

ENGINEERED PRACTICES OF ADOBE MASONRY PRODUCTION IN ZIWAY, ETHIOPIA

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ABSTRACT

A non-engineered production practice of adobe-blocks prevails in southern Ethiopia around Ziway, which are used for rural housing. These blocks have a compressive strength of less than 1 MPa and exhibit deformed shape due to excess water and non-uniform distribution of teff straw during mixing. The objective of this research was to advocate a better practice to enhance the strength of adobe masonry unit.

Tests were conducted on the soil samples for its suitability to produce adobe masonry units. Pumice aggregate and teff straw were used as additives. Compressive and flexural strength values observed for brick size specimens with 9% of pumice aggregate and 0.4% of teff straw content were 2.6MPa and 0.36MPa respectively. These values have passed the minimum requirement of California Building Code which is considered as standard for the present research. Whereas block size specimens showed compressive strength values less than the minimum requirement. Hence brick size was recommended to use in practice, over block size.

Unit cost was considered affordable as the cost of pumice and teff straw used per unit was extremely low in value. Also around 60% cost reduction was observed when adobe units were used instead of Hollow Concrete Blocks for masonry construction.

Keywords: adobe block, adobe brick, masonry unit, pumice aggregate, teff straw

INTRODUCTION

Natural materials for construction, if used directly without any process in industry, are eco-friendly, energy saving recyclable and bio-degradable. By using natural basic ingredients and by spending human energy, construction materials like un-burnt bricks can easily be produced as a low cost material which avoids carbon emission problems too [1]. Un-burnt bricks made out of earth crust, commonly called as adobe bricks possess advantage of reusing when demolished, require very low embodied energy to produce [2] and can be one of the substitutes for masonry building materials, such as Hollow Concrete Block which is manufactured by consuming greater energy.

Problem undertaken

Adobe block as masonry material, for rural house constructions, is widely used in southern Ethiopia, around places like Ziway, Meki, Alemtena, Adama/Nazereth etc. Field practices showed some flaws in the way of production that could reduce the strength of the blocks. Greater quantity of water is being used for pugging and casting that reduces density and increases shrinkage. This ultimately lowers the strength of individual unit. Uneven hand compaction and lateral bulging of wet mix after removal of mold result in distorted shape of the masonry unit. Moreover, the only additive that is being in use is teff straw, that too in a very insignificant percentage with non-uniform dispersion in the total mass which does not prove anything good as an ingredient. Hence, the core idea of the study was developed to address the practicing people to follow an engineered way of production of adobe

masonry units. For enhancing the properties of adobe unit, natural additive in addition to teff straw was used with a control over water content while mixing and casting. Attention was given that the additives selected should not increase the unit cost substantially.

Background

All over the world the practice of adobe brick masonry for rural housing is quite common since many thousands of years. During the past century, attempts were made to improve the strength and durability properties of earth made wall materials such as bricks and blocks in many facet like additives inclusion, method of compacting, etc. Un-burnt mud brick produced by human labors is called adobe, if it is pressurized to get better density, it is called as compressed earth block. If compacted by ramming, it is said as rammed earth block, if cement is used to increase strength, it is called stabilized brick/block and if it is produced by extrusion, it is green brick [3,4]. Works with banana fibers in stabilized compressed earth blocks resulted in a maximum compressive strength of 6.58MPa in Egypt [5]. Soil of Karamara near Jijiga in Ethiopia, when stabilized by addition of 10 % cement, exhibited an average compressive strength of 4.633MPa [6]. Asmamaw Tadege [7] in Addis Ababa Institute of Technology, Ethiopia had experimented on cement stabilized compressed blocks to give a maximum of 5.03MPa compressive strength at 56 days. The compressive strength of hydrated high calcium lime stabilized bricks of Sudan exhibited a maximum of around 8MPa [8]. Rammed earth blocks with 20% fly ash showed compressive strength of 0.77MPa [9] while, adobe bricks with bagasse tested in Thailand were observed to have compressive strength as high as 3MPa [10]. There were works done with additives like cow-dung, coir fibre, rice husk, etc. Out of all the above procedures, adobe brick consumes less energy for

production and proves cost effective as it avoids ramming mechanically, pressurizing by motor, stabilizing by cement or extruding by some power.

