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RESEARCH ARTICLE

Use of Mining Waste in Civil Construction

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ABSTRACT: Two types of mining waste from the Brazilian mining industry (Samarco), sand waste (RAS) and flotation mud (LFS), were used to manufacture mini bricks. The manufactured bricks were heated in a ceramic furnace at Colégio Dante Alighieri. The products obtained by using RAS became brittle after firing, so they were not used for further studies. The LFS mini bricks presented a consistent appearance and were used in subsequent tests. The selected samples were compared to commercially available blocks of the same size and tested for compressive strength and water absorption. The results showed that the waste brick samples presented water absorption values between 8% and 25%. All mini brick samples also showed compressive strength values greater than 1.0 MPA. Therefore, the LFS bricks followed the standard allowed by the Brazilian legislation for this type of material related to compressive strength and water absorption. The results indicate that these materials could be used in construction works without causing cracking or structural problems. The next step in this study is to perform the same tests, but with waste bricks that present similar standard dimensions as regular bricks. The use of waste in other processes can contribute to the reduction of environmental impacts caused by the mining industries in Brazil. This project also tackles the 8th, 9th, 11th, and 12th sustaintable goals since, if done in large scales, it could provide clean water and sanitation, make cities more sustaintable, and preserve the life on land and below water.

KEYWORDS: ECivil Engineering; Waste Management; Mining Industry; Recovery and Recycling.

Introduction

Recent disasters involving tailing dams reveal the enormous risk that these structures can present. On November 15 of 2015, a dam broke in a Brazilian state called Minas Gerais, generating several environmental impacts in the city of Mariana,[1,2] causing the death of 19 people, burying more than 200 houses, nearly extinguishing 11 species of fish, and contaminating about 680 kilometers of rivers and streams, including the Rio Doce (Figure 1).[3] In addition, the so-called Quadrilátero Ferrífero (a region also located in the state of Minas Gerais that is known for having a large number of mines) has more than 700 waste dams. Moreover, in August 2014, there was a dam disaster by the mining company Imperial Metals Corp. at the Mount Polley mine, which dumped 5 million cubic meters of tailings from copper and gold exploration into the Hazeltine and Cariboo streams in the province of British Columbia in Canada.[4] That accident caused numerous environmental impacts and affected more than 300 homes.[5,6]

In this context, besides the contamination of the environment, mining industries generate large volumes of materials. These materials are often accumulated in piles around the companies themselves, occupying important and necessary physical spaces that could have other purposes, or placed in landfills without generating any profit for the company. An alternative to this problem would be a recycling system, where this material may bring, in addition to environmental benefits, economic return.[7]

As mentioned before, mining waste is usually placed in dams, as this alternative is considered a low-cost method. A survey carried out by a Technological Research Institute (Instituto de Pesquisas Tecnológicas - IPT), located in São Paulo, Brazil, that complements the data generated by the Institute of Applied Economic Research (Ipea), indicates that around 4.86 billion tons of tailings were accumulated between 2009 and 2014 in Brazil, taking into account only 15 minerals out of a total of 70 that the country produces.[8]

Currently, iron is responsible for approximately 80% of the profit generated by the export of ores in Brazil. According to the United States Geological Survey, iron ore production in Brazil was estimated to be 398 million tons in 2013, equivalent to 13.5% of the global total. A number that places the country among the largest iron producers in the world, with an estimated reserve of 31 billion tons of iron ore, behind only Australia, with 35 billion tons.[9]

This project aims to reduce the amount of waste by the use of the mining process' by-products to obtain materials used in the construction industry. The use of waste in the composition of materials for other purposes can lower raw material costs and, consequently, the price of the final product.

One of the most commonly used materials in the construction industry is solid bricks. They are a type of block made of common clay, has no holes, and is molded with straight edges, and can be made by burning the pieces in ovens. It is considered a rustic brick and produces very resistant masonry.[10]

Bricks used in construction can be made from clay, sand, slate, calcium silicate, cement or concrete, as well as other unusual materials. Clay is the most common material to be used. For the manufacture of the brick, initially, a homogeneous mass with the raw material is made, or a mixture of raw materials. Then the material is burned at about 900ºC (in the case of clay) to form the hardened bricks. Common brick typically contains the following components: silica (50 to 60% by weight), alumina (20 to 30% by weight), lime (2 to 5% by

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weight), iron oxide (5 to 6% by weight), and magnesium oxide (less than 1% by weight).[10]

Solid brick is most commonly used today in the construction of foundations. It also provides thermal and acoustic comfort, which is the reason why it is used on such a large scale. Therefore, using mining waste to produce bricks can minimize the environmental and social degradation caused by activities of this type of industrial process.[11,12]

