Estudos em Ciências Exatas e da Terra

Desafios, Avanços e Possibilidades

Alireza Mohebi Ashtiani
(organizador)

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APRESENTAÇÃO

As ciências exatas e da terra têm uma importância muito especial e são consideradas a origem e a base principal do progresso de outras áreas de conhecimento, que ganharam destaque com a evolução tecnológica e a complexidade dos desafios humanos.

De modo geral, pode-se dizer que as importantes conquistas dos séculos passados e atuais se devem à atuação e ao avanço do campo das ciências exatas e da terra, que, através de desafios, situações e aplicações, avançaram e cruzaram as fronteiras tradicionais de outras áreas de conhecimento, resolvendo problemas complexos que abrangem diversas áreas: a isto chamamos "interdisciplinaridade".

Diante dessa realidade, o primeiro volume de **"Estudos em Ciências Exatas e da Terra: Desafios, Avanços e Possibilidades"** publicado pela Editora Artemis e apresentado em 10 capítulos, tem por objetivo dar um panorama geral dos desafios, avanços e possibilidades que envolvem essa área de conhecimento, tanto na teoria quanto na prática.

Os trabalhos aqui apresentados, de pesquisadores de diversos países, entre eles Argentina, Brasil, México, Paraguai, Portugal e Rússia, oferecem aos leitores e interessados a oportunidade de ampliar seus conhecimentos e adquirir uma visão mais profunda da área.

Alireza Mohebi Ashtiani

SUMÁRIO

CAPÍTULO 6

STUDY OF MECHANICAL BEHAVIOUR AND CORRELATIONS WITH PHYSICAL AND CHEMICAL PROPERTIES OF SOLID CERAMIC BRICKS IN ASUNCIÓN

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ABSTRACT: Given the whole research results presented at International Congresses such as IX SBTA 2011 at Belo Horizonte, Brazil, 1st I+I+D Fair 2015, F.I.U.N.A. held at San Lorenzo, Paraguay, IV ALCONPAT 2016, at Asunción and VII CONIMAT 2016 at Cusco, Peru, and the interest for these subjects, we continue researching on solid ceramic bricks quality jointed with mortars to form walls. As the former research established that bricks contribute in a larger way in its elastic and rigidity modules than the mortar, and that the final contribution is superior to those of the mortar, showing synergy between mortar and bricks in final bending and compression strength, these is shown in this paper by graphs and number after making more than 360 (880 more precisely) essays of these materials which makes walls. In this research we study not only the physical properties, but also analyze the chemical properties with traditional technologies and with EDX. The correlation between the raw materials physic and chemical properties and its compression and bending strength, brings up the importance to know these properties in raw materials in order to design and produce more efficient materials and with better performance. We combine two different raw materials from different soils in Paraguay to produce bricks in laboratory and study 20 different bricks offered in Asunción, selected in categories, to correlate its initial and final chemical and mechanical properties. Also other mechanical and physics properties are affected by chemical composition. The bricks have been categorized A, B, C and N/C (not categorized) according to Paraguayan Standard NP 17 027 77 second edition of 2015, Specifications for solid ceramic bricks, and this research will help us to know how to design better bricks using laboratory equipment such as sieves, weighing scales, X Ray Energy Disperser, compression machine, micrometer, oven, electronic devices, and other to use appropriate materials or combining them to produce well categorized bricks using local technology towards getting better.

KEYWORDS: Compression. Bending. Low walls.

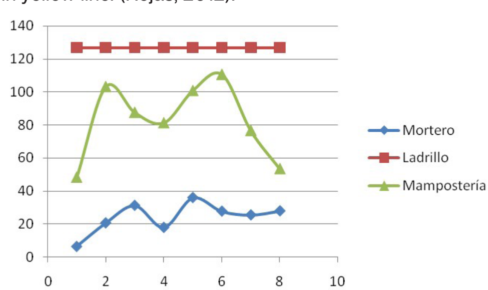
1 INTRODUCTION

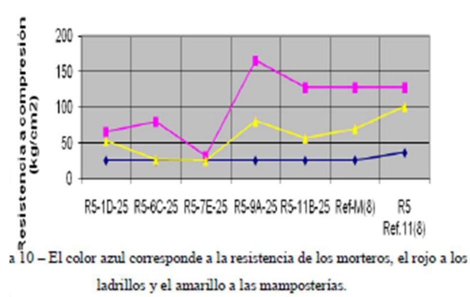
In this research there are made bricks with two different raw materials and a third from mixing these two raw materials. The purpose is to study the mechanical, physical and chemical properties and by these means compare it with those of the bricks trade at Asunción for use in civil construction. If the raw material has too much sand water may undo easyly the bricks. If it has too much clay it will contract during the process of drying, with great tendency to cracking. Silica is abundant at nature, it is a polymorphic material that means it can have different crystal structures, for example cubic in some brick and more than 50 % of silica, or hexagonal structure like feldspar and quartz respectively. The silicates came from the reaction on silica with oxides of Al, Mg, Ca, K, Na and Fe like clay and sands. The ceramic materials have not tenacity, impact, fatigue and thermal shock strength due to it scarce ductility, when a crack starts it spread easily, like our research presented at IV ALCONPAT 2016, Asunción. The materials were tested and it results can be seen next, first raw materials, materials produced and final use of it:

Table1. Water analysis according to NP 17 026 73.

