Improving the Strength of Adobe Units Using Eragrostis Teff Straw Fiber for Sustainable Construction, Wolaita Sodo, Ethiopia

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Abstract

The traditional rural house construction technique in Ethiopia, especially in Wolaita Sodo uses a lot of wood from the forests. A lot of woods taken from the forests lead to deforestation and causes global warming. And also, the modern construction material and techniques have gained some popularity in the rural areas; however, because of the high cost of modern construction materials like cement, aggregates, reinforcement bar and bricks, etc. many can't afford it. To mitigate the risk of deforestation along with using a sustainable approach for building rural houses, Adobe houses perhaps can be the best-suited solution. Eragrostis teff straw is an agro-waste and abundantly available in Ethiopia has been considered to be used as fibers in the current research. The main objective of this research is providing a sustainable method of building rural adobe houses in the WolaitaSodo, Ethiopia, by utilizing the locally available fibers and binders for a better strength with a reduced cost of construction. So that, an attempt has been made to use a suitable binder of optimum quantity and locally available natural fibers of Eragrostis teff in different percentages to prepare various mixes of adobe units and test their strength properties. A total of 144 cubical adobe unit samples was prepared and tested according to different code of standards. The experimental tests conducted for clay soils are grain size analysis, Atterberg limit, natural moisture content, specific gravity and compaction tests, for Eragrostis teff straw fiber specific gravity, natural moisture content and water absorption for different hours, and strength (compressive and water strength) tests. Experimental investigations were carried out by using Eragrostis teff straw fiber reinforced and cement stabilized adobe unit specimens with a fiber proportion of 0.5%, 1%, 1.5%, 2% by weight and 3.5% cement by weight. Compressive strength tests were conducted after 14, 21 and 56 days of curing and drying periods. Water strength tests at different time rates of submersion were conducted after 28 days of curing and drying periods. The test results show that, both compressive strength and water strength were improved when adobe units reinforced with Eragrostis teff straw and stabilized with cement. The adobe unit specimens prepared using clay soil, 3.5% cement, and 1.5% Eragrostis teff straw is suggested for load-bearing walls. Improvement in adobe units promote acceptance of adobe units as a building material in Wolaita Sodo and reduce the use of woods in rural house construction which leads to deforestation.

Keyword: - *Improve, Compressive Strength, Water Strength, Eragrostis teff straw, Adobe Units, Curing.*

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1. INTRODUCTION

Ethiopia is one of the developing countries in the world. There are lots problems faced in Ethiopia, such as faster population growth rate, deforestation and uncontrolled urbanization. The burn beating of the land to gain larger areas of cultivation and grazing for the livestock, the demand of firewood and the high timber content in traditional house building techniques in combination with high population causes deforestation, which in the long run leads to extremely high pressure on the lands of surrounding towns and cities. In these situations, need of a lowcost housing construction material is highly important. Because of all the above problems in Ethiopia especially in Wolaita Sodo, house construction is not sustainable and became a practical problem of the community. Soil with wood (Chika Bet) is widely used in many rural areas of Wolaita Sodo. However, these house construction techniques practiced in

Wolaita Sodo have serious issues because of the listed problems of deforestation. Those serious issues are consuming natural resources such as woods, improper soil, straw fiber ratio and water to the soil mix ratio, aesthetics and leads to additional costs for nails.

Fig-1: Woods from forest for rural house construction in Wolaita Sodo

The sustainable rural adobe construction techniques are very well suited to application in developing countries for several reasons. Rural adobe house construction technique uses mixing of soil, fiber and minimum amount of binders. All materials are locally available in the large majority of Wolaita Sodo areas and the construction technique is environmentally sustainable. This construction technique generally solves economic, social and environmental related problems.

Adobe is sustainable house building material, but it has the limitation of building smaller room sizes and requires frequent maintenance, which is not suitable for modern house construction. Because of these problems increasing the compressive strength of the adobe structures results in reducing the thickness of traditional walls and these leads to increasing internal room size and use adobe as a load-bearing wall, which would suit to changed modern lifestyle requirements.

