Sustainability of Adobe Structures – A Review

[1]Dr. Binaya Patnaik, [2]Temesgen Gebreyesus, [3]Getnet Kassahun
[1] Associate Professor, [2] Associate Dean, [3] Lecturer
Department of Civil Engineering,
Wolaita Sodo Univeristy, Ethiopia.

Abstract: Since ages, earth has been used as one of the common building material around the world. About 30% of the world population lives in houses constructed with earth materials. Earth materials provide environmental and economic benefits which makes it suitable and affordable for many to use as a prime building material in house construction. There are several techniques used to build a house using earth as a prime material and Adobe building technique is one which is an ancient technique dated back to 8300 BC. The adobe houses are predominantly found in less economically developed countries and rural areas, because of its less cost, simple method of construction and abundance of locally available materials. The major disadvantage associated with adobe structures are frequent maintenance and vulnerability to fast deterioration which is a major reason for rejection of adobe as a building material. However, there has been a great interest shown by researchers in preservation of this age-old building technique. So, here an attempt has been made to provide a global vision of the adobe constructions in the past, and its prospectus in the future.

Index Terms **– Adobe. Strength. Durability. Thermal Insulation. Stabilizers.**

1. INTRODUCTION

For past several thousand years, different civilizations have used raw earth as a building material for construction of houses (Houben and Guillaud, 1994). Depending upon the living requirements, environmental conditions, topography and locally available materials, mankind has come up with several techniques to build houses using earth (Bui et al., 2009). The several techniques are in use are Adobe, Cob, Wattle and Daub, Cordwood, Rammed Earth, Earthen Bag, Straw-Bale, Compressed Earth Block etc (Bansal and Minke, 1988; Niroumand et al., 2013). Adobe is a technique which utilizes dried mud bricks prepared by essentially combining earth, water and dried under sun. Adobe as a building material utilizes sand, clay and locally available straws or grasses mixed with water, forming bricks, which are further dried in the sun for about a month without being burnt in kiln or oven. Ancient architecture of Middle East and Egypt have used adobe technology for building their houses. Also, there are several evidences have been found which indicates that ancient Greece and Roman civilizations have used adobe technology for building their houses.

Earth itself is naturally unstable, however adobe walls can be self-sustaining, load bearing and energy efficient. Walls made up of adobe are generally thick which makes it a good insulator from the environmental heat (Goodhewa and Griffiths, 2005; Binici et al., 2007). When the adobe is not formed as a brick it's called as puddled adobe and can be used in cob houses. Compressed Earth Blocks are similar to adobe, except they uses less water, don't generally contain any fibres as reinforcement, mechanically compressed which makes them more uniform in shape and size and can be used immediately after casting.

2. EARTH AS A BUILDING MATERIAL

Earth when used as a building material offers wider range of advantages as below

- Environmental benefits
- Socio-Economic advantages
- Thermal comfort
- Technology Independency
- Utilization of forest and fodder waste
- Fire proof
- Non-toxic building material
- Low sound transmission

Earth is one of the most preferred building material around world because it is affordable and can provide housing to many especially in the less economically developed countries and rural areas (Taylor and Luther, 2004). When earth is used as a raw material in construction, it helps in reducing the environmental and financial impact of the construction. Adobe house construction generally uses the locally available materials and labors but doesn't need any special material, equipment, technology and skills which leads to reduction of cost drastically. Another major advantages of using earth as building material is that it doesn't attribute to emission of any kind of greenhouse gases like other building cementitious materials but is an environmental friendly building material making it more sustainable (Danso et al., 2015). Experimental studies shows that treated mud plaster helps in resisting erosion, repelling water and also offers protection to walls during rainfall (Kebs 1993).

Adobe houses have gained their popularity because of other advantages like thermal comfort, heat and sound insulation, easy repair and maintenance. Research have shown that thermal, fire and acoustic resistance properties of houses made of earth are very high and addition of fibres improves the thermal conductivity (Goodhew and Griffiths, 2005; Hall and Djerbib, 2004). It has also been found that low embodied energy aspects and energy efficiency have made the adobe houses more attractive Shukla et al. (2009).

To promote earth to be uses as a building material in large scale, many countries have come up with legal and codal provisions for designing, planning and technical aspects (Middleton, 1992; Torgal and Jalali, 2012).