Dissolved oxigen mg/lt	16,3
Chloride mg/lt	23,3
Organic material mg/lt	3
Nitrites	0
Nitrates	0
PH	5,8
Sulfates mg/lt	6

Figures 1 & 2. Mortars broken showing synergic collaboration of mortars with bricks for low walls (Rojas & López, 2011). Results varying bricks (red) and keeping constant mortars (blue line) compression resistance and low walls in yellow line. (Rojas, 2012).





Knowing these: $\zeta=P/A$; $\zeta=E.\varepsilon$; $\varepsilon=\delta L/L$ y $\eta=3V/(2.A)$ $\eta=G.\gamma$; $\gamma=\delta Ly/Lx$, $G=E/(2(1+\nu))$; and there three dimensions equations and the results of the Congresses mentioned above, show on the Figures below:

Tables 2 to 5. Essays made on low walls (IV ALCONPAT & VII CONIMAT, 2016).

Parameters	Categ A brick		Mortar with excavation soil		Low wall	
	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S
E (kg/cm²)	59.200	10.227	16.949	9360	75.500	50.099
G (kg/cm²)	35.543	5.114	10.254	7.813	32.264	20.000
σc (kg/cm²)	362,50	165,00	32,00	35,63	120,92	42,09
ε		0,0016		0,0015		0,0006154
γ		0,001067		0,0006		0.000273
τ (kg/cm²)		12,00		9,38		9,82
ν	0,167	0,000098	0,174 (0,21)	0,401	0,169	0,252
σf limelast (kg/cm²)		16,36		14,04	Comp LE	30,83
T lime last (kg/cm²)		5,45		4,69		5,45
Sizes (cm)	7x11,5x24	5x11x23		4x4x16		23x11x19,5
horizontal; vert joints sizes (cm)					1; 1	1,25; 2

Parameters	Categ C brick		Mortar with Asuncion soil (1:2:8) (pcem:sand:soil)		Low wall	
	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S
E (kg/cm²)	59.200	32.727	16.949	9360	75.500	31,858
G (kg/cm²)	35.543	16.364	10.254	7.813	32.264	10.667
σc (kg/cm²)	362,50	65,37	32,00	35,63	120,92	33,79
ε		0,0002		0,0015		0,0007692
γ		0,0000133		0,0006		0,000273
τ (kg/cm²)		12,00		9,38		4,36(7,08)
ν	0,167	0,00013	0,174(0,21)	0,401	0,169	0,493
σf elast lim(kg/cm²)		6,55		14,04	Comp LE	24,51
T elast lim(kg/cm²)		2,18		4,69		2,91
Sizes (cm)	7x11,5x24	5x11x23		4x4x16		23x11x19,5
horizontal; vert joint sizes(cm)					1; 1	1,25; 2

Parameters	Categ C brick		Mortar 1:2:6 (pcem:lime:sand)		Low wall	
	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S
E (kg/cm²)	59.200	32.727	16.949	9360	75.500	31,858
G (kg/cm²)	35.543	16.364	10.254	7.813	32.264	10.667
σc (kg/cm²)	362,50	65,37	32,00	35,63	120,92	33,79
ε		0,0002		0,0015		0,0007692

Parameters	Categ C brick		Mortar 1:2:6 (pcem:lime:sand)		Low wall	
	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S
γ		0,0000133		0,0006		0,000273
τ (kg/cm²)		12,00		9,38		4,36(7,08)
ν	0,167	0,00013	0,174(0,21)	0,401	0,169	0,493
σf elast lim (kg/cm²)		6,55		14,04	Comp LE	24,51
T elast lim (kg/cm²)		2,18		4,69		2,91
Sizes (cm)	7x11,5x24	5x11x23		4x4x16		23x11x19,5
horizontal; vert joint sizes (cm)					1; 1	1,25; 2

Parameters	N/C (S/C) brick		Mortar with excavated soil		Low wall	
	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S	López Oller Oñate	Rojas H López S
E (kg/cm²)	59.200	16.019	16.949	9360	75.500	37.440
G (kg/cm²)	35.543	16.340	10.254	7.813	32.264	16.340
σc (kg/cm²)	362,50	30,84	32,00	35,63	120,92	37,24
ε		0,0006		0,0015		0,000667
γ		0,0002		0,0006		0,0002
τ (kg/cm²)		7,08 (36,00)		9,38		6,02
ν	0,167	0,510	0,174(0,21)	0,401	0,169	0,146
σf elast lim (kg/cm²)		9,61		14,04	Comp LE	24,96
τ elast lim (kg/cm²)		3,27		4,69		3,268
Sizes (cm)	7x11,5x24	5,1x10,8x23		4x4x16		23x10,8x19,5
horizontal; vert joint sizes (cm)					1; 1	1,25; 2

With the engineering ceramics the innovation development time are lower than those of the traditional ceramics. In our country the ceramic bricks' production has advanced to mechanization and even to automation. The compressed bricks have between 10 to 20% of absorption. The produced common market bricks absorbs 20 to 30% of water. The expansion and thermal conductivity induce strength that may produce thermal shock or fatigue. There is a tendency to thermal localized disintegration or when the brick has a delamination. The molten silica has great resistance to thermal shock due to its thermal expansion that is cero. We can see on Table 6 the materials requirements for the structural function:

Table 6: Quality requirements on materials.

