Lightened Blocks of Plant Fibers and Clay Applied in Construction Systems for Housing in High Andean Areas

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Abstract. The search for sustainable construction systems to address social and environmental problems is increasingly important because there is still a high percentage of deficit in the construction of comfortable homes. This research aims to analyze the proposal of a sustainable construction system of lightened blocks made with plant fibers and clay, applied in the high Andean areas of the central Andes of Peru. For this experimental process, the analysis of the local soil that was used to manufacture the blocks was carried out, resulting in a high percentage of clay, to which plant fibers was incorporated. Then, fifty samples of blocks with different types of dosage were made and ten were selected, which were subjected to physical-mechanical compression resistance tests and compared with what was specified in international and national standards in relation to the units of brickwork. Finally, the results indicate that the elaborate blocks, compared to traditional earthen masonry units, are lighter and more resistant. This represents 57% less weight in relation to volume and 50% more resistance, this being a result of the use of plant fibers and the design of the block, which also provides better thermal insulation, likewise, this lightened block has better economic advantages.

1 Introduction

It has become an important issue for all countries around the world to tackle environmental disasters caused by different human activities. A report by the Sustainable Development Goals (SDGs) [1] points out that the misuse of energy and soils is generating a climate cataclysm that cannot be repaired. This phenomenon has affected around 3.6 billion people, causing migrations, homelessness and other problems. Therefore, the SDG 13.2 aims to generate measures related to climate change, for the common good. Given this situation, it is necessary to emphasize the use of construction systems that have a lower impact on nature, as the construction industry generates one of the highest percentages of carbon dioxide emissions in the world [2]. Thus, it is essential to bring back the use of sustainable materials such as raw earth and natural fibers, since it has been demonstrated that these have the least impact on the environment [3] and its combination has great benefits [4]. It is understood that

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using earth as a construction material has better properties than the different materials that are currently used [5]. Likewise, there is evidence that the use of natural fibers contributes greatly to the mechanical characteristics of these construction systems, such as compressive strength [6] and crack control [7], with straw fiber being one of the most optimal [8]. On the other hand, the use of these materials in constructions has been very important in the historical development of cities, since 17% of the architectural works that have been declared world heritage sites are made of raw earth [9]. One of the construction characteristics of the houses located in the high Andean areas of Peru is the use of raw earth and natural elements, as this is a practice that has been inherited by several pre-Inca cultures [10]. This construction system reflects a low percentage of cost in its execution [11], which allows having an alternative solution in case of natural disasters [12]. It also offers better thermal characteristics in comparison to conventional construction systems [13], since they represent a more economical thermal alternative rather than other materials [14] and contribute significantly to sustainability [15]. Nevertheless, it has been discarded over the years, because of its weak resistance to earthquakes, given the considerable weight of this system's structures [16]. In addition, nowadays raw earth constructions are associated with poverty and unhealthy living conditions [17].

According to data from the National Institute of Statistics and Informatics, 31.05% of the homes located in Peru have the use of earth as the predominant material, this being the most used after brick, likewise the vast majority of these are located in areas Andean highlands and this is due to the diverse characteristics that these sectors present [10]. However, many of these homes present various problems, due to the climatic factor, since these have contributed to the decrease in their resistance and rigidity properties [30] and at the same time have caused their deterioration and abandonment. On the other hand, the emergence of new construction materials such as concrete and brick are the most used today and in the last census carried out in Peru a decrease in homes built with raw earth has been observed in various high Andean areas. of central Peru, as seen in Figure 1, interpreting this as an accelerated decrease in this type of housing, which in the future runs the risk of losing it.

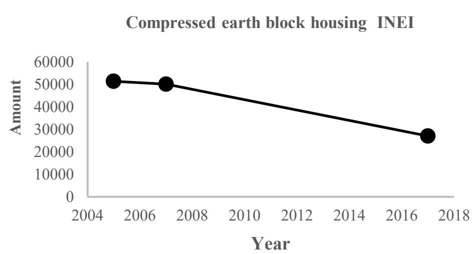

Fig. 1. Number of homes built with compressed earth blocks in the province of Huancayo, according to the censuses of the National Institute of Statistics and Informatics (INEI).

