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Experimental Investigation on Earth Block Stabilized with Binders

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Abstract*— This paper is an investigation about uses of clay bricks and stabilized compressed earth blocks. As building material, clay bricks have been used in construction since earliest times. Different stabilization agent levels of 0%, 2.5%, 5% and 7.5% were used to prepare the specimens for testing. The blocks were moulded using hand operated machine .The maximum compressive strength of 4.22 N/mm2 was obtained with stabilization level of 5% with sample 3 at 28 days curing. The strength of the specimens increases with increasing cement content with an average value of 0.35N/mm2. For instance, by increasing the stabilizing agent content from 2.5% to 5% yields of increment in compressive strength of the block.

Keywords*— earth block, binders, sustainability, clay bricks, stabilizing agent

I. INTRODUCTION

Clay is a finely-grained natural rock or soil material that combines one or more clay minerals with traces of metal oxides and organic matter. Geologic clay deposits are mostly composed of several minerals containing variable amounts of water trapped in the mineral structure.

Clays are plastic due to their water content and become hard, brittle and non–plastic upon drying or firing. Depending on the soil's content in which it is found, clay can appear in various colours from white to dull grey or brown to deep orange-red.

Clay is one of the oldest building materials on Earth, among other ancient, naturally-occurring geologic materials such as stone and organic materials like wood. Between one-half and two-thirds of the world's population, in both traditional societies as well as developed countries, still live or work in buildings made with clay, often baked into brick, as an essential part of its load-bearing structure.

Also a primary ingredient in many natural building techniques, clay is used to create adobe, cob, cordwood, and rammed earth structures and building elements such as wattle and daub, clay plaster, clay render case, clay floors and clay paints and ceramic building material. Clay was used as a mortar in brick chimney, sand stone walls where protected from water.

A stabilized earth block (SEB) or compressed stabilized earth block (CSEB), also known as a pressed earth block or a compressed soil block, is a building material made primarily from damp soil compressed at high pressure to form blocks. Compressed earth blocks use a mechanical press to form blocks out of an appropriate mix of fairly dry inorganic subsoil, non-expansive clay and aggregate. If the blocks are stabilized with a chemical binder such as Portland cement they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB).

Creating CEBs differs from rammed earth in that the latter uses a larger formwork into which earth is poured and manually tamped down, creating larger forms such as a whole wall or more at one time rather than building blocks. CEBs differ from mud bricks in that the latter are not compressed and solidify through chemical changes that take place as they air dry.

These bricks are different from the conventional red bricks that are made by burning clay. Also called as Stabilized Mud Blocks (SMB) these bricks are made by compressing a combination of earthen materials with added stabilizers. Construction using CSEB technology has been in vogue in different parts of the world for about six decades. Various types of CEB production machines exist, from manual to semi-automated and fully automated, with increasing capital-investment and production rates, and decreased labor. Automated machines are more common in the developed world, and manual machines in the developing world.

I. MATERIAL PROPERTIES

GENERAL

The main ingredients of the stabilized earth block are

- Clay (Black cotton soil)
- Sand
- Binders (Stabilizers)
- Water

A. CLAY

Clay materials have a wide variety of uses in engineering. Earth dams are made impermeable to water by adding suitable clay materials to porous soil; water loss in canals may be reduced by adding clay. sometimes with variable amounts of iron, alkali metals, alkaline earths, and other cations found on or near some planetary surfaces. Basically, clay is an alumina silicate and the formula is $\mathbf{Al_2O_3\ 2SiO_2\ 2H_2O,}$ but it is never found in pure form.

Montmorillonite - The Montmorillonite name was actually given to a Smectite clay that was found in the Montmorillon area of France. Chemical composition is $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)\ 2H_2O$ i.e., hydrated sodium calcium aluminium magnesium silicate hydroxide.

Kaolinite - a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$.

