Recycled gypsum block: development and performance

Blocos de gesso reciclado: desenvolvimento e avaliação de desempenho

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Abstract

The gypsum plaster waste is still faced a serious economic and environmental problem. Considering the high volume and the destination often inadequate. Intending to provide a mitigating alternative, this research intends to develop blocks that incorporate the industrial gypsum plaster waste through reverse logistics. For this, a physic-chemical recycling process of gypsum plaster waste was carried out on an industrial scale and the developed material was characterized in anhydrous and fresh state. Then, blocks were made with the recycled material and characterized according to NBR 16495 (ABNT, 2016). After its characterization, the material was evaluated for its mechanical performance when used in walls, regarding the tests of suspended vertical loads and hard and soft body impact, according to the guidelines included in the performance standard NBR 15575-4 (ABNT, 2013). The walls constituted with the developed material showed satisfactory performance, having, in some cases, presented superior performance in comparison to the conventional walls of gypsum blocks, according to results presented by the Technical Assessments Document - DATEC nº 27 (2015). Finally, small walls of the recycled gypsum block and gypsum glue were elaborated to verify the compressive behavior. Regarding these verifications, it was noticed that the small walls obtained good resistive capacity.

Keywords: Gypsum plaster. Waste. Recycling. Gypsum blocks.

Resumo

O resíduo de gesso ainda é considerado um grave problema econômico e ambiental. Seu volume é alto e sua destinação é muitas vezes inadequada. Visando fornecer uma alternativa mitigatória, esta pesquisa pretende desenvolver blocos que incorporem o resíduo industrial de gesso a partir da logística reversa. Para isso foi realizado um processo de reciclagem físico-química do resíduo de gesso em escala industrial e o material desenvolvido foi caracterizado enquanto pó e pasta. Em seguida, foram confeccionados blocos com o material reciclado e caracterizados conforme a NBR 16495 (ABNT, 2016). Após sua caracterização, o material foi avaliado quanto ao seu desempenho mecânico ao ser utilizado em paredes, no tocante aos ensaios de fixação de peça suspensa, impacto de corpo duro e impacto de corpo mole, conforme as diretrizes constantes na norma de desempenho NBR 15575-4 (ABNT, 2013). As paredes constituídas com o material desenvolvido mostraram desempenho satisfatório, tendo, em alguns casos, apresentado desempenho superior em comparação às paredes convencionais de blocos de gesso, conforme resultados apresentados pelo Documento de Avaliações Técnicas – DATEC nº 27 (2015). Por fim, foram elaboradas miniparedes de blocos de gesso reciclado e gesso cola para verificação do comportamento destas frente à tensão de compressão. Acerca destas verificações, constatou-se que as miniparedes obtiveram boa capacidade resistiva.

***Palavras-chave**: Gesso. Resíduo. Reciclagem. Blocos de gesso.*

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Introduction

In recent years, civil construction has opened up more space for the incorporation of new technologies that could combine speed, economy, and sustainability, aiming to reduce the cost of works and to maintain the quality standard. This situation has contributed to the appearance of new materials or the adaptation of old materials to the new market vision.

In this context, the use of gypsum blocks in the vertical partition, since it is not so widespread in the Brazilian market, has been increasingly studied in order to find advantages that justify its use, replacing technologies considered traditional, such as masonry in concrete and ceramic blocks. According to Lordsleem Junior and Neves (2012), some of these advantages can already be highlighted: shorter completion time, greater floor area, possibility of installation over the final floor, greater layout flexibility, lighter walls, lower overload in structures and foundations, greater dimensional accuracy and better thermal-acoustic comfort.

In addition to the technical advantages associated with this technology, issues related to sustainability have called attention to the gypsum components. One of those is the possibility of incorporating part of the gypsum plaster waste that are generated in the productive chain of civil construction. This process known as reverse logistics, according to Mota (2017), encourages the recycling of waste, promotes its appreciation, and reduces the use of natural resources.

Even so, the Brazilian reality shows that gypsum plaster waste is still considered an environmental and economic problem, and that this material has its destination often inadequate. Several authors point out that the practice of recycling gypsum plaster presents itself as an important and indispensable alternative for the gypsum sector (BERNHOEFT; GUSMÃO; PÓVOAS, 2011; PINHEIRO, 2011; PINHEIRO; CAMARINI, 2015).

One of the advantages of gypsum plaster waste is that it can be recycled several times; on the other hand, there are some properties that distinguish it from commercial gypsum plaster (CGP), which often present challenges in its applicability. The results show that, since the first cycle of recycling, the pastes with recycled gypsum plaster (RGP) offer a substantial reduction of the workability in comparison with a CGP, using the same water/gypsum rate (W/G), as in Pinheiro (2011) and Bardella (2011). This phenomenon was evidenced through the mini-slump test when it was noticed that the RGP pastes did not present spreading. Other authors, such as Rossetto *et al.* (2016) and Camarini *et al.* (2016), similarly verified this behavior by reducing the consistency of the material as well as reducing its fluidity, this fact usually occurs by the increase of the fineness of the recycled material and content of impurities.