METHODOLOGY

The study consisted of two major parts one, the field practice investigations and the other, laboratory investigations. Investigations were conducted on the field practices that are being followed in the production of adobe masonry units in Ziway, Meki and Alemtena areas of southern Ethiopia. The field practice investigations constituted field observations, field tests, laboratory tests and measurements. As part of field practice investigations, the places where adobe blocks are being produced were visited at different trips, production processes were observed, adobe block specimens were collected for laboratory tests and site measurements wherever required were taken. During such site visits, soil and pumice material for laboratory investigations were collected.

In the laboratory, soil suitability and characterization tests, shrinkage tests, compression and flexural strength tests of brick size and block size specimens, water content tests, optimum moisture content determination and durability test on rain were performed.

Additives and their availability: Pumice and teff straw were used as additives to enhance the properties of the masonry units. Pumice is a volcanic rock, which is light in weight, adequate in compressive strength, inert ($\text{pH} \approx 7.2$) and has rough porous texture. It has specific gravity less than one but possesses good thermal and sound insulating properties. A greater volume of pumice resources is found on Modjo to Adami-Tulu stretch in Ethiopia. These resources are naturally available in abundance in the study area [11]. Cost of one cubic meter of pumice is around eighty Ethiopian Birr and the quantity required for one masonry unit is very

meager. Therefore, it is considered to be affordable if used in the adobe masonry unit.

It is customary, wherever adobe bricks are produced, to use straw or husk for shrinkage crack reduction, however, teff straw is used in Ethiopia. Teff is cultivated in plenty as it is the major food crop in Ethiopia and teff straw is a by-product which is abundant and of less cost. Hence, it was intended to use the same as an additive in the present research too.

Tests on block size and brick size adobe specimens: For the strength tests, adobe block specimens collected from the field of practice in Ziway were considered as control specimens. They were 40cm*20cm*20cm in size. The control specimens were found to have an average teff straw percentage of 0.1 by weight.

The main variables considered in the experimental scheme were percentage weights of teff straw and pumice aggregate in total weight of the adobe unit and the size of adobe unit. The percentage weights of teff straw was varied from 0.1% to 0.5% in steps of 0.1%. Specimens with 0.05% teff straw were also cast as a percentage value lesser than that of control specimens. Having the optimum percentage of teff straw content that gives maximum compressive strength as constant, pumice percentage was varied from 3% to 12% in steps of 3% based on the dispersion of pumice in the mud mass in certain proportion. For compressive strength determination, specimens of block size, i.e. 40cm*20cm*15cm and brick size, i.e. 30cm*15cm*10cm were casted. Aggregate passing 20 mm sieve and retained in 10mm sieve was used for blocks size specimens and that passing 10 mm sieve and retained in 4.75mm was used for bricks size specimens. Number of specimens cast for compression strength and flexural strength tests are as shown in the Table 1, and 2 respectively.

As the performance of brick size specimens were better, only brick size specimens were cast for flexural strength test. To assure durability, direct test on rain was performed by exposing specimens to rain. For the durability test on rain, three specimens for each sizes, totally of 6 specimens were casted.

Table 1. Variables and number of specimens for compression test

Specimen Designation	Teff straw content %	Pumice content %	Number of specimens
*Blo1	0.05	0	6
Blo2	0.1	0	6
Blo3	0.2	0	6
Blo4	0.3	0	6
Blo5	0.4	0	6
Blo6	0.5	0	6
**Bri1	0.05	0	6
Bri2	0.1	0	6
Bri3	0.2	0	6
Bri4	0.3	0	6
Bri5	0.4	0	6
Bri6	0.5	0	6
Blo7	0.4	3	6
Blo8	0.4	6	6
Blo9	0.4	9	6
Blo10	0.4	12	6
Bri7	0.4	3	6
Bri8	0.4	6	6
Bri9	0.4	9	6
Bri10	0.4	12	6
Total			120

