Strength of Adobe bricks

Influence of different additional materials on the strength of a standard adobe brick

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Group 5:

Yarai Zenteno 4922204
Kazi Fahriba Mustafa 4842960
Patrattakorn Wannasawang 4892380
Akash Changlani 4813715
Elisa Vintimilla 4833600
Shasan Choksi 4906691

Content

1. Introduction

This report explores the results of the measured strength of adobe bricks made with different material compositions and dimensions. The experiment was carried out in two sessions: the first session consisted in the manual preparation of the adobe bricks. After left to dry for seven days, the bricks were broken one by one on the second session. The results of the series of measurements is reported in this document in order to compare the strength of the different mixtures in the adobe bricks.

1.1. Research objective and question

The main objective of the research is to identify the influence on the strength of a standard composition of adobe bricks mixture in addition to other materials. Afterwards a comparison will be drawn, based on the strength of each brick type with sourced standard strength values according to their different compositions and their dimensions.

Based on the research objectives, two main research questions were formulated: What is the standard strength of the adobe brick in addition to different material additives? How does the dimension of the brick affects its strength?

2. Methodology

2.1. Equipments and software used

The equipment used in the brick making process are a large bucket, weighing machine, a mixing drill and a masonry trowel. Image 1 shows the equipment in the sequence of use from left to right. For testing the strength of the bricks, Zwick z100 testing machine is used and the data is recorded using the testXpert software.

Image 1: *Equipments used in the brick making process*

2.2. Procedure for Brick making

To start with the brick making workshop, materials and the standard recipe to make the bricks were provided by the professor. The recipe for the standard brick composition is 30% clay, 30% fine sand, 40% coarse sand and 10% water of the total weight of the dry ingredients. A total of 30 bricks were made, with the prepared mixture and an additional 10% of a different material in 20 bricks. Three different moulds were used to prepare the bricks as shown in image 2. The bricks produced from the different moulds are in the following dimensions: small brick of 11X8X3 cm, medium brick of 13.5X9X4cm and large brick 16.5X10.5X6.5cm (figure 1).

***Image 2**: Different types of moulds, largel, medium,small(left to right)*

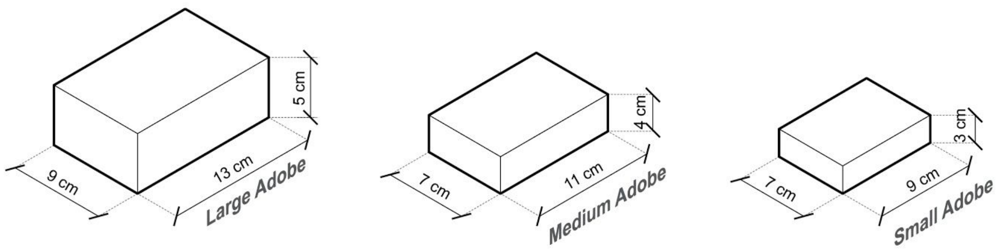


***Figure 1**: Different brick sizes*

The brick making procedure involved a total of five steps (Image 3). While preparing the standard mixture, the proper ratio of each ingredient has to be carefully measured using a weighing machine to prepare a balanced mixture. The density of the clay in the mixture is crucial to avoid excessive shrinkage and crack on drying (Clifton, J. R., & Davis, F. L., 1979).

After, the viscous mixture was combined with an additional material in the required quantity and poured into the mould in layers to ensure uniform spreading and no air gaps. It was important to thoroughly mix all the ingredients together to enhance the binding force of the bricks (Martins, T., 2006). For the variety of sizes, three different moulds were used. The medium size mould was made with a foam core and chopsticks, which was the most efficient to make uniformly shaped bricks.

All the prepared bricks are neatly labelled to identify the material composition during the breaking test.

Image 3: *Steps in brick making*

2.3. Additional materials

The first brick type was made with the standard adobe ingredients. For better comparative results five bricks were made in large size and five in small size.

The second type and the third type of bricks were made adding 10% straw and 10% wood chips respectively to the original mixture. The use of the natural fibers like straw fibres and wood chips into the mixture can improve the binding quality of the mixture, reducing shrinkage and resulting in better compressive strength of the bricks (Mohammed, A. & Bahobail, M., 2011).