BRICKS	MORTARS	LOW WALLS
Strength	Strength	Placing
Absorption	Thickness	Making process
Humidity	Water/Cement Ratio	Load Direction
Hight/Thickness Ratio	Unit deformation ε	Adherence properties
Geometry	Water Retention	horizontal and vertical joints, tie

2 OBTAINING SAMPLES AND ITS PROCESSING

We extracted two samples of soils: Firstly from “Naciente San Francisco” at General Aquino county near the city of San Estanislao at San Pedro Department and the second from the vicinity of our University Camp at the city of San Lorenzo in Central Department.

We started crushing and pulverize the raw materials. Wet crushing is more effective because it has no fine particles in suspension It were primary classified with a common method of shacking soil with water and observing the volume of different sized particles, later this was make by sedimentation at Facultad de Ciencias Agrarias UNA Laboratory of soils. After it get plastic and kneaded with potable water addition at FIUNA.

There are three basic processes to mould ceramic: the casting on “Barbotina” (great fluidity) with high water content, the plastic molding (kneaded with rational water dosage) and the compressed, that could be in dry or wet conditions, it is isostatic, toned on template, molded by injection and compressed in heating conditions that makes a more efficient process and introduced advanced technologies for more quality on engineering ceramics. In the laboratory produced bricks it were used wood molds and using the handmade techniques of mixing, knead and compression. In the group of bricks on the market at Asuncion will be used to help us contrast the results obtained by the bricks we made chemical, physical and mechanically.

3 INITIAL COMPOSITION DETERMINATION

The soils were qualified with a fast method. We introduce water and soil on a bottle and close it, shake it strongly. It was left for a little period of time to settle. The sand and silt were the first to settle, the clay stay more time in suspension and finally settles. The high of each layer give the proportion of sand, silt and clay. Then will be done sedimentation to better classification and content of organic material and using EDX (Energy Dispersive X Ray Spectrometer).

Table 7: Volumetric content of sand and clay in initial analysis before knead(qualitative).

Sample	Sand%	Silt and Clay%
M 1 (San Pedro)	60	40
M 2 (Dpto. Central)	80	20

Table 8: Properties of raw materials and the final products.

Raw Material	Final Product
Chemical global composition	Chemical global composition without volatile substances
Mineral composition: clay, sand, feldspar	Internal estructural changes
It has impurities	Appear defects or special properties
Particle size distribuition	Final grain size depends on thermal treatment
Mass homogeneity	Final product homogeneity
Kneaded and conformed	Manual in wooden molds, can be produce by machinery
Pressed (dry from 5 to 7% humidity)	Manual compaction or mechanical pressing

4 PROCESS

4.1 MIXING

It was prepared the M1 and M2 samples and were water mix and knead with hands to obtain enough consistency and homogeneity. Three samples were mix to produce bricks to be tested. The samples were M1, M2 and M3 (mixing M11 with M2) like follows:

Table 9. Percentage mixtures by volume of samples obtaining sample M3.

Sample M1	Sample M2
20 %	80 %

Table 10: Sieve analysis and organic material content of studied soil from Asuncion for mortar.

RESUME DOS TESTES					Peneiras Nº / Passantes (%)					
H.N.	L.L.	L.P.	I.P.	4	10	40	100	200	C. SUCS	Descrição
17,5	24,4	17,3	7,1	100	92,6	78,7	51,1	42,5	SC	Areias Argilosas

Analysis of sample of Asuncion soil (SC) used for mortar using wet sifting and Standards AASHTO T-53, T-88, T-89 and T-90. Density: 2,56 g/cm³. Finess module M.F.=4,3 (dry sifting) (IRAM 1505), being crushed before kneaded. Absortion = 2,0%. Organic material content=0,012% done at Soil Laboratory at Facultad de Ciencias Agrarias UNA.

Table 11: CHEMICAL COMPOSITION OF RAW MATERIALS & MORTARS ANALYSED WITH EDX (%).

Element	Washed sand	Asuncion soil	Mortar w/soil	CPIV 32 pz	Hidrated Lime
Si	95,5	78,5	38,6	10,97	0
Fe	0,7	7,7	11,1	7,3	0,21
Al	3,02	6,45	6,97	4,44	0
Ti	0,46	2,19	1,53	0	0
K	0	2,89	1,51	1,71	0,44
Mn	0	0,46	0,24	0,07	0
Ca	0	1,52	38,15	69,71	99,25
Zr	0	0,095	0,064	0	0
Zn	0,002	0,007	0	0	0
Cu	0,002	0,005	0	0	0,001
Ho	0,14	0	0	0	0
Ni	0,08	0	0	0	0
W	0,06	0	0	0	0
Ga	0,004	0	0	0	0
S	0	0	0,61	4,313	0
Ba	0	0	0,6	0	0
Sr	0	0	0,037	0,102	0
Sc	0	0	0	4,31	0,1
Ir	0	0,21	0	0	0

Table 12: CHEMICAL COMPOSITION OF RAW MATERIALS FOR LAB MADE BRICKS with EDX Spectrometer (%).