Another differentiation with respect to CGP is about the setting times. For RGP, these values are usually reduced, according to Nita *et al.* (2004) because the content of impurities creates a series of crystallization nucleus that accelerate the nucleation of new crystals in the hemihydrate. When evaluating the influence of the insertion of gypsum waste, physically benefited (only comminuted) in pastes for coating, Vieira, Trovão and Teles (2017) observed that the workable time for the paste with only 5% substitution of the CGP by the RGP is reduced by up to 69% relative to the pure CGP paste with the same W/G ratio. In general, Geraldo *et al.* (2017) identifies that, from the physic-chemical recycling (comminution and calcination) of gypsum plaster waste, there is a gradual reduction of the initial and final setting times for the pastes, with the same W/G ratios, for successive recycling cycles.

The reduction of the workability of recycled gypsum plaster waste, as well as the reduction of setting times, can be counteracted by increasing the W/G ratio. However, it should be noted that this relationship must be taken into account, since it is one of the main factors affecting the strength of the precast components, which may, in excess, increase the porosity of the material, leading to lower the strength of the material (DOMÍNGUEZ; SANTOS, 2002; LEWRY; WILLIAMSON, 1994; PERES; BENACHOUR; SANTOS, 2008).

In hardened state, the recycled gypsum plasters usually show a loss of mechanical strength, depending on the substitution content in the mixtures, the particle size and the impurity content. This phenomenon could be seen in researches such as Póvoas *et al.* (2010), Bernhoeft, Gusmão and Póvoas (2011), and Carvalho (2005). However, other authors, such as Nascimento and Pimentel (2010), Nita et al. (2004), and Geraldo et al. (2017), show that there is maintenance or moderate increase of mechanical resistance with the partial or integral insertion of RGP to the mixtures. There are several factors that interfere with the increase or decrease of mechanical properties, and possibly the variability of the recycling parameters results in different outcomes.

In July 2014, NBR 15575-4 (ABNT, 2013) came into force, presenting the minimum performance requirements for internal (IVS) and external (EVS) vertical sealing. However, in the case of gypsum blocks, there are only published data on performance of commercial gypsum blocks, as shown in DATEC-027 (DOCUMENT…, 2015). Although walls made of this material exhibit satisfactory performance levels for the tests of suspended vertical load as well as hard and soft body impact, it is not known whether this behavior remains intact for gypsum blocks made with recycled gypsum plaster waste, as far as we know there are no publications on the performance of walls made with this material.

Other verifications, such as the resistive capacity of the small walls, have been carried out for gypsum blocks and other constructive technologies, as shown by Pires Sobrinho (2009), Soto, Ramalho and Izquierdo (2013), and Oliveira *et al.* (2017). The results for conventional gypsum blocks are satisfactory, according to Pires Sobrinho (2009), because their load capacity is higher than those presented by the small walls made from ceramic bricks and concrete blocks. As the small walls is a more representative element of a masonry wall because it considers the influence of the horizontal and vertical joints, and the mooring between the blocks (ANDRADE, 2007), it is extremely importance to verify the behavior of small walls made from recycled gypsum blocks. Given this context, this work emerges as a technological aid to the academic community for the development of new material technologies that contribute to the minimization of waste and the increase of performance of buildings or their components.

Method

This research is due to a series of practical steps and laboratory analyzes that were carried out for the development of recycled gypsum blocks (RGB). The diagram in Figure 1 shows the steps followed.

Recycling of gypsum plaster and production of blocks

The recycling in this research was carried out in an industrial scale process that comprised steps typical of a conventional gypsum plaster manufacturing process, namely: comminution, calcination, and storage. The production stage of the blocks, which especially includes the mixing, hardening, and drying process of gypsum plaster, also occurred in an industry, and consisted of the mixing of the RGP to water, dumping of the paste in the mold, manual vibration and work piece finishing. The blocks produced with dimensions of 70 x 666 x 500 mm (similar to the conventional block) were driven for drying in the open air for 10 days and stored on pallets until conveyed for testing. Figure 2 depicts the main developmental stages of RGB.

Making walls in the laboratory

In order to verify the performance of the RGB wall, two (2) uncoated walls were made in the laboratory. Both were executed under a metal support with dimensions of 1300 x 2660 mm and without openings (door and window), as shown in Figure 3. The first wall was fixed at the top with polyurethane foam at 3 (three) points (Figure 4a) and the second, with gypsum glue around the perimeter (Figure 4b).

The materials used in this procedure were the RGB, interlocked with a thin layer of gypsum glue in the vertical and horizontal joints.