*Adobe Block, **Adobe Brick

Table 2. Number of specimens for flexural test

Specimen Designation	Teff straw content %	Pumice content %	Number of specimens
Bri11	0.05	0	6
Bri12	0.1	0	6
Bri13	0.2	0	6
Bri14	0.3	0	6
Bri15	0.4	0	6
Bri16	0.5	0	6
Bri17	0.4	3	6
Bri18	0.4	6	6
Bri19	0.4	9	6
Bri20	0.4	12	6
Total			60

Water-soil ratio: Water-soil ratio required for the mix was ascertained based on two criteria viz., optimum moisture content (OMC) to obtain maximum density and

workability. Standard Proctor compaction test was used to confirm the OMC required to obtain maximum density and thereby to finalize the water content required for the workable mix used for masonry unit production.

RESULTS AND DISCUSSION

Field Practice Investigation

Adobe block production practices in the surrounding areas of Ziway, Meki and Alemtena are indigenous, without any consideration of standards to ascertain strength and suitability. The soil used for adobe blocks is the crust soil which is mostly silty with clay between 10% and 15%, which agrees with the finding of Beza Tesfaye[12].

Since the block size being large the weight of an individual unit becomes more than 15kg which is too heavy to handle while construction of masonry walls. Also the block production is non-engineered in a sense that more water is added than what is required for attaining better density. Addition of more water and haphazard hand compaction result in low density, high shrinkage upon drying and distorted shape of the adobe block, even though higher water content facilitates easiness in casting. Due to these reasons the compressive strength of individual units become less than 1MPa as shown in Table 3. Freshly cast blocks show lateral bulging due to use of excess quantity of water thereby creating unevenness in the courses of masonry as well as in vertical surfaces of walls. As it is shown in Table 3, the compressive strength of the adobe blocks ranges from 0.447 to 0.708 MPa, which is less than the minimum requirement of strength as per California Building Code (CBC) [13] standard. Reasons for such poor results in compressive strength test were due to poor hand compaction and excessive water used. It was believed that, usage of teff straw can be increased so as to increase the strength and decrease shrinkage. However, teff straw percentage

was found to be insignificant in all the specimens tested. The strength reduction could possibly be because of insufficient quantity and non-uniform dispersion of the straw in the soil mass.

Table 3 Tests on adobe block specimens collected from the field practice in Ziway

No.	Weight (kg)	Compressive strength (MPa)	Teff straw (%)	Moisture content during testing (%)	Shrinkage based on length reduction (%)
1	15.3	0.447	0.125	3.2	3.75
2	16.1	0.708	0.099	3.1	3.6
3	15.5	0.628	0.102	2.9	3.64
4	15.9	0.566	0.115	3.3	3.62
5	15.6	0.645	0.098	3.2	3.64
6	16.0	0.612	0.088	3.2	3.6
Average	15.7	0.601	0.104	3.15	3.64

The length reduction due to shrinkage was taken based on the mold size used by the local people and the actual length of the casted block after dried. Shrinkage percentage compared to the mold length was on an average of 3.64% which is acceptable based on the maximum limit of 10% as per Houben and Guillaud, [14]. Moreover, the moisture retention during usage of the block was on an average 3.15% which is acceptable as it is within the maximum permissible limit of 4.0% as per CBC standards [13]. Hence, the moisture content at usage and average shrinkage of the block in the local practice were found acceptable.

The present research is thus aimed to show alternative solution to overcome the said drawbacks and to improve the properties of adobe block manufactured in the current

practices without significant increase in production cost.

LABORATORY INVESTIGATIONS

Strength enhancing measures: Strength enhancing measures considered in this study include: reduction of block size to brick size, addition of optimum quantity of pumice and teff straw, addition of correctly calculated quantity of water.