This research aimed to analyze the proposal of a construction system made of straw and clay fibers in various high Andean areas of central Peru, since these are the places that still have houses made of raw earth, as well as they are the most affected by the constant waves of cold weather that take place every year, with no improvement in their thermal insulation conditions. Considering the location, it is suggested to use the resources generated by the place. These areas produce wheat and other cereals, which are discarded in large quantities. By implementing this construction system, it is feasible to eliminate these wastes in a more ecological [18] and beneficial way in the construction sphere [19]. These resources were chosen due to their connection to the construction system proposed, and also because its usage does not generate any negative impact on the environment. The study problem in this research was chosen to demonstrate the qualities of this lightweight block through various tests. This could be a sustainable, economical and efficient alternative to the conventional constructions that are currently applied [20]. These sustainable construction alternatives are emphasized in order to promote and apply them in future housing projects in the high Andean areas. However, all the above would be in vain if there is no cultural change among designers, builders and users [21].

2 Study area and methodology

2.1 Study area

The study area is located in the high Andean areas of central Peru, located between 3500 meters above sea level. These places are characterized by having very cold climates, in the same way these are places in which a vernacular architecture project has been developed, which is currently gradually being lost. [22].

2.2 Methodology

To carry out the research, materials from the area were selected, such as the earth from which the clay was extracted and straw as plant fiber.

Earth is one of the most used construction materials in the construction industry, due to factors such as abundance and proximity [23]. For the investigation, the geotechnical characteristics of the land were analyzed, based on the Peruvian Technical Standards, this analysis was carried out in a soil laboratory, which defined that the land used in the investigation has the following composition, 32.83% gravel, 15.5% sand and 51.67% clay (Figure 2 and 3) likewise, this is found in the low plasticity gravelly clay group having a plasticity index of 19 (Figure 4).

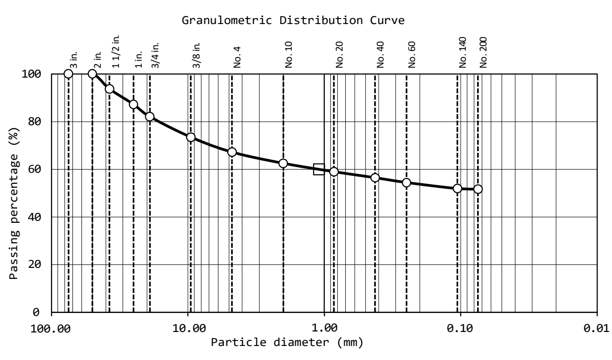

Fig. 2. Particle size distribution curve.

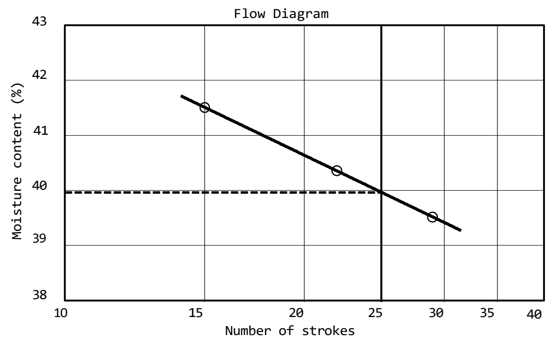

Fig. 3. Determination of the liquid limit.

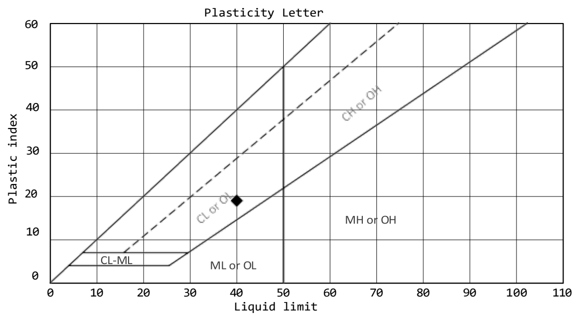

Fig. 4. Determination of the plasticity index.

