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Soil-Cement Bricks Incorporated with Granite Cutting Sludge

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Abstract* — The ornamental rock industry generates worldwide huge amounts of wastes in the form of sludge. This sludge is usually destined to rivers, lakes, and landfills, resulting in environmental and economical problems. This works investigates the reuse of granite-cutting sludge as an alternative raw material into a soil-cement bricks body, replacing soil by up to 30 wt.%. The granite-cutting sludge and soil samples were characterized regarding chemical composition, X-ray diffraction, and particle size distribution. Soil-cement bricks are uniaxially pressed and cured for 28 days. The effects of the sludge addition on the technological properties (e.g., volumetric shrinkage, water absorption, and compressive strength) have been determined. From the experimental results, the granite-cutting sludge proved to be a good alternative raw material to the manufacture of soil-cement bricks, and at the same time, this application could help in reducing the environmental impacts of the ornamental rock industry.

Index Terms— **Granite, Reuse, Sludge, Soil-cement bricks, Valorization.**

I. INTRODUCTION

With the advent of the global climate change a growing interest in the environmental preservation and sustainable development has occurred worldwide. In this context, special attention has been given to the destination of solid wastes from industrial activities. Additionally, the environmental regulations have become more and more restrictive. Based on these problems, the research centers, universities, and industry have been continually challenged to convert such pollutant solid wastes in new renewable raw materials.

In recent years, the ornamental rock industry has presented constant growth associated with the generation of wealth and jobs worldwide. Brazil is currently the sixty world producer of natural ornamental rocks, behind China, India, Turkey, Italy, and Iran. In 2012, Brazilian ornamental rock production totaled 9.3 million of tones manly of granite rocks [1]. Despite of its economical and social importance, the ornamental rock industry generates large amounts of waste materials. For example, during the rock-cutting operation about 25 - 35 % of the rock block is converted into waste material [2]-[3].

The ornamental rock wastes are generate mainly in form of an aqueous sludge composed essentially of rock powder, abrasive metallic shot, lime, and water. It is very difficult to establish a practical use for the ornamental rock-cutting sludges produced. For this reason, in developing countries, the sludges have been disposed over the years usually in the environment and hydric resources without any treatment. Therefore, the ornamental rock sludges may cause environmental pollution with negative consequences for human health, flora, and fauna. In fact, the uncontrolled disposal of ornamental rock-cutting sludge in rivers and lakes causes high level of contamination and turbidity in water [2], [4]-[6]. Dry sludge generates fog that could be easily inhaled by the people, resulting in air pollution and serious problems of public health such as silicosis and lung cancer [7]-[8]. It tends to be dragged by the wind, and then it is deposited on the flora (crops and vegetation). The landscape's aesthetic is also affected. In recent years, a part of the total volume of sludge produced has been disposed in private sanitary landfills. However, this method has high cost for the ornamental rock-cutting plants.

Chemically, the dry ornamental rock-cutting sludges are composed of SiO_2, Al_2O_3, K_2O, CaO, and Fe_2O_3 [9]. Thus, they have important technical value when used as alternative raw materials in the production of building materials. In fact, the ornamental rock-cutting sludges have been applied in many building materials such as clay bricks, roofing tiles, pavement blocks, floor tiles, mortars, cement, and concrete [2], [5], [10]-[21]. However, little is known about reuse of granite-cutting sludge in soil-cement brick formulations [22]-[23]. The soil-cement bricks have several advantages when compared with conventional clay bricks, including low cost, improved properties, and elimination of the firing process with high energy consumption.

In the light of environmental preservation and recycling, the present study focuses on the incorporation of granite-cutting sludge into soil-cement brick body as partial replacement for natural soil.

II. MATERIALS AND METHODS

The raw materials used were soil, granite-cutting sludge, and Portland cement. The soil sample, provided by a local ceramic industry, was dried at 110 ºC, and sieved until a fraction passing through a 4 mesh (4.75 mm ASTM) sieve. The coarser particles were rejected. The granite-cutting sludge sample was collected in a rock-cutting plant located in south-eastern Brazil. The sludge sample was dried at 110 ºC for 24 h in an oven, and then crushed and homogenized. The resulting powder was sieved until a fraction passing through a 200 mesh (75 µm ASTM) sieve. Commercial Portland cement (type CP III- 40RS) was used.

