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ANALYSIS OF ECOLOGICAL BRICKS MADE OF SILTY-SANDY SOIL, CEMENT, WOOD CHIPS AND PAPER, BASED ON STRENGTH, COST AND DEFORMATION

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Summary. Brick manufacturing involves firing clay at high temperatures, generating excessive consumption of energy and resources. Therefore, the need to replace the traditional brick with an ecological brick was born. The objective of this research is to manufacture an ecological brick using cement, silty-sandy soil, wood chips and bond paper, seeking to provide beneficial properties. The soil was first graded and stabilized with Portland cement. To prevent the chips and bond paper from absorbing the mixing water used, they were placed in saturation for 48 hours. The idea was to use a first dosage with half the volume with paper, shavings or both, and then a second and third dosage with a variation of +/- 10%, respectively. In order to perform the necessary tests, NTE INEN 3066 establishes the requirements and test methods. The results show that an ecological brick with 40% of chips resists 39 kgf/cm2 (28%) more than a traditional one, while an ecological brick with 50% of chips resists 31 kgf/cm2 (22%) more than a traditional one, in addition, the traditional brick is more economical, however, its elaboration is due to an industrialized process which minimizes its cost compared to an ecological brick. The ability of the ecological brick to deform and continue to receive load, unlike a traditional brick that reaches its maximum resistance without major deformation, is important because it would allow a building to have a more elastic behavior.

Key words: Compression, deformation, dosages, silty soil, wood chips.

ANÁLISIS DE LADRILLOS ECOLÓGICOS FABRICADOS CON SUELO LIMO-ARENOSO, CEMENTO, VIRUTA Y PAPEL, EN BASE A RESISTENCIA, COSTO Y DEFORMACIÓN

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Resumen. El ladrillo involucra en su fabricación la cocción de arcilla a grandes temperaturas, generando un consumo excesivo de energía y recursos. Por ello nace la necesidad de sustituir el ladrillo tradicional por un ladrillo ecológico. El objetivo de esta investigación es fabricar un ladrillo ecológico utilizando cemento, suelo limo-arenoso, viruta de madera y papel bond, buscando que aporten propiedades beneficiosas. Primero se clasificó y estabilizó el suelo con cemento Portland. Para evitar que la viruta y el papel bond absorban el agua de mezclado utilizada, se colocaron en saturación durante 48 horas. Se partió de la idea de utilizar una primera dosificación con la mitad del volumen con papel, viruta o ambos, para luego hacer una segunda y tercera dosificación con una variación de +/- 10%, respectivamente. Para realizar los ensayos necesarios, la normativa NTE INEN 3066 establece los requisitos y métodos de ensayo. Los resultados muestran que Un ladrillo ecológico con 40% de viruta resiste 39 kgf/cm2 (28%) más que un tradicional, mientras que un ladrillo ecológico con 50% de viruta resiste 31 kgf/cm2 (22%) más que un tradicional, además, el ladrillo tradicional es más económico, sin embargo, su elaboración se debe a un proceso industrializado lo que minimiza su costo frente a un ladrillo ecológico. La capacidad del ladrillo ecológico de deformarse y seguir recibiendo carga a diferencia de un ladrillo tradicional que alcanza su resistencia máxima sin mayor deformación, es importante pues le permitiría a una edificación tener un comportamiento más elástico.

Palabras clave: Compresión, deformación, dosificaciones, suelo limoso, viruta de madera.

Introduction

The construction of buildings and housing is a fundamental aspect nowadays due to the significant demographic and population growth, which causes an increase in the demand for construction materials, which is why it is important to look for alternative materials to replace the traditional ones, reduce costs, provide safety and reduce the negative environmental impact, since several studies have shown that the environmental situation is precarious, several human activities and especially the procurement and manufacture of construction materials produce a negative environmental impact due to various factors.

Wood shavings and paper are common and abundant wastes in our environment, wood shavings are a waste obtained in sawmills, paper is found as a waste in educational establishments, companies, bookstores, etc., and we are looking for ways to recycle these materials to give them a new use, helping to reduce the negative environmental impact that is generated when they are discarded. These materials have a common characteristic, which is their light weight, so including them in elements such as bricks would reduce their weight, which would produce constructive and economic benefits. Another characteristic of wood chips and paper is their elasticity, which would help a brick to have a large deformation instead of "exploding" abruptly as a normal brick would when subjected to a large load. As the chips and bond paper are materials that become waste after fulfilling their function, the feasibility of this study is very broad since it does not demand high manufacturing costs, in addition to the fact that its production does not involve a large amount of energy as would a normal brick that is baked in ovens at high temperatures, generating considerable CO_2 emissions.