For the 4th, 5th and 6th brick type, experimental ingredients like cotton, plastic thread and sponge pieces were used respectively for each batch of three specimens. Cotton is chosen to be experimented with, due to its cultivation possibility within the Zaatari camp. Cotton fibers also have a moderately good tensile strength and it absorbs water easily and is breathable (Zupin, Z., & Dimitrovski, K., 2010).

Synthetic fibers like plastic thread and sponge is chosen due to its cheap price and easy availability. Table 1 shows a cumulative data of the different brick types produced with the different materials.

Brick Type	Standard Composition	Size	Dimension	No. of Specimens	Additional Materials 10%
1	Clay 30% Fine Sand 30% Coarse Sand 40% Water 10% of total dry mixture	Large	16.5 x 10.5 x 6.5	5	N/A
		Small	11 x 8 x 3	5	
2		Medium	13.5 x 9 x 4	5	 Straw
3				5	 Woodchips
4		Small	11 x 8 x 3	3	 Cotton
5				3	 Plastic
6				3	 Sponge

***Table 1**: Different types of bricks produced*

2.4. Method of Strength test

The strength test was conducted at the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. All the bricks were arranged in order according to the composition. Each dried brick was placed on a wooden plank and levelled with a metal plate on top for even load distribution. The metal plate was used only for the bricks with an uneven surface.

The initial state of the brick was photographed. The piston of the Zwick z100 was slowly lowered on the brick with a gradual acceleration in force until the brick breaks, as shown in Image 4. The final state of the bricks was photographed and the maximum load before breakage and the maximum deformation of the brick was recorded using the software testXpert. The process was repeated for all the brick types.

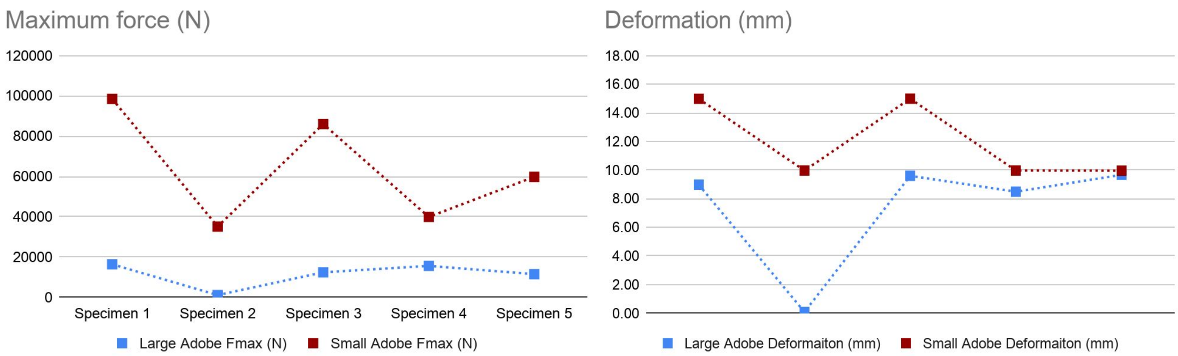
***Image 4**: Steps for strength test*

3. Results (of testing for each category)

3.1. Estimation of ultimate strength per category

a. Large adobe brick vs. small adobe brick

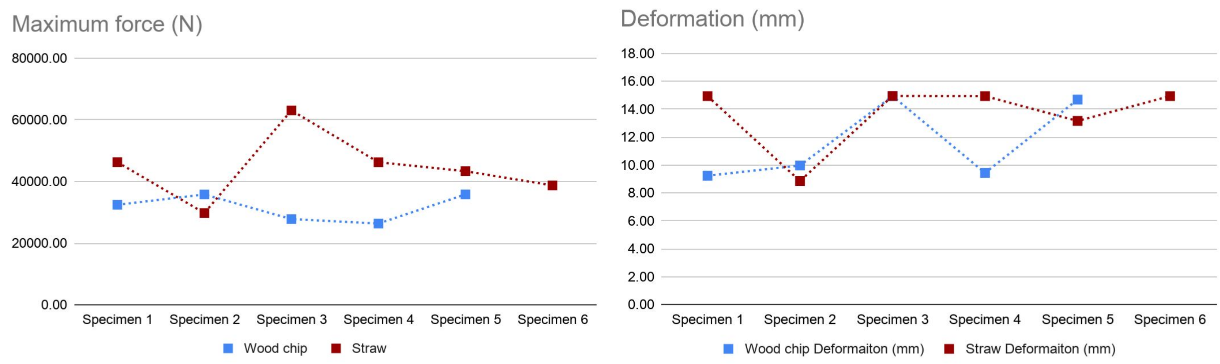
The standard adobe bricks were made in two sizes, five of the specimens in small size and five in large size. The strength of the bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



