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Incorporation of the Sludge of Sewage Treatment Plant on Ceramic Bricks Manufacture: An Exploratory Study

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Abstract

Treatment processes used in most sewage treatment stations generate as by-product a material named sludge. The amount of sludge grows proportionally with the increase in effluent collection and treatment services, which in turn must accompany population growth. The disposition of waste generated in an environmentally correct and economically viable way is one of the biggest challenges faced by companies that operate sanitation services. The ceramic industry presents a great potential for the use of this waste. The goal of this work was to evaluate the effect of the incorporation of the sewage sludge in the ceramic mass for the manufacture of solid bricks. The water absorption was lower for bricks with 10% sludge, but it increased for bricks with 15% sludge, resulting in products that presented water absorption slightly beyond of the limit of the standard NBR 15270. However, the results are promising because they show that additions of 10% or 15% sludge increased the compressive strength markedly.

Author Keywords. Ceramic Brick, Sludge, Sewage Treatment Stations, Waste.

Type: Research Article

1. Introduction

Nowadays, there are many environmental impacts resulting from the development of society and population increase. The final disposal of waste from sewage treatment is a problem that has been highlighted in recent years, mainly due to the large amount of sludge generated and the growing commitment on the part of the authorities that regulate the disposal of these waste to minimize environmental impacts (Weng, Lin, and Chiang 2003).

The Brazilian National Environment Council – CONAMA (CNMA 2006) considers that the production of sludge is an intrinsic characteristic of the processes of treatment of sewage, presenting an increase, at least, proportional to the population growth. A solution for its disposition is urgently needed, since the sludge is considered a potential source of risks to public health and the environment, potentiating the proliferation of disease vectors and pathogenic organisms (CNMA 2006).

In many cases, sewage treatment plant designs ignore the destination of this material. Subsequently, it ends up being managed in an emergency situation by operators, with high financial and environmental costs, threatening, in some cases, the benefits of the entire sewage collection and treatment system (Duarte 2008).

The processing and disposal of sludge can represent up to 60% of the operating cost of a sewage treatment plant (Von Sperling 2002). The solidification and stabilization processes of industrial solid waste in solid matrices, such as ceramics, cement and concrete mortar have been shown to be a viable alternative for use in civil construction products (de Castro et al. 2015). In the last decades, the number of studies on the use of industrial waste have increased and have many times proved its viability for manufacturing. The specialists around the world, are continuously seeking for cost-effective solutions for a future utilization of the generated sludge (Jianu et al. 2018). Such studies are mainly of ceramic materials, with the benefits through the immobilization of heavy metals in the ceramic matrix. These results were observed in the work of Romano et al. (2020), that the ceramic pieces had immobilized within their structure, the heavy metals adsorbed in the added rice husks. Besides, with the process of sintering being carried out at high temperatures allowing the complete destruction of pathogenic organisms (Areias 2015).

In this work, an exploratory experimental research was carried out in order to check if the incorporation of the sludge from a sewage treatment plant could be used as raw-material for the manufacture of ceramic products for the construction sector. Here, we evaluate the effect of the incorporation of the sludge of a sewage treatment plant in the ceramic mass for the manufacture of ceramic solid bricks. Therefore, solid bricks incorporating 10% and 15% of sludge were produced and characterized with the following properties: linear shrinkage, average water absorption index, loss of ignition and compressive strength. Comparisons were made to the commercial solid bricks produced by the company. The analysis also included checking if the produced bricks met the minimum quality requirements according to Brazilian standard ABNT NBR 13270-2. The sewage treatment plant is located near the city of Montes Claros (state of Minas Gerais, Brazil) and produces about 3000 ton of sludge per year. The ceramic products are produced in a plant from the company Montezuma Ceramic located at 10 km distance and produces about 30 000 ton of bricks per year.

2. Materials and Methods

2.1. Materials

The materials to be used in this experimental work are clay and sludge. The clay used in this study comes from the Montezuma Ceramic plant, located in the city of Montes Claros (Brazil), and it is collected with an excavator and later deposited and stored in a yard where it remains and rests for one year. The plant uses two types of clay, mixing them in a special treatment before being used in brick production. They differ in color and particle size. The company produces and trades essentially ceramic bricks.