The great importance of cement today is evidenced by the fact that it is the most produced material in the world with about 4070 million tons per year according to the latest statistics provided by Index Mundi in 2013 in its Hydraulic Cement report: World Production, By Country. The growth in cement consumption is directly related to the increase in the world population and to the development of countries, since this involves civil engineering works, infrastructure, etc., according to different studies, concrete and mortar will continue to be the cheapest means of construction, at least in the short term, and their consumption will continue to increase in proportion to population growth and development. For these reasons, this study seeks to use cement as a material in the manufacture of ecological bricks.

In our environment there is still not enough research on new construction materials to replace traditional materials partially or completely, the lack of interest in the care of the environment by most professionals and contractors causes that not enough importance is given to the search for new materials. Speaking of bricks specifically, such lack of interest in the environment generates ecological damage at the time of construction, as bricks are one of the most demanded materials in the country and in America in general, and taking into account that their manufacture generates considerable CO_2 emissions, more research should be carried out on new ecological materials to replace traditional ones, in addition to providing beneficial properties in terms of resistance and economy.

A construction material widely used for masonry is brick, which involves in its manufacture the firing of clay at high temperatures, which produces an excessive consumption of energy and unrecoverable resources, in addition to the generation of soot and carbon monoxide. Due to these circumstances, the need arises to find a way to replace the traditional brick with an ecological brick that involves in its manufacture recycled materials that are common in our environment and also eliminates certain processes that do not generate an excessive consumption of resources, since they are generally unrecoverable.

Wood shavings and paper are common and abundant wastes in our environment, wood shavings are a waste obtained in sawmills, paper is found as a waste in educational establishments, companies, bookstores, etc., and we are looking for ways to recycle these materials to give them a new use, helping to reduce the negative environmental impact that is generated when they are discarded. These materials have a common characteristic, which is their light weight, so including them in elements such as bricks would reduce their weight, which would produce constructive and economic benefits.

Materials

It has been demonstrated that stabilized soil has a superior durability and technical quality compared to adobe or simple rammed earth. The emergence of compressed earth block production technology, in European, African and Latin American countries, and its application in construction since the 1950s, has continued scientific progress and experimentation, as well as its technical merits, as stated by CRA Terre (as cited in Gatani 2000). An abundant body of knowledge has been developed by research centers, industrialists, entrepreneurs and builders, making this technology an alternative to other technologies of today.

Begliardo, Sanchez, Panigatti, Casenave and Fornero (2006) state that cement-treated soil can be made with:

- Clean granular soil.
- Mixture of granular and fine soils, predominantly silty.
- Mixture of granular and fine soils, predominantly clayey.
- Loamy soils.
- Clay soils.

However, the soil suitable for making soil-cement bricks is sandy in nature, with a proportion of fines that gives it low plasticity for block molding (Roseto 2006).

The Instituto Ecuatoriano de Normalización INEN establishes the norms to carry out the necessary tests to determine the soil plasticity index.

- Granulometric analysis of soil (NTE INEN 696)

The granulometric analysis consists of separating a sample into several fractions, Coyasamín (2016) states that the sample is separated according to its size by sieving the material using a series of meshes or sieves that are specified in the Ecuadorian Technical Standard INEN 154, with their measurements determined as shown in Table 1. Ecuadorian Technical Standard INEN 696 (2011) states: This test method is mainly used to determine the graduation of materials (...). The results are used to determine the compliance of particle size distribution with the requirements of the applicable specifications and to provide information necessary for the control of the production of various aggregate products and aggregate-containing mixtures. (p.1)

- Determination of the liquid limit of soils (NTE INEN 691)

The Ecuadorian Institute of Normalization in its Standard NTE INEN 691 (1982) defines the liquid limit as: "A test method consisting of determining the water content of a soil, (...) using a mechanical device (Casagrande Cup) in which, with a certain number of blows, the creep of the soil is established under standardized conditions." (p.1). In addition, it establishes that this test should be done only with the fraction of soil that passes the 425 μm sieve (No. 40).

- Determination of soil plasticity limit (NTE INEN 692)

The Ecuadorian Institute of Normalization in its Standard NTE INEN 692 (1982) defines the plastic limit as follows: "This test method consists of determining the water content of a soil at the boundary between its plastic and solid behavior, for which the rolling process is used to gradually evaporate the water that begins to crack or disintegrate." (p.1). As in the liquid limit, it is specified that this test should be done only with the fraction of soil that passes the 425 μm sieve (No. 40).