***Graph 1:** Maximum force on the different standard adobe bricks(left); Maximum deformation of the different standard adobe bricks(right).*

b. Medium adobe wood chip vs. straw

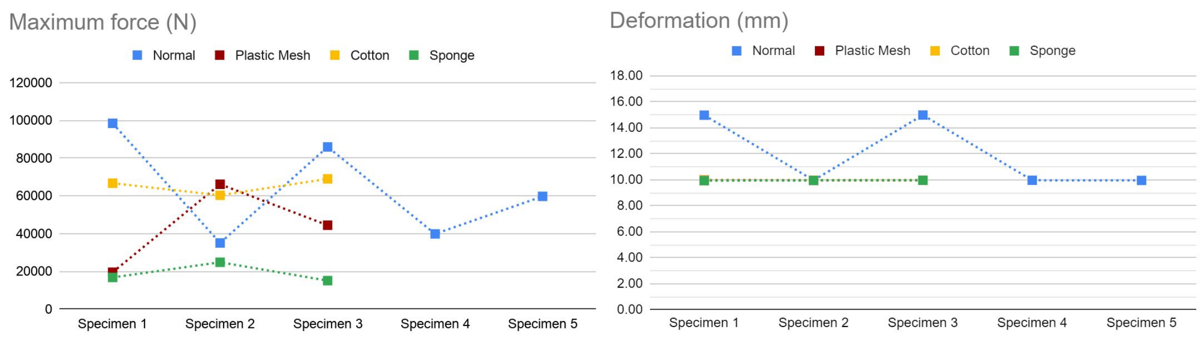
The medium size adobe bricks were made in two batches of five specimens each. The first batch was made with additional 10% straw fibers and the 2nd batch with additional 10% wood chips. The strength of the medium sized adobe bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



Graph 2: *Maximum force on the adobe bricks with straw and wood chips(left); Maximum deformation of the adobe bricks with straw fibers and wood chips(right).*

c. Small adobe normal vs. plastic mesh vs. cotton vs. sponge

The last sets of adobe bricks were made in small sizes. Five specimens of normal adobe bricks were compared with bricks made of 10% additional cotton, plastic mesh and sponge respectively in batches of three. The strength of the small sized bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



Graph 3*: Maximum force on the small adobe bricks with cotton, plastic mesh, sponge and standard adobe(left); Maximum deformation of these adobe bricks(right)*

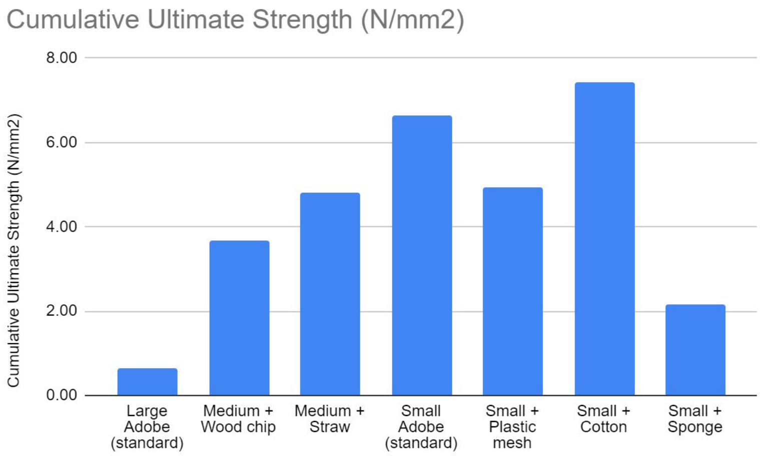
3.2. Estimation of safe design strength per category

The results of the brick breaking test show that most of the bricks undergo an instant breakage due to their brittle behaviour. For all the bricks, with the exception of two or three, the force and deformation at breakage could not be obtained from the experiment.