In the WolaitaSodo Zone, the soil is used as extensively in the traditional mud house construction (Chika Bet). Chika Bet is the mixture of soil, Eragrostis teff straw and water plastered on wood structure. However, this technique has lots serious effects on physical and mechanical properties, economic and environmental problems. Earth materials provide environmental and economic benefits which makes it suitable and affordable for many to use as a prime building material in rural house construction. The adobe houses are predominantly found in less economically developed countries, because of its less cost, simple method of construction and abundance of locally available materials. The major disadvantage associated with adobe structures is frequent maintenance and vulnerability to fast deterioration. However, there has been a great interest shown by researchers in the preservation of this age-old building method. Adobe is sustainable house building material, but has the limitation of building smaller room sizes and requires frequent maintenance, which is not suitable for modern house construction [26]. Because of these problems increasing the compressive strength of the adobe structures results in reducing the thickness of traditional mud walls and these leads to increasing internal room size, which would suit to changed modern lifestyle requirements. To increase room size and age of rural adobe houses, it is obvious to improve the durability and strength of adobe units by stabilizing with binders and reinforcing with fibers.

2. LITERATURE REVIEW

In the past, different literatures were conducted on the sustainability of the adobe structure in different parts of Ethiopia. The Adobe construction is one of the oldest building methods in the world. About 30% of the world population live in houses constructed with earth materials. About 50% of the population in developing countries, including the majority of rural areas and at least 20% of urban and marginal urban areas live in a house made of earth [26].

2.1. Earth house construction techniques

Adobe, compressed earth block, cob wall, rammed earth, and wattle and daub are some of the common techniques of earth building. Using earth for wall construction has distinct advantages. Earth is highly available locally, economical, recyclable and environment friendly and it provides better thermal comfort than other materials.

Utilization of adobe block as a house building material offers a number of advantages: [25]

- Sufficient availability of soil and environmentally sustainable
- Socioeconomic advantages
- Excellent thermal performance
- Technology Independency and not need complex techniques
- Utilization of forest and fodder waste
- Good fire proof
- Nontoxic building material
- Passes low sound transmission through walls
- Flexible to shape any design and services
- Manufactured by the locally available equipment

Researchers have shown that thermal, fire resistance and acoustic properties of houses made of earth are very high, addition of fibers improves the thermal conductivity and has low embodied energy aspects and energy efficiency. The following are disadvantages with adobe houses [25].

- Low compressive strength.
- Less durability.
- Frequent and tedious maintenance.
- Low toughness and highly vulnerable to seismic action.
- High water permeability.
- Strength dependent on soil characteristics.
- Higher drying shrinkage.

According to NjikeManette et al. [4], they were clearly discussed to determine the effects of hand compaction on the strength and durability of compressed earth blocks. And, they were concluded that the hand pressure used to compact the compressed earth block and use of cement in mixes increases the density of compressed earth blocks and this results increase in compressive strength and durability of the blocks.Any type of soil used as a construction material for rural housing, for example black cotton soil durability and mechanical strength is improved when the soil mixed with different admixtures. The compressive strength having 60% more than the compressive strength of normal brick and water absorption is 20% less than the normal brick when black cotton soil mixed with different stabilizers and adhesive materials [5]. Based on the findings of [6], the soil is stabilized with 10% to 20% of stone dust and 5% of cement enhances the mechanical strength and durability of adobe bricks.According to C.Egenti et al. [7], 8% of cement stabilization of Aviele lateritic soil was compressive strength of 10.3MPa and coefficient of water absorption 9 [Kg/(N2*min)]; while a sand cement block ratio of 1:4:2 gave compressive strength of 8.2MPa and coefficient of water absorption 5.3 Kg/(N2*min).Humberto Varum et al.[3] discussed the behavior characterization of adobe and rammed earth constructions along with the research development of retrofitting and seismic performance enhancement solutions. They reviewed that the compressive strength of adobe ranges from 0.13Mpa to 2.15MPa and the tensile strength of adobe ranges from 0.13MPa to 0.4MPa. And, they discussed the mechanical behavior of adobe masonry wall was performed in order to study the bond strength between adobe units and mortar using them bond wrench method, and to characterize the shear strength of the interface between the adobe units and the mortar.