After the tests, it is necessary to define the type of soil according to its characteristics as mentioned by Bañón and Beviá (2000) based on the classification given by the American Association of State Highway and Transportation Official- AASHTO (2009).

For the determination of the group index and soil classification, the one given by the American Association of State Highway and Transportation Official- AASHTO (2009) is used. It considers seven basic groups of soils, numbered from A-1 to A-7, and some of them have subdivisions; A-1 and A-7 have two subgroups while A-2 has four, as mentioned by Bañón and Beviá (2000). It is also stated that, if it is desired to determine the relative position of the soil within the group, it is necessary to determine the group index (GI) as expressed in equation [1], which is expressed as an integer value between 0 and 20, as a function of the percentage of soil passing through the #200 ASTM sieve. (Bañón and Beviá, 2000).

$$IG=(F\_200-35)\ [0.2+0.005(LL-40)]+0.01(F\_200-15)\ (IP-10)\ [1]$$

Where:

F200 is the percentage of soil passing the #200 sieve, expressed as a whole number.

LL is the liquid limit of the soil, expressed as an integer.

IP is the soil plasticity index, expressed as an integer.

Cadena (2013) defines Portland cement as a hydraulic cement that is composed mainly of hydraulic calcium silicates, which set and harden when a chemical reaction occurs with water, called hydration. During this reaction, cement combines with water to form a paste which, when sand is added, is called mortar. The ASTM C 150 standard defines different types of cement, according to the uses and needs of the construction market:

Type I.- This type of cement is for general use, and is used when special properties and characteristics are not required. Among the uses where this type of cement is used are: floors, pavements, buildings, structures, prefabricated elements. (Coyasamin, 2016, p11)

Type II - Portland cement type II is used when protection against moderate sulfate attack is required, such as in drainage pipes. In cases where maximum limits are specified for the heat of hydration, it can be used in large volume works and particularly in hot climates, in applications such as retaining walls, piles, dams, etc. (Coyasamín, 2016, p12)

Type III: This type of cement develops high strengths at early ages, at 3 and 7 days. This property is obtained by grinding the cement more finely during the grinding process. Its use is due to specific construction needs, as in the case of roads and highways. (Coyasamin, 2016, p12)

Type IV - Portland cement type IV is used when, due to the needs of the work, the heat generated by hydration must be kept to a minimum. The uses and applications of type IV cement are directed to works with massive structures, such as large dams. (Coyasamin, 2016, p12)

Hydraulic blended cements have been developed because of two fundamental aspects: first, the industry's interest in energy conservation and second, the economics of their production.

To stabilize the soil this study applied Portland cement, which is a hydraulic cement that is composed mainly of hydraulic calcium silicates, which set and harden when a chemical reaction with water occurs, called hydration (Cadena, 2013).

Regarding the process that water goes through with cement, Del Campo (1963) states that, when cement is kneaded with a certain amount of water, a plastic, moldable mass is formed, which little by little, as time goes by, loses its plasticity, and the wet appearance it had at the beginning disappears. "Technologically, it is said that the paste is setting, the process continues, and there comes a moment when it stops being plastic and becomes a rigid body. When this change in its structure occurs, it is also said that the setting period has ended and the hardening period has begun." (p.38)

Wood shavings and paper are common and abundant wastes in our environment, wood shavings are a waste obtained in sawmills, paper is found as a waste in educational establishments, companies, bookstores, etc., and we are looking for ways to recycle these materials to give them a new use, helping to reduce the negative environmental impact that is generated when they are discarded. These materials have a common characteristic, which is their light weight, so including them in elements such as bricks would reduce their weight, which would produce constructive and economic benefits. Another characteristic of wood chips and paper is their elasticity, which would help a brick to have a large deformation instead of "exploding" abruptly as a normal brick would when subjected to a large load.

