the corrugated mold top is raised and the excess gypsum is removed. After the end of the water/gypsum reaction, the panel is demolded. The time required for the full process is about 16 min.

The ceiling panels presently investigated, as shown in Figure 2, were molded by a small business (manufactory) using a water/gypsum ratio of 1.00 and manual mixing. Four panels were made (commercial gypsum paste, recycled gypsum paste, and mixed pastes with 25 and 50% recycled gypsum). The dark panels in the front are made of recycled gypsum and the light colored ones of commercial gypsum.

Right after molding, recycled gypsum panels tend to be darker than those made of commercial gypsum. However, this is a minor problem, as the color tends to become lighter over time and the panels become visually similar to those made of commercial gypsum. Furthermore, as both types of panels are painted afterwards, color differences are set off.

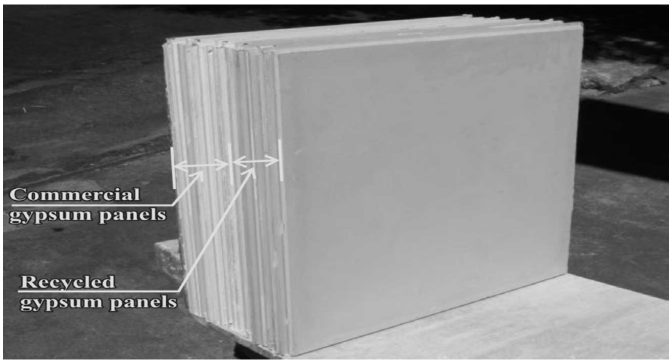

Figure 2. Panels made of recycled and commercial gypsum

Panels made of recycled gypsum are more workable than those made of commercial gypsum, as observed during the panel molding. The recycled gypsum paste was more homogeneous and consistent, in contrast to the commercial gypsum paste, which was more fluid. To improve the workability of recycled gypsum pastes, the best option is to use mixed pastes, with 25 or 50% recycled gypsum. They have a more fluid aspect, similar to commercial gypsum. Figure 3 shows the molding of the plates, where one can observe that the workability of recycled gypsum paste (Figure 3-A) is higher than that of commercial gypsum paste (Figure 3-B).

A) B)

Figure 3. (A) Molding of plaster panels with recycled gypsum (B) Molding of plaster panels with commercial gypsum

The ceiling panels were subjected to bending strength tests following NBR 12775 (1992). The three-point test was performed, as proposed by Gram & Gut (1994), with a span length of 100 mm. Table 2 presents the mean values of bending strength for each type of paste obtained in four tests. The results show that the mechanical properties of recycled gypsum panels are compatible or even better than those of commercial gypsum panels, even with a narrower minimum and maximum range, 8.83%, in contrast to 35.23% for commercial gypsum. The panels made of 25 and 50% recycled gypsum mixed paste had strength values (3.02 and 2.78 MPa) higher than those of commercial and recycled gypsum (2.55 and 2.63 MPa).

Table 2 - Bending strength (MPa)

Type of paste[1]	Minimum strength	Mean strength	Maximum strength
Commercial	2.10	2.55	2.84
Recycled	2.49	2.63	2.71
Mixed 25%	2.84	3.02	3.15
Mixed 50%	2.60	2.78	2.96

NOTE: [1]Percentage presents of recycled gypsum in mixed pastes.

CONCLUSIONS

The results obtained in this research indicate that gypsum recycling and the use of recycled gypsum in the production of ceiling panels are technically feasible. From the results, the following highlights are made:

1. For recycled gypsum paste with water/gypsum ratios between 0.70 and 0.80, the compressive strength values were higher than the minimum value set forth in NBR 12129 (1991) (8.4 MPa), being higher even than the values of commercial gypsum for the same water/gypsum ratio.
2. Mixed gypsum pastes with 25 and 50% recycled gypsum had higher mean values of simple compressive strength at 28 days than pure gypsum and commercial gypsum pastes. Specimen age was noted to be a determining factor of compressive strength.
3. The bending strength of recycled gypsum panels was compatible with the mean bending strength values of panels made of commercial gypsum. The mixed pastes were again more efficient, with higher values than those for recycled and commercial gypsum. The hardness values of recycled and commercial gypsum pastes were compatible. The pastes with a water/gypsum ratio of 0.70 met the specifications of NBR 13207:1994.
4. The normalized values of units of mass of gypsum powder varied the most. Commercial gypsum had a mean unit of mass of 646.18 kg/m3, while that of recycled gypsum was 328.95 kg/m3. The results of commercial gypsum were compatible and even

higher than those reported by Hincampié Henao & Cincotto (1997) (range of 596-606 kg/m3). In contrast, recycled gypsum had lower values than those in the technical literature, such as those reported by Harada & Pimentel (2009) (530 kg/m3) and Lima & Camarini (2011) (447,65 kg/m3).

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