Compression Molding of Gypsum Blocks Using Ecological Brick Machines

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Introduction

Gypsum is an inexpensive material to obtain and use in civil construction. Its low specific weight combined with the high productivity of walls built with gypsum blocks are also positive points.

The Gypsum Pole of Araripe (Pernambuco state of Brazil) is the biggest gypsum reserve of South America. About 400 companies generate 12,000 direct jobs and 60,000 indirect ones, as well as they produce 2.8 million tons of gypsum per year. The Gypsum Pole of Araripe manages 95% of gypsum production in Brazil [1].

Gypsum blocks houses have been built in the region that produces this material in Brazil, usually by the flow mixture casting, the traditional method. However, deficiencies are related to this mixture casting. Low compressive strength, low water tolerance and low durability have been reported. Some companies are using additives to minimize then, demonstrating the market interest to innovate in this field.

Confirming some problems of the usual casting techniques (industrial or artisanal), Moura [2] studied gypsum blocks with and without water repellent. It was not achieved the minimum strength of 1.5 MPa preconized by ABNT NBR 15270-1:2005 [3] and ABNT NBR 13207:1994 [4]. The blocks also did not achieve satisfactory performance in water absorption tests.

In this context, Kanno [5] studied the high performance plaster with compressive strengths around 90 MPa. The samples were molded applying UCOS method (humidification, compaction and drying). Initially, the gypsum powder (HH) is wet by spraying water (water/plaster around 0.20), followed by homogenization and compacting [5]. The author emphasizes that this amount of water is very close to the minimum required for full hydration. This is also the maximum content of water that can be absorbed by the powder during the compaction [5]. After the 10 MPa pressure, a hardened body can be immediately removed from the mold. After compacting, the hydration reaction starts (monitored by temperature increase) and is not more necessary the pressure for the reactions [5].

The UCOS method works based on intercrystalline adhesion forces. A great part of the strength is due to the presence of confined water [5]. The author highlight that this technique uses water in two fundamental processes: dissolution - hydration of the HH and adhesion process. The last one in a much smaller contribution.

However, in order to obtain 90 MPa, Kanno [5] uses alpha gypsum with reduced particle size (≈300 μm) and high energy compaction (≈ 10 MPa), which leads to high production costs. Strict control of particle size implies in high amounts of energy to grind, as well as the control of drying temperatures and pressures.
On the other hand, much lower compressive resistances are necessary to apply the gypsum blocks in civil construction walls. 3.0 MPa as the minimum for usual gypsum closing walls, according to the General Order SINAT 008:2012 [6]. Nowadays this rule is the reference for parameters using gypsum in popular constructions. In the same order of magnitude, 6.0 MPa are normalized for masonry concrete blocks (elements above or below ground level) and higher than 3.0 MPa (above ground level elements), according to the NBR 6136:2008 [7]. In the case of soil-cement blocks without structural function, the mean values must be greater than 2.0 MPa, according to the NBR 10834:2012 [8].


Thus, how it is not necessary compressive resistances as high as 90 MPa for the desired application, it is proposed an UCOS adaptation with no grain-size controlled β-gypsum, less pressure and less time of pressure. The idea is to obtain a compression molding gypsum blocks with similar performance (mechanical compressive strength and water absorption) to soil cement blocks and plain concrete blocks. The proposed adaptations allow to use a simple green bricks machine to fabricate the gypsum blocks.

In this scenario, an innovative method to fabricate gypsum blocks is proposed using commercial beta gypsum and a machine to make compressed earth blocks.