Absorption test

To carry out the necessary tests, the Ecuadorian Institute of Standardization in its standard NTE INEN 3066 establishes the requirements and test methods for concrete blocks, this standard was chosen because of the use of cement in the manufacture of ecological bricks. Annex D of the Ecuadorian Technical Standard NTE INEN 3066 defines the following procedure for the absorption test:

"Immerse the test units in water at a temperature between 16 °C and 27 °C for a period of 24 hours to 28 hours." (Instituto Ecuatoriano de Normalización, 2016)

"Determine, then, the mass of the completely submerged units, while suspended a wire, and record this value as Mi (mass of the submerged sample)." (Instituto Ecuatoriano de Normalización, 2016)

"Remove them from the water and allow them to drain for 60 seconds ± 5 seconds on a wire mesh, remove the visible water from the surface with a damp cloth, determine their mass and record this value. Repeat this procedure every 24 hours until the difference in mass between two consecutive weighings is less than 0.2%. Record this result as Ms (mass of the saturated sample)." (Instituto Ecuatoriano de Normalización, 2016)

"Dry them in a ventilated oven, between 100 °C and 115 °C. Weigh the units every 24 hours until the difference in mass between two consecutive weighings is less than 0.2 %. Record this result as Md (oven-dried sample masses)." (Instituto Ecuatoriano de Normalización, 2016)

Once the procedure described above has been carried out, the Ecuadorian Institute of Normalization has established the following equations for the calculations:

$$Absorción, (kg/m^3) = \frac{M_s - M_d}{M_s - M_i} \times 1000 \qquad [2]$$

Where:

Ms is the mass of the saturated unit (kg),

Mi is the mass of the submerged unit (kg),

Md is the mass of the oven-dried unit (kg).

Compression test

The parameters for the preparation of the samples to be tested can be found in Annex E of Ecuadorian Technical Standard 3066, which states that: After delivery to the laboratory, store the units (...) at a temperature of 24 °C ± 8 °C and a relative humidity of less than 80 % for at least 48 hours. However, if faster compression results are needed, store the units (...), with a stream of air from an electric fan passing through them, for a period of at least 4 hours. The oven should not be used to dry these units. (p19)

It also establishes the formula for determining the compressive strength:

$$Resistencia\ a\ la\ compresión = \frac{P_{máx}}{A_n} \qquad [3]$$

Where

- Pmax. = maximum compressive load, (kgf)
- An = net area of the unit (cm2)

Method

Soil identification and classification

The natural soil was obtained from the Borma sector of the Déleg canton in the province of Cañar, using UTM coordinates as reference: 728813.73 E; 9687510 S; Zone 17M. We worked with material that passes the N°4 sieve and it was observed that it is a silty soil, so to reduce its plasticity we chose to add sand, having a soil: sand ratio of 1:1. Once these conditions were established, the following tests were carried out to classify the material.

According to the procedure established in the Ecuadorian Technical Standard INEN 691, the liquid limit of the natural soil is calculated and then the liquid limit of the soil added with sand, as shown in Table 1 and Table 2, respectively.

Table 1
Natural soil water content

# of jar	# of strokes	Wet weight + Jar (g)	Dry weight + Jar (g)	Jar Weight (g)	water content
16	**43**	28.64	25.62	17.57	27.28
15	**30**	27.66	24.83	17.81	28.73
9	**21**	28.24	24.92	17.07	29.72
6	**13**	28.36	24.82	16.96	31.05

Table 2
Soil water content plus sand

# of jar	# of strokes	Wet weight + Jar (g)	Dry weight + Jar (g)	Jar Weight (g)	water content
15	**40**	29.9	27.45	17.81	20.26
22	**32**	29.25	26.85	17.69	20.76
31	**23**	31.87	28.84	17.89	21.67
6	**13**	30.22	27.14	16.96	23.23

Results:

- Liquid limit of natural soil = 29%
- Liquid limit of sand = Non-plastic
- Soil liquid limit + sand = 21%

According to the procedure established in the Ecuadorian Technical Standard INEN 692, the plastic limit of the natural soil is calculated and then the plastic limit of the soil added with sand, as shown in Table 3 and Table 4, respectively. Additionally, applying INEN 692, the plasticity index of the materials is calculated.

Table 3
Plastic limit of natural soil

# of jar	Wet Weight +Tartar (g)	Dry Weight +Tartar (g)	Jar Weight (g)	water content	Average water content (%)
27	8.38	7.99	6.05	16.74	
24	9.01	8.54	6.21	16.79	**17.0**
4	11.39	10.93	8.72	17.23	
34	9.24	8.71	6.21	17.49	

Table 4
Plastic limit of soil plus sand

# of jar	Wet Weight +Tartar (g)	Dry Weight +Tartar (g)	Jar Weight (g)	water content	Average water content (%)
27	8.25	7.87	6.05	17.27	
24	8.47	8.09	6.21	16.81	**17.2**
4	11.64	11.13	8.72	17.47	
34	8.99	8.51	6.21	17.27	

- Natural soil plasticity index = 29% - 17% = 12%
- Soil plasticity index + sand = 21% - 17.2% = 3.8%

Subsequently, the particle size is determined (Table 5).