3. DISADVANTAGES AND MEASURES TO OVERCOME ISSUES

In spite of a wider range of benefits of houses made with earth, there are certain disadvantages with respect to strength and durability (Alfred and Ngowi, 1997) because of which it has been widely replaced with other stronger alternative materials for house construction [Foruzanmehr and Vellinga (2011) and Kairamo (1975)]. Following are certain disadvantages with adobe houses.

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

Studies have shown that adobe has poor mechanical properties in terms of strength and durability along with poor resistance to water and moisture attack Degirmenci (2008). High permeability leads to collapse of the earth structures when exposed to sever rainfall Bengtsson and Whitaker (1986) and Reman (2004). Absorption of water makes the adobe swell and upon drying, cracks due to shrinkage gets developed. The cyclic process of absorption and drying finally results in failure of the adobe structure.

To save the ancient process of house construction using locally available earth, it is highly imperative to understand the ways to improve the strength and durability aspects of adobe structures. Studies have shown that stabilization of earth with natural or artificial reinforcements and suitable stabilizers have helped in improving the strength and durability of adobe structures (Binici et al., 2005; Morel et al., 2007; Aubert et al., 2013; Jaquin et al., 2009; Illampas et al., 2014). The natural fibres have been found to be lower in toxicity and embodied energy compared to artificial materials John et al. (2005). The choice of stabilizers are generally based on the nature of the earth used in adobe structures. Different stabilizers used are soluble silicate silanes or siloxanes, isocyanates, lime, cement, gypsum, basaltic pumice, rubber firbes and plastic wastes etc. Most common natural fibres used for earth stabilization across world are are rice husk, straw, sugarcane bagasse ash, jute etc (Ramirez et al., 2012; Khosrow et al., 1999). Other research have shown that processed waste tea (Demir, 2006), pineapple leaves (Chan, 2011), hibiscus cannabunus (Millogo et al., 2014) when uses as natural fibres also helps in improving mechanical properties of adobe houses. Studies conducted by Ranjan et al., 1999 shows that with increase in the fibre length, strength and stiffness of earth construction increases because of increase in contact area of fibres with the soil.

Understanding the fact that use of stabilizers and natural and artificial reinforcing materials in the earth helps in improving the strength and durability properties of adobe structures, an attempt has been made here to collate and compile the various researches which have been carried out in the past related to this. The findings of the earlier researches are put in tabular form below for the quick understanding (Table 1).

Table 1: Research Studies on Adobe

Sr.No.	Authors	Experiment	Methodology	Observation
1	Enrico Quagliarini and Stefano Lenci. (2010)	The influence of natural stabilizer and natural fibers on the workability and mechanical properties of ancient Roman adobe bricks.	Conducted experimental investigation on the workability and mechanical properties of Roman ancient adobe earthen bricks by changing the proportion of on situ soil, straw and coarse sand in the mixture to produce adobe bricks.	It was concluded that • preferable clay content is 12 and 16% (by weight) into the bearing adobe structure elements; • natural fibres helps in controlling the plastic behavior and influences the breaking way of the adobe blocks.
2	G. Araya-Letelier et al. (2018)	Study on the influence of pig hair, a massive food industry waste, as reinforcement in adobe mixes.	Conducted experimental investigation on the compressive strength, flexural toughness and drying shrinkage cracking of adobe mixes with different fiber dosage and fiber length.	It was concluded that, dosage of 0.5% fibre by weight of dry soil using 7mm length of fiber was optimal for crack control, flexural toughness and impact strength without statistically affecting flexural and compressive strength.