**Experimental Methodology**

**Materials.** Commercial β-type of gypsum was used. Commercial Standard-S plasterboards.

**Mix Proportions.** The water added to the mixture was 18%, 20% (water necessary for complete hydration of the HH) and 22% of the mass of gypsum. Details of the mix proportions are presented in Table 1, as well as the nomenclatures. All results are compared with a commercial Standard-S plasterboard properties (GPB) (Fig. 1). It was also compared with similar blocks moulded by flow casting method.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Material</th>
<th>Casting</th>
<th>Water-gypsum relation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFM</td>
<td>β-type of gypsum</td>
<td>Flow mixture</td>
<td>60</td>
</tr>
<tr>
<td>GPB</td>
<td>Commercial Product</td>
<td>Flow mixture</td>
<td>70</td>
</tr>
<tr>
<td>GB18</td>
<td>β-type of gypsum</td>
<td>Adapted UCOS</td>
<td>18</td>
</tr>
<tr>
<td>GB20</td>
<td>β-type of gypsum</td>
<td>Adapted UCOS</td>
<td>20</td>
</tr>
<tr>
<td>GB22</td>
<td>β-type of gypsum</td>
<td>Adapted UCOS</td>
<td>22</td>
</tr>
</tbody>
</table>

**Block Molding.** The water was manually sprayed on the gypsum for 1 min (Fig. 2). To spray the water is associated with the gradual hydration process and homogenization, avoiding the formation of cakes. Mixed using a manual mixer during 2 minutes (Fig. 3). In the sequence, the humid material was disposed of into the mold without previous manual compaction in one minute maximum (Fig. 4). Compaction pressure of 1.2 MPa was applied during 2 minutes using a commercial ecological brick machine (Fig. 5). No demoulding agent was necessary to the aluminum mold. The blocks were demoulded using the own machine mechanism. Finally, the blocks were cured at 40°C during 48 hours. Comparatively, flow mix blocks (GFM) were also molded using the machine mold without pressure. They have the same UCOS block format (Fig. 6). The flow mixture casting blocks were demoulded after seven minutes and cured for 48 hours without direct sun (Fig. 7). Traditionally, commercial gypsum blocks and boards are cured in this way.
Fig. 1. Commercial Standard-S plasterboards used for comparison results.

Fig. 2. Manual water sprayed process of the gypsum.

Fig. 3. Manual mix method.
Fig. 4. Disposing of the humid material into the mold without previous manual compaction.

Fig. 5. Compression molding using a commercial ecological brick machine.

Fig. 6. The aspect of flow casting gypsum method.
Compressive Strength. Universal testing machine (200 t capacity and 10t sensor's full range) was used to carry out the compressive tests. The compressive strength was determined in accordance to the standard ABNT NBR 8492:2012 [9] after 15 days of moulding. The male and female type ecological brick blocks were divided in half and the pieces bonded together with Standard-S plaster adhesive (Fig. 8), by indications from standard NBR 8492:2012 [9]. It was used 15 samples for each mix proportion.

Total Water Absorption. Total water absorption of brick samples was measured in accordance to the guideline SINAT n° 008:2012 [6], used to water repellent gypsum blocks. However, it was used for all systems in this paper. This test method determines the quantity of water absorbed in six hours. As water absorption tests for soil-cement blocks demand 24 hours (ABNT NBR 13555:2012 [10]), this time was also adopted.

Capillary Absorption. The tests of capillary absorption were performed with an adaptation of the NBR 9779:2012 [11], and also by the RILEM Method II.4 (Water Absorption Tube Test) [12]. The Test Method No. II.4 is designed to measure the quantity of water absorbed by the surface of a masonry material over a definite period of time. This technique provides a simple means for measuring the rate at which water moves through porous materials such as masonry.
Wetting-drying Cycles. An accelerated wetting-drying test procedure was developed to study the aging behavior of the gypsum blocks under environmental effects involving repeated exposure to rain and the sunshine. The specimens were subjected to water immersion for 12 hours. The blocks were then heated to 40°C for 12 hours. The temperature was maintained at this level for a sufficiently long period to slowly dry out the capillary pore. In total, five cycles were carried out. Compressive strength was measured at the end.

Real-time Testing. GB20 type block samples were immersed in stagnant water for 25 days. In the sequence, these same blocks were used to construct a wall (1.20 x 1.20 m²) that was exposed to the Caruaru-PE’s environment weather for one year. It was also exposed to drips from the roof (Caruaru-PE’s environment weather) with the drop height of 3 meters for eight months.