The sludge used in this work comes from the Sewage Treatment plant, located in the same city (Montes Claros). The preliminary treatment system of the unit includes railing, Parshall gutter and sandbox. The secondary treatment system is equipped with UASB (reactors upward flow anaerobic and silt blanket), percolating biological filters (FBP), secondary decanters and elevation of the treated effluent recirculation. The unit also counts with a modern system that assists in the treatment process of the generated sludge and biogas from sanitary sewage treatment. The biogas management system collects the methane gas (CH_4) generated in the anaerobic reactors and pumps it through pipes to a biogas reservoir. Subsequently this gas is used as a burner. This reservoir of gas also supplies a thermal dryer used for sludge dewatering produced in the reactors. Figure 1(a) shows the Sludge Thermal Dryer and Figure 1(b) the final residue after drying. Figure 2(a) presents the clay mass and Figure2(b), the sludge sieved.

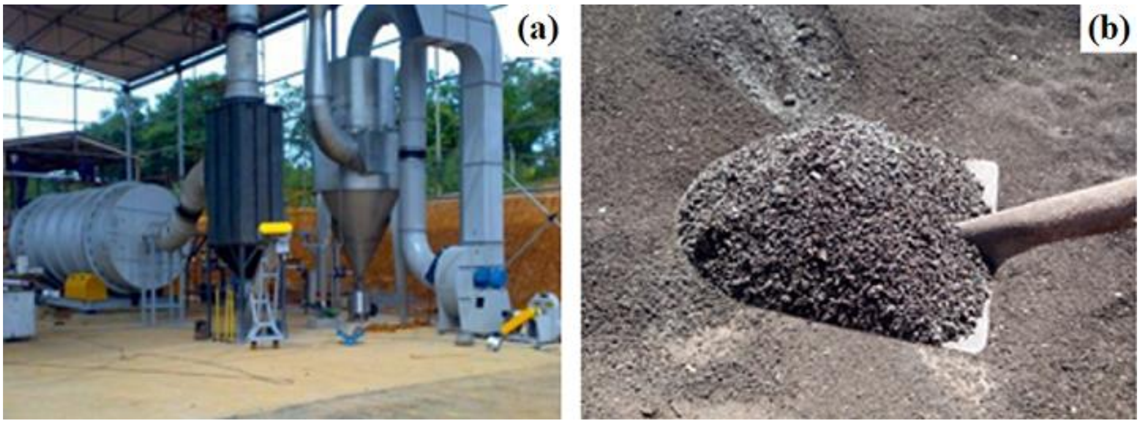

Figure 1: (a) Thermal sludge dryer and (b) dried sludge

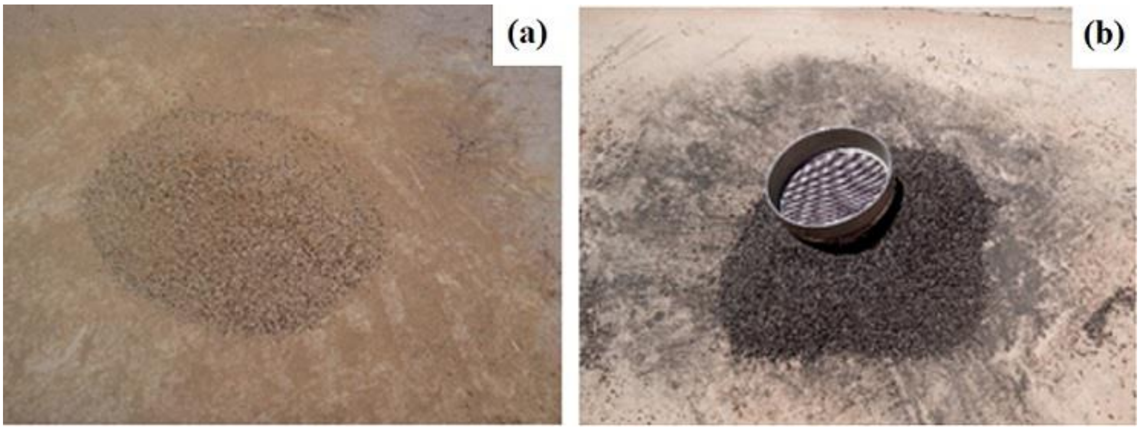

Figure 2: (a) Clay mass and (b) sludge sieved

2.2. Materials characterization

The clay was characterized in terms of: (i) granulometry according to NBR 7181 (ABNT 1984); (ii) the plasticity limit and the plasticity index following the NBR 7180 (ABNT 2016b); (iii) the liquidity limit according to NBR 6459 (ABNT 2017b); and (iv) the specific gravity following NBR 6458 (ABNT 2016a). The sludge was not analyzed according to the norms mentioned above due to its putrescibility.

The granulometry of the raw materials interferes directly in the properties of the ceramic results and the plasticity, besides the discontinuous granulometric distribution causes an increase in porosity and shrinkage (Duarte 2008). Also, the amount of water is needed to make the mixture workable, but the excess water resulting in problems (cracks) during drying and burning the products. For the clay used was observed that the material had a uniform distribution of the particles: 99.7 % passed through sieve Nr 10 (# 2.0 mm); 98.4 % passed through sieve Nr 40 (# 0.42 mm); and 95.0% passed through the sieve Nr 200 (# 0.074 mm). Such distribution allows less voids in the mass, contributing to the improvement of the characteristics of the ceramics.