Thus, looking into the values of the maximum force and the deformation at the maximum force, a safety factor value was considered for obtaining a safe design strength value based on the literature review. As found, with a safety factor of 2.5, the compressive strength values should have a minimum value of 0.34 N/mm2 (Clifton, J. R., & Davis, F. L., 1979). From table 2, it can be seen that the values of compressive strength for the bricks made, lies between 2.61-7.43 N/mm2, that are well above the limit mentioned in the literature. Thus a safety factor of 1.5-2 is feasible to be considered. Also due to the absence of the 1st floor and the absence of any snow load on the roof eliminates the need for a higher safety factor for the limited compressive load on the structure.

3.3. Cumulative Ultimate strength results for the different compositions and dimensions

Graph 4 shows the comparison of the ultimate compressive strength of all the brick samples according to the material composition and different dimensions. The ultimate compressive strength was calculated for each brick type using the average value of the maximum force(N) for each type divided by the area(A) according to the dimension of the bricks, as shown in table 2.



***Graph 4**: Overall bar chart representing the ultimate strength of the different brick types*

3.4. Young's Modulus

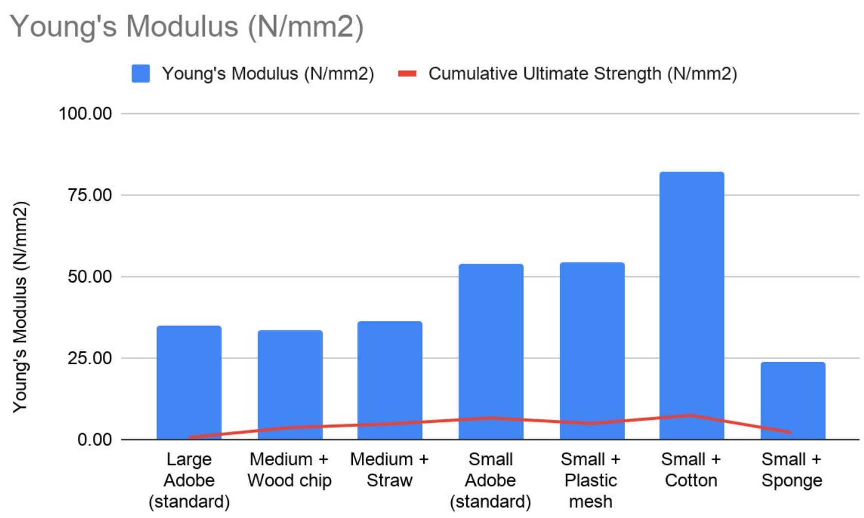
Young's modulus (E) is the material property to measure the change in length under compression or tension (Encyclopedia Britannica, 2019). The average maximum force (N) and average deformation (mm) according to the material composition of each specimen type was calculated.

The values are used to calculate the Young's modulus (E) with the formula E = stress/ strain = (FL) / (A * dL), where F is the applied force, L is the initial length, A is the area, dL is the deformation (Sciencing, 2018), as shown in table 2.

Specimen Type	Area(mm2)	Avg. maximum force (N)	Avg. maximum Deformation (mm)	Young's Modulus (E)(N/mm2)	Compressive strength(N/mm2)
Large adobe	17325	11341.382	7.366	**35.01**	0.65
Small adobe	8800	58312.17	12.48	**54.02**	6.63
Wood chip	12150	31682.28	11.66	**33.37**	2.61
Straw	12150	44592.73	13.63	**36.44**	3.67
Cotton	8800	65397.79	9.98	**81.94**	7.43
Plastic Mesh	8800	43408.75	9.98	**54.41**	4.93
Sponge	8800	18955.03	9.96	**23.8**	2.15

***Table 2**: The average Young's modulus and compressive strength values for the different brick types*

Graph 5 shows the graphical representation of the comparative young's Modulus values for the different brick types.



***Graph 5:** The graphical representation of the average Young's modulus for the different brick types*

4. Discussion of reliability of the data

4.1 Analysis of the result

In this section the results obtained of the brick making experiment will be discussed and compared as per the division established in the section before. The specimens were divided into three main groups, one as a control group with the normal composition of the adobe bricks, the second with the addition of straw and wood chips, and the third one with other experimental additions such as cotton, plastic fibers and sponge.

a. Large adobe brick vs. small adobe brick

The standard adobe bricks were made in two sizes, five of the specimens in small size and five in a large size to obtain a comparative result. Analysing the deformation recorded on both types of specimen, the large adobe specimens showed lower values.