Soil suitability and characterization: Usually, the suitability of soil for the production of adobe masonry units is decided based on the percentage of ingredients of soil such as clay, silt and sand. Rough examinations on dry strength and ingredients content were assessed, as preliminary examinations, by dry strength test, adhesion test, roll test and sedimentation test. To confirm the soil type, Atterberg's limit tests and particle size distribution tests were conducted. Based on the American Society for Testing Materials (ASTM) soil classification chart, the soil type identification was finalized.

By dry strength test, it can be concluded that the soil is suitable for adobe masonry unit production, when dry soil balls of 2cm diameter are not able to be broken by pressing in between index finger and thumb [15]. Samples tested that way were strong enough not to get broken.

In adhesion test, a ball of moist soil when penetrated by a spatula, exhibited less resistance to the penetration without any difficulty but grubby upon withdrawal and thus the sample was considered to be of low clay content. On the other hand, if the ball of soil shows greater resistance for penetration and if clay particles are able to adhere in the lateral surface of the spatula, soil should be considered to have high clay content [8,14].

In roll test, when a ball of moist soil was rolled to a thread of 3mm diameter and subsequently flattened between thumb and

index finger to form a ribbon of width between 3mm and 6mm, it showed about 9cm length before it broke. This indicated that the soil contained less clay content. As per roll test, if the ribbon length is between 5cm and 10cm, soil has less clay content and if ribbon length is between 25cm to 30cm, soil has high clay content [8,14].

Sedimentation test, called jar test, was done by saturating the soil mass in a measuring jar and allowing the soil particles to settle down in layers for 48 hours. Sedimentation test result was observed for the sample to have 15% clay content, 35% silt content and 50% sand content. According to Wilson [16], the optimum percentage of clay content in brick earth shall be around 30%, silt and sand together shall become the remaining 70%. VSBK-CESEF [17], recommend in a range that clay 20% to 35%, silt 25% to 45% and sand 20% to 45%. Whereas, according to WikiHow [18], both sand and clay content shall be greater than 33.33%. There is no perfect consistency in the soil ingredient percentage as recommended by different organizations/experts, rather there could be a common understanding that clay percentage, if high, can cause greater shrinkage and subsequent shrinkage cracks, and if it is low, cohesive property of soil may be less but will not show excessive shrinkage and could avoid cracks. This shows that the soil of the study area is suitable to produce adobe masonry unit.

Soil Classification: Apart from these preliminary tests, Atterberg limits and particle size distribution analysis by dry and wet methods, were used to determine the soil classification. Results of Atterberg limit test showed that the soil has liquid limit (LL) of 30.88, plastic limit (PL) of 28.13 and plastic index (PI) of 2.76. Moreover, from the particles size distribution analysis using wet sieving, the percentage passing through sieve number 200 is greater than 51%. Based on the

unified soil classification system chart [19] the soil classification was found inorganic sandy silt of medium compressibility, as it is exhibiting PI value of less than 4. One of the important parameters influencing the soil compression strength, i.e. the specific gravity of the soil was found 2.5, which is close to the standard limits for specific gravity as mentioned in text books, for ‘silt with sand’ category [20].

Shrinkage test: Shrinkage of soil sample after drying was done to check whether it is within the tolerable limit. For this test, 4cm*4cm*60cm mold was filled with wet sample, hand compacted and allowed to dry for seven days. The specimens showed a shrinkage of 1.8cm reduction in length after 7 days drying which becomes 3% of length of the mold, while allowable limit is less than 10% of the length of mold [14]. The shrinkage percentage is less than that of the shrinkage shown by the specimens collected from field practice.

