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DESIGN AND PRODUCTION OF A NEW CONSTRUCTION MATERIAL (BRICKS), USING MINING TAILINGS

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ABSTRACT
In the present work, tailings from mining and metallurgical activities in the mining district of Pachuca – Real del Monte were characterized to determine the mineral phases present, the chemical analysis and its granulometric characteristics, seeking for an alternative use of this material. The principal results found pointed that these mining tailing are principally composed of silicates, sulfates and carbonates, as majority phases. Then this material was used to produce construction materials (bricks) with some properties quite similar or even higher to those presented by commercial materials. The most important properties found were related to values such as compression resistance showing results ranging from 0.3 to 41.5 kg/cm^2, the absorption was from 1.86 to 23.4 %, permeability from 8.7 x 10^{-5} to 2.67 x 10^{-4} cm^3/s and volumetric weight was from 1296 to 2116.4 kg/cm^3. These last values were also treated in a simple correlation of couples of these variables to elaborate a model statistics of multiple correlations of these variables, with adequate results that fit well with the proposed model. Finally, the comparison and dependence of compression resistance and permeability was analyzed with such model in a computer program getting good results.

KEYWORDS: Mining tailings; Construction material; Absorption; Permeability; Compression resistance

I. INTRODUCTION
The mining district *Pachuca-Real del Monte* is located in the south central part of the state of Hidalgo, belonging to the geologic province of Neovolcanic. The mining district consists of deposits of epigenetic origin, with hydrothermal deposits of low temperature and shallow. Formed by the flows of hot water into the pre-existing cracks and deposited by igneous processes through layers of andesite, rhyolite and pyroclastic [1].
The veins found within the mining district of *Pachuca-Real del Monte* go in two directions, East-West and North-South, having several mineral species such as quartz, bustamite, calcite, pyrite, galena, chalcopyrite, chalcocite, covellite and argentiferous sulfides with some contents of Ag and Au natives, principally. In these sulfides, commonly are present in a 3-4 % within the vein [1]. With a mineralization of the type Ag-Pb-Zn-Au in an area of approximately 130 km^2 [2], of which 45 km^2 are polymetallic mineralization of Pb-Zn-Ag as sulfides and sulfosalts [3], and this type of mineralization comes from *San Pedro Corralitos, Chihuahua* to *Pachuca de Soto, Hidalgo* covering over 1600 km in length *(CRM, 1992)*.
This mining district has had a period of 471 years of mining, which has generated 6 % of world production of Ag and 16 % of the national production of Ag [2]. In addition to the production of Ag, have also been produced Au, Zn, Pb, CU, Fe and Cd, although mining has been focused primarily on the Ag and Au.
During the 471 years of mining in the district, have been generated different types of mining wastes, commonly classified as acid mine drainage waters, pulps that transports solids in suspension, radical elements, abandoned

wastes with no known mineral processing as mineral already processed known as mining tailings or dumps, which are the most abundant in the state of *Hidalgo* [4].
The principal characteristic of these dumps is that they were produced in three technologically different periods: a) 353 years of exploitation in rudimentary form, known as Benefit yard (grinding – amalgamation using Hg - melting), b) for 47 years of exploitation through milling - cyaniding c) 70 years of intense exploitation grinding – flotation - cyaniding.
In the mining district of *Pachuca-Real del Monte* there are 4 dumps of mining tailings, which include three deposits within the urban area of the county of *Pachuca de Soto* and the other deposit is within the town of Velasco, County of *Omitlán de Juárez*. It is noteworthy that these tailings deposits have a total of 108.1 million tons of material, occupying about 1200 hectares within different urban spots mentioned [5], and given that in the area where these tailings are deposited there are seasons of strong winds in some months, the presence of these deposits is a serious environmental problem due to the uprisings of columns of material during the period from February to April and November occasionally, causing some health problems in airways and in the eyes of the people who living near to the dumps of mining tailings.
Thus, the deposits of mining tailings of *Dos Carlos* and *Velasco*, were deposited since 1912 (date on which the deposition of these kind of residues started) and with the oldest wastes found prior to this year, we found that they have particle sizes more large and a higher content of Ag and Au [3].
Therefore is proposed the reuse of the material, because it has higher silica content and components such as alumina, alkalis and alkali earth oxides [4,6]. This material could be used due it has a particle size ranging mainly between 53 and 177 microns, heavy clays considered as binders [7-8], and in some cases, certain amounts of refractory materials such as expanded perlite and/or vermiculite, that in conjunction could give excellent properties to the mixture. That is the reason why this work it also aims at developing a new kind of bricks, using a new material which is obtained with a major amount of the mining tailings and that could exhibit good green strength, an adequate compressive strength, good permeability, good adsorption and volumetric weight; quite similar or better than those found in conventional bricks.