Table 1 presents the values obtained in the tests to determine the limits of liquidity and plasticity of the clay. The plasticity index was calculated using the difference between the liquidity limit and the plasticity limit. It was not possible to determine the liquidity and plasticity limits of the sludge, therefore it was considered a non-plastic (NP) and non-liquid (NL) material. The same was considered in the work of Araújo (2008). The clay presented a liquidity limit equal to 43% and a plasticity limit equal to 24%, generating a plasticity index equal to 19%, which characterizes it as clay highly plastic (IP>15). The results of Atterberg's tests of sludge–clay mixtures indicate that the value of plastic limit is inversely proportional to the amount of sludge in the brick (Weng, Lin, and Chiang 2003).

Material	Liquidity Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Clay	43	24	19
Sludge	NL	NP	NP

Table 1: Consistency Limits

The clay and sludge, after being collected, were dried inside an oven at 110 °C for 24 hours, untied and sieved, using the #2 mm sieve (Nr 40).

The sludge was classified as being from Class II A (CNMA 2006), that means the residue is not dangerous and not inert according to NBR 10004 (ABNT 2004). It may present minority biodegradability, combustibility or water solubility. To assess these features, other tests not available in this exploratory work would have to be carried out.

2.3. Brick molding

The clay and sludge were mixed and moistened with the minimum water as possible to allow molding with good plasticity. Then, the specimens were shaped in wooden molds and drying in shade, protected from the wind for two days. Figure 3(a) and Figure 3(b) show the molding and the moment of identification of the bricks, respectively.