Once ready, the bricks need to be tested to see if they are suitable for the application. According to Pablos *et al.* (2009), the most suitable tests for bricks are compressive strength, water absorption, air permeability, and solubilization, in which the first two tests are the most important.[12]

Water absorption determination in bricks is essential as it checks the percentage of water absorbed by them, which if it is not ideal can damage the structure. The compressive strength test, on the other hand, verifies the load capacity that the blocks support when subjected to forces exerted perpendicularly on their opposite faces (Figure 2). This test determines if the samples offer adequate mechanical strength and simulates the pressure exerted by the weight of the construction on the bricks. Failure to comply with the minimum normative parameters indicates that the wall may present structural problems such as cracks. Consequently, the failure to comply with a minimum parameter of compressive strength > 1.0 MPa will present risks of collapse in the construction.[13] The limit of compressive strength is calculated by the maximum load divided by the original section of the specimen.

The compressive test can be performed on the universal testing machine by adapting two flat plates, one fixed and one movable. It is between them that the sample is supported and held firm during compression.

This project differs from current literature because, unlike the vast majority of tests, this procedure can be easily done on a larger scale, which can assist in the production of bricks and consequently decrease the amount of mining waste faster than usual.

■ Methods

Bricks with smaller dimensions than ordinary bricks were used in this study to save the mining waste provided by the Samarco industry. Thus, the original measurements of the common bricks were divided by 4, and the following measurements were obtained: height: 1.3 cm, length: 6 cm, and width: 2.9 cm. After the determination of the dimensions, the drawings were sent to the Dante Alighieri College joinery, which made the plywood molds, with a thickness of 0.5 cm (Figure 3).

The LFS (flotation mud) had a pasty consistency, so it was used directly in the molds. The sand waste was a brittle residue so a binder was required, so that it could be shaped into a brick. The binder used was carboxymethylcellulose, known as CMC. Five grams of the binder was dissolved in water to a volume of 1 liter in a volumetric flask.

The solution was mixed with the sandy residue to form a pasty mixture. The pasty samples of the two residues (LFS and RAS) were placed in the plywood molds. There were six samples of each type of waste, totaling 12 samples (Figure 4).

All bricks dried for 15 days and were then placed to heat in a ceramic kiln (JUNG, Figure 5). The samples were placed in the oven for eight hours until they reached 900ºC. The oven was set to remain at 900 ˚C for 20 minutes and, after that time, the temperature began to decrease, reaching a final temperature of 40 ˚ C. The total time spent in the oven was 16 hours.

Mechanical Tests :

The compressive strength and water absorption tests were performed in partnership with the Pontifical Catholic University of São Paulo - PUC-SP, Marquês de Paranaguá campus (Figure 6). These tests were performed only with the pre-selected bricks.

Compressive Strength Teste:

Firstly, the commercial bricks were cut in the cross-section to have the same dimensions as the mini waste bricks using an AEG Policorte saw, model SMT-355 (Figure 7). The cut bricks can be seen in Figure 8.

A high concentration of BR2 is needed for cancer cell deliverFor the tests of compressive strength and water absorption, the tests were performed following the standard ABNT NBR 8492 (Cement soil brick - Dimensional analysis, determination of compressive strength and water absorption - Test method).[14]

To carry out the compression test, following the previously mentioned standard, 300g of cement (CP II-E32) were weighed on a scale (Mars - AD50K) and mixed with 150 ml of water until a homogeneous paste formed, which was deposited in a porcelain capsule (Figure 9).

For the assembly of the test material, a layer of cement was placed directly on the glass support and then half of the bricks were added under that layer, and so on until it formed a kind of hamburger (Figure 10).

The material was entirely covered by the prepared cement. After that, the bricks dried for 14 days so that it could be tested on the hydraulic press (Figure 11).

Water absorption test:

The water absorption test was also performed following the ABNT NBR 8492 standard. First, the brick mass was determined before and after placing it in a drying oven (Figure 12). Then, the samples were immersed in water (Figure 13), and after twelve hours, the mass of the wet block was measured. The percentage of water absorbed by the sample was determined by the difference between the two values found. At the end of the analysis, the brick was required to have a water absorption between 8% and 25%.[14]

■ Results and Discussion

Brick rating after heating:

Two types of waste were used by Samarco and were labelled as flotation mud (LFS) and sandy waste (RAS). The chemical composition from both of the samples is shown in Table 1. According to Table 1, both samples had silicon and iron oxides as the main compounds. However, the LFS sample had a 14.8% lower silica content and 9.8% more iron than the

RAS sample. Mini bricks molded by using both residues, after heating at 900ºC in a furnace provided by Colégio Dante Alighieri (commonly used for ceramic materials), had the appearance shown in Figure 14.