3	Christian Bock Hyeng et al.(2016)	Study on mechanical properties of sustainable adobe bricks stabilize with recycled sugarcane fiber waste.	Conducted experimental investigation on adobe bricks stabilized with different proportion of sugarcane fiber to check compressive strength, shrinkage and deterioration when immersed in water.	The tests established that addition of sugarcane fiber waste improved the compressive strength, shrinkage, resistance to moisture penetration and durability of adobe bricks. The optimum percentage of sugarcane fibre waste was found to be 3% of soil by weight from strength perspective.
4	Noorwirdawat Ali et al. (2016)	Study on physical and mechanical properties of compressed earth brick containing bagasse ash.	Conducted density test, compression test, initial rate absorption test and water absorption test of compressed earth brick mixed with partial replacement of cement by sugarcane bagasse with four different proportion.	The test results indicated that, use of bagasse ash as stabilizer improves the compressive strength and decreases the density of earth bricks. The optimum percentage of bagasse ash was found to be 20%.
5	Muntohar et al. (2011)	Study on enhancing strength of adobe blocks by stabilizing adobe mixes with lime and reinforcing with rice husk ash.	Conducted compressive strength and flexural strength test on adobe blocks stabilized with lime and reinforced with rice husk ash.	It was found that both compressive and flexural strength of adobe blocks were improved by stabilizing with lime and reinforce with rice husk ash.
6	Vilane et al.(2010)	Enhancing the strength of adobe bricks stabilized with cement and reinforced with molasses, cow-dung and sawdust.	Conducted laboratory experiment to check compressive strength of adobe bricks stabilized with cement and reinforced with molasses, cow-dung and sawdust.	Results showed that adobe bricks stabilized with cement and reinforced with molasses improved the compressive strength.
7	V. Sharma et al. (2015)	Utilization of natural reinforcement to enhance sustainability of adobe structures.	Conducted experimental investigation to check strength and durability of stabilized adobe blocks reinforced with Pinus Roxburghii and Grewia Optiva.	Results show that both strength and durability improved when adobe blocks stabilized with cement and reinforced with natural fibers.
8	L. Vignesh kumer and B. Jai Vignesh. (2017)	Study on use of bagasse ash as stabilizer in adobe bricks.	Conducting compressive strength and water absorption test of stabilized adobe bricks.	Results show that partial replacement of bagasse ash is used to improve compressive strength and for less water absorption.
9	Tang et al. (2007)	Enhancing the strength of adobe bricks by stabilizing with cement and reinforce with discrete short propylene fiber.	Conducted compressive strength test, shear strength test and stiffness test for stabilized and reinforced adobe blocks.	Their results shows that adobe blocks stabilize with cement and reinforced with propylene fiber improve compressive strength, shear strength, decrease in stiffness and decrease in post peak strength.
10	Turanli and Erdogan (1996)	Study on structural behavior of adobe structures.	Conducted experimental investigation on load carrying capacities of adobe structures stabilized with straw, fly ash and plaster reinforcement.	Their result shows that the load carrying capacity of stabilized adobe structures improved by addition of fly ash, straw and plaster reinforcement.
11	Ghavami et al. (1999)	Study on the compressive strength of adobe blocks stabilized with coconut and sisal fibers.	Soil was stabilized with coconut and sisal fibers and compressive strength test was conducted on the adobe bocks.	The results showed that stabilization of adobe blocks with coconut and sisal fibers increases the compressive strength.

12	Ngowi, A. B. (19978)	Study on the methods to improve the traditional earth construction.	Soil was stabilized with cement, lime and bitumen and reinforced with natural fibres and cow dung.	The test results showed that the specimens with lime and cement had improved strength.
13	Heathcote, K. A. (1995)	Study on the durability of earth construction.	Soil was stabilized with different proportions of cement.	The test results showed that the specimen with 7.5% cement has an improved durability property.
14	Ren, K.B. and Kagi, D.A. (1995)	Study on the improvement of durability of earth bricks by impregnation.	Soil was stabilized with sodium silicate solution, silioxane and silicone emulsion.	The test results indicated that the specimens treated with stabilizers had better durability than untreated samples.
15	Binici et al. (2005, 2007, 2009)	Study on the strength and durability of fibre reinforced mud bricks.	Soil was stabilized with cement, gypsum and basaltic pumice and reinforced with plastic fibres, polystyrene and straw.	Earth brcks reinforced with plastic fibers had an increased compressive strength, elasticity, thermal insulation, and earthquake resistance.
16	Ramirez et al. (2012)	Study on the use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks.	Soil was stabilized with lime and reinforced with Sugarcane bagasse ash.	The test results showed that earth brick samples with 10% SCBA + 10% lime had improved strength and durability properties.
17	Guettala et al. (2006)	Study on the strength and durability of stabilized earth bricks.	Soil was treated with cement, lime and resin.	The brick samples stabilized with resin and 5% cement had better durability.
18	Danso et al. (2015)	Study on the effect of fiber aspect ratio on mechanical properties of soil building blocks.	Soil was reinforced with bagasse, coconut, oil palm fibers.	Addition of oil palm and coconut fibers helped in increasing the strength.
19	Taallah et al. (2014)	Study on the mechanical properties and hygroscopicity of compressed earth blocks.	Soil was stabilized with cement and date plam fibres was used.	Earth blocks with 8% cement + 0.05% fiber showed and improved performance.
20	Kumar et al. (2006)	Study on the compressive strength of highly compressible earth bricks.	Soil was reinforced with plain and crimped polyester fibres.	The samples reinforced with fibres showed improved compressive strength.

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