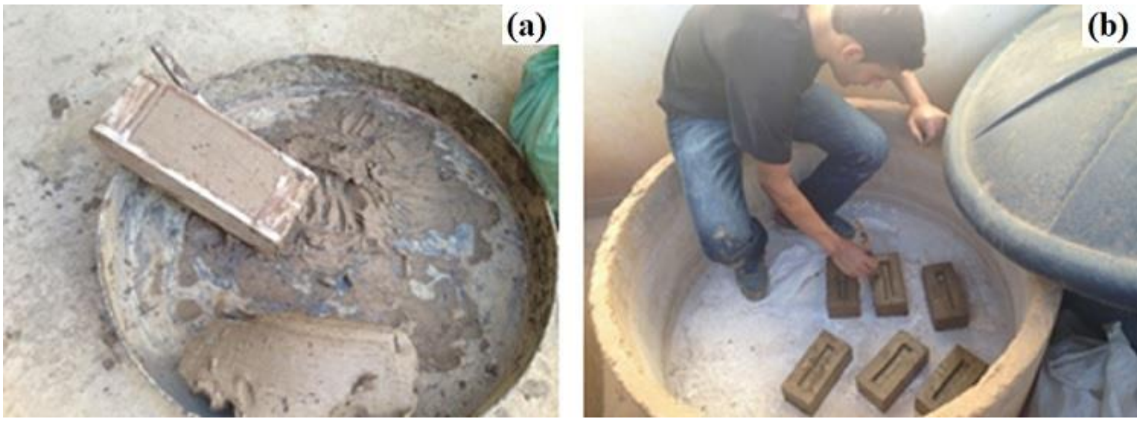

Figure 3: (a) Molding and (b) identification of specimens

The correct drying time is necessary for bricks acquire slow and gradual retraction, eliminating water and keeping the structure during firing, without cracks (de Castro et al. 2015). Therefore, the bricks were dried at laboratory conditions for 10 days, and burned in a muffle furnace at a temperature of 900 °C with a heating of 5 °C / min until reaching the plateau temperature. Then, maintained for two hours. The cooling was carried out at the same rate until room temperature, around 26 °C. Figure 4(a) and Figure 4(b) show the specimens before and after the firing.

The test to obtain the compressive strength was carried out according to the NBR 6460 (ABNT 1964). Initially, the bricks were torn in half, with the aid of an electric saw. Then the two larger smooth faces were joined through a thin layer of cement mortar of approximately 3 mm. After 24 hours, one side of the prism was covered with the cement paste in order to obtain a regular surface. After hardening, the other side was smoothed. These prisms were placed submerged in water for 24 hours, removed and superficially wiped just before the test. Figure 5(a) and Figure 5(b) show the preparation of the prisms and the equipment used in the test.

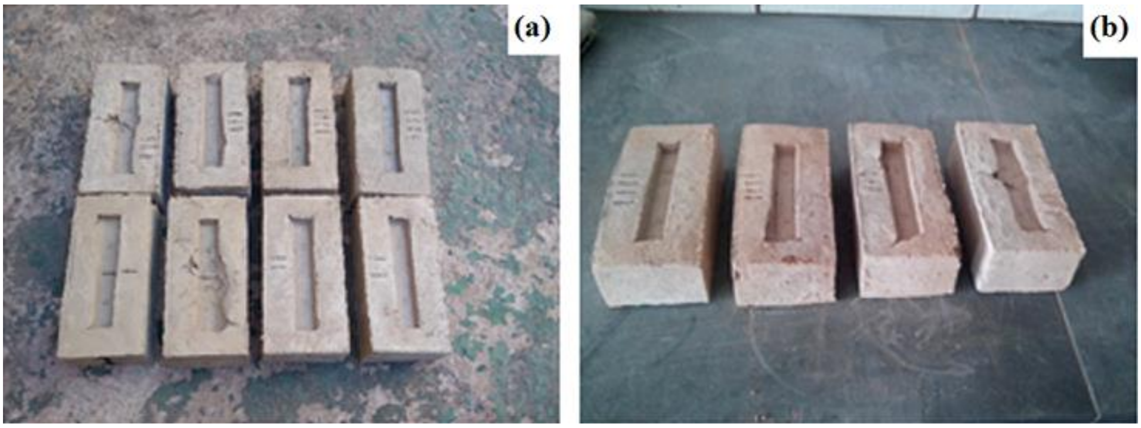

Figure 4: (a) Specimens before drying and (b) after burning.