Element	From San Pedro	From Departamento Central
Si	82	53,9
Fe	7,3	20,9
Al	6,6	18,8
Ti	2,3	2,5
K	0,7	2,3
Ca	0	1,3
Mn	0,25	0,17
S	0	0
Zr	0,084	0,077
Sr	0,006	0,005
Rb	0	0,008
Y	0	0,004
Ba	0,75	0

Element	From San Pedro	From Departamento Central
Zn	0	0
V	0	0
Ta	0	0,14
Tm	0	0
Soil classification	Clay Arenaceous sand	Clay Arenaceous sand
Sand	56%	72%
Silt	16%	4%
Clay	28%	24%
Color	Brownish grey	dark red
Organic mat	2,43%	0,34%

4.2 KNEADED

There were made three wood molds. Before Kneading, the molds are moisten to avoid absorption from the mixing raw material water, avoiding also lost of water and cracking. When the desired consistency, form and sized were accomplished they are compacted with a wooden plate.

Shaped: clays has plain molecules electrically charged on its surface, attracts water as a thin layer of lubricant between plain surfaces. With enough moisture clays are plastic and can be molded, extruded, turned and shaped, but when they are dry they have enough strength to be stack and heat in ovens.

During compaction it was observed that Sample M1, have a good plastic knead. Sample M1 and M2 were better compacted due to a good particle distribute size that will be observed in its volumetric mass and compression strength.

Photographs: 1 and 2: Kneaded and compacted materials in molds.

4.3 DRYING

The bricks were leave 3 days to direct sun heat inside molds). On the first day of sun they suffered big cracks on sample M. Sample M3 suffered some little cracks and Sample M2 has no cracks. Afterward they were taken out from their molds and placed sideways 1 day to direct sun heat (Sample M1 was cracked on 4 parts), 3 days under cover (because of rain), then one more day at direct Sun heat, 1 day more under cover with natural light to finish the drying process. Resuming the drying was made between 25 and 30°C during 8 days.

Photographs 3 and 4: Solar drying in molds and outside molds on edge:

Table 13: Sizes after drying at normal atmospheric conditions and direct solar lightning for 5 days, covered (natural light) 3 days:

Sample-Color	Weight [g]	Large [cm]	Wide [cm]	Thickness [cm]	Volume [cm³]	Volumetric mass [g/cm³]
M1-Black	1087,8	22	11	3,84	929,28	1,170
M2-Red	1595,0	22	11	3,92	948,64	1,681
M3-Brown	901,7	20	11	2,83	622,60	1,450

4.4 THERMAL TREATMENT

The raw material for bricks has normally 3 components: pure clay like kaolin ($Al_2O_32SiO_22H_2O$), for melting feldspar and as filler quartz or silica that reduces contraction and without function during oven-cooked. Clays at low temperature flows more and are cooked at 1000°C. The cracks for sudden temperature changes are a problem in ceramics. ΔT (en °K) is the difference of temperature for not inducing cracks on the brick. Being α the expansion coefficient, so the surface layers gets cool quickly suffers $\alpha\Delta T$ contraction strains. But the surface is part of a bigger element that is still hot but it has to keep its original sizes producing $E\alpha\Delta T$ tension. It surpass fracture tension σ_{TS}, the surface of the element will get cracked and shatter later, the maximum temperature will obtain from this equation: $E\alpha\Delta T=\sigma_{TS}$.

The thermal fluency is a problem for 1/3 Tm, (Tm is fusion temperature). At about 2/3 Tm approximately, particles sinter, they join together forming little necks that grows reducing the surface area and densifying the particles, does not reach theoretical density, because exists a residual porosity (little round holes) that have little effect on mechanical strength. The atoms diffused from borders of grains of necks with different orientations to the pores and fill it. Them the atoms moves by diffusion on grain border helped from the inner diffusion of grains. The surface area reduction defines the process and diffusion velocity controls its velocity.

a) The small particles sinter more quickly because of it high surface area and the impulsive force is greater and diffusion distances are less (Sample M1). b) The sinter velocity varies with temperature as so its diffusion coefficient: $d\rho/ dt = (C/a^n) \exp(-QRT)$. ($\rho$ is density, α the size of the particle, C and n are constants y T absolute temperature. (n its generally 3 and Q is equal to the activation energy for the diffusion on border grain).

For sinter compacted powder of different selected sizes and water in mould, dry and with enough strength is introduced to the oven. It was said that when more little is the particle the best for minimal cracking and more strength, but will see that we need for more strength little, medium and big particles (big: sand), it will contract, in sintering the grain will grow much bigger than initial sizes. By compressing and heating it can be obtain bigger densities and little grains. About 1% approximately of additives like OMg make sinter velocity bigger without making strength bigger. The samples were thermal treated on oven for 3 hours at 1000 °C. The samples were weighted before and after the thermal process: $\Delta\gamma(\%) = (\gamma f - \gamma i)/\gamma i \times 100$ and $\Delta V(\%) = (Vf - Vi)Vi \times 100$.

Figures 3: Microstructural characteristics of ceramics. Compacted powder particles (a) Sinter, (b) reducing surface area and energy in pores and (c) final structure with little pores nearly spherical.