Humphrey Danso et al. [8], were studied partial replacement of sugarcane bagasse fiber by mass to increase the durability and mechanical strength of the soil blocks. And finally 0.5% sugarcane bagasse fiber replacement by mass, enhance both durability and strength of the blocks.

Vandna Sharma et al. [9], were studied the enhancing sustainability of rural adobe houses of hills by the addition of vernacular fiber reinforcement. Increased compressive strength also results in a reduced thickness of adobe mud walls, thereby increasing internal room size, which would be useful to produce fiber mix adobe bricks with improved compressive strength properties and the building materials are environmentally sustainable. Vandna Sharma et al. [10], were studied enhancing durability of adobe by natural reinforcement for propagating sustainable mud housing. And they conclude that this result would propagate durable mud housing on a large scale by reducing the housing shortage, especially in developing countries, economizing use of natural resourced, reducing energy consumption during manufacturing of modern construction and most importantly to provide sustainable way of living.Marwan Mostafa and Nasim uddin [11], were studied to improve the mechanical properties of compressed earth block with the addition of banana fiber in the block mixes. And, banana fiber, compressed earth block is meet strength, toughness and durability; therefore this block is versatile, affordable and environmentally appropriate building material for construction of rural houses.Christien Bock-Hyeng, Ph.D et al. [12], were studied mechanical properties of sustainable adobe bricks stabilized with recycled sugarcane fiber waste. And, on their research the use of abandoned sugarcane fiber waste in adobe bricks will contribute to the development of more durable, sustainable and stronger adobe brick structure, as well as reduce the environmental and economic challenges, it is associated with disposal of sugarcane wastes. Gabriela Catalan et al. [13], were studied the optimum addition of hemp fibers and straw fibers in adobe bricks to increase the mechanical strength and thermal conductivity. Millogo Y. et al. [14], were studied to enhance the physical and mechanical properties of pressed adobe blocks by reinforcing with hibiscus cannabinus fibers with contents of 0.2% to 0.8% by weight and with the length of 3cm and 6cm.

Thomas Mathew and Sujatha Unnikrishnan [15], were studied the utilization of sugarcane bagasse ash and red mud in the manufacture of compressive earth blocks. The results showed that the waste materials can be successfully incorporated in the manufacture of compressed blocks.

G. Araya letelier et al. [16], were discussed to determine the effects of natural fiber length and the amount of natural fiber added on the physical and mechanical properties of adobe earth blocks. And, they concluded that fiber reinforced adobe mixes that is 0.5% fiber amount and 7mm length is used to manufacturing adobe blocks because of it provides positive results in the flexural toughness, drying shrinkage cracking and impact strength without affecting flexural strength and compressive strength. Humphrey Danso [17], was reviewed past studies soil sample usages and selection of suitable soil for earthen construction. Plastic fiber in chopped form from carry bags and mineral water bottles were added 0.1% and 0.2% by weight of soil as reinforcement to enhance the strength of soil blocks. The block made of 0.1% plastic fiber by weight and soil showed an increase in compressive strength of 3%-10 %. [18]. The usage of industrial wastes Elazig Ferrochrome slag and gypsum as stabilizer for unfired clay brick enhances both physical and mechanical properties [19]. Forty percent (40%) replacements of waste glass power on clay brick enhance 20.24% compressive strength. Therefore, 40% replacement of waste glass power in clay brick is optimum and can be used as construction material [20].

3. MATERIALS AND METHOD

The materials used for this study are soil, teff straw fiber, cement, water and different laboratory equipments for tests, etc... Soil reinforced with straw fibers and stabilized with different binders is an ancient technique and has been used in different construction systems around the world. Soil stabilization and reinforcing improve both the strength and durability of adobe units.