Small walls

For the execution of the test that evaluates the behavior against axial compression, four (4) small RGB walls were developed with dimensions of (0.07 x 0.60 x 1.20) mm. For all samples, a thin layer of capping was made, composed of gypsum plaster (Figure 5); the capping reduces the effects of irregularities at the top and bottom of the test piece and to provide a more even distribution of stress.

Figure 1 – **Diagram of activities**

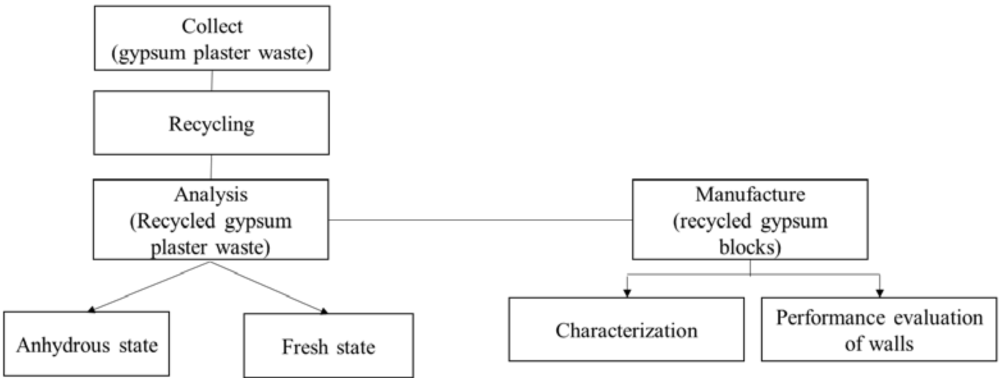


Figure 2 – **Recycling and making of blocks**

(a) Calcination (b) Mixture of the past (c) Block manufacturing

Figure 3 – **Walls fixed in a metal support**

Figure 4 – **Details of wall fixing**

(a) With polyurethane (b) With gypsum glue

Characterization of materials

The RGP characterization tests were as follows:

(a) in the anhydrous state: sieve analysis and bulk density according to NBR 12127 (ABNT, 2017a); e

(b) in the fresh state: mini-slump for the definition of the water/gypsum plaster ratio and the kinetics of temperature for checking the setting times.

The choice of the mini-slump test was due to the convenience and the possibility of comparing the laboratory results with those practiced by the industry. The test is similar to Pinheiro (2011) and consists of checking the diameter formed by the gypsum plaster paste when flowing on a glass slide. A PVC (truncated-cone) mold was used; the apparatus is open at both ends, 4 cm in diameter at the lower end, 2 cm in diameter at the upper end and 6 cm in height.

The kinetics of temperature provides the curves of hydration of the gypsum plaster, where heat released is related to time. It is possible to determine the initial setting time (paste varies 0.1 ºC/min) and final setting time (decrease in temperature), with reference to the methodology dictated by Antunes, Oliveira and John (1999) and used by several other authors.

The RGB characterization tests were as follows:

(a) density;

(b) flexural strength; and

(c) surface hardness, according to the guidelines of NBR 16495 (ABNT, 2016).

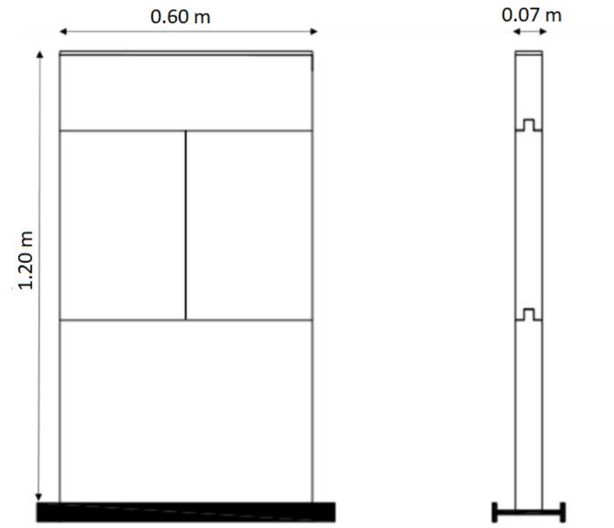
Mechanical performance of walls

The performance tests used are prescribed in NBR 15575-4 (ABNT, 2013). Only those referring to structural performance were considered, such as suspended vertical loads, hard body and soft body impact, as shown in Figure 6. The main goal of the tests was to verify the behavior of the walls when submitted to the respective requests, setting them in the levels of performance (minimum, intermediate or higher) expressed by the Brazilian Standard. Finally, to simulate the compressive behavior of the constructive system (block + gypsum glue); the methodology proposed by Pires Sobrinho (2009) was used to evaluate the compressive strength of small walls.

Suspended vertical loads

The test of suspended vertical loads was reproduced in 2 (two) walls by a maximum eccentric vertical load of 0.9 kN. The applied load remained for more than 24 hours. The fastening elements of the standard piece were S (plastic) anchor bolt sleeve with a diameter of 10 mm (S10), and screw. The fixation site of the system was visually inspected during the test; after the total removal of the load, the occurrences in the wall, the existence or not of displacement of the fixation system, as well as the instantaneous and residual horizontal displacements of the walls were verified.