The bricks obtained by the addition of the bonded RAS had a brittle appearance and therefore were not suitable for use in the manufacture of bricks used in civil construction, as shown in Figure 14. It is believed that the RAS residue was not suitable for the manufacture of mini bricks because its silica content was extremely high (79.3) when compared to the LFS percentage (64.5). However, through research, this solid waste can apply to other areas.

The bricks obtained from flotation mud appeared to be adequate, so they were chosen to continue this study.

The masses of each brick sample before and after heating using the LFS and their respective measurements are shown in Table 2.

The bricks obtained from LFS lost weight after heating at 900ºC due to the loss of water contained in the raw material. The bricks also showed a reduction in length and width after the heating. However, the height measurement was, at times, equal to or greater than the initial measure, showing that the material expanded in the furnace during firing. The percentage of mass loss for samples 1 to 6 was 20.77 g; 21.53 g; 20.44 g; 20.86 g; 21.10 g; 21.0 g, respectively.

Water absorption and compressive strength test results:

The LFS and the common bricks samples presented a cross-section cut at the same dimensions as that of the mini bricks for comparison and were weighed with a scale and measured with a caliper. The data obtained was used to calculate the percentage of water absorption. Water absorption tests were done in duplicate, and the results are shown in Table 3 as well as in Figure 15.

As can be seen in Table 3 and Figure 15, all samples had water absorption values lower than 25%, which is the limit of the standard applied by Inmetro (2019). Thus, the waste bricks met the requirements of the Brazilian law and therefore, when used in a building, would not be damaged by moisture.

The compressive strength tests were performed on four different samples, and the results are shown in Table 4 and Figure 16.

The bricks made by residue presented compressive strength values slightly lower than the values obtained for common bricks, as can be seen in Table 4. All samples presented compressive strength values greater than 1.0 MPa, and therefore meet the requirements of the Brazilian law. 15 A wall formed by the waste bricks would not present cracking problems, and there would be no risk of collapse.

■ Discussion

Aiming to improve the results in both tests, concrete can be added to the composition of the brick. After that, performing dry curing would be necessary, because this procedure is essential for the concrete to achieve a better performance since it improves the resistance and the durability of the brick. If not done correctly, dry curing can cause cracks and make the surface layer weak, porous, and permeable. The chemical characteristics of mining waste are very close to those required for the production of ceramic products. The manufacturing of pavement and replacement of aggregates for concrete manufacturing are also options for which the chemical composition is not very rigorous. Particle size and strength are characteristics very important for this type of material, and can be evaluated for use in civil construction. Finally, it is possible to measure the application of tailings for the manufacture of cement, since the high content of iron in cement can eliminate the incorporation of powdered iron in conventional cement. Samarco solid waste used in this study has iron in high quantity and could be used for cement production.[6,15]

In aiming for better results, the addition of slate (20%) or chamotte (3%) to the brick making process could improve the results of the resistance tests by, respectively, 41% and 150%, as these residues increase the permeability, improving the drying and firing procedure. Besides, increasing the temperature in the heating process to 1000°C could improve the results of the absorption tests.[16,17]

■ Conclusion

Samarco's sandy waste was not suitable for the manufacture of mini-bricks because it was brittle after the heating process. It is believed that the RAS residue was not suitable because its silica content was almost 15% higher than the content of sílica from LFS. The silica content may have been responsible for the brittle appearance of the RAS bricks, so the residue from the flotation step was used for further testing. The bricks obtained from the LFS presented mass loss after burning between 20.44% and 21.53%. The bricks also showed a reduction in length and width during firing. However, the height measurement was, at times, equal to, or greater than the initial measurement. In the water absorption tests, the two samples of waste bricks presented values between 8% and 25%, and, therefore, fit the current Brazilian law. All mini-brick samples had compressive strength values greater than 1.0 MPa, and therefore met the requirements of the law for civil construction in Brazil. These results indicate that LFS residue bricks won't cause cracking or structural problems. The next step of this study will be to perform the same tests but on waste bricks with equal dimensions as ordinary bricks as well as evaluate the addition of other materials to the composition of the bricks.

■ Acknowledgments

Thanks to Samarco for supplying waste samples, to teacher Lucia for the help in making bricks and burning the samples, to the chemistry lab for help with the entire Project, and to Rodrigo Braga of the Pontifical Catholic University of São Paulo - PUC-SP, Marquês de Paranaguá campus for his assistance in the water absorption and compressive strength tests.