3.1. Laboratory tests for Soil and Eragrostis Teff Straw Fiber

The soil samples used to manufacture adobe units were taken from Wolaiita Sodo area, around Wolaita Sodo University, Ethiopia. The soil was taken from 1m depth below the natural ground level by removing the soil rich in artificial organic matter. Soil tests are analyzed using ASTM standard procedures and soil classifications are identified according to the unified soil classification system (USCS) [21]. After the right soil is selected for the production of adobe units, it was sieved for screening of large particles in the soil for adobe unit production. The experimental investigations were carried out to determine the physical properties of the soil. The experimental test carried out were water content, specific gravity, grain size analysis, plastic, and liquid limit, maximum dry density and optimum water content. The results of these tests are shown that the soil is CL as per the USCS standard. This research selects cement as stabilizing material because of the limits of plasticity index from7% to 29% and the liquid limit ranges from 25% to 50% for cement stabilization [22]. Based on physical properties of the soil and reviewed previous studies, this soil is appropriate for adobe earth house construction.

Table-1: Soil properties test results

Soil Properties	
Natural Moisture Content (%)	19.18
Air-dry Moisture Content (%)	15.28
Specific Gravity	2.63
Liquid Limit (%)	49.1
Plastic Limit (%)	26.77
Plastic Index	22.33
Maximum Dry Density (KN/M3)	13.17
Optimum Moisture Content (%)	32.39

Fig-2: Screened Clay Soil for Preparing Adobe Specimens.

Fig-3: Laboratory Tests for Soil Property

The eragrostis teff straw fiber is an organic material it gets from the agricultural process. Eragrostis teff straw serves as a reinforcing material and it helps to improve both strength and durability of adobe units. Eragrostis teff straw is a durable, easily applicable, accessible, cheap and not chemically hazardous material. The average length of the Eragrosis teff straw fiber used in this research is 30mm. The Experimental investigations carried out for Eragrostis teff straw fiber are water content analysis, specific weight analysis, and water absorption rate analysis. The experimental results are tabulated in Table3.2 below.

Table-2: Eragrostis teff straw fiber test results

Fiber Properties	
Cross-section	Circular
Length (mm)	30
Range of Diameter (mm)	0.1-1
Specific Weight (g/cm3)	0.18
Natural Moisture Content (%)	13.84
Water Absorption in 5 minutes (g/min)	0.73
Water Absorption in 10 minutes (g/min)	0.375
Water Absorption in 1 hour (g/min)	0.063
Water Absorption in 2 hours (g/min)	0.033

Fig-4: Eragrostis Teff Straw Fiber.

The cement used for this research is PPC Dangote cement having a normal strength of 32.5 MPa. PPC cement is highly durable, less cost, and emits less carbon dioxide than OPC cement. Water is one of the major materials in the production of adobe units. Water used in this study is free from any contaminants, no taste or odor and used as a drinking water.