The highest deformation being of around 15 mm and the lowest being 10 mm for the small bricks. The highest deformation for the large bricks being of around 9 mm and the lowest of 0.09 mm deformation. It should be noted that the specimen 2, with the lowest deformation of the large bricks had a low maximum force value, at 1100 N, and showed a brittle behaviour by breaking almost as soon as the test was applied to this specimen (Image 5), thus amounting to a relatively low deformation when compared with the other specimens of the same batch.

The large adobe bricks, as per observation in general showed brittle behaviour and the material seemed to be very dry in its composition.

Image 5. Specimen 2, of the large adobe bricks broke right in the middle.

On the other hand, when comparing the maximum force, the small adobe bricks showed significantly higher values. The Specimen 1 of the small adobe bricks had a maximum force of 98,500 N, being the highest value. While Specimen 1 of the large adobe bricks had its highest maximum force at 16,400 N.

The small specimens also showed the highest deformation, which could mean that other circumstances should be taken into consideration, such as the thickness to length ratio of the bricks.

It has to be considered that, some of the load during the experiment could have been distributed to the wooden slab, when the bricks were tested, due to the slenderness of the small bricks.

Another consideration is the final state of the bricks after the test was done. Both types of specimens (small and large) were completely destroyed by the end of each test as shown in the images below.

Image 6. *Left, large adobe brick broken example. Right, small adobe brick broken example.*

b. Medium adobe wood chip vs. straw

The medium size adobe bricks were made in two batches of five specimens. The first batch contained additional 10% straw fibers and the second batch was made with additional 10% wood chips.

Looking at the deformation found in both types of bricks, the highest deformation was around 15 mm for both of them, and the lowest deformation was around 9 mm also for both of them.

Since they behaved in similar ways in the deformation, further analysis on the maximum force was done. The highest maximum force was obtained by the specimen 3 from straw, with 63,061 N, and the lowest at 26,408 N from woodchip.

On average the straw bricks had a better behavior than the wood chip bricks. Image 6 also shows the two bricks that performed the best at the end of the test, comparing the different types, the woodchip bricks crumbled into smaller pieces, whilst the straw bricks crumbled in thin slabs and stayed tighter and closer together when taken to their breaking point.

Image 7. *Left, wood chips adobe brick broken example. Right, straw adobe broken example.*

c. Small adobe normal vs. plastic mesh vs. cotton vs. sponge

The last sets of adobe bricks were made in small sizes. Five specimens of normal adobe bricks were compared with bricks made of 10% additional cotton, plastic mesh and sponge respectively in batches of three.

During the testing of these smaller specimens, an unknown problem with the machine was encountered, meaning that not all the data was obtained and recorded for some of the specimens.

Comparing the deformation of the two available types of brick, the bricks with sponge showed lower deformation values (10 mm) than the control bricks with the normal composition (max. 15 mm).

Nonetheless, some discussion can be made by observing the image 7, once the test was applied. The least deformed brick was the cotton, followed by the sponge, then the plastic and finally the normal brick, which showed the most deformation of the four types.

The addition of different components caused a bridging effect that holds together the soil and so they still seem intact even after they've reached their failure point, probably amounting to a better ductile behavior.

Image 8. *Left to right: cotton, sponge, plastic and normal examples.*

On the maximum force the bricks could withstand, the highest values were obtained by the brick with the normal composition of adobe, though the three cotton specimens tested were also amongst the highest values and had a stable behaviour. As seen on Graph 3, both the cotton and sponge had more stable values, whereas the normal brick and the one with plastic mesh as additive had sudden jumps on values, depending on the test performed.

d. Comparison of all types of specimens.

Comparing the performance of each type of brick depending on the size, as seen on Graph 4, shows that the smaller specimens had better results. The medium and small specimens had a cumulative ultimate strength of above 2.00 N/mm2. The large adobe brick had a cumulative ultimate strength of 0.66 N/mm2.