II. MATERIALS AND METHODS

Materials
Once sample was taken in the deposits of the mining tailings (from Dos Carlos and Velasco), this was homogenized and selected for its subsequent characterization. Then it was done the chemical, morphological, mineralogical characterization and also was done the evaluation of the particles size distribution, through the techniques of atomic absorption spectrophotometry using a Perkin Elmer 2380 spectrophotometer, Scanning Electron Microscopy with microanalysis scattering X-ray energy using a microscope JEOL JSM 6300 SEM fitted with a Noran EDS, X-ray diffraction with a Diffractometer Inel Equinox 2000 and the sizes distribution analysis by wet sieving using sieves Tyler® series with an aperture of 177, 149, 105, 74, 53 and 37 µm, where 100 g of sample were sieved and the fractions obtained were dried at room temperature and then were weighed.
Subsequently 19 ceramic compounds were elaborated using mining tailings from deposits of *"Dos Carlos"* and *"Velasco"*, mixing the material from the burrows with heavy clay and adding in some cases expanded perlite or vermiculite, as the case. Of the 19 composites, 13 were developed using a mixture of jal and heavy clay, and the remaining 6 composites were prepared using burrows, heavy clay and adding expanded perlite or vermiculite, as appropriate. Finally, all the composites were sintered in the form of briquettes using a (Nabertherm model P310) muffle furnace at 1100 °C, maintaining the mixture for one hour at this temperature, and then were cooled to a temperature of 25 °C.

Methods
Furthermore, sintered materials were characterized to determine their resistance to compression, absorption, permeability and specific weight. The compressive strength was evaluated using a press Elvec and imposing a burden on the specimen until rupture. The absorption test was performed by saturation of water for 24 hours by submerging the sample in a test tube, by weighing before and after water saturation in the sample. The permeability test was carried out adding water into a capillary on the sample and finally the specific weight was determined with the measurement of volume and weighing of sample.
Moreover, using multiple regression and correlation of variables we can assume that compressive strength is affected by absorption and the permeability; and in turn the permeability is affected by absorption. According to the above, for adjustment and possible forecasts to make, the following equation will be used:

$$Z = a + b_1X + b_2YX \qquad (1)$$

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For purposes of this regression model and multiple correlations, has been appointed by the degree of involvement of one variable to another; absorption (X), permeability (Y), and compressive strength (Z). This in order to calculate the following determinants:

$$A = \begin{matrix} n & \sum X & \sum XY \\ \sum X & \sum X^2 & \sum X^2 Y \\ \sum X^2 & \sum X^3 & \sum X^3 Y \end{matrix}; \quad B = \begin{matrix} \sum Z & \sum X & \sum XY \\ \sum XZ & \sum X^2 & \sum X^2 Y \\ \sum X^2 Z & \sum X^3 & \sum X^3 Y \end{matrix}; \qquad (2)$$

$$C = \begin{matrix} n & \sum Z & \sum XY \\ \sum X & \sum XZ & \sum X^2 Y \\ \sum X^2 & \sum X^2 Z & \sum X^3 Y \end{matrix}; \quad D = \begin{matrix} n & \sum X & \sum Z \\ \sum X & \sum X^2 & \sum XZ \\ \sum X^2 & \sum X^3 & \sum X^2 Z \end{matrix} \qquad (3)$$

These matrices are used by Kramer's rule for solving simultaneous equations, which ultimately generate the unknowns a, b_1 and b_2, using the following formulas:

$$a = \frac{B}{A}; b_1 = \frac{C}{A}; \ b_2 = \frac{D}{A} \qquad (4)$$

Finally, is obtained the correlation coefficient of the variables in the multiple regression model and correlation of variables that are affected each other and said correlation coefficient was calculated according to the following formula:

$$R^2_{XYZ} = \left(\frac{R^2_{XY}+R^2_{XZ}-2(R^2_{XY}\cdot R^2_{XZ}\cdot R^2_{YZ})}{1-R^2_{YZ}}\right)^{1/2} \qquad (5)$$

For modeling and computer simulation, were used data obtained in tests on composites using COMSOL Multiphysics 4.4 and subsequently evaluating the permeability properties and compressive strength, simulating separately each of the properties. To determine the permeability, were used the composites 11, 16 and 18, compared with a conventional brick and having as boundary conditions at steady state speed fluid inlet at the top; an initial pressure of 0 Pa in the side faces and bottom face, taking into account the acceleration of gravity and the variables of the fluid (μ_{water} = 1x10^3 Pa • s ρ_{water} = 997.048 kg / m^3), the permeability and porosity of each of the composites analyzed and of the conventional brick. For the determination of ownership of permeability, the following formulas were used according to Darcy's law:

$$u = -\frac{k}{\mu}(\nabla P + \rho g \nabla D); \qquad \nabla \cdot (\rho u) = Q_m \qquad (6)$$

Under the condition of entry into a contour, we have the following formula

$$-n \cdot \rho u = \rho u_0 \qquad (7)$$

Under the condition of pressure on a contour, having the following formula:

$$P = P_0 \qquad (8)$$

Meanwhile, to evaluate resistance to compression were used the composites 13, 15 and 19, compared with conventional brick and boundary conditions in a time-modal solver by applying load at the top of the composite and through the Z-axis, while maintaining symmetry behavior at the bottom as variables and corresponding coefficients of compressibility and stiffness of each sample. As the load applied is going on to each sample, can be measured using the formula that is under natural frequency:

$$-\rho\omega^2 u - \nabla \cdot \sigma = Fv, \quad i\omega = \lambda \qquad (9)$$

Under the condition of temporal-modal solver, we have the following formula:

$$\rho = \frac{\partial^2 u}{\partial t^2} - \nabla \cdot \sigma = Fv \qquad (10)$$

Under the condition of surface charge in a contour has the following formula:

$$\sigma \cdot n = FA \qquad (11)$$

Under the condition of symmetry in a contour has the following formula:

$$n \cdot u = 0 \qquad (12)$$

III. RESULTS AND DISCUSSION

The mineralogical characterization performed by XRD to the material of the dam Dos Carlos (Figure 1), shows that the major mineral phases are quartz, andesite, anorthoclase, orthoclase and berlinite. Minor species such as albite, jarosite of hydronium and argentite were also found. And finally as trace phases, were determined the calcite, gibbsite, natrojarosite, jarosite, romboclasa, anhidryte, trydimite, hematite, wustite, pyrite, gyrolita, magnetite, argentojarosite, pyrolusite and cristobalite.

