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Composite utilizing residues of marble and granite for building popular homes

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ABSTRACT

The use of composite materials for the construction industry has been the subject of numerous scientific studies in Brazil and worldwide. This paper presents a composite that was obtained from waste generated in the process of obtaining plates of granite and marble, cement, gypsum, sand, crushed EPS and water. These wastes cause great damage to the environment and are thrown in landfills in large quantities. Several blocks from varied compositions were manufactured and preliminary tests of mechanical and thermal resistance were performed, allowing the selection of the most appropriate proportion. Manufacturing processes and assembly of the blocks to build an experimental residence were discussed. The blocks were obtained in two configurations: with voids and with PET bottles filling. It was studied which type of block and residue was more viable for the proposed order. The formulation that was more efficient in terms of mechanical and thermal resistances was: 1.0 Cement +2.0 Sand +1.0 Styrofoam +1.0 Marble and Granite Powder+Water. The mechanical strength of the blocks was above 3.0 MPa. The thermal resistance of the blocks was confirmed by the maximum difference between the inner and outer walls of 8.0 °C. The acoustic absorption levels were higher than the levels provided by the conventional bricks, but lower than the minimum level of a material that has acoustic insulation capacity around 45%.

1. Introduction

The interest for the use of residues like cement parts for the manufacturing of blocks is linked to its low cost of acquisition, high availability, and the preservation of the environment [1–9].

The amount of residues that the ornamental rocks industry produces in Brazil range around 1,610,000 t per year. The use of this residue for the production of blocks destined for construction work is a way to reduce the negative impacts on the environment caused by the improper disposal, and also to reduce the consumption of natural resources [10–18].

Most of these tailings are discarded in decantation ponds and landfills, which are formed by materials of high fineness generated by processes such as cutting, polishing, and glossing of marble and granite plates [10–21].

According to a publication of the ministry of cities, the housing deficit in Brazil is about 6.490 million units that correspond to 12.1% of homes in the country. Although there was a significant drop of the number of Brazilian housing deficit in comparison to 2007, which was around 10%, the Brazilian population rose from 184 million to 194 million, which represents an increase of 5.5%, lowering the reach of the increase of housing units [22]. Globally the problem of the housing deficit would be lessened if the rhythm of housing construction doubled in the next 15 years [23].

Seeking to reduce the edification cost of a residence and to contribute to the reduction of the housing deficit, it was obtained a composite material composed of cement, marble and/or granite residue, gypsum, EPS (Expanded Polystyrene), sand and water, with inferior cost in relation to the conventionally used building materials. The obtaining and use of such composite had also as objective a contribution to withdraw harmful residues (marble/granite, EPS and PET) from the environment.

Cement, gypsum and sand are the conventionally used materials for the residential construction. The cement has plastic and reinforcement functions; the sand can present a fillment or a reinforcement function, depending on its relation with the cement; the gypsum has plastic and curing accelerator function. The EPS is also widely used in construction with plastic, thermal and fillment functions. The marble and granite had fillment function, reducing the amount of inputs in the concrete obtaining and increasing its resistance to compression.

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There were built blocks with full and/or empty 500 ml PET bottles. Such bottles had thermal and fillment functions, providing the block a mass reduction and increase in its thermal resistance.

The blocks had an area of around 0.2 m^2 with which were built four rooms, that would compose a house, with an area of 8.1 m^2 each. The research determined which type of block is more viable in relation to a combination of mechanical, thermal and acoustic resistances. Preliminary tests were concluded to determine the formula of the most adequate composite.

The referred block has as main characteristics its low-cost, good compressive strength, low thermal conductivity, good aesthetics, versatility and easy processes of manufacturing and assembly.

Another advantage of the produced composite is its fast curing process, allowing a considerable agility to its constructive process. It shall be noted that the good surface finishing of the produced block consequently results in a reduction of the labor costs, since the finishing work would be no longer needed.

It is also important to highlight the uniqueness of this research. It brings a combined research of the mechanical, thermal and acoustic resistance of the proposed composite. It is also important to emphasize that, in addition to the characterization of the designed and produced composite, rooms were built, which demonstrated a mechanical viability of the proposed material, being the thermal and acoustic resistance tests realized in prototypes instead of restricted studies to models richly presented in the relevant literature [22–25].

2. Materials and methods

In this section are detailed the materials and processes that were utilized in the manufacturing of the proposed composite blocks and the methods for the characterization of the composite. The property that was focused in the research was the compressive strength. Subsequently, it was prioritized the thermal resistance and, as a third parameter, the acoustic resistance.