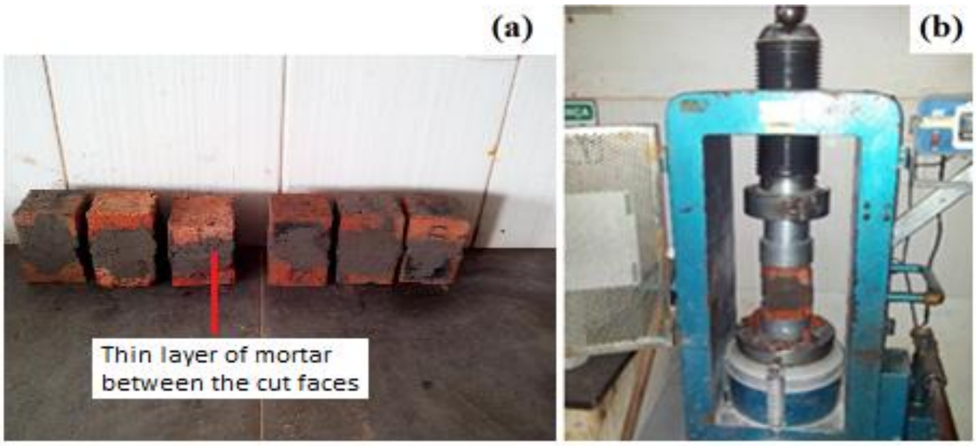

Figure 5: (a) Preparation of the prisms and (b) performing the test

2.4. Standards and equations

In Brazil, the ceramic solid bricks are regulated by the standards NBR 15270 (ABNT 2017a). The apparent specific gravity of the burnt specimens by the dimensional method is determined according to NBR ISO 5017 (ISO 2013), being calculated from the Equation (1).

$$\rho = \frac{M}{V} \tag{1}$$

where ρ is the specific gravity (g/cm^3) M is the mass (g) and V (cm^3) the apparent volume of burnt brick.

Dimensional analyzes for the calculation of linear shrinkage were carried out in accordance with the NBR 15270-3 (ABNT 2005). The specimens are measured before and after burning with the aid of King tools caliper for determining the linear retraction, being calculated using the Equation (2).

$$SLB\ (\%) = \frac{Ld - Lb}{Ld} \times 100\% \tag{2}$$

where SLB is the linear shrinkage of the burnt specimen, Ld is the length after drying and Lb is the length after burning.

The loss of ignition is an important parameter because it indicates the presence of organic matter in the ceramic mass. To perform the test, according CEMP 120 (CEMP 2015), the bricks, after being dried, are weighed before and after firing. The percentage of mass loss is calculated according to Equation (3).

$$LMF\ (\%) = \frac{Mbb - Maf}{Mbb} \times 100\% \tag{3}$$

where LMF is the loss of ignition, Mbb is the mass before burning and Maf is the mass after firing.

The water absorption test is carried out in accordance with NBR ISO 5017 (ISO 2013). The specimens are dried in an oven until a constant mass to be obtained and, then immersed in water for 24 hours. After that, the excess surface water is removed from each specimen and the mass is recorded. The water absorption index (WA) is calculated according to Equation (4).

$$WA\ (\%) = \frac{Ms - Md}{Md} \times 100\% \tag{4}$$

where Ms is the mass of the saturated sample and Md is the mass of the dry specimen.

For ceramic bricks, NBR 15270-2 recommends water absorption index should not be less than 8% or greater than 22% (ABNT 2017a). Other author recommends that the water absorption index shall be between 10% and 18%, once values below imply difficulties in adhering to the coating mortar and above values indicate porosity and permeability of the bricks (Petrucci 1998).

Regarding the compressive strength of solid bricks, NBR 7170 (ABNT 1983) establishes that the minimum must be the values indicated in Table 2, according to the category. The guarantee of minimum compressive strength values influences the safety and durability of the building, in addition to leading to less loss in transport and handling during the brick laying process.

Category	Compressive Strength (MPa)
A	1.5
B	2.5
C	4.0

Table 2: Minimum compressive strength

Source: ABNT NBR 7170 (ABNT 1983)

3. Results and Discussion

3.1. Preparation of ceramic bricks

Two compositions were prepared with incorporations of sludge into the ceramic mass in the percentages of 10% and 15% (by mass). This decision was based on the research works of de Castro et al. (2015), Duarte (2008), and Keerthana et al. (2019) who suggested a proportion between 10% and 20% to obtain a product with greater guarantee of technical quality. The study of Tay (1987) affirms that the maximum percentages of dried sludge and sludge ash that could be mixed with clay for brick making are 40% and 50% by weight, respectively. Beyond that, bonding of the mixture is poor and extrusion of the bricks results in "dog-earing" of the products (Tay 1987).