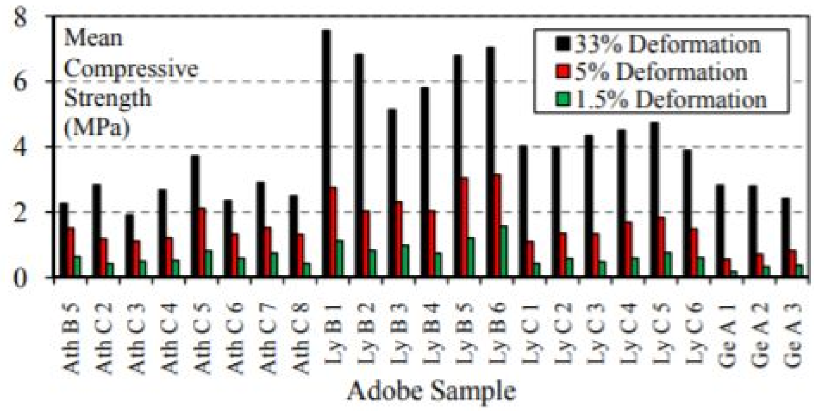
The greatest performance in terms of the Young's Modulus, compressive strength and ultimate strength were found in the small adobe bricks with the normal composition and the small brick with cotton addition, as well as the medium brick with straw addition.

Among these three types, the cotton brick showed the least average deformation, of 9.98 mm. The cotton bricks had an average Young's Modulus of

81.94 N/mm2 (table 2), relatively higher than the straw and normal bricks. On the other hand, it should be mentioned that the thickness of the small specimens could be crucial to these results, since part of their good performance could be awarded to the wooden slab where they were tested absorbing part of the loads.

4.2 Comparison with standard/other source strength values

In a study of the mechanical behaviour of adobe mansory of the University of Cyprus (Illampas R., Ioannou I., & Charmpis D., 2011), the specimens with higher deformation percentage also had the highest compressive strength. The compressive strengths varying from 0.5 N/mm2 to almost 8.0 N/mm2, similar to the values obtained and discussed previously, giving reliability to the results (These bricks had a 5 x 10 x 10 cm dimension).



***Graph 6**. Mean values of compressive strength. At least four specimens from each brick were tested. (Illampas, R. , 2011)*

Another research that studies adobe's mechanical properties from the University of Aveiro tested two different types of walls with compressive strength ranging from 0.82 N/mm2 to 0.95 N/mm2. The average Young's Modulus was 117.3 N/mm2 and 138.3 N/mm2 for the two different types tested, much higher than the ones calculated from the specimens tested in this experiment.

In an experiment done by the Czech Technical University in Prague (Gubasheva S., 2017), the results on the compression test show a range in the Young Modulus from 98 N/mm2 to 211 N/mm2, also higher than the values obtained in the experiment, and an average of 2.88 N/mm2 of compressive strength . Other findings from this author shows that only the full earth large bricks visibly cracked even before doing the tests, and some further observations on the addition of other materials such as straw conclude that it helps in the behaviour of produced large bricks.

4.3 Reliability and Limitations

To ensure scientific rigour five specimens of each type were built so a proper comparison was possible. Comparison with values found in literature and other research papers was also conducted to evaluate the reliability of the results.

One of the limitations of this study was that the brick were measured when they were made and not after they got dry, which some studies explain that the shrinkage on the brick between this two steps affects it mechanical properties.

Another limitation was the sudden jumps on values could be due to inconsistencies by human error when mixing and doing the mix. Also the even distribution of the additives could be a factor affecting the results.

There was also a problem during the compression test of the small bricks, due to the small thickness, various times, the machine was not able to record the deformation value and only the failure strength was shown. So lack of reliability on the machine could compromise the results found. It is also possible that the wooden slab used for supporting the bricks absorbed part of the force applied to the bricks, amounting to higher values for the small bricks.

Finally, the amount of bricks tested were too little to be able to draw concrete conclusions from the specimens.

5. Conclusions

The test on the adobe bricks revealed that the mechanical properties of the material display great variation depending on the size of the brick and if additional materials are added to the original composition of the adobe mixture.

The larger bricks showed brittle behaviour and performed the worst when compared to the other specimens tested. Among the small bricks the one with sponge had the worst results and the one with cotton had the best results. On the other hand, among the medium bricks the straw ones had the least deformation and the highest Young’s Modulus; these bricks also looked fairly intact by the end of the test. Comparing all these results, the use of straw as an additive could increase the overall performance of the adobe bricks if a larger brick is desired. For the application of these values on the structural analysis, the values found comparable with the literature were taken for a reliable structural performance. An average of 150 MPa for the Young's Modulus will be used, and a compressive strength limit of 2.6 N/mm2. The safety factor taken into account is 2 based on the literature as mentioned before.

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