3.2. Preparation of Adobe Units and Mix Proportions

All adobe units prepared for this research have prisms shape. One hundred forty-four (144) adobe units were prepared for cured and air-dried test. Adobe unit samples were prepared with the dimension of 190mm*90mm*90mm as per Indian Standards (IS: 4332-1, 1967) [23]. All prepared adobe units were from soil, soil plus 3.5% cement, soil plus 3.5% cement plus 0.5%, 1%, 1.5%, 2% straw fiber by weight of soil. Adobe units mixed were arranged according to maximum dry density (MDD) and optimum moisture content (OMC) from standard proctor test [26]. The soil was sieved and screened by 1.18mm sieve before ready to mix. Then the soil and cement mixed in the dry state, the straw fiber is added and mixed properly until it becomes uniformly arranged. And mixing materials with hands properly with the addition of water till to optimum moisture content. It must be noted that two different types of optimum moisture contents, that are OMC from the soil only and OMC from the soil-cement mix. The soil, soil-cement, and soil-cement-straw fiber mix mechanically compact with 30 blows in equal three layers in the timber molds. The sample specimens were taken out from the timber molds after 7 days, cured and air-dried at normal temperature for different periods of time. The unstabilized and unreinforced, stabilized and unreinforced, and stabilized and reinforced sample specimens were subjected to different laboratory tests. For each type of adobe units, four-sample tests were taken for all strength and durability tests. The test results were the average of four test results. The variation of more than 5% was not considered in the calculation of the test results. This research study incorporated production and testing of unstabilized unreinforced sample specimens (0% cement plus 0% straw fibers), stabilized unreinforced samples (3.5% cement plus 0% straw fibers) and stabilized reinforced sample specimens (3.5% cement plus 0.5%, 1%, 1.5%, 2% straw fibers by weight of soil). The mixture proportions are listed in Table 3.3.

Fig-5: Preparation of Adobe specimens

Table-3: Mix proportions

<table>
<tr><th></th><th>Denotation</th><th>Soil (%)</th><th>Cement (%)</th><th>Teff straw fiber (%)</th><th>OMC (%)</th></tr>
<tr><td>1</td><td>A</td><td>100</td><td>Nil</td><td>Nil</td><td>32.39</td></tr>
<tr><td>2</td><td>B</td><td>96.5</td><td>3.5</td><td>Nil</td><td rowspan="5">28.81</td></tr>
<tr><td>3</td><td>C</td><td>96</td><td>3.5</td><td>0.5</td></tr>
<tr><td>4</td><td>D</td><td>95.5</td><td>3.5</td><td>1</td></tr>
<tr><td>5</td><td>E</td><td>95</td><td>3.5</td><td>1.5</td></tr>
<tr><td>6</td><td>F</td><td>94.5</td><td>3.5</td><td>2</td></tr>
</table>

3.3. Strength Tests

3.3.1. Compression Test

The compression test was used to determine the amount of compressive load which adobe units can bear without before fracturing, as well as describe stress carrying capacity of adobe units. The equipment used for compression test was compressive machine and metallic plates. A Controls compressive testing machine with maximum capacity of 2000KN was used. Compressive strength test was carried out for all treated and untreated adobe units. Compressive strength sample specimens were prism with the dimensions of 190mm*90mm*90mm as per Indian standards (IS: 4332-1, 1967) [23]. The compressive load was applied at the rate of 0.04N/mm2/s until adobe units fractured. The compressive strength test and stress carrying capacity tests of adobe unit specimens were conducted after 14, 28, and 56 days of air drying and curing.

Fig-6: Compressive strength test

3.3.2. Water Strength Tests

The water strength test is the determination of the water strength coefficient fro wet and dry compressive strength of adobe unit sample specimens [10]. The water strength coefficient is the ratio of wet compressive strength to dry compressive strength after immersion in clean water. This test was conducted for all adobe units sample specimens after 28 days of curing and air drying. The equipment used for this test was compressive strength machine, metallic plates, and flat-bottomed bucket. The water strength tests are done for 28days of curing after immersion in water for 24hr and 14dys.

4. RESULT AND DISCUSSIONS

The properties of soils, mixture of soil with cement and teff straw fiber test results were presented in Table 4.1 below.

Table-4: List of adobe mixtures

Mix Designation	Mixed Materials	Number of Samples
A	Soil+0%Cement+0%teff straw fiber	24
B	Soil+3.5%Cement+0%teff straw fiber	24
C	Soil+3.5%Cement+0.5%teff straw fiber	24
D	Soil+3.5%Cement+1%teff straw fiber	24
E	Soil+3.5%Cement+1.5%teff straw fiber	24
F	Soil+3.5%Cement+2%teff straw fiber	24
Total Number of Samples		144

Table 4.1 shows that, the test results of the standard proctor test of soil-cement mix with varying with cement amount of 3%, 3.5%, and 4%. It shows that, the maximum dry density increasing with an increase in cement amount up to 3.5% and maximum dry density decrease in further addition of 4% cement. Therefore, the addition of 3.5% cement is an optimum value that will be used in adobe mixes, because it has given maximum dry density. These tests were used 3.5% cement as a stabilizer for soil. The compaction test results are presented in Table 4.2.