For each composition, two specimens were molded, with the dimensions 19.0 x 9.0 x 5.7 cm according to NBR 7170 (ABNT 1983). Table 3 shows the formulations for the mixes that were prepared, as well as the quantities of raw materials used.

For comparative purposes, eight commercial specimens (with no sludge) were used as reference. These specimens were tested to determine the apparent specific gravity, water absorption index and compressive strength.

Mixture	Clay (%)	Sludge (%)	Clay (kg)	Sludge (kg)
I	90	10	5.40	0.60
II	85	15	5.10	0.90

Table 3: Mix composition and formulations

3.2. Characterization discussion

Figure 6 shows the effect of adding the sludge on the specific gravity ceramic. A trend for reduced density is observed for increasing the sludge content. The commercial reference (0% sludge) presented a value higher than the research specimens.

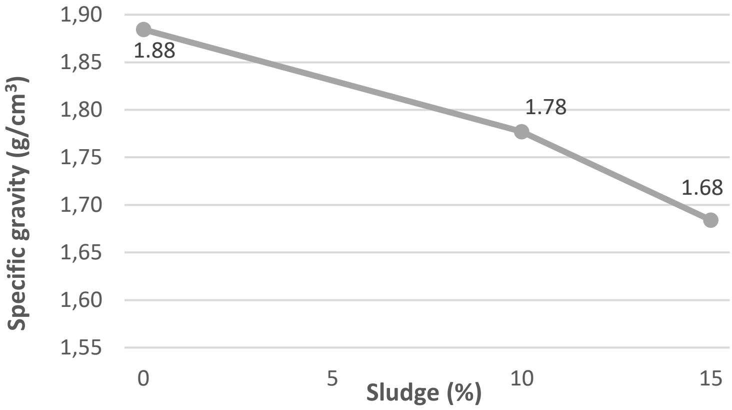

Figure 6: Specific gravity of burnt bricks

The linear shrinkage test for ceramic parts consists of an important technological parameter that must be considered. During the drying process and burning the shrinkage causes tensions that can generate defects and compromise the quality of the parts (Areias 2015). The tests show the average values of linear shrinkage of 5.1% and 6.1% for the formulations with 10% and 15% of sludge incorporated, respectively. This trend is explained because the linear firing retraction increases with the percentage of sludge incorporated mainly due to the volatilization of organic matter. It is important to note that a high density is favorable to the sintering processes, on the other hand, it can be harmful to the previous drying and to the elimination of organic matter in the initial firing temperatures, due to the reduction of the permeability of the ceramic pieces, which can cause cracks (Areias 2015).

Regarding the loss of mass for the compositions made with 10% and 15% sludge, an increase in loss on ignition of 16.8% and 18.0% was observed, respectively. Once again, this trend is explained due to the volatilization of organic matter present in the sludge. The utilization of different types of materials into fired clay brick obtain various advantages in terms of physical and mechanical properties such as low density, lightweight bricks, better strength and even reducing energy consumption during firing (Kadir and Rahim 2014).

Figure 7 illustrates graphically the evolution of the average rates of water absorption of the bricks as a function of the sludge content. The minimum and maximum limits established in accordance with NBR 15270 (ABNT 2017a), 8% and 22%, respectively, are presented, too.

A trend for increase water absorption is observed for increasing the sludge content. The commercial reference brick, without added sludge, had a higher water absorption index than the specimen with 10% sludge and very close to the limit established by the standard.

The increase of the water absorption is associated with increased porosity of the bricks, and the sample with 15% sludge showed a water absorption index higher than 22%. More studies are necessary, especially because the mix with 15% sludge surpassed the 22% of water absorption. Note that, the less water absorbed, the more durability of the brick and resistance to the natural environment are expected (Weng, Lin, and Chiang 2003).