Water content for mixing: As per the standard proctor compaction test, OMC was found as 23.2%. (Fig. 1). Hence, the

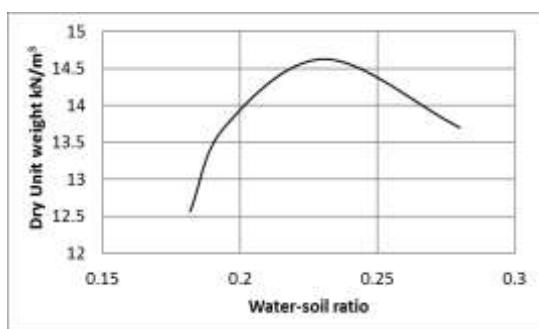


Figure 1: Proctor compaction test results

water content to be added to the specimen preparation was fixed as 25% as it gave a better lower limit of workability. The percentage of water that created bulging of lateral dimensions was as high as 35%.

Moisture content test: The moisture content at the time of testing was found to be on an average 3.2% for brick and block specimens. This is very low value of moisture retention after drying and solidification of blocks and bricks. As per

CBC [13], adobe units shall have moisture content not exceeding 4% by weight. Having this as reference, moisture retention in the specimens cast was considered to be within the tolerable limit.

Compression test: The compression test results of block and brick specimens showed that adobe bricks have better compressive strength compared to adobe blocks (Fig. 2).

The compressive strength of both adobe brick and adobe block has a positive response to teff straw, however, the response was considerable in case of adobe block than adobe brick. The increase in percentage of teff straw showed same compressive strength, for both block and brick, beyond 0.4%.

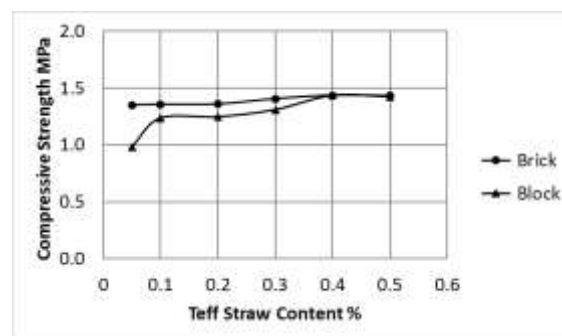


Figure 2: Compression strength of adobe brick and block with teff straw

Hence, taking the optimum value of 0.4% teff straw as a constant, compressive strength test was conducted for different percentage of pumice aggregate for both the adobe block and bricks. The adobe bricks show better compressive strength of more than 2.5MPa (Fig 3). The failure of block size specimens happened earlier than that of brick size specimens. This could be due to the splitting failure planes in the middle portion of the thickness of specimen being more. Whereas in case of less thick brick size specimens, the shear developed between the surfaces of specimen and platen reduce the formation of splitting failure planes in the central core part of the specimens [21].

Because the soil is sandy silt, the bond capacity was less (even though the density

was better), and the specimens showed low values of compression strength, in general. Both the adobe brick and block had a positive response to the increased percentages of pumice. The response of adobe brick is still significant as compared to adobe block. However, the compressive strength attained by both, except the brick specimens with 9% and 12% pumice aggregate, and with optimum teff straw percentage, were below the minimum requirement of compressive strength of 2.06MPa with reference to CBC [13].

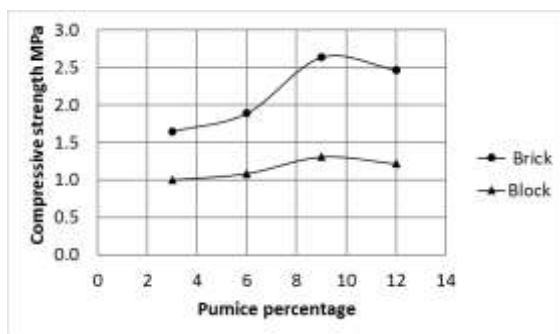


Figure 3: Compression strength of adobe brick and block with pumice and 0.4% teff straw

In general, the performance of silty, less cohesive soil of Ziway had been found to increase with both of the additives used. The optimum percentage of pumice to attain maximum compressive strength with an optimal teff straw content is 9%, which showed that with increased percentage of pumice, the compressive strength was increasing up to the addition of 9% pumice, and show a decreasing trend thereafter. This could be due to the irregular, rough textured surfaces of pumice that enable it to have increased bonding capacity of the mixture as a whole. The cohesion property of silty nature of soil had not contributed much for compressive strength as in the case of specimens without pumice aggregate. The reason for the decrease in compressive strength beyond 9% increment of pumice could be because the clay as a binding agent became considerably lower in the

total mass and also due to the presence of highly denser aggregate percent.