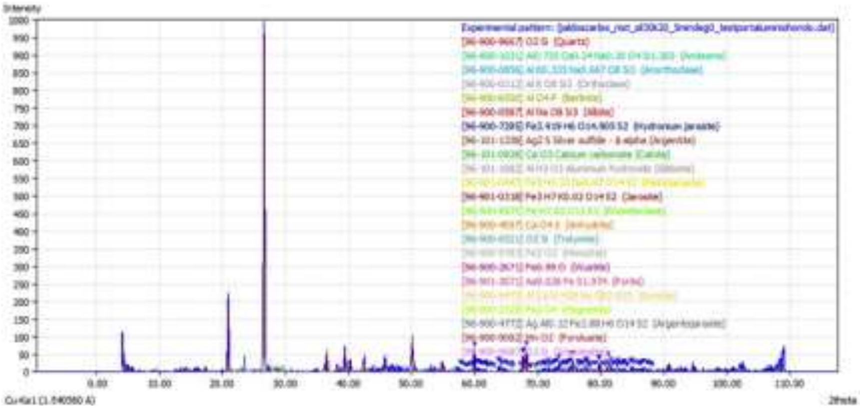

Figure 1. XRD spectrum showing the principal mineral species of the mining tailings dam of Dos Carlos

The mineralogical characterization of the mining tailings from the Velasco dam is shown in Fig. 2, where can be seen the presence of major species such as Quartz, Berlinite, Orthoclase, Albite and Ferrosilicon. Also can be observed in a minor amount, species such as Gibbsite, Anhydrite, Cristobalite and Calcite. In the trace phases can be recognized to the Jarosite, Romboclase, Hematite, Alunite, Pyrite, Trydimite, Natrojarosite, Magnetite, Argentite, Wustite and Maghemite.

Figure 2. XRD spectrum of the mineral from tailings dam of Velasco

The chemical characterization (semi - quantitative) and morphological determination done by SEM-EDS to the material from dam ”Dos Carlos”, shows that particles of jal have an angular shape and within these particles are present small amounts of Ag (Figure 3a). Also by EDS analysis, was found that the major elements of this kind of material are Si, Al, Fe, S, K and O, also presenting some trace elements such as Ag, Mg, Ca, Mn, Cu, Zn and Pb (Figure 3b). In the same way was noted that some elements are present as oxides such as Si, Al, Ca, Mg, Mn and Fe; in addition to other elements such as Ag, Cu, Pb, Zn and Fe that in some cases are present in the form of sulfides.

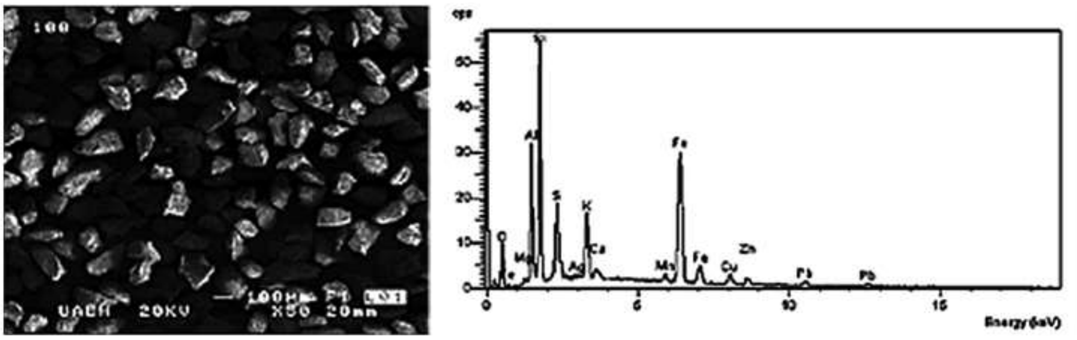

Figure 3. (a) General image of the material from tailings dam “Dos Carlos”, retained in mesh 100 (50 x and 20 kV); (b) EDS spectrum taken to the same sample (SEM-EDS)

For the material of the tailings dam "Velasco", particles with an angular morphology were found and also could be observed the presence of Ag within these (Figure 4a). Similarly, by EDS it was determined that the major elements present are Si, Al, Fe, S, K and O and as trace elements Ag, Mg, Ca, Mn, Cu, Zn and Pb (Figure 4b). In this case, it was noticed that some elements are present as oxides such as Si, Al, Ca, Mg, Mn and Fe. But the remaining elements such as Ag, Cu, Pb, Zn and Fe in some cases are present as sulfurs.

The chemical characterization made on the material of the tailings dam “Dos Carlos” by AAS is shown in table 1. It was found that SiO_2 content is greater than 70%, which is within the specifications for making bricks for construction industry. Additionally, there are some considered plastics components (Na_2O, K_2O, CaO, MgO, MnO and Al_2O_3), which promote a good green strength property. It is noted that according to the content of Na_2O, K_2O and CaO, this type of material could be considered as mixed feldspar, which can be used in the manufacture of building materials.