Each analyzed parameter followed relevant standards of ABNT and ASTM (ABNT – 15220-1, 15220-2, 15270-1, 15575, 10151, 13818, 6502; ASTM Standard D3878-01, ASTM Standard D638-99) [26].

For the manufacturing phase of the blocks the following steps were followed: (1) collect the residues, (2) transport the residue to a manufacturing block site, (3) prepare the molds, (4) clean the parts that form the mold, (5) apply the coating agent [22].

Subsequently, each constituent material was separated, and afterwards each element was mixed for the preparation of the composite, which was poured in the mold. After manufacturing 500 blocks, the rooms were constructed.

The proposed composite was obtained by using varied proportions of cement, marble and granite powder, gypsum, EPS, and sand. Water was added in the proportion of approximately 50% of the dry volume to enable the mixture and the homogenization of the composite. An amount of each mixed constituent was measured by volume to facilitate the operation, which was carried out in a container with known volume. Table 1 shows the constituent elements of the proposed composite. The manufacturing process of the blocks in two configurations, with empty and full PET bottles, are shown in Fig. 1.

Table 1
Constituent elements of the proposed composite.

Nomenclature	Material
MP	Marble powder waste
M/GP	Marble/granite powder waste
C	Cement
S	Sand
G	Gypsum
STY	Styrofoam
W	Water

Initially the compressive tests were realized with diverse mixing proportions, varying the proportions of cement, marble and granite powder, gypsum, EPS, sand, and water. Through the analysis of three samples of each formulation, manufacturing cost, mechanical resistance and thermal resistance were evaluated. The formulation that was more efficient for mechanical and thermal resistances was chosen as: 1.0C+2.0S+1.0STY+1.0PM/G+WATER.

This formulation was selected for the composite blocks that were used for the construction of three rooms, that are shown in Fig. 2. Room 1 (R1) was built with marble powder residue composite blocks with voids, Room 2 (R2) was built with conventional eight holes bricks, Room 3 (R3) was built with marble/granite powder residue composite blocks with PET bottle fillment and Room 4 (R4) was built with marble/granite powder residue composite blocks with voids.

The tests that were performed for the characterization of the composite were: DRX, FRX, size analysis, apparent density, SEM, compressive strength; thermal resistance, water absorption, thermal comfort and acoustic resistance [22–39].

2.1. Thermal conductivity and thermal diffusivity test procedure

Conductivity and thermal diffusivity were measured using Quickline 30 equipment (Anter Thermal Properties Corp.). The equipment made the measurements of thermal properties based on the analysis of the thermal response of the material with respect to the excitation through a thermal flow.

This heat flux is produced by electric heating of a resistor inserted in the sensor which comes into direct contact with the material under analysis. Measurements of thermal conductivity and thermal diffusivity were based on periodic sampling of temperature as a function of time.

The sensor was fixed on top of the sample, heating the specimen to a temperature of 50 °C. The data was sent and recorded on a computer. The tests were performed in three samples for each marble/granite residue. For each sample the thermal properties were determined in five points.

2.2. Thermal comfort test procedure

Measurements were made with open and closed doors and windows. Data collection was performed on days with good solarimetric conditions. K type thermocouples were fixed in the central region of the housing unit at a height of 1.5 m in relation to the floor. The chromel-alumel type thermocouples were connected to a digital thermometer to measure the internal ambient temperature.

The data acquisition on the walls was done manually by means of an infrared thermometer, model HIGHMED HM-88C, positioned on the wall at a distance of 0.1 m. Temperatures were measured from 8:00 a.m. to 2:00 p.m.

The temperatures of the internal and external surfaces of the tile were measured with an infrared thermometer also every thirty minutes. They were measured at three points on both surfaces.

An Instrutherm thermal stress meter, recorded the following meteorological parameters: internal air temperature, wind speed, wet and dry bulb temperatures, obtaining with these last two parameters the relative humidity of the air. The parameters were measured every half an hour.

Global solar radiation was measured with an Instrutherm radiometer. Instantaneous global solar radiation was measured every thirty minutes.

2.3. Acoustic test procedure

A function generator was used to obtain the acoustic signal for the acoustic test of the proposed composite. For the transmission of the sound were coupled to the equipment four Leadership speakers and a subwoofer, which was in charge of directing the sound to the wall.