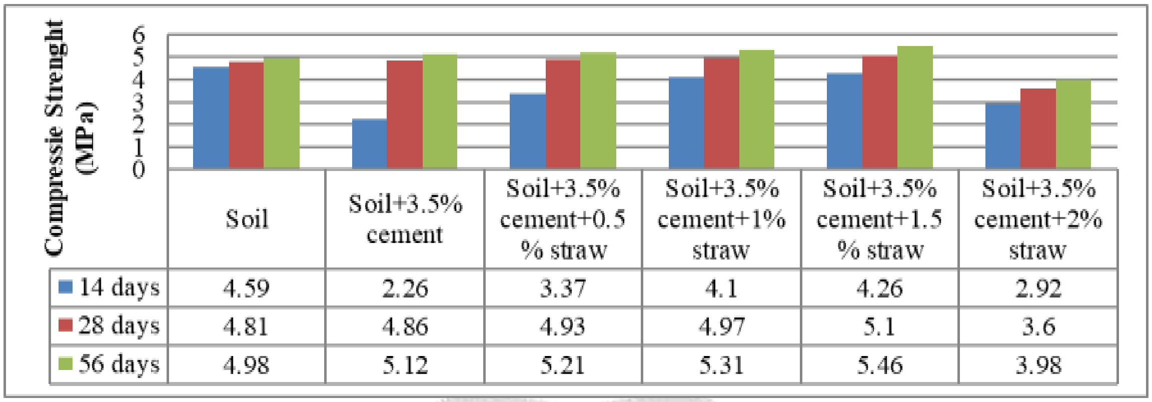
Fig-7: Standard proctor compaction test for soil-cement mix

Table-5: Standard proctor tests to find optimum amount of cement

Designation	Mixes	Maximum Dry Density (KN/m3)	Optimum Moisture Content (%)
A	Soil	13.17	32.39
	Soil+3%Cement	12.73	27.63
B	Soil+3.5%Cement	13.53	28.81
	Soil+4%Cement	13.45	32.96

From the analysis of test results of the compressive strength, for 14 days curing period, the maximum early gain in strength is shown by mix A (Soil+0%Cement+0%teff straw fiber) and followed by mixture E, D, C, F, B. The compressive strength of mix B (Soil+3.5%Cement+0%teff straw fiber) is less than the other mixes because of the curing period is not enough to increase the compressive strength. For 28 and 56 days of curing period, the maximum gain in strength are shown by mix E (Soil+3.5%Cement+1.5%teff straw fiber) and followed by mixture D, C, B, A, F. So that, the addition of 3.5 % cement and inclusion of teff straw fiber (0-2%) in the soil mix increases the compressive strength after 28 and 56 days of curing and drying period. The compressive strength of 28 and 56 days of mixture E (Soil+3.5%Cement+1.5%teff straw fiber) is 5.1MPa and 5.46MPa. The increment in compressive strength for 28 and 56 days of curing period of mix E is 5% and 9.64% respectively.