B. SAND

Sand generally composed of rounded particles, and may or may not contain clay or other impurities. It is obtained from the banks and beds of rivers.The river sand, passing through 2.36 mm sieve and retained on pan sieve, conforming to Zone II is used as fine aggregate in the present study. The sand is free from clay, silt and organic impurities. Sand content in the mixes apparently can reduce water absorption and weight loss even though does not affect the compressive strength significantly.

The sand was tested for its physical requirements such as gradation, fineness modulus, specific gravity, water absorption and bulk modulus in accordance with **IS: 2386-1963.**

C.BINDERS

Binder or Binding agent is any material or substance that holds or draws other materials together to form a cohesive whole mechanically, chemically, by adhesion or cohesion. In a more narrow sense, binders are liquid or solid substances that harden by a chemical or physical process and bind fibres, filler powder and other particles added into it. Binders are loosely classified as organic (bitumen, animal and plant glues, polymers) and inorganic (lime, cement, gypsum, liquid glass, etc.). There are lot of stabilizing agents available for block making. Some of them are Cement, lime, polymers and chemicals such as Diammonium phosphate (DAP), Magnesium phosphate, Pottasium chloride (Kcl)…etc. Di-ammonium phosphate binder is eco-friendly and easily available when compared to the above mentioned binders, hence the blocks are made by using it.

DI-AMMONIUM PHOSPHATE

- It is one of a series of water-soluble ammonium phosphate salts in brown colour that can be produced when ammonia reacts with phosphoric acid. IUPAC name of DAP is Diammonium Hydrogen Phosphate
- Chemical formula is $(NH_4)_2HPO_4$.
- Other names are ammonium monohydrogen phosphate, ammonium phosphate dibasic.
- Molecular mass : 132.06 g/mole
- Appearance : Brown or Yellow or White in colour
- State : Pellets or Powder form
- Solubility: Soluble in water and Insoluble in alcohol, acetone and liquid ammonia.

D. WATER

Fresh potable water free from organic matter and oil is used for mixing. Water in required quantities were measured by graduated jar and added to the concrete. The pH value should not be less than 6.

The water used for mixing shall be clean and free injurious amounts of oils, acids, alkalis, salts, sugar, organic material or other substances that may be deleterious to block. However the water is conformed to IS 456: 2000 clause 5.4.

III. PROPORTION AND CALCULATION OF MATERIALS

As observed from literature reviews water absorption, as well as porosity, increases with clay content. Sand content in the mixes apparently can reduce water absorption and weight loss even though does not affect the compressive strength significantly. From the study of literature reviews it explains clearly that the proportion of **Clay: Sand** to be used for better strength characteristics is **1: 2**.

Stabilizer for CSEB playing an important role in creating bonding between soil-stabilizers mixes. One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability From the study of literature reviews it explains clearly that the proportion of stabilizing agent levels various from 0% to 8%. Usage of stabilizing agent above 8% will not contribute to any strength related characteristics of earth block and becomes uneconomical.

By considering NEW MEXICO EARTHEN BUILDING MATERIALS CODE (NMCA) – TITLE 14: CHAPTER-7: PART-4**,** Shape of specimen to be used is defined in Subsection B of 14.7.4.8 NMAC, table 1. From this code cylinder to be used for specimen making should be in height to diameter ratio is “2”. The standard cylinder which is used for concrete testing has 100mm in diameter and 200mm in height. But for Earth block, the cylinder specimen has chosen with size of 83mm in diameter and 165mm in height.

PROPORTION OF CLAY AND SAND

Weight of the sand and clay required is calculated by using code NMAC (NEW MEXICO EARTHEN BUILDING MATERIALS CODE) TITLE 14 : CHAPTER-7 : PART-4, TRIAL PROPORTION CALCULATION as reference. The above mix proportion in clause 5.2 was adopted for all specimens. The following table 5.1 shows the particulars of clay and sand.