The chemical compositions of the soil and dry granite-cutting sludge samples were determined using an energy-dispersive X-ray spectrometer (EDX 700, Shimadzu). The loss on ignition was determined by calculating the wt.% differences between a dried sample at 110 ºC and a calcined sample at 1000 ºC for 2h. Structural characterization was carried out by X-ray diffraction using Cu-Kα (λ = 1.5418 Å) radiation and 1.5º (2θ)/min scanning speed in a conventional diffractometer (XRD 7000, Shimadzu). The particle size distribution was determined by a combination of sieving and sedimentation procedures, according to NBR 7181.

Soil-cement brick compositions were prepared (Table I) using soil, granite-cutting sludge and Portland cement mixtures. In this study, the soil was partially replaced by up to 30 wt.% granite-cutting sludge. A traditional soil-cement brick body (soil: cement – 8:1) was used as a reference. The mixtures were moistened with water at 16 wt.% of the total mass. Portland cement and water proportions in the mixes were taken as constant to exclude the effect of these variables on the microstructure and technical properties. A laboratory mixer was used to produce homogeneous soil/sludge/cement mixtures, which were achieved after 15 min of mixing. Cylindrical soil-cement bricks (37 mm in diameter) were prepared by uniaxial pressing, and then cured for 28 days in a humid chamber (95 % humidity at 23 ºC).

The following as-cured physical and mechanical properties of the soil-cement bricks were determined: volumetric shrinkage, water absorption, and compressive strength. Visual inspection also has been accomplished. Volumetric shrinkage values were obtained from volume variation of the cylindrical pieces. Water absorption values were determined from weight differences between the as-cured and water-saturated pieces (immersed in cold water for 24 h). The compressive strength (σ) of the cured bricks was determined according to $\sigma = F/A$, where F is the applied force (N) and A is the cross-sectional area (m^2). The tests were carried out on a universal testing machine (model 5582, Instron) at a constant loading rate of 0.5 mm/min. Laser scanning microscopy was used to examine the fracture surfaces of the soil-cement bricks after 28 days of curing.

Table I: Batch compositions used in experiments

Samples	Soil (g)	Granite Sludge (g)	Cement (g)
SV0	88.0	0.0	11
SV1	79.2	8.8	11
SV2	70.4	17.6	11
SV3	61.6	26.4	11

III. RESULTS AND DISCUSSION

The X-ray diffraction pattern of the granite-cutting sludge sample after drying is shown in Figure 1. The sample presented peaks that are mainly characteristics of quartz (SiO_2), microcline ($KAlSi_3O_8$), mica ($KAl_2Si_3AlO_{10}(OH)_2$), calcite ($CaCO_3$), and hematite (Fe_2O_3), with predominance of quartz. These results confirmed the presence of mineral components typical of granitic rocks [24]. However, the presence of calcite and hematite in the sludge is related to the metallic shot and Ca-based aqueous slurry used as abrasive and lubrificant during the granite-cutting operation. The soil sample, as shown in Figure 2, exhibited peaks that are characteristics of quartz (SiO_2), kaolinite ($Al_2O_3.2SiO_2.2H_2O$), illite ($(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$), gibbsite ($Al_2O_3.3H_2O$), and goethite ($Fe_2O_3.H_2O$), with predominance of quartz.