Table 2 shows the chemical analysis of the material from dam of mining tailings of Velasco, it is observed that the silica content exceeds 60% (in weight) and is very close to the specifications for making bricks. Likewise, the contents of components considered plastic-type (Na_2O, K_2O, CaO, MgO, MnO and Al_2O_3), is observed in greater proportion than in the material of the dam Dos Carlos, which compensates the large amount of silica present in the material, giving so a better plasticity while the point of melting for the material from the dam of mining tailings may be less than the melting point of silica and this can be due to the presence of alkali and alkaline earth oxides. Similarly, the content of alumina increases the refractoriness of the composite. Therefore, this material can also be treated as mixed feldspar (like in the case of the dam material Carlos Dos) and can be equally used in the manufacture of building materials.

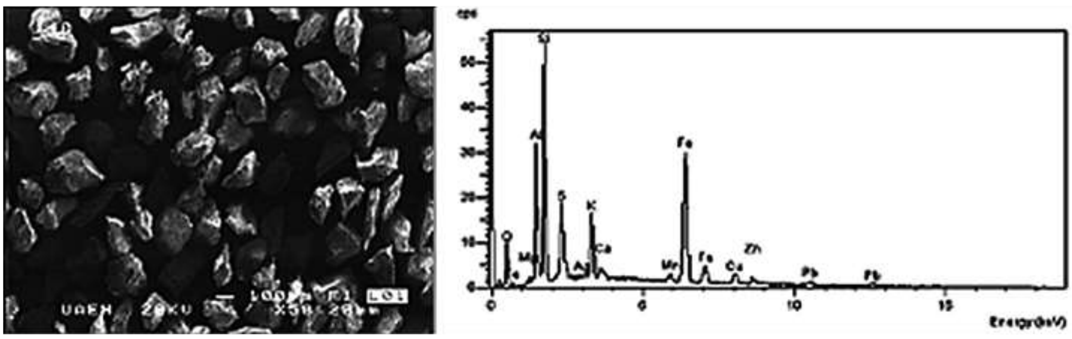

Figure 4. (a) General image of the material from tailings dam of “Velasco”, retained at mesh 140 (50 x and 20 kV); (b) EDS spectrum of the same material (SEM-EDS)

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Table 1. Chemical analysis of material for tailings dam Dos Carlos

Compound	% Wt.	Element	ppm
SiO_2	70.43	Ag	55.00
Al_2O_3	7.320	Au	0.580
K_2O	0.080	Ba	658.0
Na_2O	2.320	Be	1.000
CaO	0.690	Cd	5.920
FeO	2.410	Co	8.800
Fe_2O_3	2.800	Cr	68.40
MnO	0.730	Cu	88.10
MgO	0.540	Mo	9.500
TiO_2	0.530	Ni	64.20
P_2O_5	0.120	Sb	0.550
		Sc	7.000
		Sn	4.860
		Sr	106.4
		U	0.760
		W	5.850

During the sieve analysis of material from tailings dam Dos Carlos, it was found that the greatest weight is retained in particle size of 149 microns with 19.18%, later on a sharp decrease occurs up to 37 microns where the minimum weight retained is 4.50% (Figure 5). These results define that this type of material can be used to produce ceramic and construction materials, because it presents optimal particle sizes that fall within corresponding specifications.
During the sieving analysis of the material from Velasco dam, it was observed that the highest percentage is in the particle size of 105 microns with 20%. In addition approximately 15% of fine particles with sizes less than 37 microns (Figure 6) was found According the above, the particle sizes found are corresponding with specifications for materials that can be used in the production of ceramic materials and construction.
Were prepared six ceramic briquettes with a mixture of material from the tailings dams (Dos Carlos and Velasco) and a mixture of heavy clay, as shown in Table 3. For the preparation of ceramic composites was used a percentage of jal suitable to provide the greatest resistance after firing, plus a lower percentage of heavy clay with high plasticity and a minimum amount of heavy clay with low plasticity and jal were used in the ceramic composites 1 to 9. In the case of ceramic composites from 10 to 12 were used higher percentages of heavy clay in order to increase its plasticity before cooking and to increase the strength of the composite after firing.

Table 2. Chemical analysis of material for tailings dam Velasco

Compound	% Wt.	Element	ppm
SiO_2	62.72	Ag	83.00
Al_2O_3	6.440	Au	0.280
K_2O	2.890	Ba	376.3
Na_2O	1.020	Be	1.650
CaO	3.770	Bi	0.870
FeO	2.410	Cd	24.80
Fe_2O_3	3.440	Co	4.670
MnO	1.560	Cr	31.00
MgO	1.160	Cu	124.2
TiO_2	0.260	Mo	3.300
P_2O_5	0.070	Ni	28.83
		Sb	3.680
		Sc	3.830
		Sn	1.570
		Sr	135.5
		W	11.90

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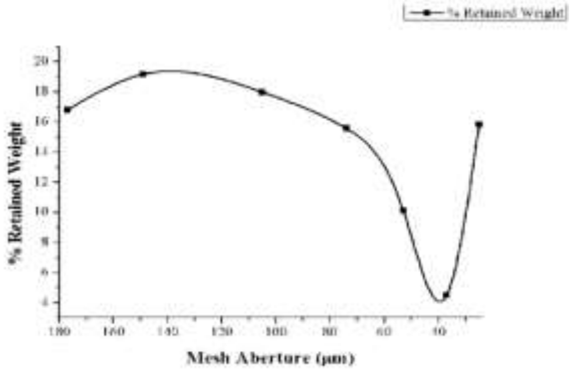