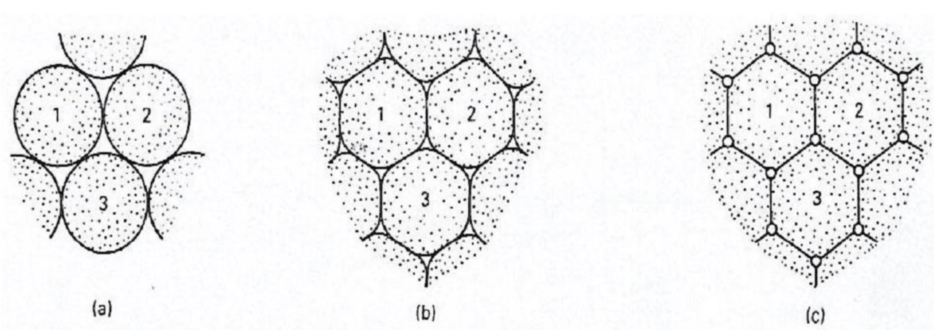


Figure 4: Distributed sizes for raw materials and ceramic products. (a)Distributed granulometric sizes, (b) uniform and (c) discontinue granulometric sizes of raw materials for bricks.

(a) (b) (c)

Figure 5: Excessively fine M1 (unsuitable), discontinue M2 (less suitable) and Well graded M3 (more suitable combination).

Figures 6 and 7: Thermal treatment process of the sample of bricks produced wet clay contraction because water´s elimination during drying. Contraction might be up to 20% of volume. (F.H. Norton).

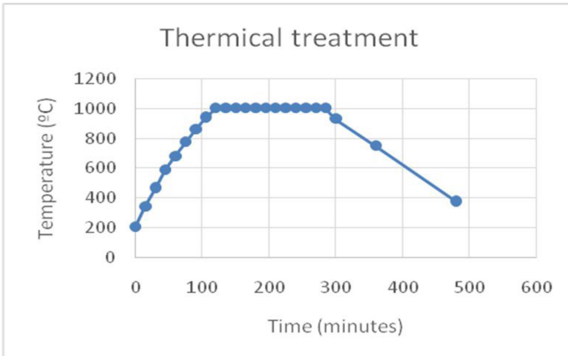


Table 15: After cooking these results were registered:

Sample-Color	**Δγ (% Unitary mass Variation)**	**ΔV (Volume Variation (%))**
M1-Black	6,25	-24,52
M2-Red	5,67	-13,22
M3-Brown	9,32	-20,03

Table 16: Variation of unitary mass and volume of laboratory made bricks.

Sample - Initial color	**Mass [g]**	**Length [cm]**	**Wide [cm]**	**Thickness [cm]**	**Volume [cm^3]**	**Volumetric mass [g/cm^3]**
M1-Black	930,4	21,0	10,0	3,55	745,50	1,248
M2-Red	1493,0	21,0	10,5	3,80	837,90	1,782
M3-Brown	829,2	19,0	10,5	2,60	518,70	1,599

5 PHYSICAL AND MECHANICAL AND TESTS RESULTS

According to NP 17 029 77 the ceramic bricks were tested to compressive strength hand were categorized according to Paraguayan Standard NP 17 027 77, 2nd Edition, 2015.

Table 17: Sizes obtained were registered:

SampleM1	**1**	**2**	**Average**
Large [cm]	10	8	9
With [cm]	10	10	10
		Área [cm^2]	90

SampleM2	1	2	Average
Large [cm]	10	10	10
With [cm]	10	10	10
		Área [cm²]	100
SampleM3	**1**	**2**	**Average**
Large [cm]	10	8	9
With [cm]	9	8	8,5
		Área [cm²]	76,5

From the thermal-gravimetric analysis initial and at the end it was noticed that Sample M3 had a medium volume loss compared to M1 & M2, which gives a better distributed granulometric inside due to the mix of both raw materials to obtain a better knead and compaction to more homogeinity before, during and after sinter. Another data is that the same sample M3 increase more it volumetric initial mass. Representing it a good energy efficiency. Sample M2 was less afected by volumetric and mass volumetric variation. Probably because of the high percentage of sand. Sample M1 got more volumetric mass and volumetric decrease from initial ones. These due to the plasticity (more clay) and the existence of organic material in higher percentage noticed visually by the black color of it raw material. (White color after sinter).

Table 18: The compression strength obtained (NP 17 029 77):

Sample	Area (cm²)	Máximum load [Kg]	Compresive Strength [Kg/cm²]
M1	90	2200	(24,44) 2,4 MPa
M2	100	5600	(56,00) 5,6 MPa
M3	76,5	6300	(82,35) 8,2 MPa

Brick sample M3 was categorized B with more than de 7 MPa of compression strength and less than 20% of absorption, also bending strengths should be studied, given sizes there should be a correlation between both strengths. Brick M2 categorized C with compression strength higher than 5 MPa and less than 25% of absorption. Brick M1 with more clay and silt content and organic material is not categorized, being not suitable for Wall structures.

Table 19: Results of categorizing 20 bricks marks marketed in Asunción, 7 selected also for testing with EDX.

Bricks	Categorized A	Categorized B	Categorized C	Not Categorized (S/C)
Characteristics And Media Results	Red color (3 of each) Semi-pressed	Red color (2 trade marks, 3 of each) Semi-pressed	Red color(2 trade marks, 3 of each) Semi-pressed	White color (2 trade marks, 3 of each) Semi-pressed
Especific gravity	1,76g/cm³	1,78g/cm³	1,89g/cm³	1,52g/cm³
Absorption	12,71%	16,43%	12,48%	21,7%

Large (cm)	23,30	22,80	22,75	22,75
Width (cm)	11	10,8	10,75	10,8
High (cm)	5,2	5,05	4,9	5,2
Comp. strength	16,5MPa	8,2 MPa	6,2 MPa	3,2MPa

Table 20: BENDING OF BRICKS CAT- A, C & N/C(S/C). 21/10/2014.