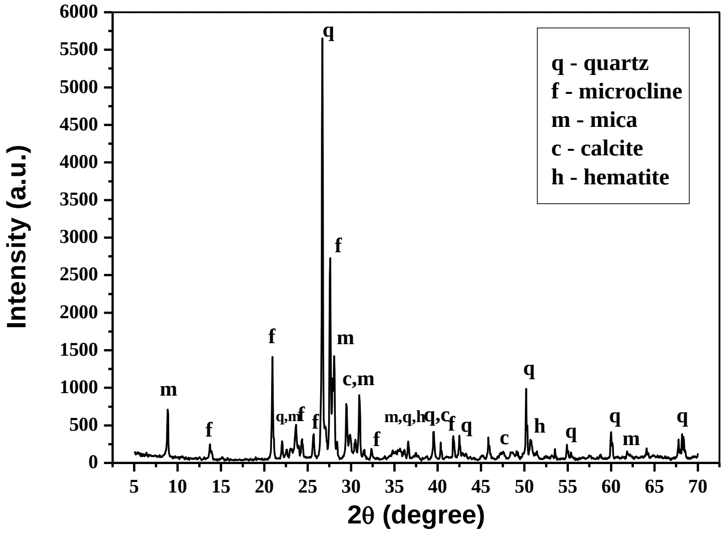


Fig 1: X-ray diffraction pattern of the granite-cutting sludge

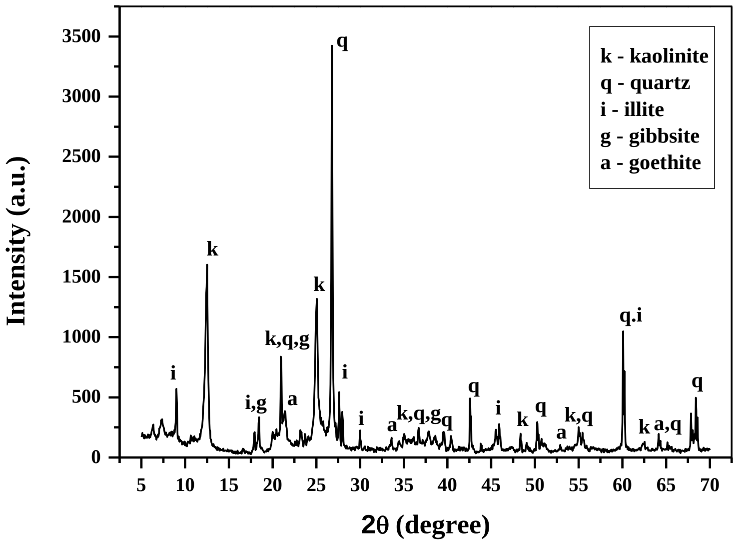


Fig 2: X-ray diffraction pattern of the soil

The chemical compositions of the soil and granite-cutting sludge samples, as well as their loss on ignition, are given in Table II. SiO_2, Al_2O_3, and Fe_2O_3 predominantly compose the soil sample. SiO_2 is present in the structure of clay minerals such as kaolinite and illite, as well as free quartz particles. Al_2O_3 does not occur in its free form in the soil sample, it is bounded to the clay minerals and gibbsite. Fe_2O_3 is present in the structure of the goethite. The loss on ignition (8.27 wt %) is mainly attributed to the dehydroxylation of clay minerals and dehydration of hydroxides [25]. Chemically, the granite-cutting sludge is mainly composed of SiO_2, followed by Al_2O_3, CaO, K_2O, and Fe_2O_3. SiO_2, Al_2O_3, and K_2O are present in the structures of microcline and mica. SiO_2 also is present as free quartz particles. CaO is present in the structure of calcite. Fe_2O_3 is present in the structure of hematite. The loss on ignition (4.21 wt.%) is associated mainly with the decomposition of calcite. Thus, the chemical composition results are consistent with the mineral phases identified by X-ray diffraction (Figures 1 and 2).

Table 2: Chemical composition of the raw materials

Components	Soil (wt. %)	Granite Sludge (wt.%)
SiO_2	46.26	58.92
Al_2O_3	29.20	14.69
Fe_2O_3	8.47	2.48
CaO	0.70	11.10
K_2O	3.35	6.41
TiO_2	1.85	0.49
V_2O_5	0.05	-
ZrO_2	0.16	0.02
MnO	0.01	0.06
SO_3	1.68	1.62
Loss on ignition	8.27	4.21