Figure 5. Distribution of particle sizes of the material from the Dos Carlos tailings dam

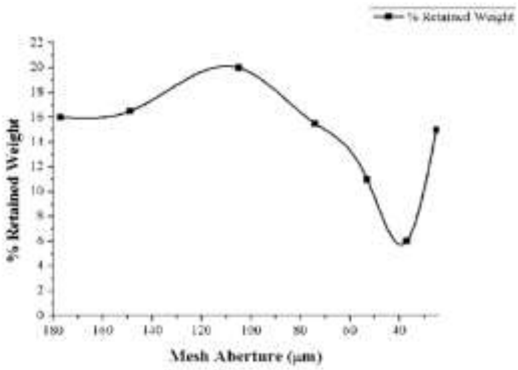

Figure 6. Distribution of particle sizes of the material from Velasco tailings dam

Table 3. Relation of mixtures of jal and clay used for the manufacture of each ceramic compound

Ceramic compound	Jal (% Wt.)	High plasticity clay (% Wt.)	Low plasticity clay (% Wt.)
1	66.7	26.7 RC_3	6.67 BC_1
2	63.0	31.0 BC_1	6.00 YC
3	63.0	31.0 RC_3	6.00 YC
4	60.0	34.0 RC_3	6.00 RC_2
5	60.0	40.0 YC	---
6	60.0	40.0 BC_1	---
7	60.0	40.0 RC_3	---
8	55.0	45.0 RC_2	---
9	50.2	49.9 RC_2	---
10	45.3	54.7 RC_2	---
11	40.5	59.6 RC_2	---
12	35.6	64.4 RC_2	---
13	100	---	---

Note: RC is Red clay; BC is Black clay and YC is Yellow clay

Importantly the material from the Dos Carlos dam was used for compounds 1 to 12, while for the preparation of composite 13, the material from Velasco dam was used.

Clay having some degree of plasticity was used in the case of compounds 1 to 7 as well as composites of 11 to 13, allowing the building material can be handmade or with some facility. Furthermore, composites 9 and 10 have an average plasticity, which favors the material can be processed using a press to have a better conformation and a proper handling in green stage.

After sintering of ceramic compounds their appearance was evaluated, which revealed that due to use of heavy clay, besides the improved strength properties and the better plasticity, this material is able to generate a wide range of natural colors, and particularly for composite number 13, was observed a glaze without the need to use any additional premium material, such as enamels or even some type of glassy cover (Figure 7).

Figure 7. Ceramic compounds made with tailings and clay

Additionally, six ceramic briquettes were made from the mixture of mining tailings from dams of Dos Carlos and Velasco together with appropriate amounts of heavy clay, adding expanded perlite or vermiculite as appropriate, such as shown in Table 4.

Table 4. Relationship of mixtures used to prepare ceramic compound for the bricks elaboration

Ceramic compound	Jal (% Wt.)	Heavy clay (% Wt.)	Aggregate (% Wt.)
14	66 (Dos Carlos)	35 BC_1 (Black Clay)	5 (Perlite)
15	55 (Dos Carlos)	40 BC_1	5 (perlite)
16	95 (Velasco)	---	5 (Perlite)
17	60 (Dos Carlos)	35 BC_1	5 (Vermiculite)
18	55 (Dos Carlos)	40.0 BC_1	5 (Vermiculite)
19	95 (Velasco)	---	5 (Vermiculite)

The appearance of the different compounds mentioned reveals that the use of heavy clays together with the properties of strength and plasticity can generate a wide range of natural colors such compounds. Also, for the case of compound 16, it was observed a very similar glazy formation to that noted in compound 13 but with an increasing proportion of the glassy surface layer (Figure 8).

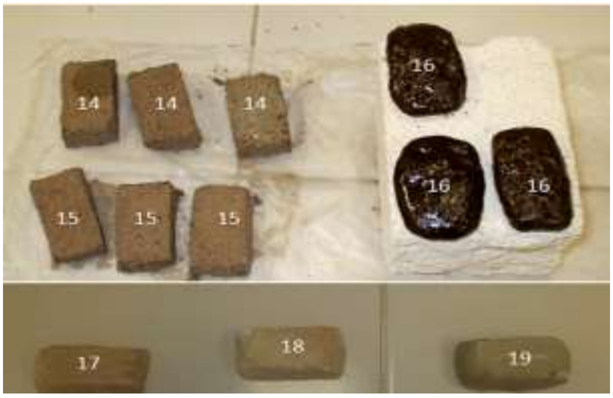

Figure 8. Ceramic compounds made of jal material with addition of expanded perlite and vermiculite

Photomicrographs of conventional brick structure (Figure 9a and 9b) and a brick made with one of the composites produced (Figures 9c and 9d) were taken. In these photomicrographs the presence of porosities in

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the two samples is observed, but in the conventional brick are observed in greater numbers than brick made with a ceramic composite. Also, a more uniform texture is observed in the composite that in the conventional brick. Due to the more uniform texture and to the lowest concentration of porosities in composites made with jal, these can be considered as they have less capacity to absorb liquids and the compression strength can be greater than, or similar to that found in a construction material; this increased resistance may be generated by a smoother surface, fewer cracks and pores, which causes that stress concentration in these cavities be minimum and the effort is distributed evenly along the surface normal to effort of compression.