Figure 5 - **Illustration of the small walls: (a) front view and (b) side view**



(a) Front view (b) Side view

Figure 6 - **Performance tests**

(a) Suspended vertical loads (b) Hard body impact (c) Soft body impact

Impact of hard body

The hard body impact test was performed on the same wall where the suspended vertical load test was performed. Initially, the solid steel sphere was positioned in a resting position, tangent to the wall. Then the sphere (5 kg) is removed until its center of mass reaches the drop height "h" required to produce 2.5 J and 10 J impact energy. Finally, it is released in pendulum movement using the specified impact energies to the wall. The impacts are applied in random and distinct points, that is, each impact is applied at a different point. After the test, the damages caused to the wall were verified, as well as the depths of the dents.

Impact of soft body

The soft body impact test was the last test performed on the wall. The process consisted in erecting and releasing in free fall in simple pendulum movement a leather bag with dimensions specified by the Brazilian Standard, filled with sand and light material, and weight of (400 ± 4) N, in order to reach the impacts energies of 60 J, 120 J, 180 J, 240 J, 360 J, and 480 J. After the shocks were carried out, all the occurrences and the instantaneous and residual horizontal displacements produced by the impacts on the wall were recorded.

Compression of small walls

The non-eccentricity compression test of small walls was carried out with reference to the methodology proposed by Pires Sobrinho (2009), where a reaction gantry was used with load control and displacement by means of a servomotor mechanism. Structured as an autoreactive frame, the gantry that has three hydraulic jacks, with a load capacity of 500 kN, was displaced under a loading speed of 0.2 MPa/s.

Results and discussions

Sieve analysis

The physical properties results of the recycled and commercial gypsum powders are shown in Figure 7 and in Table 1.

The comminution process carried out on the RGP resulted in the formation of a material thicker than CGP. Therefore, the FM presented by the RGP is higher.

For material passing through the sieve of 0.29 mm, NBR 13207 (ABNT, 2017b) establishes a minimum percentage of 90% for CGP, which did not occur for RGP. Non-attendance was due to the greater presence of coarse grains in that material, as can be observed in Figure 7.

Figure 7 – **Particle size distribution of RGP and CGP**

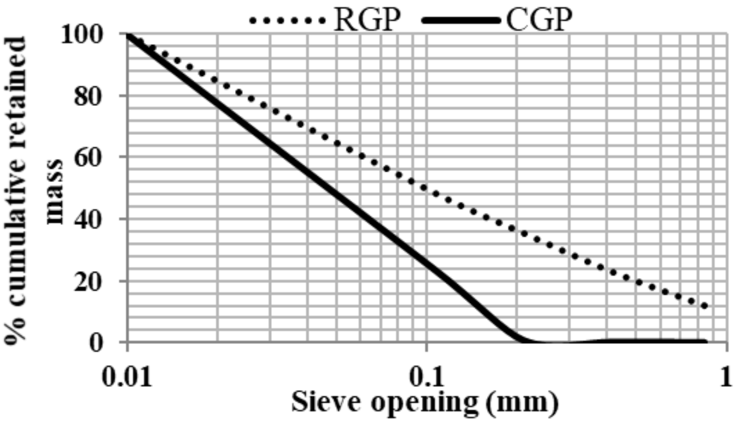


Table 1 – **Results of physical properties of RGP and CGP**

Material	Proprieties		
	Fineness modulus (FM)	Passing through the sieve of 0.29 mm (%)	Bulk density (BD) (g/cm³)
RGP	1.19	64.56	659.5
CGP	0.25	99.36	621.7

The bulk density (BD) results of the RGP was not affected by the larger grains. Probably the intergranular voids left by the coarse grains were filled by the finer grains. In all cases, both RGP and CGP presented higher values than those established in the standard, which determined BD ≥ 600.00 g/cm³.

Mini-slump

The typical spreading adopted for β-type gypsum plaster pastes in the precast components industry is 7.5 cm (MUNHOZ, 2008). Thus, to obtain the same spreading, CGP was found to have W/G ratio of 0.62 and RGP, 0.70.

The increase in the W/G ratio of the RGP sample in comparison to the CGP, in order to obtain the minimum reference spreading, corroborates with the premise that the increase of the waste content reduces the workability of the gypsum plaster paste due to the impurity content.

In comparison with other studies, such as Pinheiro (2011) and Rossetto *et al.* (2016), the spreading obtained by the RGP paste in this research was higher, taking into account the same ratio W/G of the mixtures used by these authors. It is believed that this scenario occurred due to differences in the particle size distribution of the material and the form of calcination adopted in the recycling stage.

Setting time

Figure 8 shows the hydration kinetics of RGP and CGP with W/G ratios of 0.70 and 0.62, respectively. The results show that the temperatures recorded during most of the hydration process are higher in the CGP.