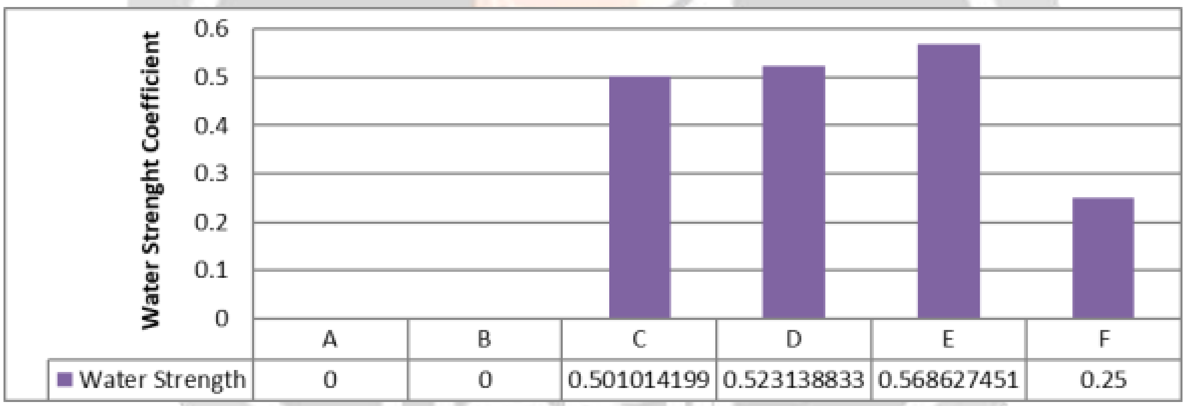
Soil stabilization with cement and reinforced with tef straw fiber used for load-bearing or structural walls. According to Spence and Cook (1983) [24], were presented the average earth brick strength, range from 3-3.5MPa for load-bearing requirements of normal two-story buildings. The study results confirmed that adobe unit specimens stabilized with cement and reinforced with teff straw fiber enhance the compressive strength and can be adopted for important construction works, especially mixes of soil and 3.5% cement stabilizer with 1.5% teff straw reinforcement. The compressive strength value required by Indian standards for traditional Mudbrick is 1MPa [9]. However, the maximum value of 28 days compressive strength of this research is 5.1MPa. This implies that it is possible to construct a mud house in Wolaita Sodo area.



	Soil	Soil+3.5% cement	Soil+3.5% cement+0.5 % straw	Soil+3.5% cement+1% straw	Soil+3.5% cement+1.5 % straw	Soil+3.5% cement+2% straw
14 days	4.59	2.26	3.37	4.1	4.26	2.92
28 days	4.81	4.86	4.93	4.97	5.1	3.6
56 days	4.98	5.12	5.21	5.31	5.46	3.98

Chart-1: The compressive strength of adobe unit specimens for 14, 28 and 56 days of curing

This test is the ratio of wet compressive strength to dry compressive strength for all adobe unit specimens. The minimum permissible value of this coefficient has been taken as 0.5 [9]. From water strength tests, mix E (Soil+3.5%Cement+1.5%teff straw fiber) has the highest water strength value of 0.56. Adobe unit specimens of mixes D and C have a considerable value of 0.52 and 0.5 respectively. These values are fitted with permissible limit 0.5. Unreinforced adobe unit samples do not have water strength because the samples are immediately deteriorated and break when immersed in water. These test shows that, adobe unit specimens stabilized with cement and reinforced with teff straw fiber enhance the durability compared with unreinforced adobe unit specimens.



	A	B	C	D	E	F
Water Strength	0	0	0.501014199	0.523138833	0.568627451	0.25

Chart-2: Water strength test result

These tests were the ratio of wet compressive strength to dry compressive strength for all adobe unit specimens after 14 days of immersion in water. The mix E (Soil+3.5%Cement+1.5%teff straw fiber) shows that, the highest water strength value of 0.169 in 1 day of air drying followed by mix F, D, and C with the values of 0.144, 0.135, and 0.124 respectively. The results obtained from laboratory tests, for mix E (Soil+3.5%Cement+1.5%teff straw fiber) has the highest water strength value of 0.943 in 7 days of air drying followed by mixes D, C, and F with the values of 0.926, 0.915, and 0.694 respectively. This test shows that stabilized and reinforced adobe unit specimens get 94.3% of the compressive strength after 14 days of immersion within 7 days of drying, especially mix E (Soil+3.5%Cement+1.5%teff straw fiber).