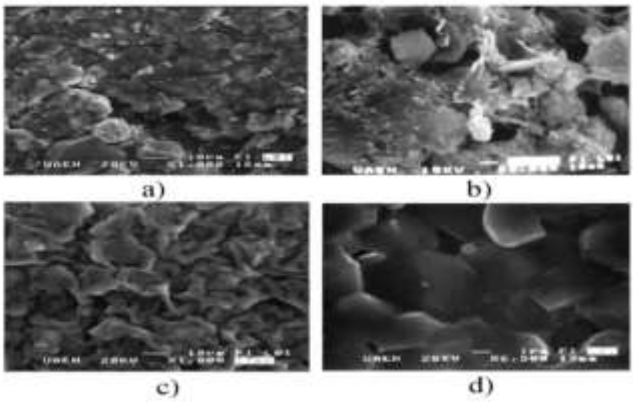

Figure 9. (a) & (b) Conventional brick (SEM-SE); (c) & (d) Ceramic compound made of a mixture of jal and additive (SEM-SE)

The results of tests of absorption, permeability, resistance to compression and volumetric weight, are presented in Table 5 for each of the prepared mixtures, comparing with the properties for conventional bricks (CB) found in construction industry.

Table 5. Results of values of volumetric weight, absorption, permeability and compressive strength for each of the prepared mixtures, comparing with the values of a conventional brick (CB)

Sample	Volumetric weight (kg/m^3)	Absorption (% Wt.)	Permeability (cm^3/s)	Compressive strength (kg/cm^2)
CB	1604.00	21.38	0.000226	26.22
1	1859.09	17.12	0.000231	1.640
2	1971.43	12.68	0.000156	6.230
3	1783.48	17.89	0.000243	8.440
4	2226.75	14.24	0.000193	3.760
5	1656.57	13.72	0.000142	6.440
6	1988.24	12.13	0.000139	6.370
7	2034.16	16.41	0.000226	0.920
8	1759.26	15.79	0.000208	2.200
9	1446.76	21.09	0.000267	0.400
10	1616.16	19.53	0.000255	0.430
11	1840.28	23.40	0.000278	0.300
12	1670.59	17.61	0.000239	0.990
13	2116.40	17.93	0.000248	24.47
14	1717.00	14.72	0.000156	27.03
15	1905.00	17.32	0.000174	41.54
16	2100.00	1.860	0.000087	6.290
17	1745.00	15.34	0.000156	26.36
18	1774.00	14.12	0.000122	32.90
19	1465.00	24.78	0.000260	32.83

According to the data, it was found that the sample 15 has better properties than the conventional brick, plus there are other composites with nearby properties that exhibit this type of brick. And in others, inclusive, there are far superior properties of composites made with tailings material, such as shown for sample 19.

It can also be seen that in the case of volumetric weight, samples were obtained with higher or close to the conventional brick values except for samples 15 and 19. This is due to the use of heavy clay and tailings material since the use this material increases the weight of the composite, which seeks to prevent the formation of porosity by adding expanded perlite or vermiculite.

For absorption, lower or similar values to those of conventional brick were obtained, except for samples 11 and 19. This might be possible because they were given a smooth finish to the composites and then treated to remove external porosity in each of the samples. In the case of the permeability, were obtained values less than or equal to that found in conventional brick, except those of samples 1, 3, 9, 10, 11, 12, 13 and 19. This was achieved by preventing the formation of external pores that could interconnect each other with internal pores of the composite.

In the case of the compressive strength, very low values were found in almost all composites compared to the values shown for the conventional brick, except in the composites 14, 15, 17, 18 and 19, besides obtaining appropriate values in the case of the composite 13. It was sought to increase the compressive strength by the compaction direct in the mold and adding materials such as perlite and vermiculite, during process.

Furthermore, simple linear regression and correlation between pairs of variables was evaluated. These were taken from Table 5, where the variables likely to be affected each other is shown, so it was determined that are related to the three properties that are: absorption, permeability and compressive strength. The following three pairs formed encompasses all possible involvement of other variable, being rated as follows: absorption - permeability, absorption - compressive strength and permeability - compressive strength.

Within the first couple of variables, corresponding to absorption - permeability (Figure 10), a positive slope of 1x10-5 was obtained and an interception of 4x10-5 with good correlation, which in this case is of 0.7358 between the two variables, which is meaningful that in most cases, while higher is the absorption within the composites an increased permeability is achieved.

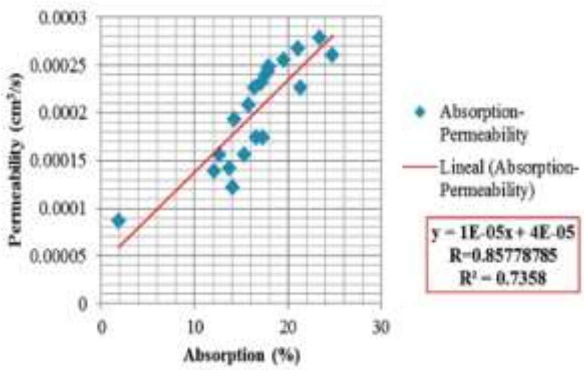

Figure 10. Simple linear correlation between absorption and the permeability

In the second pair of variables corresponding to absorption - compression strength (Figure 11), it was observed a positive slope of 0.419 and interception of 5.858, with a very low correlation of 0.858, which imply that there is no definite trend in increasing absorption and increased of the fluctuations in the compressive strength.