Results and Discussion

Compressive Strength. The compressive strength of UCOS gypsum blocks at varying water concentrations is shown in Fig. 9, compared to the gypsum flow casting blocks (a/g = 0.60 – GFM). 95% confidence intervals for the mean are shown. The compressive strength of UCOS gypsum blocks increased from three to four times when compared to the flow casting blocks one. The best compressive strength behavior in to the 0.20 water concentrations, confirming the necessary water to the hydration reactions informed by Kanno [5]. The 0.22 water concentration was studied to avoid some loss of water during the mixing process, but the loss on the compressive strength value indicates that there was an excess of water, prejudicing the crystalline adhesion. As can be seen in the Fig. 9, the average 2.20 MPa of the gypsum flow casting blocks is not in the accordance with the minimum value required by the Directive SINAT nº 008:2012 [6] (3.0 MPa). On the other hand, all UCOS blocks respect the minimum values required, not exclusively by Directive SINAT nº 008:2012 [6] (3.0 MPa) but also by the NBR 6136:2008 [7] for plain hollow concrete blocks for masonry - type C, for use in masonry structural applied above ground (4.0 MPa). The UCOS blocks are also according to the NBR 8491:2012 [13] (2.0 MPa).

![Fig. 9. Compressive strength of UCOS gypsum blocks at varying water concentrations, compared to the gypsum flow casting blocks. 95% confidence intervals for the mean.](image)

Total Water Absorption. Total water absorption of UCOS gypsum blocks at varying water concentrations can be seen in Fig. 10 for six hours immersion, compared to the gypsum flow casting blocks and the commercial gypsum plasterboard. Results from 24 hours are shown in Fig. 11. 95% confidence intervals for the mean are shown. Water absorption of 40% (GPB) and 30% (GFM) were observed to flow casting method pieces after six hours of immersion (Fig. 10). Both of then reach almost 50% after 24 hours of immersion (Fig. 11). On the other hand, these values were
reduced to less than half: 13.20% (GB18), 13.56% (GB20) and 13.61% (GB22) when the UCOS casting method in the case of six hours of immersion (Fig. 10). The water stability of all UCOS blocks can be observed in the Fig. 11: 13.95% (GB18), 13.94% (GB20) and 14.54% (GB22). So, while GFM increased the total water absorption value in 20% from six to 24 hours and GPB in 10%, the values were almost maintained in the case of UCOS blocks. There was not an influence of the water concentration and the time immersion on the total water absorption of the UCOS blocks. All were around 13%. So, to use UCOS was positive in all studied water concentrations from the viewpoint of the total water absorption. It was reduced more than 50% for six hours of immersion and more than 70% for 24 hours of immersion.

**Fig. 10.** Total water absorption of UCOS gypsum blocks at varying water concentrations after 6 hours, compared to the gypsum flow casting blocks and the commercial gypsum plasterboard. 95% confidence intervals for the mean.

**Fig. 11.** Total water absorption of UCOS gypsum blocks at varying water concentrations after 24 hours, compared to the gypsum flow casting blocks and the commercial gypsum plasterboard. 95% confidence intervals for the mean.

**Capillary Absorption.** The capillary absorption of UCOS gypsum blocks at varying water concentrations can be seen in Fig. 12, measuring absorption height using NBR 9779:2012 [11]. Results of this property using the RILEM Method II.4 are shown in Fig. 13. Both of then were compared to the gypsum flow casting blocks and the commercial gypsum plasterboard. As can be seen in the Fig. 12 (NBR 9779:2012 [11]), to use the UCOS method decreases the capillary absorption. 90 min was the time necessary to absorption height be 20 cm in the flow casting systems (GPB and GFM), starting with 8 cm. On the other hand, the time increases to 165 min to reach the same 20 cm in the case of UCOS blocks. The UCOS blocks curves are very similar,
regardless the water/gypsum ratio. This positive behavior to capillary absorptions is confirmed by the results obtained based on the RILEM Method II.4 (Fig. 13). The 4 ml of the water on the tube was almost instantly absorbed (0-1 min) in the case of gypsum flow casting pieces (GPB and GFM). These time increase to the minimum of 28 min (1 ml) until 55 min (4 ml) in the case of UCOS blocks.