For the RGP pastes, the initial setting time was evidenced in the 7th minute, with a temperature of 31.6 ºC, and the final setting time was identified at 35 minutes, where it registered 48.8 ºC. Thus, the useful time (Δt = Ti - Tf), according to the concept presented by Antunes, Oliveira and John (1999), Bernhoeft, Gusmão and Póvoas (2011), and Póvoas *et al.* (2010), was 28 minutes, while for the CGP, the useful time was 26 minutes, starting at the 8th minute and finishing at the 34th.

In practice, during the blocks manufacturing, the behavior of RGP paste showed differences in relation to CGP analyzed by Antunes, Oliveira and John (1999). The initial setting time on the final induction period which for the aforementioned authors represented the moment when the operator starts to apply the paste, corresponded in the RGP pastes to the final time of application, because between 5 and 6 minutes the RGP paste was hardened and between 6 and 10 minutes the finished block was ready to be demolded.

Characterization of the recycled gypsum block (RGB)

The classification/accordance of RGB fabricated with W/G ratio of 0.70, in relation to NBR 16464 (ABNT, 2017c), is described in Table 2. From the values found, it was verified that the blocks are classified as medium density, high hardness, and meet the requirements of flexural strength.

Behavior under the action of suspended vertical load

During the execution of the test of suspended vertical load, it was found that in the stage of fixing loads in the “French hand”, every 3 minutes, no damages were identified on the wall or the fastening system. After 24 hours, this time considered for long-term testing by NBR 15575-4 (ABNT, 2013), it was verified that there were no failures that compromised the serviceability limit state, such as fissures and chipping of the wall or crushing of the fastening system. The wall remained intact and the fastening system without significant displacements for a maximum load of 0.9 kN. Table 3 shows the records of the loads used and the criterion established in the performance standard for the test.

The instantaneous and residual displacement limits specified in the standard follow the relation, respectively: hdi < h/500 and hdr < h/2500, where "h" is the height of the wall. Thus, the hdi and the hdr limits applied to the survey are 5.3mm and 1.1mm, respectively. During the application of loads of 0.5 kN, 0.7 kN and 0.9 kN, the maximum instantaneous displacements were below the normative limit (Figure 9a) and during the removal of the same loads the maximum residual displacements were also below the normative limit (Figure 9b).

The evaluated system showed satisfactory performance for the maximum load of 0.9kN, and, in relation to the limits of displacement, presented values below that specified in the standard. Thus, the vertical sealing system with RGB complied with the minimum performance level of NBR 15575-4 (ABNT, 2013).

Also, according to this standard, the maximum long-term test load (24 hours in the test) includes a safety factor of two in relation to typical situations of use. The service load in this case is half of the load adopted in the test, and then it can be considered that the RGB system can use a maximum load under conditions of use of up to 0.45kN.

The DATEC-027 (DOCUMENTO..., 2015) evaluated walls with conventional gypsum blocks of 70 mm and 100 mm (thickness). In comparison with the presented results, the walls with RGB showed to be similar, since in both of them the level of performance was minimal, considering that the same fixation systems (sleeve and screw) were also used.

Figure 8 - **Kinetics of temperature hydration curves for RGP and CGP**

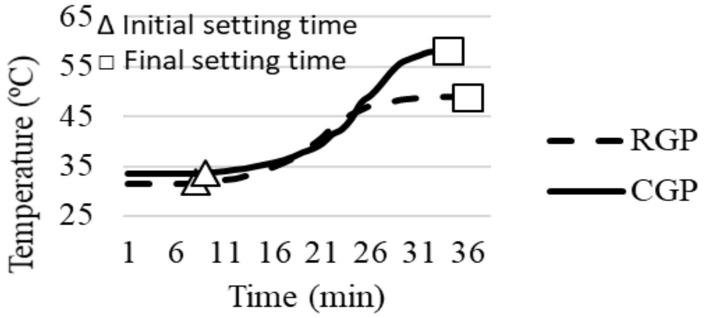


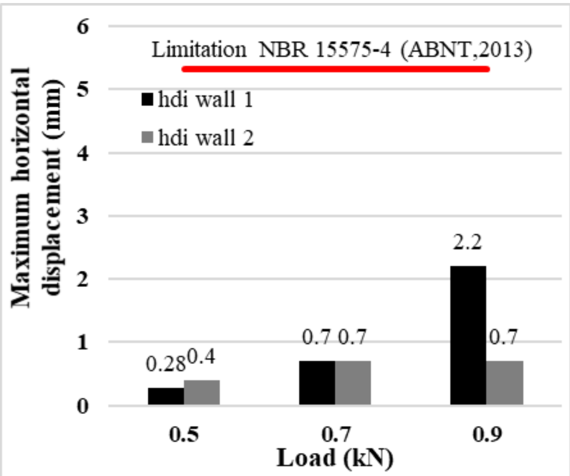
Table 2 - **Results of the characterization of the blocks**