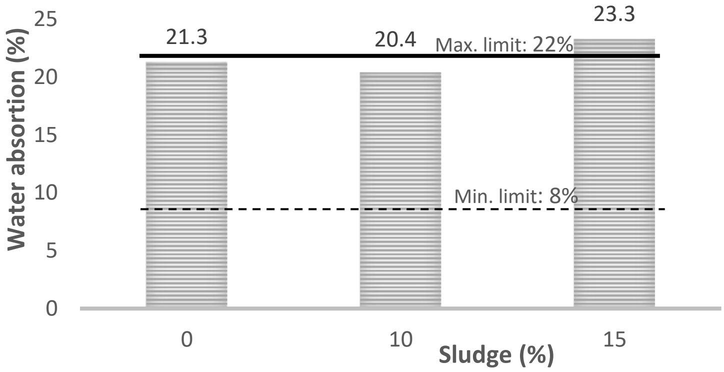

Figure 7: Water absorption

The study of Weng, Lin, and Chiang (2003) also concluded that the fire temperature is an important factor that influences the water absorption, the firing shrinkage and the density of the bricks. However, the temperature variation was not analyzed in this exploratory work.

The compressive strength was also tested. It was verified the load capacity that the ceramic bricks of all the mix could withstand when subjected to the compression forces applied in the direction perpendicular to the length, that is, on the face intended for laying. Figure 8 shows graphically the compressive strength of bricks as a function of the percentage of sludge incorporated into the ceramic mass. It is observed that the bricks manufactured with 10% and 15% of sludge reached sufficient strength to be classified in Category C (> 4.0 MPa). Moreover, it is observed that considering the standard deviation, obtained values may be considered similar. The reference bricks (manufactured without the addition of sludge) reached lower strength, being classified in the Category B (2.5 to 4.0 MPa). It is observed that the 10% sludge led to the best results. Similar findings were reported by Weng, Lin, and Chiang (2003). Other study, using cement, quarry dust and tannery sludge in the mixtures obtained maximum value of compressive strength in the 20% of sludge replacement in bricks (Amsayazhi and Mohan 2018).

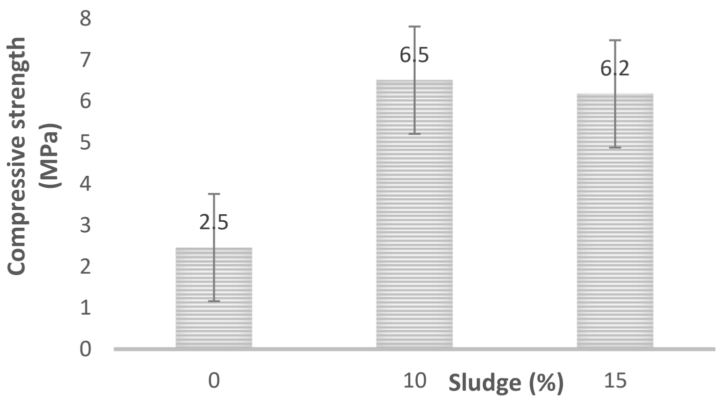

Figure 8: Compressive strength of specimens

4. Conclusions

This work intends to contribute to the solution for a sustainable development. It deals with the possibility of using a waste material from a sewage treatment plant as a raw material in the production of construction materials. From this exploratory experimental research, the following conclusions are taken:

- regarding to the retraction linear, the bricks with higher sludge content presented higher linear shrinkage;

- regarding the absorption index of water, the mix containing 15% sludge slightly surpassed the limit established by the standard;
- regarding the compressive strength, all mix compositions showed values higher than the minimum established by the standard, with the mixes incorporating sludge reaching a strength class higher than the reference mix;
- overall, the 10% sludge led to the best results.

This exploratory experimental research showed that an economic and environmental opportunity is anticipated for the incorporation of sludge of the sewage treatment plant in the ceramic mass for the manufacture of bricks of the ceramic plant. Therefore, an extensive study is suggested, among others: more specimens, more mix contents, leaching and solubilization tests in the specimens, life cycle analysis, and other types of bricks.

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