Table 5

Soil granulometry plus sand

Sieve No	Diameter (mm)	Retained weight	% retained	% passing
4		0.00	0.00	100.00
10	2	20.09	5.41	94.59
40	0.425	149.12	40.13	50.46
100		156.28	42.06	16.40
200	0.075	43.20	11.63	0.77

With the results obtained from the above tests, the material is classified as shown in Table 6. Based on the classification obtained, the beneficial use of using soil plus sand in the study is confirmed. Once the desirable characteristics have been found, the remaining materials for dosing are prepared.

Table 6
AASHTO material classification

Sample	Group	Type of materials characteristics	Rating
Natural soil	A-2-6 (0)	Gravels and silty and clayeysands	Regular
Soil+ Sand	A-1-b (0)	Gravel fragments, stone and sand	Excellent to good

Chip sampling and preparation

The chips chosen are medium and fine, discarding coarse chips because their dimensions could generate porosities in the bricks. The wood chips come from two types of wood, oak and eucalyptus. To prevent the chips from absorbing too much of the mixing water used, they were left in saturation for 48 hours as shown in Figure 1, and it was decided to cover them to prevent evaporation and thus conserve moisture.

Figure 1
Chip and paper in the process of saturation

Sampling and preparation of bond paper

Bond paper can be found in public and private institutions as waste, because after fulfilling its function it is considered garbage. For this study, bond paper was obtained and recycled from the Universidad Católica de Cuenca, Azogues.

75gr. bond paper was chosen because it is the most widely used in the field. To prevent the paper from absorbing the mixing water used, it was left in saturation for 48 hours as shown in Figure 2.

Figure 2
Paper in the process of saturation

Using a Hobart mixer, the 75 g bond paper was homogenized by shredding it and adding water until a uniform consistency was achieved, as shown in Figure 3.

Figure 3
Bond paper homogenization

Brick manufacturing

The dimensions of the molds were chosen according to the traditional bricks existing in the market, thus having already established dimensions of 12cm x 24cm x 8cm.

The fine aggregates (cement and soil plus sand) are mixed in the proportions foreseen according to the dosage chosen, until they are correctly homogenized, as shown in Figure 4. The paper, chips or both, as the case may be, are added to this mixture and mixed and homogenized again until an appropriate workability is obtained. If necessary, water is added to the mixture to improve its workability and to obtain an optimum mixture for working, as shown in Figure 5.

Figure 4
Dry blending of cement, soil and sand

Figure 5
Homogenization of all materials

Consequently, the mixture is placed in wooden molds and then beaten with a rubber hammer to get the material to settle properly and eliminate excess air. After ensuring the correct distribution of the material and covering empty spaces, the mold is removed, leaving the ecological bricks as shown in Figure 6, which also shows the presence of a metal plate used to level the upper face that will receive the load in the compression tests.

Figure 6
Demolded bricks with presence of leveling plate

Dosages

For this research, we worked with a soil-cement volume ratio of 1:1.5 because we are looking for the "ecological mortar" to have a good percentage of cement to increase resistance.

Mixes are started with 50% of the volume of a brick with paper, chips or both, as the case may be. With this starting point, it was considered to make dosages containing 60% and another with 40% of the mentioned materials, i.e., the idea was to use a first dosage with half of the volume with paper, chips or both, and then make a second and third dosage with a variation of +/- 10%, respectively. Table 7 shows the volumes of each material used in the dosages.

Table 7
Volumes of material required to manufacture one unit of ecological bricks

Material	40% V (cm^3)	50% V (cm^3)	60% V (cm^3)	40% P (cm^3)	50% P (cm^3)	60% P (cm^3)	40% P+V (cm^3)	50% P+V (cm^3)	60% P+V (cm^3)
Cement	1656	1380	1104	1656	1380	1104	1656	1380	1104
Soil plus sand	1104	920	736	1104	920	736	1104	920	736
Paper	----	----	----	1840	2300	2760	920	1150	1380
Chip	1840	2300	2760	----	----	----	920	1150	1380

Absorption and compression tests

The Ecuadorian Technical Standard NTE INEN 3066 establishes the parameters to carry out absorption and compression tests on concrete blocks, applying the following equations. Once the procedure described above (Figure 7) has been carried out, the Ecuadorian Institute of Standardization has established the following equations for the calculations:

$$Absorción, (\%) = \frac{M_s - M_d}{M_d} \times 100 \qquad [4]$$

Where:

Ms is the mass of the saturated unit (kg),

Md is the mass of the oven-dried unit (kg).