Requisites	Results	Standard deviation	Coefficient of variance (%)	Observance or normative classification
Density	1081.90	8.66	0.80	Medium density
Surface hardness – Shore C	82.00	1.63	1.99	High hardness
Flexural strenght	1.31 MPa	0.12	8.92	Accord (>1,2 MPa)

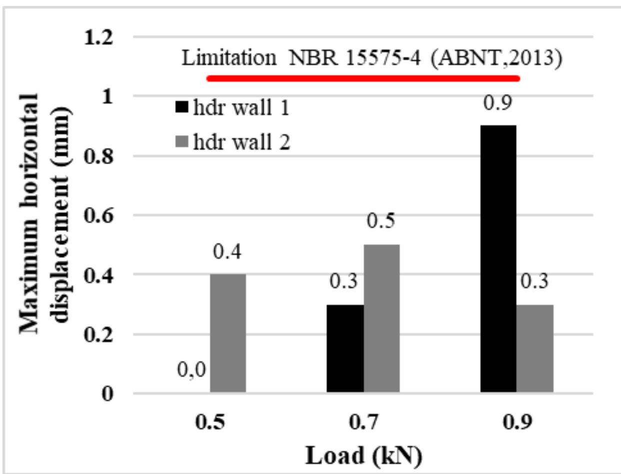
Table 3 - **Results of suspended vertical load**

Loads (kN)	Time	Occurrence on walls 1 and 2	Requirements NBR 15575-4 (ABNT, 2013)
0.5	after 3 minutes	No occurrences	No occurrences of failures that compromise the serviceability limit state
0.7	after 3 minutes	No occurrences	
0.9	after 3 minutes	No occurrences	
0.9	after 2 hours	No occurrences	
0.9	after 24 hours	No occurrences	

Figure 9 - **Maximum horizontal displacement**



(a) Instantaneous



(b) Residual

Behavior under the action of hard body impact

Results of the hard body impact test showed no visual occurrences on RGB walls, such as cracks, scaling, delaminations or any other type of damage in relation to 2.5 J impacts (service impacts). In relation to the impacts with energy of 10 J (safety impacts), no ruin occurrence was observed, which is characterized by the rupture of the wall or complete penetration of the steel sphere (ultimate limit state), as detailed in Table 4.

Regarding the depth of the dents, for the 2.5 J energy, among the 10 evaluated, there was none that presented value above the 2 mm limit specified in the standard (Figure 10a), being only superficial. For the energy of 10 J, there was no complete penetration of the steel sphere as shown in Figure 10b. Thus, the vertical sealing system with RGB presented superior performance level.

DATEC-027 (DOCUMENTO…, 2015) evaluated the behavior of two conventional gypsum block wall, one performed with 100 mm (thickness) and the other executed in 70 mm (thickness) in terms of hard body impact resistance. In both cases, the walls satisfactorily withstand impacts with 2.5 J and 10 J energies, but the technical document concluded that the system met the minimum performance level. In this way, when comparing them with the walls of RGB, it is verified that the system developed with recycled material presents better performance.

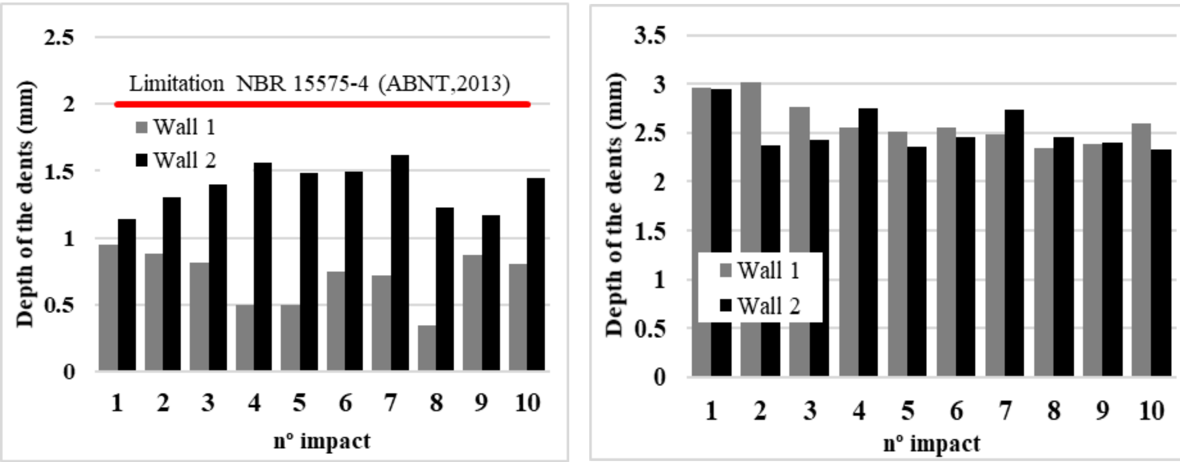
Behavior under the action soft body impact