Vegetable fiber (straw) is a natural element obtained from agricultural waste. These have thermal and structural properties, since their great adhesion with mud allows them to be used as a construction element. [24]. Likewise, the use of this allows avoiding the increase of cracks in the block [25]. On the other hand, various studies have shown that straw increases the resistance of blocks built from earth. [26]. For the research, straw fibers with a length that varied between 40 cm and 50 cm were used.

The study began with the design process of the lightened block with dimensions of 25cm wide, 50cm long and 30cm high. These dimensions were chosen to demonstrate the lightened characteristic of the block, since traditional adobes are usually very heavy according to its size [13]. Likewise, it was decided to make two internal holes, which have a radius of 5cm, with the aim of lightening the weight of the block and locating the reinforcements in the construction process of a wall, thus avoiding cracks and displacements. The design of the block can be seen in Figure 5. This design was made in reference to the tests, studies and techniques carried out by Jorge Belanko.

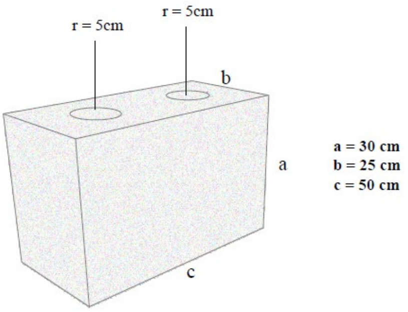

Fig. 5. Dimensions of the lightened blocks.

The construction process of the lightened blocks begins with sifting the earth to filter the clay from any other contaminating element and then proceeds to mix it with water, subjecting the clay to a hydration process, to obtain a liquid element, which can be combined with plant fiber (straw), as shown in Figure 6. After making the mixture between the clay, water and straw, it begins to be introduced into the previously manufactured molds, these are compacted and intertwined as shown in Figure 7 and Figure 8, in the same way to obtain the holes planted in the design, it was decided to use PVC pipes with a diameter of 4".

Fig. 6. Dimensions of the lightened blocks.

Fig. 7. Assembly of the lightened block.

Fig. 8. Assembly of the lightened block.

Once the mold was filled with the mixture, it was left to dry for a period of 28 days. During that period it was decided to remove the PVC pipes on the fifth day and then on the tenth day the molds began to be removed. In Figure 9 you can see the blocks outside the molds.

Fig. 9. Unmolded blocks.

Taking into account the construction process of the proposal for the lightened blocks, 50 samples were made with different dosages, in which the proportions of water, clay and straw were varied. Of the samples made, 10 were selected for the tests. The dosages carried out for the selected samples can be seen in Table 1.

Table 1. Setting Word's margins.

Sample	**Proportion % of inputs**		
	Clay	**Straw**	**Water**
M01	80.00	10.00	10.00
M02	70.00	20.00	10.00
M03	70.00	10.00	20.00
M04	60.00	30.00	10.00
M05	10.00	80.00	10.00
M06	10.00	70.00	20.00
M07	20.00	70.00	10.00
M08	20.00	60.00	20.00
M09	30.00	50.00	20.00
M10	20.00	50.00	30.00

After the selection of lightened blocks, tests of resistance to compression were carried out, using a hydraulic press, which allowed more accurate results to be obtained. The testing process can be visualized in Figure 10.

Fig.10. Resistance tests.

3 Results

Below are the results obtained when evaluating the samples of the prepared blocks. These results are classified by their volume, weight, density, resistance and comparison with other built systems.

3.1 Sample volumes

The results of the volume of the blocks were analyzed with the dry samples, for their calculation the voids proposed in the design were taken into account. It can be seen in Table 2 and Figure 11 that sample number 09 (M09) has the largest volume of blocks with a total of 0.0394 m3 and sample number 08 (M08) has the smallest volume of blocks with a total of 0.0320 m3. The results of the dimensions shown in Table 2 are different from the prototype in Figure 5, due to the dosing and drying process to which each block is subjected.