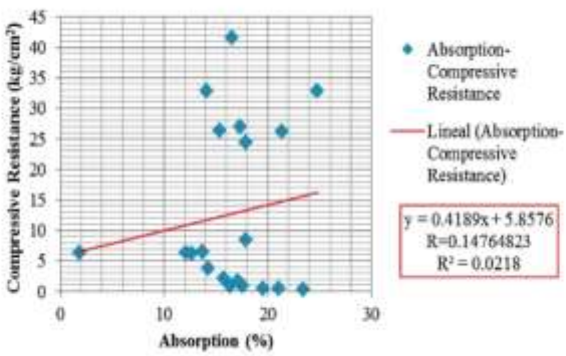

Figure 11. Simple linear correlation between absorption and the compressive strength

In the third and final pair of variables corresponding to permeability - compressive strength (Figure 12), was observed a negative slope of 56622 and an interception of 24.18, with a very low negative correlation between this couple of variables (of the order of 0.22472205). Implying that there is not a definite trend in the increased permeability, with the promoting of the increases and decreases of fluctuations in the compressive strength.

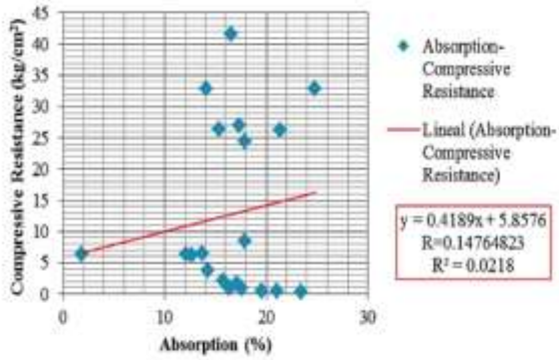

Figure 12. Simple linear correlation between permeability and the compressive strength

Once found the values of the unknowns, the values of compressive strength are calculated, adjusted according to the regression model and multiple correlations for variables that are dependent each other. So the following graphs (Figure 13) were obtained with the original and adjusted values of compressive strength when this variable is entirely dependent on the permeability and the absorption.

Thus, it was possible to obtain an index of the linear multiple correlations of 0.7758, indicating that the correlation between the three variables according to the proposed model is quite good, reflecting that the absorption affects the permeability and to the compressive strength. Similarly, the permeability in turn affects the compressive strength.

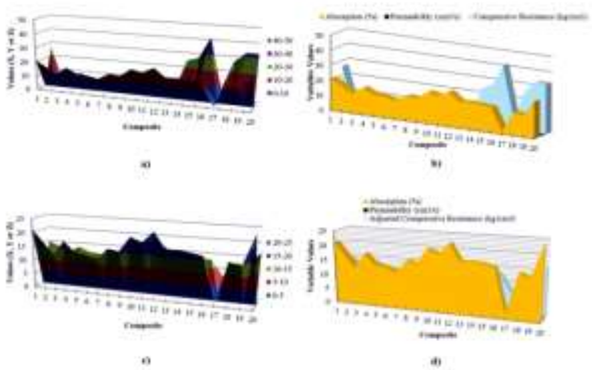

Figure 13. (a) & (b) Linear multiple correlations of the variables of absorption, the permeability and the compressive strength; (c) & (d) Setting the absorption, the permeability and the compressive strength according to the formula $Z = a + b_1X + b_2YX$

During simulation of permeability, the rate of fluid flow is observed from the permeability obtained in each of the composites tested, ranging from 3.53 $x10^{-8}$ m/s to 5.9 $x10^{-5}$ m/s, whereas for conventional bricks, the values are from 2.64 $x10^{-7}$ m/s to 3.13 $x10^{-5}$ m/s. So in the first evaluated composite (Figure 14a), it was found a rising trend in the X and Y axis to the upper edges thereof, with values of fluid velocity of 2.5 $x10^{-7}$ m/s in the top center and of 8.11 $x10^{-6}$ m/s in the vicinity of the upper edges, which is due to pressure differences in the solid and outside. On the other hand, along the Z axis, two different areas of fluid velocity with a parabolic behavior through the normal area to the Z axis and with a fluid velocity value of 2.29 $x10^{-5}$ m/s are presented. This increase in velocity is due to acceleration of the fluid by gravity, which subsequently decreased and maintained at a constant fluid velocity of 1.7 $x10^{-5}$ m/s. The second composite evaluated (Figure 14b) and the third (14c) have a behavior similar to the first, going from the upper edges to the center in the direction of the X and Y axes with fluid velocities from 1.11 $x10^{-5}$ m/s to 4 $x10^{-8}$ m/s in the second composite and speeds from 2.09 $x10^{-5}$ m/s to 2.5 x10^{-7} m/s in the third. Similarly, it was exhibited a parabolic behavior down to the Z axis, with speeds from 4.8 x10^{-6} m/s to 3.95 x10^{-6} m/s for the second composite and speeds from 8.95 x10^{-6} m/s to 7.66 x10^{-6} m/s for the third.