A Deform mm	C Deform mm	S/C defor mm	Load - kg
0,00	0,00	0,00	0
0,00	0,01	0,00	40
0,01	0,01	0,00	80
0,05	0,02	0,01	120
0,06	0,03	0,01	140
0,07	0,06	0,01	160
0,08	0,07	0,04	180
0,08	0,08		200
0,10	0,09		220
0,10	0,10		280
0,11			340
0,11			400
0,13	luz libre=15 cm		440

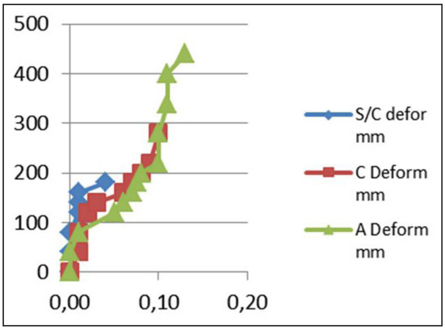


Table 21: Specifications for solid ceramic bricks according to NP 17 027 77.

REQUIREMENTS	**CATEGORIES**		
	A	**B**	**C**
Compressive strength (MPa)	Minimum 9	Minimum 7	Minimum 5
Bending strength (MPa)	Minimum 3	Minimum 2	Minimum 1,5
Water maximum absorption (%)	Maximum 20	Maximum 20	Maximum 25

Table 22: Load analysis for the bottom bricks.

Vertical load for 1 m of wall		
Reinforced Concrete Crosspiece Load	78,41	kg
Roof tile load	180,09	kg
Tejuelón load	82,8	kg
Overload	80	kg
Total Roof load over wall	421,30	Kg/m
Wall load over lower bricks	792	Kg/m
Total load over lower bricks	1213,30	Kg/m
Load over wall	1,01	Kg/cm²
Increase coefficient for wall: 1,6	1,62	Kg/cm²
Horizontal load coefficient: 1,2	1,94	Kg/cm²
Security coefficient: 2	3,88	Kg/cm²

This last load should be less than the following 3 values (Coefficient. Standard AGIES NR-4):

a) Minimun mortar resistance: 12,19 kg/cm² x0,6 =7,314 kg/cm²>3,88 kg/cm². Verifies the considered load.

b) Brick compression resistance: 126,8 kg/cm² x 0,53= 67,204 kg/cm²>3,88 kg/cm², Verifies.

c) Small wall resistance: 42,09 kg/cm² x0,6=25,254 kg/cm²>3,88 kg/cm². Verifies all. The bricks and mortars forming small walls verifies with security coefficient for these loads.

Figures: Essays on low walls.

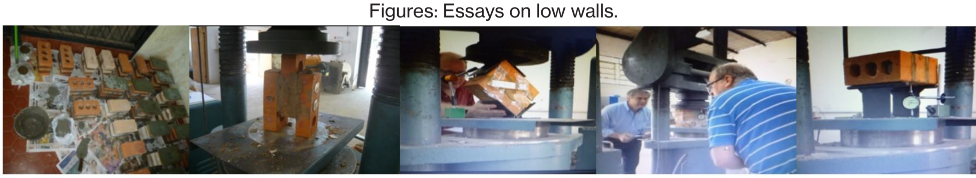
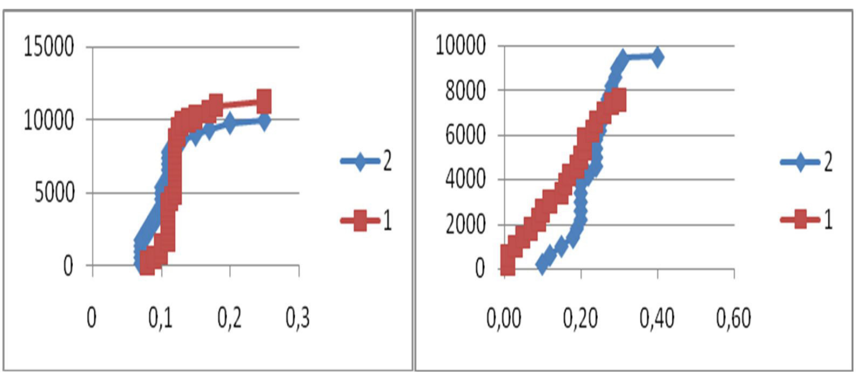
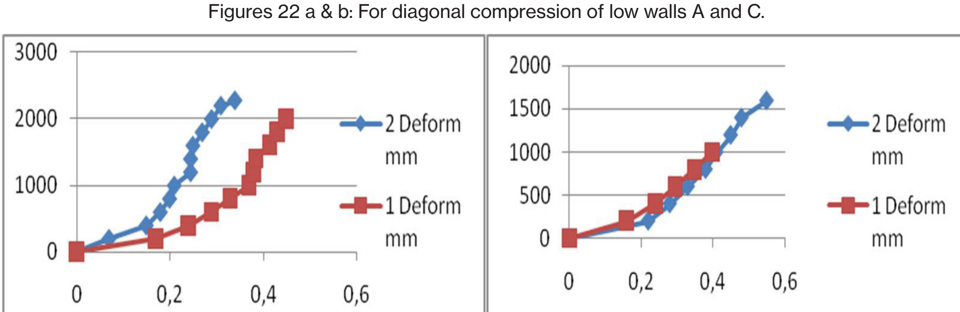