Due to the effect of platen shear at the interface between steel platens of the compression tester and mud block/brick being dominating, the strength shown by bricks is greater than the strength shown by block specimens [21]. The block specimens failed due to splitting of failure planes in the vertical and in steep inclined directions at the mid height of specimens due to its greater thickness. Hence the failure of blocks was at lower load values. Satisfactory failure patterns similar to the concrete cube specimens were observed in almost all the brick and block specimens after the test (Fig 4). All four exposed surfaces cracked approximately equally with little damage to the faces in contact with the platens [22].



Figure 4: Failure pattern of adobe brick at the end of compression test

Flexure test: The flexure tests were conducted on the adobe brick specimens with the same variations in teff straw and pumice percentages as that of compression tests. The result showed, that every increment of pumice percentage improves the flexural strength of the adobe brick when compared to the adobe brick without pumice. Despite this the flexural strength was below the threshold under all level of pumice except 0.9% (Fig. 5 and 6) with reference to the CBC [13], which is 0.35MPa. The mix proportion that gave maximum compressive strength (0.4% teff straw and 0.9% pumice aggregate) also resulted in maximum modulus of rupture

of 0.36 MPa which is greater than the minimum required modulus of rupture value as per CBC [13].

Durability test on rain: Generally, the durability of un-burnt mud bricks based on water absorption need not be checked if it is plastered [4]. Moreover, it may show disintegration after immersion in water even for half an hour. But rain as it occurs, the test was conducted as a direct field test

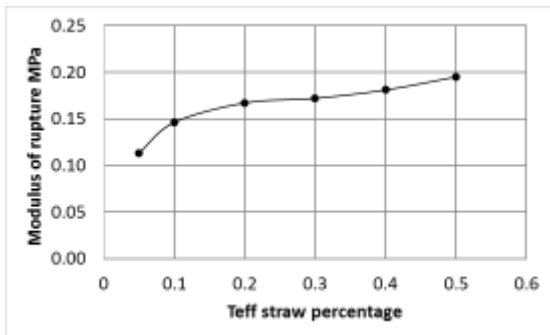


Figure 5: Modulus of rupture variation with different teff straw percentages

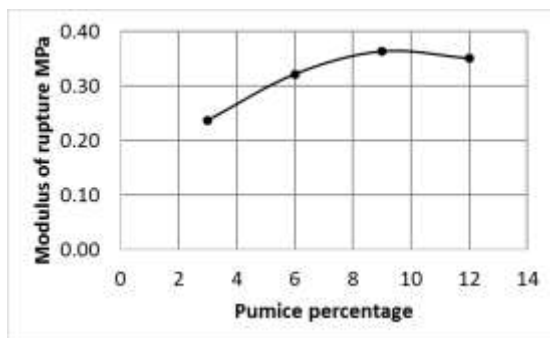


Figure 6: Modulus of rupture of adobe brick with pumice aggregate and 0.4% teff straw and effects were observed.

The mud blocks were kept in rain for two weeks and the effects were observed as seen in the photo shown in figure 7. The rain occurred almost every day at least for an hour. Usually there won't be a continuous rain more than one to two hours in these localities. After two weeks' exposure to rain, the samples show less than 10 mm erosion which could be considered as less than the thickness of plaster.