Fig. 12. Capillary absorption by NBR 9779:2012 of UCOS gypsum blocks at varying water concentrations, compared to the gypsum flow casting blocks and to the commercial gypsum plasterboard.

Fig. 13. Capillary absorption by RILEM Method II.4 of UCOS gypsum blocks at varying water concentrations, compared to the gypsum flow casting blocks and the commercial gypsum plasterboard.

**Wetting-drying Cycles.** Residual compressive strength after wetting-drying cycles can be seen in Fig. 14. There are results of UCOS gypsum blocks at varying water concentrations, as well as to gypsum flow casting blocks. 95% confidence intervals for the mean are shown. It is emphasized that it was not possible to test all gypsum flow casting blocks. They lost mass and it was impossible removing the samples without dissolve them. On the other side, all UCOS blocks exhibit residual compressive strengths around 3 MPa, superior to the initial compressive from flow casting samples. In this way, the UCOS method was positive to the durability based on wetting-drying cycles when compared to the traditional one casting method. Although it was observed a significant decrease in
mean compressive strength after wetting and drying cycles (around 50%), it is still possible to keep their structural behavior as masonry.

![Graph showing compressive strength](image)

**Fig. 14.** Residual compressive strength after wetting-drying cycles of UCOS gypsum blocks at varying water concentrations, compared to the gypsum flow casting blocks. 95% confidence intervals for the mean.

**Real-time Testing.** The appearance of the GB20 blocks prepared by adaptation of the method UCOS after immersion for 25 days in stagnant water is exposed in Fig. 15. The choice of GB20 blocks was due to this system has shown a better performance in terms punctual resistance, water absorption and capillary absorption. In general, all the UCOS blocks presented similar behavior. It is noteworthy that the blocks did not suffer visual changes and no loss of mass after 25 days of immersion. The possible changes were assessed visually through the mark left by the pressing matrix screw, as shown in Fig. 15. The aspect of GB20 blocks submitted to the drips during eight months is exposed on the Fig. 16 that confirms a good durability behavior. Lastly, the aspect of the GB20 block masonry wall exposed for six months to the Caruaru-PE’s environment weather can be seen in Fig. 17 and for one year in Fig. 18. Although the direct contact with the soil, the wall showed good durability behavior after one year in this real-time testing.

![Image of GB20 block](image)

**Fig. 15.** The aspect of the GB20 block after 25 days of immersion showing the remaining mark left by the pressing matrix screw.
Fig. 16. The aspect of the GB20 block after eight months exposed to the drip situation.

Fig. 17. The aspect of the GB20 block masonry wall exposed for six months to the Caruaru-PE´s environment weather.

Fig. 18. Aspect of the GB20 block masonry wall exposed for 6 months to the Caruaru-PE´s environment weather.
Conclusions

It is possible to mold \( \beta \)-type gypsum blocks applying UCOS method (humidification, compaction, and drying) and a simple ecological brick machines under compression around 1.2 MPa for 2 minutes. In general, the commercial plasterboards show similar behavior that the flow casting ecological bricks studied. Comparatively to flow casting blocks, the compressive strength increases until four times and total water absorption decreases 50% for six hours and more than 75% for 24 hours of immersion. Capillary absorption also was reduced. The best UCOS block was UB20, with w/g ratio 0.20, although, in general, the other UCOS blocks (UB18 and UB22) presented similar behaviors. An experimental wall using B20 blocks (after 25 days of immersion in stagnant water) kept the integrity after one year exposed to the Caruaru-PE’s environment weather. The blocks exposed to the drips after eight months also exhibited the same aspect. In this way, qualitatively evaluated in real time, good durability. In this way, the UCOS blocks are adequate to be used as non-structural masonry and above ground.

References