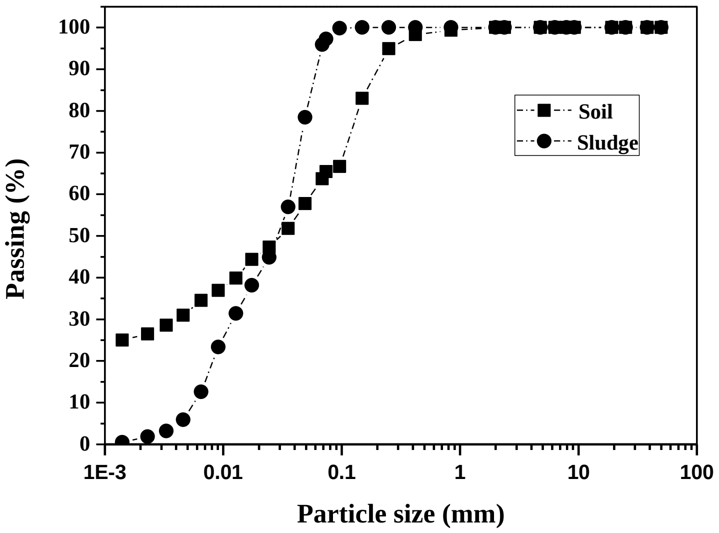


Fig 3: Particle size distribution of the granite-cutting sludge and soil

The particle size distributions of the soil and sludge samples are presented in Figure 3. Both samples presented a wide range of particle sizes. Most of the granite-cutting sludge particles are concentrated in the silt size range ($2 \leq x < 63$ µm) with about 91 %, whose average particle size (D_{50} is the 50 % passing size in the cumulative distribution curve) is $D_{50} = 28$ µm. The major size ranges of the soil sample are sand (> 63 µm) with 39 %, silt ($2 \leq x < 63$ µm) with 35 %, and clay (< 2 µm) with 26 %, whose average particle size is $D_{50} = 32$ µm. This indicates that the granite-cutting sludge presents a compatible granulometric behavior for incorporation into soil-cement mixes.

The quality of the soil-cement bricks after curing for 28 days, which is the usual curing period adopted in industrial soil-cement brick production, was determined in terms of volumetric shrinkage, water absorption, and compressive strength. The pieces with 0 wt.% sludge (SV0 sample) were considered as the reference soil-cement bricks. The appearance of the soil-cement bricks after curing is shown in Figure 4. After visual inspection, it was found that no soil-cement brick showed any indication of intrinsic cracks or defects resulting from manufacturing or handling, independently of the added granite-cutting sludge amount. In addition, the incorporation of the granite-cutting sludge caused only slight change in the colour of the soil-cement bricks.