By simulating the property of compressive strength with respect to the distortion energy, a distortion obtained in each of the composites was observed, fluctuating between compressions of 1.19 x10^{2} N/m^{2} to 1.66 x10^{5} N/m^{2}; in comparison with that observed for the conventional bricks that goes from 9.25 x10^{1} N/m^{2} to 1.21 x10^{4} N/m^{2}. In the first composite evaluated (Figure 14e), distortion occurs by a compressive stress of 1.52 x10^{5} N/m^{2} in the Z axis direction, which generates a distortion in the top through the normal uniform area of the composite, subsequently decreases a stress distortion of 1.37 x10^{5} N/m^{2} and centralized in the X and Y axes to decrease the distortion due to a compressive stress of 1.06 x10^{5} N/m^{2} in the center of the bottom and in X and Y axes to a compressible effort of 6 x10^{4} N/m^{2}, thus reducing distortion and subsequently continue to decrease in positive and negative direction on the X axis in the second composite evaluated (Figure 14f) and in the third composite (Figure 14g) a similar behavior is observed, except that the maximum distortion effort is presented in the edges with an effort value of 2.84 x10^{4} N/m^{2} in the second composite and of 1.44 x10^{4} N/m^{2} in the third, being that from the top in Z-axis direction, having a compressible distortion effort focused by 1.35 x10^{4} N/m^{2} in the second and of 1.08 x10^{4} N/m^{2} in the third, while in the negative Z axis at the same points centralized in the X and Y axis, efforts of 9.3 x10^{3} N/m^{2} and 8.2 x10^{3} N/m^{2}, for the respective composites were found and also occurs at the bottom of both composites, lower distortion stress in positive and negative direction on the X axis, that have been generated in the order of 2 x10^{3} N/m^{2} for the second composite and of 1.8 x10^{3} N/m^{2} for third.

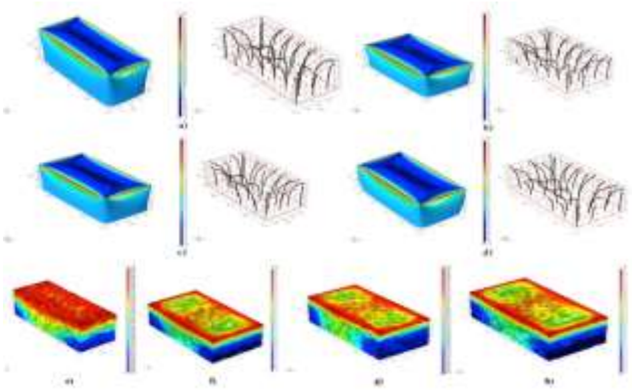

Figure 14. (a), (b), (c) & (d) Simulating of Darcy velocity for composites 11, 16, 18 and a conventional brick; (e), (f), (g) & (h) Simulating the compressive strength in the composites 13, 15, 19 and in a conventional brick

IV. CONCLUSION

A comprehensive mineralogical and chemical characterization of the material from the tailings dams of Dos Carlos and Velasco was performed, finding that this material has a high content of silica. Also were found some contents of alumina and oxides, which are precursors of phases like quartz, plagioclase and orthoclase.
Moreover, due to the low hydrothermal activity found in the area of the mining district, was also found the presence of three types of jarosites within the material of the tailings dam of Dos Carlos and two types of jarosites in the tailings dam of Velasco.
In the tailings dams, the presence of silica phases such as quartz, cristobalite and tridymite was found. Also are present in this material, mineral phases of silico-aluminates like anorthoclase, albite, orthoclase, ferrosilite and gyrolite, phosphates like berlinite, sulfates like jarosite, natrojarosite and hidroniojarosite, sulfates from the alunite group and sulfates like Plaster and Anhydrite. Carbonates such as calcite, small amounts of sulphides such as pyrite and sulfosalts such as argentite, galene, sphalerite, rhomboclasa, besides the presence of oxides such as hematite, magnetite, maghemite, wustite and pyrolusite are also presented.
Thus it can be concluded that the material of the tailings Dos Carlos and Velasco, can be used as a substitute for feldspars, due to their chemical and mineralogical composition since the material of both tailings presents a chemical composition quite similar to mixed feldspars. For this reason, both tailings were used for the manufacture of building materials elaborating 13 initial composites and 6 more composites with the addition of perlite and/or vermiculite as reinforcement.

Furthermore, the values of compressive strength, volume in weight, permeability and absorption of these compounds were determined to compare them with the properties exhibited by commercial bricks. It was found that for composites 13 to 19, except the composite 16 were found values very similar or even superior to that of a conventional brick. These values can be promoted by the existence of a more even surface, which gives a compressive resistance quite similar or greater. Likewise, is presented in the preparation of composites fewer porosities over conventional brick, which promotes absorption and lower permeability. This was also shown from the simulations in permeability through Darcy's Law, suggesting that the low porosity and intrinsic permeability of the composites are generated by the uniform surface. Furthermore, the low proportion of pores generates very low fluid velocities and which are in the order of 3.53 $x10^{-8}$ to 5.9 $x10^{-5}$ m/s.
Moreover, the compressive strength is promoted by increased stress distribution due to the presence of a proportion of homogeneous stresses and low stress concentrators of the surface, leading to a dissipation more uniform and of distortion, where efforts are going to both the top and bottom of the composite and along the X and Y axes, from the center to the periphery.
Finally, we conducted a correlation of the variables; absorption, permeability and compressive strength, in pairs and in a multiple way. It was found that the pair, absorption - permeability has more correlation because if there is no absorption of liquid within the sintered material there is no good permeability. In the multiple correlations of the three variables mentioned above, a model of the type where variable X could affect to Y and Z was developed, being variable Z also affected by Y. And to perform the mathematical procedure and convert the serial data matrices for subsequent resolution by the Kramer´s rule and thus determine the variables a, b_1 and b_2 for adjustment of the variable Z model, having that the adjustment of this variable is minimal with respect to their original values and having a good correlation with the model of proposed data unadjusted for the variable Z, concluding that the original values of absorption - permeability - compressive strength, are very close to ideality.

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