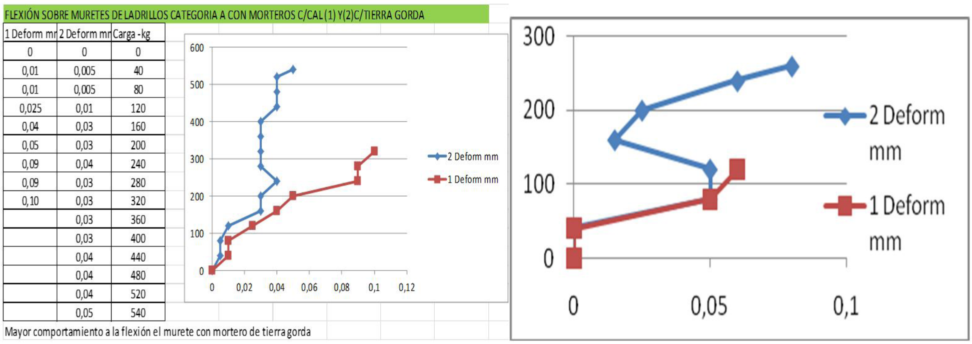
Figure 20 & 21: Load (kg) vs Strain (mm) at compression of low walls made with Cat A and C bricks.



Figures 22 a & b: For diagonal compression of low walls A and C.

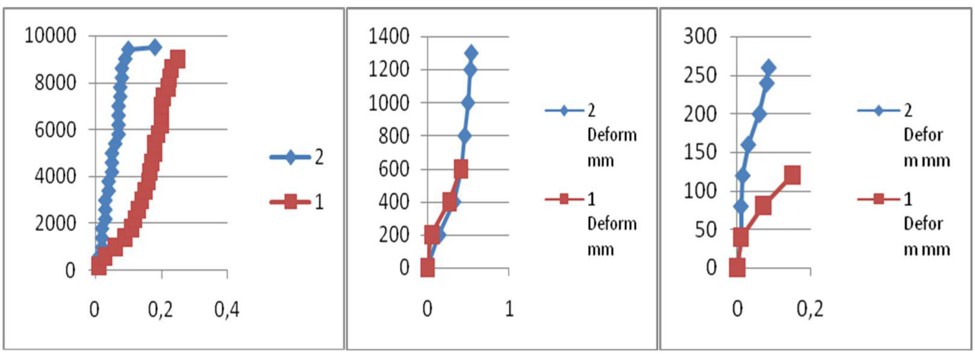


Figures 23 a & b: For lateral bending of low walls A and C.



1 Deform mm	2 Deform mm	Carga -kg
0	0	0
0,01	0,005	40
0,01	0,005	80
0,025	0,01	120
0,04	0,03	160
0,05	0,03	200
0,09	0,04	240
0,09	0,03	280
0,10	0,03	320
	0,03	360
	0,03	400
	0,04	440
	0,04	480
	0,04	520
	0,05	540

Figures 24 to 26: for compression, diagonal compression and lateral bending of Not categorized low walls, shows the irregular mechanical behavior and lack of category of S/C low walls bricks.



6 CHEMICAL RESULTS EDX

According to chemical elements proportions at the analysis with EDX it was obtained what follows:

Table 23: Chemical composition of laboratory made bricks result from the study with EDX (%).

Element	M3 brown	M2 red	M1 black
Si	60,7	56	74,4
Fe	17,8	20,7	9,1
Al	15,4	17	9,5
Ti	2,2	2,3	1,8
K	2	2,2	1,5
Ca	1,2	1,4	2,4
Mn	0,15	0,1	0,2
S	0,17	0	0,21
Zr	0,01	0,07	0,05

Element	M3 brown	M2 red	M1 black
Sr	0,005	0,006	0,006
Rb	0,006	0,008	0,003
Y	0,004	0,004	0,005
Ba	0	0	0,7
Zn	0	0	0,002
V	0,098	0,106	0
Ta	0	0,09	0
Tm	0,18	0	0

Table 24: Chemical composition of asuncion´s market bricks results from EDX analysis (%).

Element	cat A brick	Cat B brick	Cat C brick	S/C(N/C)brick
Si	59,6	58	61,95	61,35
Fe	15,7	20,2	17,15	14,55
Al	11,7	16,2	12,55	17,2
Ti	1,7	2,4	2,1	2,5
K	6,9	2,2	2,5	2,75
Ca	3,3	0,7	2,9	0,8
Mn	0,19	0,07	0,075	0,085
Zr	0,08	0,065	0,0815	0,067
Sr	0,01	0,007	0,01	0,009
Rb	0,013	0,008	0,0085	0,0095
Y	0,006	0,005	0,006	0,0055
Zn	0,004	0,003	0,0045	0,0045
Ba	0,7	0	0,525	0,57
Ta	0,08	0	0	0
V	0	0,105	0,0505	0,038
Tm	0	0	0,113	0
Cu	0	0	0	0,002