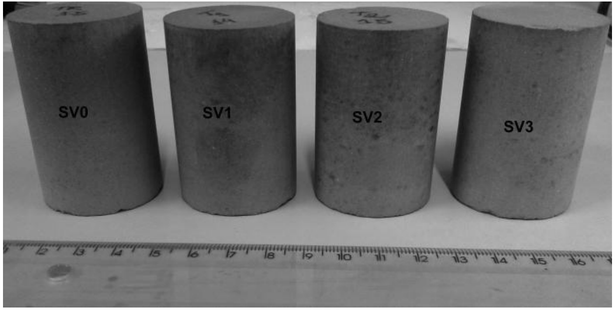


Fig 4: Soil-cement bricks after curing at 28 days

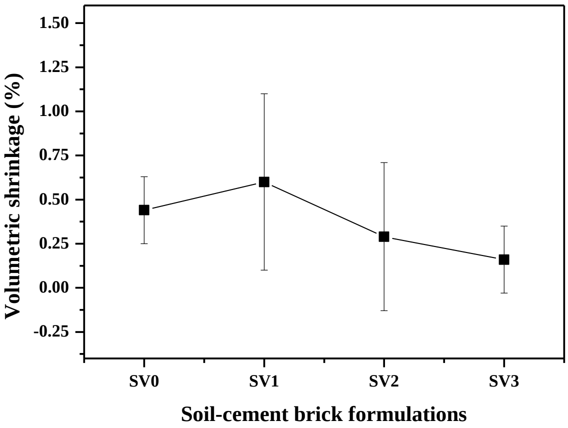


Fig 5: Volumetric shrinkage of the soil-cement bricks versus waste content

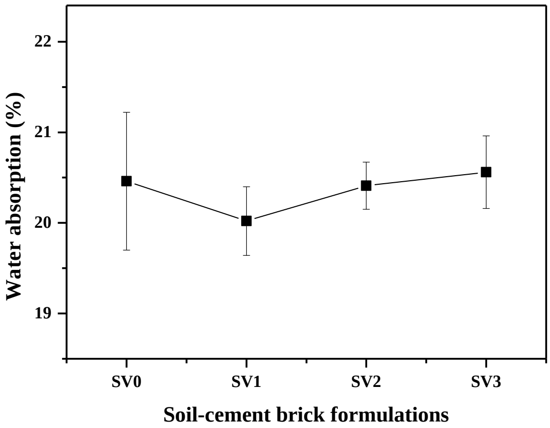
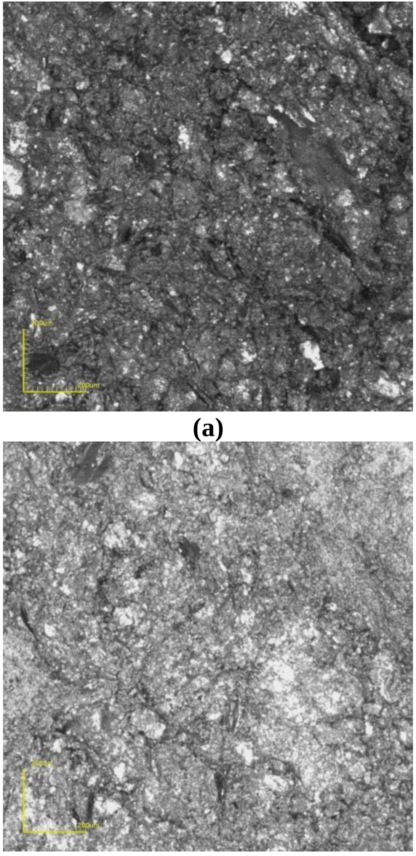


Fig 6: Water absorption of the soil-cement bricks versus waste content

The volumetric shrinkage of the soil-cement bricks is shown in Figure 5. It can be seen that all the soil-cement bricks exhibited low values of volumetric shrinkage. These values are within the safety limits of industrial production of soil-cement bricks.



(a)

(b)

Fig 7: Confocal micrographs of the fracture surfaces of the soil-cement bricks: a) SV0; and b) SV3

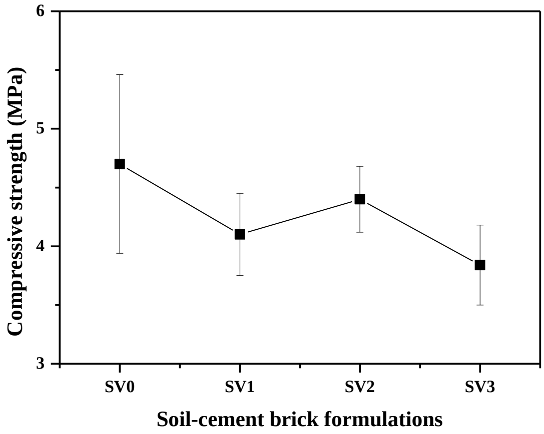


Fig 8: Compressive strength of the soil-cement bricks versus waste content

Fig. 6 shows the water absorption (level of open porosity) of the soil-cement bricks. The water absorption showed only slight differences with the granite-cutting sludge addition, where the variation observed is found within the limits of dispersion. The granite-cutting sludge behaves as a filler material in the soil-cement mixture. In fact, the granite-cutting sludge is a non-pozzolonic material (i.e., it has low chemical activity as cementitious material) [21]. The water absorption also is related to the microstructure of the cementitious matrix. Fig. 7 shows the fractured surface of the soil-cement bricks cured for 28 days. It is noticed that the sludge-free bricks (Figure 7a) had a microstructure very similar to that of 30 wt.% sludge added bricks (Figure 7b). Thus, the correlation between water absorption and microstructure is well established.

The mechanical strength of the soil-cement bricks was determined in terms of compressive strength (Fig. 8). The compressive strength is considered the most important technical property for building materials. As can be observed, the compressive strength presented only a slight difference with the granite-cutting sludge addition, supporting the water absorption (Fig. 6) and microstructure (Fig. 7) results. The obtained results were compared with the Brazilian specification of compressive strength ($\sigma \geq 2$ MPa) for industrial production of soil-cement bricks [26]. As can be seen in Figure 8, the partial replacement of soil with granite-cutting sludge produced soil-cement bricks with excellent mechanical strength. This is very important because the granite-cutting sludge could be used as a sustainable alternative raw material in soil-cement bricks formulations.

IV. CONCLUSION

The results of this study showed that the granite-cutting sludge could be a renewable alternative raw material for the production of soil-cement bricks. It has been established that the partial replacement of soil with granite-cutting sludge, in the range up to 30 wt.%, allows the production of soil-cement bricks with good physical and mechanical properties. Thus, the reuse of granite-cutting sludge into soil-cement brick body is an excellent method for environmental pollution prevention and valorization of sludges from the ornamental rock industry.

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