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Author

Pedro Valim Hespanha Gonçalves is a senior in an Italian private school called Colégio Dante Alighieri. This project was developed in a program called Cientista Aprendiz. He aims to use the knowledge he has obtained for further studies in architecture area and civil engineering.

Figure 1: Area devastated after the rupture of the dam containing mining waste from the Samarco company. Source: https://ferdinandodesousa.wordpress.com/2017/08/17/.

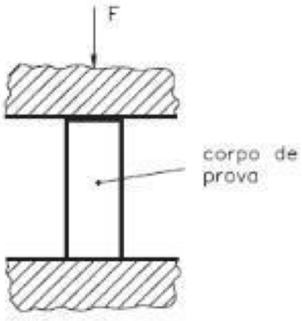

Figure 2: Compression test outline. Source: http://www.inmetro.gov.br/.

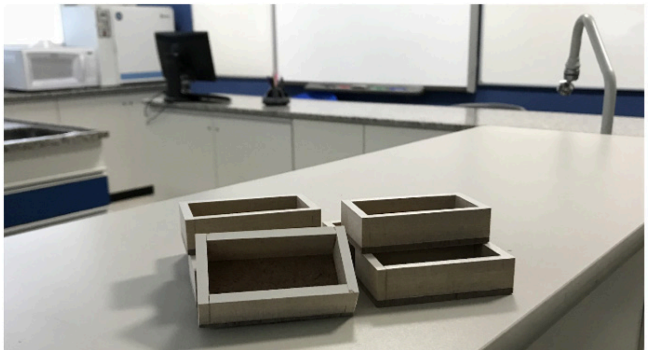

Figure 3: Brick molds made from plywood in the Colégio Dante Alighieri's laboratory.

Figure 4: Mini bricks made from Samarco waste. On the left: sandy residue (RAS), and on the right: flotation mud (LFS).

Figure 5: Ceramic material oven from Colégio Dante Alighieri.

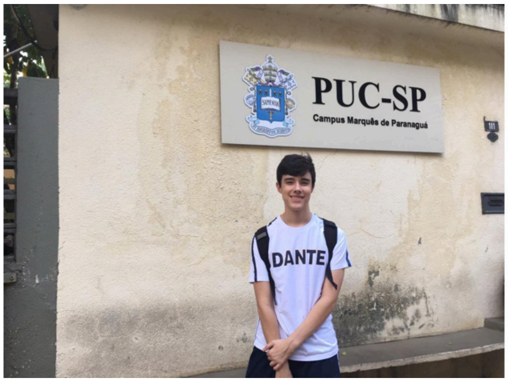

Figure 6: PUC-SP, Marquês de Paranaguá campus.

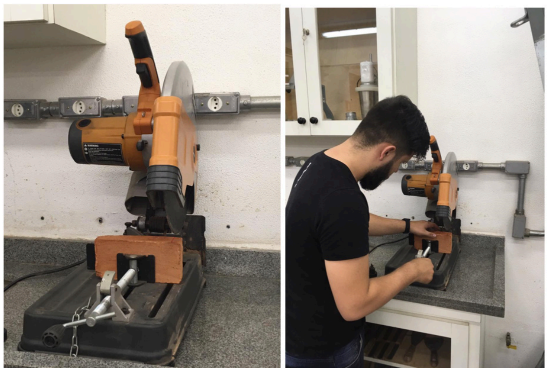

Figure 8: Waste bricks and common bricks after cutting in the civil engineering laboratory at PUC-SP.

Figure 9: Cement being weighed on the scale and the cement mass prepared after adding water.

Figure 10: Cement being weighed on the scale and the cement mass prepared after adding water.

Figure 11: Hydraulic press used for brick compression tests (brand: Solotest).

Figure 12: Determination of the mass of bricks in PUC-SP laboratory analytical balance.

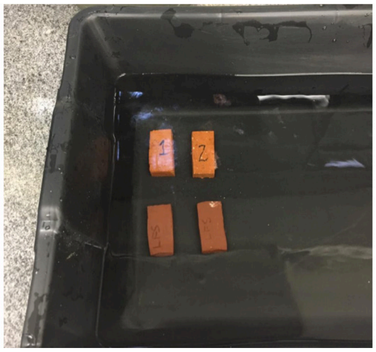

Figure 13: Bricks submerged in water for water absorption testing.

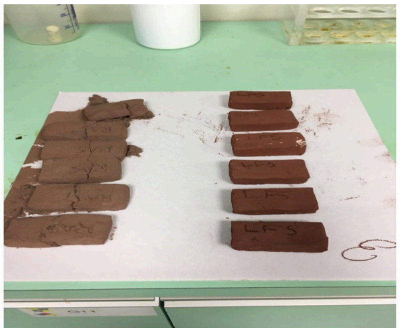

Figure 14: Residue bricks after heating.