Table 2. Result of the volume of the dry samples.

Sample	Dimensions meters (m)			Volume (m3)
	Long	Wide	High	
M01	0.50	0.26	0.30	0.0358
M02	0.50	0.25	0.30	0.0343
M03	0.51	0.26	0.30	0.0366
M04	0.50	0.25	0.29	0.0332
M05	0.50	0.24	0.30	0.0328
M06	0.50	0.25	0.29	0.0332
M07	0.50	0.26	0.30	0.0358
M08	0.50	0.25	0.28	0.0320
M09	0.50	0.26	0.33	0.0394
M10	0.50	0.26	0.30	0.0358

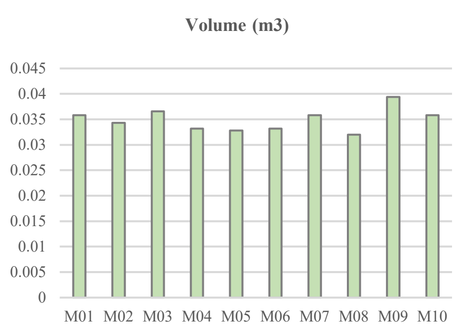

Fig. 11. Result of the volume of the dry samples.

3.2 Sample weight

In Table 3 and Figure 12 it can be seen that sample number 01 (M01) has the greatest weight of the blocks with a total of 37.08 kilograms, this being the one with the percentage of clay in its highest composition, according to Table 1 For its part, Sample number 05 (M05) has the lowest weight of the blocks with a total of 12.70 kilograms, this being the one with the highest percentage of vegetable fiber (straw) in its composition, according to Table 1.

Table 3. Sample weight result.

ID	Sample	Weight (kg)
Blocks	M01	37.08
	M02	33.52
	M03	31.52
	M04	28.46
	M05	12.7
	M06	13.92
	M07	14.96
	M08	19.88
	M09	23.16
	M10	24.72

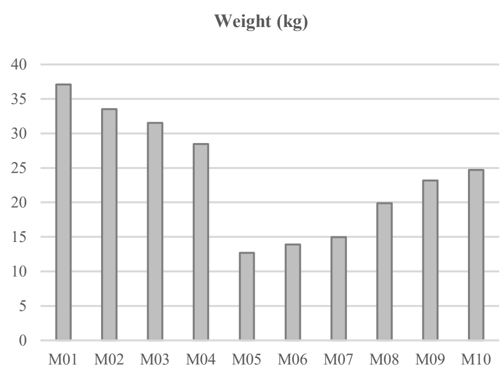

Fig.12. Sample weight result.

3.3 Sample density

In Table 4 and Figure 13 it can be seen that sample number 01 (M01) has the highest block density, with a total of 1034.90 kg/m3. Meanwhile, sample number 05 (M05) has the lowest block density with a total of 386.85 kg/m3.

Table 4. Sample density result.

ID	Sample	Density (kg/m3)
Blocks	M01	1034.90
	M02	976.42
	M03	860.98
	M04	857.61
	M05	386.85

	M06	419.46
	M07	417.53
	M08	620.46
	M09	587.63
	M10	689.93

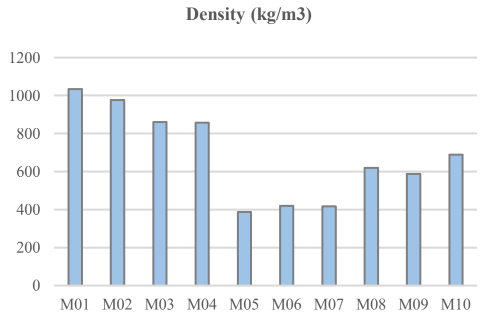

Fig.13. Sample weight result.

3.4 Sample resistance

In Table 5 and Figure 14 it can be seen that sample number 02 (M02) has the highest compressive strength of the blocks with a total of 27.74 kg/cm2. Meanwhile, sample number 05 (M05) has the lowest compressive strength of the blocks with a total of 10.28 kg/cm2.