The results of the soft body impact test showed that the RGB walls satisfactorily withstand the energies provided by use and safety impacts. According to NBR 15575-4 (ABNT, 2013), the impacts provided to the internal vertical sealing (IVS) to achieve intermediate or higher performance levels should be 60, 120, 180 and 240 Joule, applied once. It was observed that up to 180 J of energy the RGB walls did not present any type of occurrence, whereas for 240 J small cracks appear but do not compromise the structural stability of the wall. Damage in the walls were identified only with 480 J impact energy (value above the maximum requirement for internal vertical sealing), when there were cracks and disintegration of some parts of the system (block and gypsum glue) as described Table 5.

Table 4 – **Results of the hard body impact test**

Impact		Occurrence on walls 1 and 2	Requirements NBR 15575-4 (ABNT, 2013)
Nº of impacts	Energy (J)		Nº of impacts
10	2.5	No occurrences	No occurrence of failures that compromised the serviceability limit state
10	10	No occurrences	No occurrence of failures, characterized by rupture or complete penetration (ultimate limit state)

Figure 10 – **Depth of the dents**



(a) Energy of 2.5 J (b) Energy of 10 J

Table 5 – **Results of the soft body impact test**

Energy (Joule)	Wall 1 Occurrences	Wall 2 Occurrences	Requirements - NBR 15575-4 (ABNT, 2013)
60	No occurrences	No occurrences	No occurrences of failures
120	No occurrences	No occurrences	No occurrence of failures; limiting the occurrence of displacement
180	No occurrences	No occurrences	Localized failures are allowed
240	Small cracks on the side of the wall	Small cracks in gypsum glue	No collapse
360	Increase in the number of lateral cracks and cracks in the block	Cracks in the block	Not required for IVS
480	Detachment of gypsum glue / increase in the thickness of lateral cracks and increase in the length of cracks in the wall	Detachment of gypsum glue / detachment of gypsum glue in some joints / lateral cracks and increase of cracks in the wall	Not required for IVS

The limit of the occurrence of displacement, according to the performance standard, follows the relation: hdi < h/125 and hdr < h/625, where "h" is the height of the wall. Thus, for this study, the instantaneous displacement limit was 21.3 mm while the residual limit was of 4.3 mm. The displacements observed during the test, both instantaneous and residual, were below normatively specified, as shown in Figure 11.

DATEC-027 (DOCUMENTO…, 2015) shows the results of field tests in the following three situations: gypsum block with 100 mm (thickness) under beam, 70 mm (thickness) under beam, and 70 mm (thickness) under ribbed slab. In all situations, the walls satisfactorily withstand the impacts with energies of 60 J, 120 J and 240 J, not reaching the maximum limits of displacement.

For all the cases, the walls executed with the RGB showed same performance or superior to those presented in the literature, without any type of structural damage.

Small RGB walls

When analyzing the behavior of the small walls during the stress test, it was observed that, in general, the first cracks formed near the vertical joint located at the top of the small RGB wall. The prolongation of these cracks occurred along the block, axially. Figure 12 shows the typical post-break scenario of one of the RGB small wall tested.

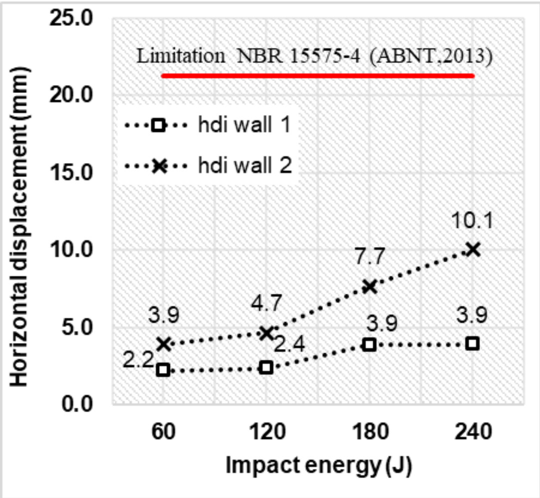
After obtaining the maximum rupture stress, the gradual decrease of the stress was observed under continuous addition of the deformation, which, according to Freitas (2008), constitutes a softening regime. According to Shah, Swartz and Ouyang (1995), this behavior occurs in the zone of inelastic processes (zone of damage or development of the crack). Figure 13 shows the stress vs. strain diagram of the small RGB walls, evidencing this behavior.

The tension supported by the small RGB walls was similar to the ones made from commercial gypsum blocks, studied by Pires Sobrinho (2009), being on average 15% lower than the average stress, as shown in Table 6.