It also establishes the formula for determining the compressive strength:

$$Resistencia\ a\ lacompresión = \frac{P_{máx}}{A_n} \qquad [5]$$

Where

Pmax. = maximum compressive load, (kgf)

An = net area of the unit (^{cm2})

Figure 7
Compression test of an ecological brick with chips

Results

Compressive strength and deformation

Once the compression tests were carried out, it was observed that the strength of the ecological bricks containing paper in their dosage was below the strength of traditional bricks. It is also observed that the ecological bricks with 40% and 50% chip content exceed the stress resisted by traditional bricks by 28% and 22% respectively, the effect of curing on the bricks does not vary more than 10kg/cm2, so the effect is not taken into account. The following stress-strain plots show the behavior of traditional brick vs. Ecological bricks.

Figure 8
Effort vs. Deformation, traditional brick and chip bricks

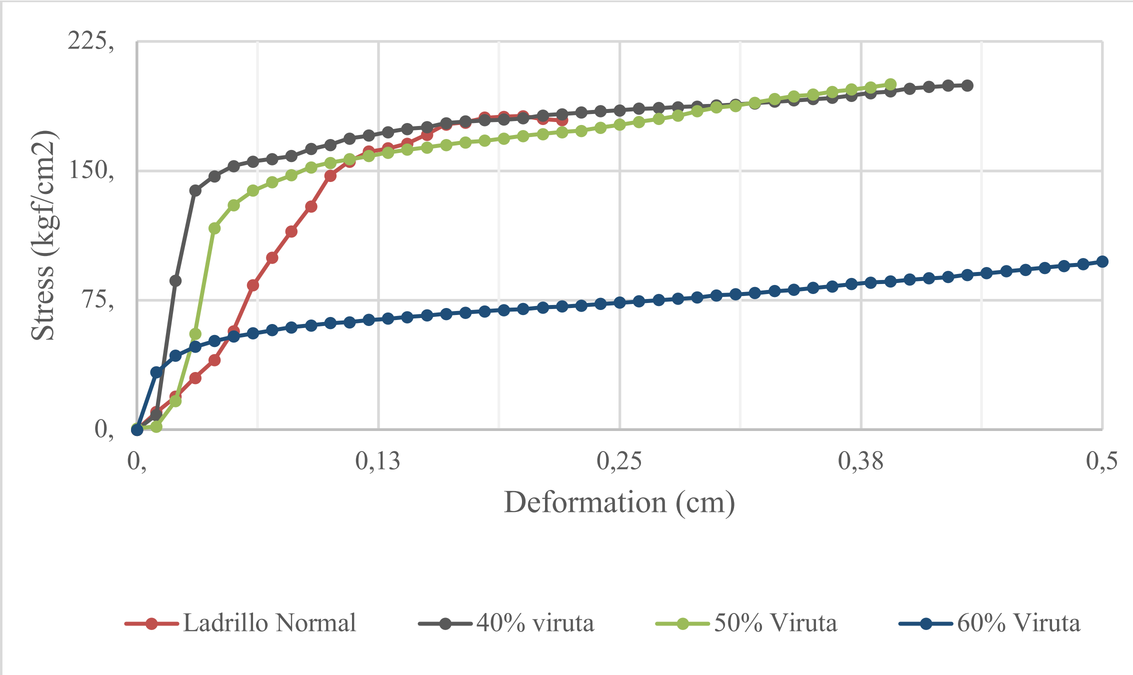


Figure 9
Effort vs. Deformation, traditional brick and paper bricks

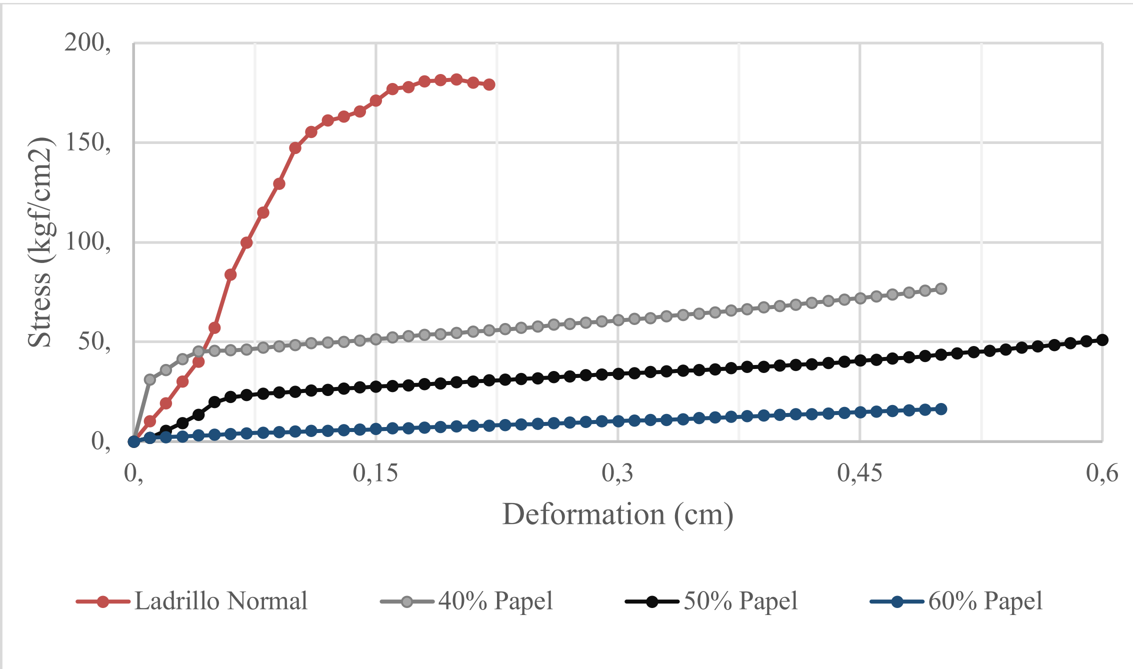
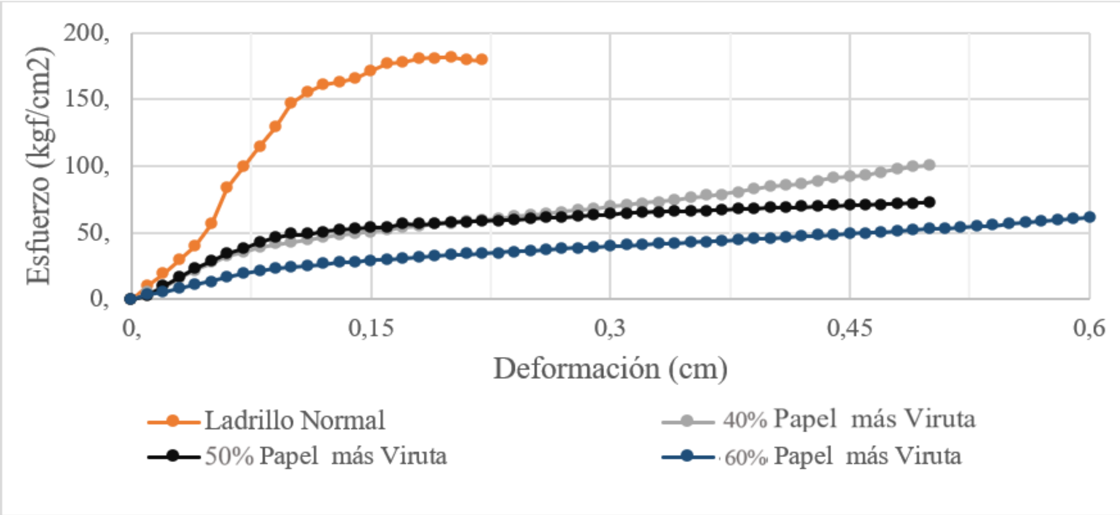


Figure 10

Effort vs. Deformation, traditional brick and bricks with chips plus paper



The graphs in Figures 8, 9 and 10 show that the ecological bricks have the capacity to continue receiving load and continue deforming, unlike traditional bricks that reach their ultimate stress and stop resisting load, i.e., traditional bricks show brittle failure, while ecological bricks show ductile failure. In addition, from a seismic point of view, a lighter building generates lower lateral inertial forces. In the same way, the failure presented by the ecological bricks would allow people not to be affected by falling walls during an earthquake, due to their deformation, without brittle failure (Figure 11).