Table 5. Sample resistance result

ID	Sample	Resistance (kg/m2)
Blocks	M01	21.56
	M02	27.74
	M03	25.35
	M04	23.84
	M05	10.28
	M06	11.50
	M07	12.85
	M08	15.94
	M09	18.01
	M10	21.34

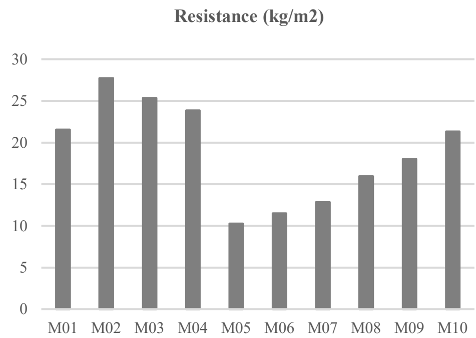

Fig.14. Sample resistance result

3.5 Comparison with other construction systems

For the analysis of the lightened block, a comparison was made with other construction materials that are currently used, such as adobe and brick, the latter being the most currently used.

First, the comparison of the resistance of each material was carried out, with the data obtained in the research, the references and technical specifications of the material, in the case of brick. For the following comparison, the cost per square meter of manufacturing a wall with the different materials was taken into account; To analyze the unit price of these, cost programs and budgets were used. Finally, the comparison of the degree of contamination of each material was carried out taking into account the construction process of each one. The comparison results can be seen in Table 6.

Table 6. Comparison results with other materials

Material comparison			
Housing typology	**Resistance (kg/cm2)**	**Cost in soles per m2**	**Pollution degree**
Lightened Block	23.84	9.46	Low
Adobe	10.8	16.06	Low
Noble material (brick)	130.00	62.96	High

In Table 6 you can see the 3 types of comparison that were carried out with other materials, the first being the resistance comparison, in which the brick has the best result. In the following comparison, the cost per square meter was analyzed, with the lightened block design being the lowest cost. Finally, the degree of contamination of each material was compared, with brick being the highest, since this is the one that emits the most carbon dioxide at the time of its manufacture.

4 Discussions

According to the results obtained, it is proven that the majority of the blocks show better compression resistance behavior compared to what is required in standard E.080 of the National Building Regulations of Peru, for the design and construction of reinforced earth

[28], which indicates that the minimum resistance of the earth blocks must be 10.2 kg/cm^2. Medina Cercado [29] points out that according to the Spanish Association for Standardization, UNE 41410 (Standard for compressed earth blocks for walls and partitions), the earth blocks must have a density of 1700 kg/m3 and have a compression resistance of 13.25 kg/cm2. The results demonstrate that the made blocks have a lower density and a better resistance to compression behavior regarding this standard. This is important, since it has been possible to achieve larger dimensions with minimum weights.

5 Conclusion

The study carried out demonstrated that it is possible to achieve blocks of earth and straw that are lighter and have larger dimensions than what is established in the E.080 standard, complying with the requirements of mechanical studies required in said standard. Likewise, the established design, which has circular holes, allows the block to be light and at the same time have a better framework compared to traditional earth blocks. It is observed that the variation in percentages of these elements such as straw, clay and water significantly influence the results of lightness and resistance of the block. Regarding the contribution to the environment, the elements used do not generate any pollution, thus being a construction system that contributes to the care of the environment.

Likewise, the proposed lightened block presents better benefits compared to traditional adobe and brick, being the most economical block and presenting lower degrees of contamination compared to other materials, these being the most important points for the future of the construction of buildings in homes located in the high Andean areas. On the other hand, it is intended to revalue construction systems based on raw earth, which promote constructions that are respectful of nature, since this represents a great contribution to stopping the giant steps of pollution in today's world. It is intended that the results obtained can be used in future studies, which promote these construction systems and can be applied in homes in the high Andean area.

6 Acknowledgements

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