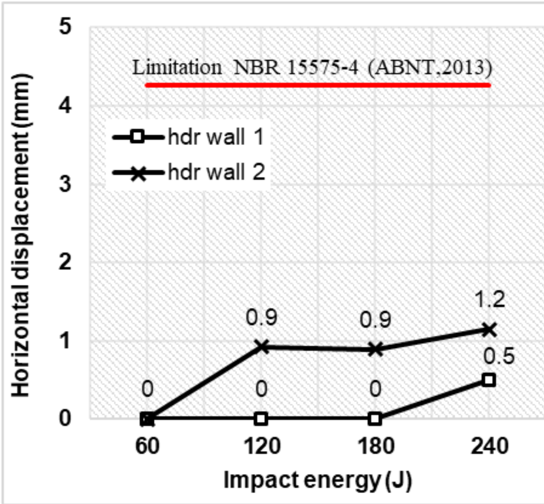
Compared with other types of traditional masonry, such as concrete blocks, it is observed that there is similarity of the average stress of small walls executed with RGB. This is verified when evaluating the results presented by Soto, Ramalho and Izquierdo (2013) (Table 6).

When verifying the results of Oliveira *et al.* (2017), about average stress of small ceramic brick walls, small RGB walls were double the resistant capacity (Table 6).

Figure 11 - **Horizontal displacement**



(a) Instantaneous



(b) Residual

Figure 12 – **Typical post-break scenario**

(a) Front view

(b) Side view

Figure 13 - **Diagram of stress x strain of small RGB walls**

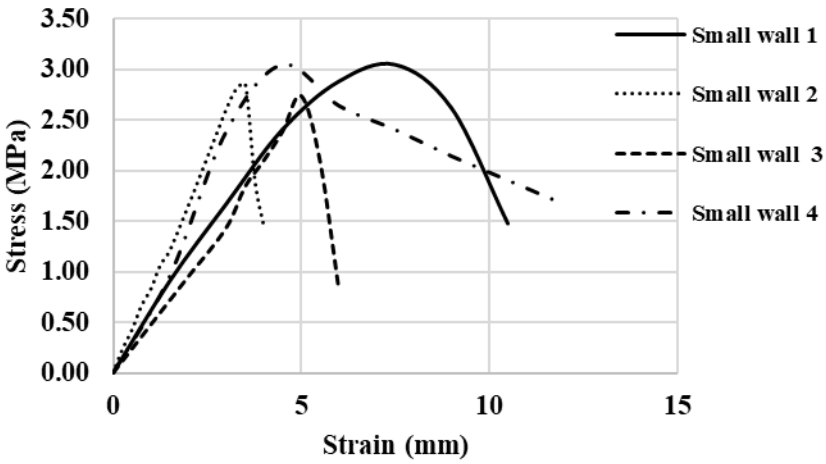


Table 6 – **Test results of small walls**

Description of small walls	Average strength of rupture (kN)	Average stress (MPa)	Standard deviation	Coefficient of variance (%)
Small wall of RGB (0.6m x 1.2m x 0.07m)	12.72	3.02	0.76	5.97
Small commercial gypsum block wall (0.10m x 0.6m x 1.2m) (PIRES SOBRINHO, 2009).	-	3.57	-	-
Small concrete walls (0.14m x 0.79m x 0.99m) (SOTO; RAMALHO; IZQUIERDO, 2013)	-	3.08	-	-
Small ceramic brick wall (0.09m x 0.60m x 1.20m) (OLIVEIRA *et al.*, 2017)	-	1.04	-	-

Conclusions

The recycling process adopted in this research showed that it is possible to obtain RGP with physical properties similar to the CGP, as shown in the physical property tests for anhydrous and fresh state. It is emphasized that such results were obtained for only one sample and that other tests with different conditioners and statistical analyzes can prove the efficacy of the process. Tests including chemical and microstructural analysis are recommended.

The paste with 100% recycled gypsum plaster waste proved to be feasible for block manufacturing, although its application time (workable) was short. The RGB, from a physical and mechanical point of view, met the requirements stipulated by the gypsum block standard for civil construction - NBR 16494 (ABNT, 2017c). Other tests such as fire resistance, watertightness and acoustics may reinforce the technical feasibility of using this material in internal vertical sealing.

The walls built with the RGB presented satisfactory performance against the structural requirements established in NBR 15575-4 (ABNT, 2013) for internal vertical sealing, presenting, in some cases, superior performance to conventional gypsum block walls. The performance levels found for the RGB walls, in terms of resistance to suspended vertical loads and resistance to the hard and soft body impact, are characteristic of systems that respond satisfactorily to the service and security requests, without damage to both the serviceability and the ultimate limit state.

Referring to the axial compression tests of the small walls, there was a reduction of the compressive behavior of the RGB system compared to conventional gypsum blocks. However, when confronted with other traditional systems, such as small walls made from concrete blocks and ceramic bricks, small RGB walls show same and superior resistive capacity, respectively. Thus, the RGB for internal vertical sealing points to a satisfactory potential, if exposed to conditions of use, in the overall of buildings.

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