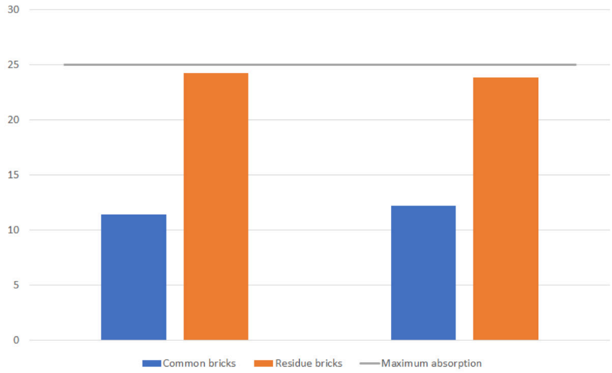

Figure 15: Results of water absorption in percentage.

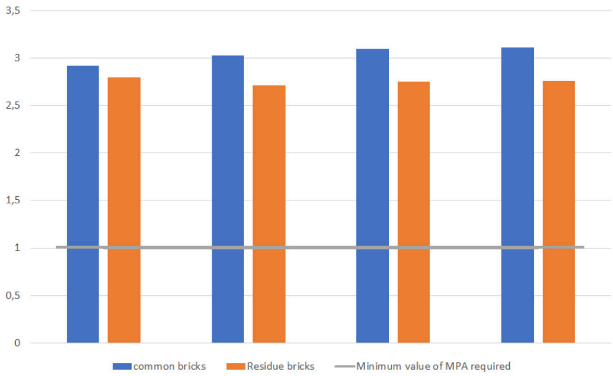

Figure 16: Results of compressive strength tests in MPa.

Table 1: Chemical analysis of the RAS and LFS samples.

COMPONENT	CONTENT % (RAS)	CONTENT % (LFS)
SiO_2(%)	79.3	64.5
Fe_2O_3(%)	19.3	29.1
Al_2O_3(%)	0.46	2.13
Cr_2O_3(%)	0.15	0.051
MgO(%)	0.04	0.040
SO_3(%)	0.04	0.414
P_2O_5(%)	0.03	0.074
K_2O(%)	0.03	0.155
CaO(%)	0.03	0.182
Others	< 0.7	< 3.0
LOI (%)	0.5	2.55

Table 2: Characteristics of the bricks before and after heating.

MINI BRICKS	CHARACTERISTICS BEFORE HEATING				CHARACTERISTICS AFTER HEATING			
	M (g)	L (cm)	W (cm)	H (cm)	M (g)	L (cm)	W (cm)	H (cm)
1	67.45	6.0	2.9	1.3	53.44	5.9	2.6	1.5
2	68.97	6.0	2.9	1.3	54.12	5.8	2.8	1.7
3	69.88	6.0	2.9	1.3	55.60	5.8	2.8	1.4
4	67.13	6.0	2.9	1.3	53.13	5.6	2.9	1.3
5	66.44	6.0	2.9	1.3	52.42	5.7	2.8	1.4
6	66.76	6.0	2.9	1.3	52.74	5.9	2.8	1.4

M = mass; L = length; W = width; H = height.

Table 3: Results of the water absorption test.

TYPE	DIMENSIONS (CM)	DRY WEIGHT(G)	WET WEIGHT(G)	ABSORPTION (%)
CB1*	2.31 x 5.87	37.58	41.85	11.38
CB2*	2.25 x 5.62	33.79	37.90	12.18
RB1**	2.13 x 5.82	55.52	68.95	24.20
RB2**	2.16 x 5.75	53.34	66.04	23.82

*CB = Common brick ; **RB = Residue brick.

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Table 4: Results of compressive strength tests.

SAMPLE	DIMENSIONS (CM)	AREA (CM²)	AXIAL FORCE	CHARGE	MPa
CB1	2.43 x 3.03	7.3629	215	29.200	2.920
CB2	2.36 x 2.95	6.962	211	30.307	3.030
CB3	2.24 x 3.07	6.8768	213	30.973	3.097
CB4	2.23 x 3.10	7.3629	229	31.101	3.110
RB1	2.14 x 2.79	5.9706	167	27.970	2.797
RB2	2.07 x 2.83	5.8581	159	27.141	2.714
RB3	2.21 x 2.88	6.3648	175	27.494	2.749
RB4	2.19 x 2.78	6.0882	168	27.594	2.759