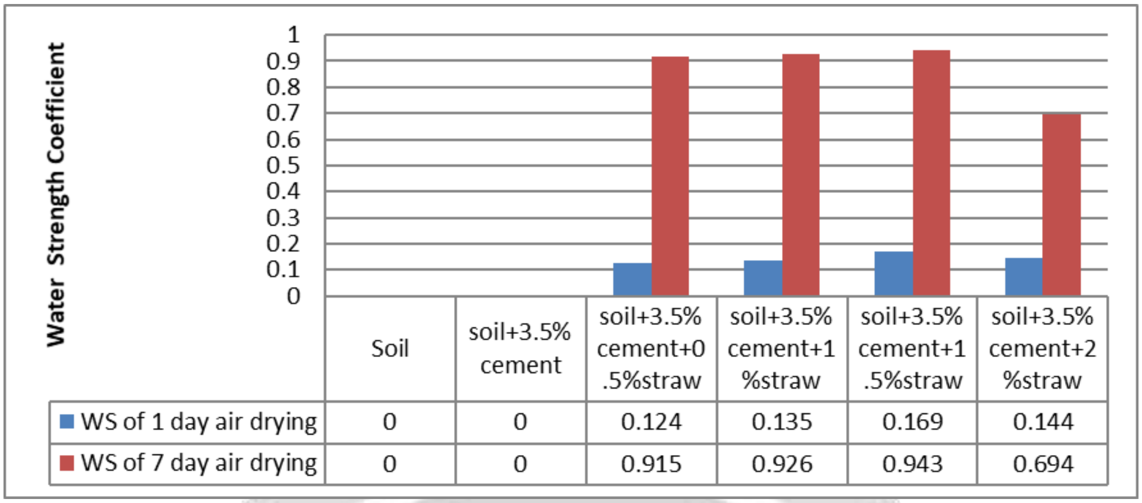


Chart-3: Compressive strength after 14 days of immersion in water

5. CONCLUSIONS

This research is providing a new and simple construction technique for rural housing in Wolaita Sodo areas by enhancing the strength and durability properties of adobe units. This also provides a foundation for developing an earth house construction system in Wolaita Sodo area.Thrteff straw fiber in a proportion of 0.5, 1, 1.5 and 2% weight is added to clay soil to enhance adobe strength and durability. A total of 144 sample specimens are for laboratory tests. The test results obtained for soils are natural moisture content (19.18%), specific gravity (2.63), plastic index (22,33), maximum dry density (13.17) and optimum moisture content (32.39).The test results for Eragrostis teff straw fiber are natural moisture content (13.84%), specific gravity (0.18), water absorption in 5minute (0.73), water absorption in 10 minute (0.375), water absorption in 1hour (0.063) and water absorption in 2 hours (0.033).

The experimental results show that, the stabilized and reinforced soil samples were improved in strength and durability compared with unstabilized and unreinforced soil samples.

- The 28 and 56 days of curing strength of mix E (Soil+3.5%Cement+1.5%teff straw fiber) was recorded the highest value with about 5% and 9.64% respectively compare with mix A (Soil+0%Cement+0%teff straw fiber).
- After 24 hours of immersion in water for water strength test indicated that, mix E (Soil+3.5%Cement+1.5%teff straw fiber) has a higher water strength value of 0.56. So that, mix E (Soil+3.5%Cement+1.5%teff straw fiber) maximum improvement in strength as compared with other mixes.
- After 14 days of immersion in water, the test result shows after 1 and 7 days of drying, mix E(Soil+3.5%Cement+1.5% teff straw fiber) has the higher water strength coefficient of 0.17 and 0.943 respectively. This shows Mix E (Soil+3.5%Cement+1.5% teff straw fiber) has a maximum water strength and get back around 94.3% of the compressive strength after 7 days of drying.

The appropriate mix of adobe units are containing soil (95%), cement (3.5%), and teff straw fiber (1.5%) with a water content of 28.81%. Therefore, mix E (Soil+3.5%Cement+1.5%teff straw fiber) is more better for manufacturing strong and sustainable adobe units for rural house construction in WolaitaSodo area. .

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