References	
(yellow)	Lesser values in better Categories
(dark grey)	Higher values in better Categories
(green)	Higher values in worst Categories
(light grey)	Lesser values in worst Categories
(white)	Similar values on market or intermediate category in laboratory bricks
(pink)	Intermedium values in better laboratory made category

From the A and B brick Categories composition we saw that they were with less percentage of Si and without Cu. Category A brick has less Al and Ti and without Vanadium. But is has greater contents of K, Ca, Mn, Ba, Rb and Ta. The contents of Fe, Zr, Sr, Y, Zn, and Tm were similar for all the categories. Bricks from categories B, C and Not Categorized has more content of Ti and V and lesser contents of K, Ca, Mn, Rb, Ba, Ta. Not categorized bricks also contents Copper. The laboratory made bricks M3 (Categorized B by compression strength) contents less Si, Fe, Al, Ti, K, Ca, Mn, S, Zr, Sr, Rb, Y, Ba, Zn, V and Ta and more Tm than the not Categorized M1 brick. Also the M1 brick (S/C) has more content of Si, Ca, Mn, S, Y, Ba, and Zn, less of Fe, Al, Ti, K, Zr, Rb and O % of V, Ta and Tm. The C categorized brick M2 has the lower content of Si, Mn, S (0%) and higher contents of Fe, Al, Ti, K, Zr, Sr, Rb, V and Ta. O% content of S, Ba, Zn and Tm.

According to the elementary composition bricks with Si composition around 58 to 60,7%, The presence of Fe and Al is also important and we can see in the raw materials, and in the bricks between 15 and 20 % and 11 to 17%, have categorization, also the presence of less Titanium that affects more color than strength. It is also the making technology important to be correctly know. Values of Fe and Al lower than 10% in raw materials shows lower mechanical properties. The more quantity of K, Mn, Rb, V and less quantity of Ca, Ba, Zn, Ca are important for bricks hand made. More K, Mn, Ca, Rb, Ba and Ta enhance the compression strength if the brick is made by mechanical pressure.

All these data let us know that the composition is important, but also the technique used to make. It is remarkable that the Si has a limited range quantity for good compression strength.

Also some elements as Fe, Al, K, Ca. Mn, Rb are very important contents on the final product (the brick). Also it´s remarkable that the presence of Ti is always there and it is limited to a maximum of 2,2 % for handmade bricks and to 1,7% for mechanically made bricks. The color of the brick also give us a tip of its properties if they are well designed, also may tell us the qualitative contents of Fe (more red), Ti (more clear and white), and may be other elements that gives its final color.

7 CONCLUSIONS

The final results show us that the brick mixed with both raw materials offers more compression strength. This is explained that it was made from 25% of clay (31% total fines (clay and silt) being acceptable and 69% of sand. This brick (Categorized B) has better mechanical properties than the one with 28% of clay and 16% of silt (44% of total fines) and 56% of sand (bigger grains) who was Not categorized and the categorized C with even more sand than the first (72%) and 28% of total fines who has an intermedium compression strength. This size contribution on strength is because the well granulometric distribution helps knead and compaction. On sample M3 it was observed the biggest decrease in mass of the three samples after sinter, also the volumetric mass and the sizes. From the termal-gravimetric analysis initial and at the end it was noticed that Sample M3 had a medium volume loss compared to M1 & M2, which gives a better distributed granulometric inside due to the mix of both raw materials to obtain a better knead and compaction to more hoimogeinity before, during and after sinter. Another data is that the same sample M3 increase more it volumetric initial mass. Representing it a good energy efficiency. Sample M2 was less afected by volumetric and mass volumetric variation. Probably because of the high percentage of sand. Sample M1 got more volumetric mass and volumetric decrease from initial ones. These due to the plasticity (more clay) and the existence of organic material in higher percentage noticed visually by the black color of it raw material. Generally but not always the volumetric mass and density increases strength, this we can see on absorptions under 20% requirement for A and B Bricks categories according to Standard NP17 027 77, second edition, 2015. It is not necessary more density for strength, but bricks with low density and volumetric mass has lower strengths because of the voids increase. Also it was observed more compression strength with less thickness, they sinter at lower temperatures, better also with small particles, clay and silt, but it is not good because of the mechanical behaviour in wall structure, very thin bricks bends at lower loads. Final sizes are very important and this standard considered it (we were part of the Standard Technical Committee 17). Establishes that minimum sizes are 22 cm x11 cm x 4,5 cm. It is recommended once obtain the raw materials combine it to produce a well distributed granulometry before Knead.

These final results let us know that the composition is important, but also the technique used to make. It is remarkable that Si has a limited range quantity for good compression strength.

Also some elements as Fe, Al, K, Ca. Mn, Rb are very important contents on the final product (the brick). Also it´s remarkable that the presence of Ti is always there and it is limited to a maximum of 2,2% for handmade bricks and to 1,7% for mechanically made bricks. The color of the brick also give us a tip of its properties if they are well designed, also may tell us the qualitative contents of Fe (more red), Ti (more clear and white), and may be other elements and heating technique that gives its final color.

Every brick with different raw materials should be sampled and tested to obtain the better combination because this will affect it strength and durability to support loads and environment during useful time.

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ÍNDICE REMISSIVO

A

B

C

E

F

L

M

O

P

S

U