Hence the effect was considered to be not of much deteriorating. If plastering is applied on the bricks the abrasive effect of water on adobe bricks is negligible. If the plastering is done in cement mortar, the question of erosion is absolutely nil

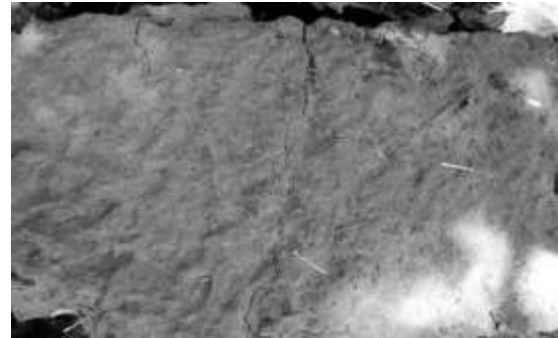


Figure 7: Adobe brick exposed to normal seasonal rain fall after 2 weeks

COST ANALYSIS

The cost of production of bricks/blocks was determined based on the current market prices of materials and labors. For calculating the cost of soil for one masonry unit, the loose volume required for the volume of masonry unit could be used based on guidelines given by Burch [23]. Thereby, having the cost of one truck of soil, the cost of soil for one brick could be calculated. The number of masonry units that could be cast on one day could be approximated thereby based on the labor cost per day, the cost of labor for the production of one block/brick could be calculated. Having the weight of pumice aggregate required for one masonry unit, the unit weight of pumice and the cost of one truck of pumice, with some contingency cost overrun, the cost of pumice required for one unit of masonry could be calculated. Mud blocks/bricks seems to be a cheaper material when compared to hollow concrete blocks which are the present days' largely used material for walls. Table 4 shows the cost calculation.

7.5 cents and 15 cents increase for the cost of teff straw for bricks and blocks, respectively, as the calculation shows is very meager amount.

Also the cost of walls of a small service house of 3 rooms with Hollow Concrete Block and with adobe units was calculated. Hollow Concrete Block is the commonly used wall making material in any building

in the study area. Burnt bricks are not all in practice. Hence Hollow Concrete Block is considered as a counterpart for the adobe bricks under research.

Table 4: Cost calculation

S.No.	Particulars	Adobe Brick	Adobe Block
1	Unit Volume (m ³)	0.0045	0.012
2	Loose volume of soil/unit (m ³)	0.00594	0.01584
3	Volume of one truck soil (m ³)	10	10
4	No. of units/truck soil	1683	631
5	Cost of soil/unit brick or block (Birr)	0.375	1
6	Labor cost/ unit (Birr)	0.75	1.00
7	Weight of one unit (kg)	5.8	12
8	Weight of 9% of pumice	0.522	1.08
9	Weight of pumice/unit	0.54	1.17
10	Cost of pumice / unit (Birr)	0.000062	0.000133
11	Total cost of one unit (Birr)	1.125062	2.000133
12	Total cost of one unit (Birr)	1.20	2.15

The number of Hollow Concrete Block required for 1m² is 13 pieces, and on an average the current cost of a single Hollow Concrete Block at Hawassa is 8birr. Hence, the average cost of Hollow Concrete Block required per unit area is 104 Birr. Whereas, the number of adobe brick required per square meter is 30 pieces and the cost of single adobe brick is 1.2 Birr as determined in this study (Table 4). Therefore, the cost per unit area of adobe brick 36 Birr. In the same way the adobe block cost per unit area is calculated to be 45.15 Birr.

Therefore, the percentage of cost reduction in purchase of both bricks and blocks are found to be 65.37% and 56.56% respectively as compared to Hollow Concrete Block. The cost reduction for

both case (adobe bricks and adobe blocks) are more than double as compared to the unit cost of Hollow Concrete Block. The unit cost of adobe brick is still better than adobe block, which is obvious that the thickness is smaller than adobe block.