Figure 11

Masonry failure at the Millennium School - Pedernales Ecuador

Note. Prepared by Eng. Xavier Nieto Cárdenas

Compressive strength and deformation

The weight obtained shows an advantage of ecological bricks as they are lighter than traditional bricks, as shown in Table 8 below. This difference in weight compared to traditional bricks is approximately 1 kilogram. This difference can be magnified when analyzing the weight of a wall made with fired clay bricks; therefore, if the weight is greater, the supporting structure must be more resistant, which will increase its cost.

Table 8
Weight of bricks tested

Description	Weight
Traditional Brick	4.13 kg
Brick with 40% chips	3.46 kg
Brick with 50% chips	3.30 kg
Brick with 60% chips	2.70 kg
Brick with 40% Paper	3.15 kg
Brick with 50% paper	2.44 kg
Brick with 60% paper	1.88 kg
Brick with 40% chips plus paper	2.98 kg
Brick with 50% chips plus paper	2.94 kg
Brick with 60% chips plus paper	2.48 kg

Cost comparison

Since bricks with 40% and 50% of chips achieve the same strength as traditional bricks, a cost analysis of these elements alone was carried out. For the analysis of tables 9 and 10, only the value of the materials used was considered, leaving aside the production processes, since a traditional brick is produced in large-scale factories, while this research on ecological bricks, being innovative, is based on unit production.

Table 9
Cost of manufacturing a brick with 40% of chips

MATERIALS				
DESCRIPTION	**UNIT**	**QUANTITY**	**P. UNIT**	**COST**
Portland Cement	kg	3.98	0.15	0.597
Clean sand	m3	0.000552	10.25	0.006
Natural soil	m3	0.000552	0.1	0.0001
Wood chips	m3	0.001840	1.00	0.001
TOTAL				0.60

Table 10
Cost of manufacturing a brick with 50% of chips

MATERIALS				
DESCRIPTION	**UNIT**	**QUANTITY**	**P. UNIT**	**COST**
Portland Cement	kg	3.31	0.15	0.496
Clean sand	m3	0.000460	10.25	0.005
Natural soil	m3	0.000460	0.00	0.0001
Wood chips	m3	0.002300	1.00	0.001
TOTAL				0.50

Discussion and conclusions

Once the results of the study have been obtained, the following conclusions can be drawn:

The proposed dosages resulted in different values after the simple compression test, being evident a higher resistance for the dosages that contain a greater amount of cement, it is also observed that the wood chips provide lightness to the brick and optimum resistance, while the paper, although it manages to significantly reduce the weight, reduces the resistance of the brick. The dosages that reach and exceed the resistance of a traditional brick are those containing 40% and 50% wood chips.

In dosages with 36% cement, 24% soil plus sand and 40% chips or paper, the production cost, handling only values of materials, would be 60 cents or in other words 71% more than a traditional brick, while in dosages with 30% cement, 20% soil plus sand and 50% chips or paper, the production cost, handling only values of materials, would be 50 cents or what is equal to 43% more than a traditional brick.

The cost of an ecological brick is higher, but other factors must be taken into account, such as weight, since being approximately 1 kg lighter means that the base structure will have to support less weight, which would reduce construction costs.

An ecological brick with 40% chips resists 39 kgf/cm2 (28%) more than a traditional brick, while an ecological brick with 50% chips resists 31 kgf/cm2 (22%) more than a traditional brick. The strength of the other dosages is below the strength of a traditional brick, but could be compared to the strength of a class B concrete block.

An important factor is the ability of the ecological brick to deform and continue to receive load, unlike a traditional brick that reaches its maximum resistance without major deformation. This capacity is important because it would allow a building to have a more elastic behavior.

In the ecological aspect, the bricks of this research have several advantages over traditional bricks, starting with the fact that they do not require firing kilns, which means that they do not generate large CO and soot emissions, thus reducing the negative environmental impact.

Another important factor is the material used, because by recycling a common material such as wood chips, we contribute in an excellent way to the care of the environment.

The following recommendations can also be established:

Regarding the process of this research, the plasticity index of the natural soil must be taken into account and try to reduce it if necessary, since it is essential to achieve an appropriate mixture with the cement and achieve the required strength.

It is important to use molds with smooth surfaces that ensure a good finish of the brick, this is important at the time of the simple compression test because the load will be distributed uniformly. Finally, the curing time of 28 days of curing must be respected.

Continue with the research of ecological materials that can replace the traditional ones, and go deeper into the economic aspect of bricks with a percentage of chips, considering other important factors at the time of construction.

Compare with other elements such as pumice and concrete blocks, and vary the dimensions of the elements used in this research.

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