COMPARATIVE STATEMENT OF FIELD PRACTICE AND LAB INVESTIGATIONS

The comparative statement, as shown in Table 5, explains the defects in the field practice of Ziway and remedial measures that could be taken up based on the laboratory investigations. The differences between field practice and laboratory investigations, with respect to additives and water soil ratio used, way of production, effects observed after molding and drying, optimum percentages of additives, strength attainment and cost are highlighted in this section

Table 5: Comparative statement of field practice and laboratory investigation

No.	Particulars	Field practice	Laboratory investigation
1	Base Material	Crust soil	Crust soil
2	Additives	Teff straw + Water	Teff straw + Pumice + Water
3	Water soil ratio	Not maintained	0.25
4	Compaction	Haphazard Hand Compaction	Careful Hand Compaction
5	Mixing	By Shovel	By Trowel and hand
6	Shape	Uneven shape due to lateral bulging	Shape maintained due to controlled water content
7	Density	Randomly obtained	Maximum density obtained due to controlled water content
8	Size	Block size: (40cm*20cm*20cm)	Suggested size is brick size: (30cm*15cm*10cm)
9	Average weight/unit	> 15kg (block)	5.8 kg (brick) – reduced due to pumice addition and size reduction
10	Ease of handling	Difficult as it is heavy	Easy as it is lighter
11	Teff straw %	Randomly used on an average of 0.1%	Optimum Teff straw % - found out as 0.4% by weight of the unit
12	Optimum Pumice content	Nil	9% by weight of the unit
13	Compressive strength	0.6 MPa	2.6 MPa obtained for optimum percentages of additives
14	Compressive strength Code compliance as per CBC(2013)	Not satisfactory	Minimum required is 2.06MPa (300psi) Obtained is 2.6 MPa - Satisfactory
15	Flexural strength MPa	Not conducted	0.36
16	Flexural strength Code compliance as per CBC(2013)	Not applicable	Minimum required is 0.35MPa (50psi) – Obtained is 0.36 MPa - Satisfactory
17	Unit cost	Birr2.0 (for 0.016m ³) Produced and sold by house members (Unpaid labor) Birr 0.5625 for 0.0045 m ³	Birr1.2 (for 0.0045m ³) – with labor cost included Birr0.45 (for 0.0045m ³) – without labor cost

CONCLUSIONS

As the use of adobe blocks in rural constructions is a common practice in many parts of the country including some towns in rural pockets (like Ziway town), improving the quality of adobe is of paramount importance. The quality of adobe masonry units produced and used in the field practice was found to be non-engineered. To address this objective, the soil sample from Ziway town was collected and adobe bricks and adobe blocks of different mix ratios with additives such as teff straw and pumice aggregate were tested for their performance and the following conclusions were derived.

The compressive and flexural strength of adobe brick made of soil from the study area with additive of 0.4% Teff straw, 9% pumice aggregate and with workable water soil ratio of 0.25 was improved. With these level of additives, the brick specimens showed a maximum compressive strength value equal to 2.6 MPa which is more than four folds of the control specimens value (0.601 MPa) and with maximum modulus of rupture value of 0.36 MPa. Moreover, the compressive strength (2.6 MPa) of the adobe brick was found to fulfill the minimum requirement as per CBC [13].

The adobe brick and adobe block exhibit good rectangular prism shape when the workable water soil ratio of 0.25 was used. Moreover, the shrinkage property exhibited by the specimens was within the tolerable limits; which confirm suitability of the soil for brick production.

Cost of one brick was estimated to be birr. 1.20 inclusive of labor which is quite cheaper and affordable for the rural community. Percentage reduction in cost of bricks and blocks was amounting around 60% when compared to HCB purchase.

In general adobe block size specimens showed less strength values, therefore, adobe bricks size can be the best option rather than adobe blocks. Adobe bricks can be easy to mold and handle after drying when compared to adobe blocks. Weight reduction is also considerable with bricks due to pumice addition.

RECOMMENDATIONS

In the field of practice in Ziway it could be recommended that pumice aggregate of 9% by weight of total block along with 0.4% teff straw can be added to achieve maximum strength. It is recommended to use 25% water content which could give good workability, density and avoid excessive shrinkage at drying and deformation.

The adobe brick is suitable for partition walls too, as they are not exposed to severe moisture variations.

As an extension to the present work, the effect of pumice material with wide range of aggregate sizes on the strength of adobe bricks may be studied to examine whether strength enhancement is possible further more.

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