Table 3.1 Proportion of Clay and Sand**

PARTICULARS	CLAY	SAND
Proportion	1	2
By Weight	3.132 kg	6.756 kg

Note: **** - Proportioning by weight is done for single specimen

PROPORTION OF STABILIZING AGENTS AND WATER CONTENT

Soil samples are mixed in various proportions and stabilizers are also mixed in various proportions with the mixed quantity of soil samples to find the strength of Stabilized Earth Blocks (SEB) with different composition and at different proportions

NMAC (NEW MEXICO EARTHEN BUILDING MATERIALS CODE) TITLE 14: CHAPTER-7: PART-4 Subsection-C of subpart- 9, TRIAL PROPORTION CALCULATION. The blocks are made by varying the ratios of the stabilizing agent as 2.5%, 4%, 5% and water content as 90%, 95%, 100%, 110%.

The following table 3.2 shows Proportion of Stabilizing Agent and Water Content.

Table 3.2 Proportion of Stabilizing Agent and Water Content

S.NO	STABILIZING AGENT VARIATION (%)	WATER CONTENT VARIATION (%)	MIX VARIATION NUMBERS
1.	2.5	90, 95, 100, 110	4
2.	4	90, 95, 100, 110	4
3.	5	90, 95, 100, 110	4
Total number of mix variations			12

Note: weight of stabilizing agent and water is calculated in terms of dry weight of clay.

IV. EXPERIMENTAL INVESTIGATION

Experimental investigation have been carried out on earth block specimens make by predetermined proportion for clay and sand 1:2 with various proportions of stabilizing agent as 2.5% , 5.0%, 6%, 7.5% of dry weight of clay. Hence the properties of earth block have been arrived by conducting laboratory tests.

PREPERATION AND CASTING OF BLOCK

The exact quantity of materials for the specimens were weighed and kept ready for dry mixing. clay and sand is mixed thoroughly by using trowel. The stabilizing agent was spread over the mixture and the dry mixing is carried out. Then the water required for the mixture was added part by part and through mix is ensured. The mix was turned up and down with the help of hand trowel until the the mix attained a uniform appearance and the water is spreaded evenly.

The wet mix after mixing was immediately filled in three layers in the mould and compacted well by using tamping rod. Mould should be cleaned and oiled before the filling. The specimens were also filled with wet mix in three layers in the cylindrical mould and compacted. Then the mould is kept in the table vibrator and gets vibrated. As Vibration was applied for the mould to expel the excess water, so that the mix is settled well. Then the top of the specimens were floated off with a trowel to get smooth surface finish.

The following figure 4.1 shows the dry mixing of clay, sand and DAP and figure 4.2 shows the casting of blocks.

Fig 4.1 Mixing of clay, sand and DAP

Fig 4.2 Casting of blocks

CHEMICAL STABILIZATION

Clay soils are those which show volumetric changes in response to changes in their moisture content. Such soils swell when the moisture content is increased and shrink when the moisture content is decreased. However, in order to limit the disturbances, various solutions based on stabilization techniques have been developed with more or less satisfactory results. soil stabilization refers to changing the physical properties of soil in order to improve its strength, durability, or other qualities. Recently, Extensive studies have been carried out on the stabilization of clay soils using either mechanical or chemical stabilization.

Soil chemical stabilization mainly depends on chemical reaction between stabilizing agent and soil minerals. The product used for the chemical stabilization of these soil is DAP. The chemical reaction between the stabilizers and clay mineral as follows.

$$Al_2O_3\ 2SiO_2\ 2H_2O + (NH_4)_2HPO_4 + H_2O + SiO_2 \xrightarrow{\text{Air curing}}$$

(Clay) (DAP) (Water) (Sand)

$$(NH_4)_2 . Al_2O_3\ PO_4.\ SiO_2 + 4\ H_2O$$

(Ammonium alumino phosphate silicate) (Evaporated)

(Solid structure)

DEMOULDING AND AIR CURING

The specimens were kept in the mould for a day. After demoulding the block specimens were cured in open atmosphere for a period of 28 days. Curing is very essential for Stabilized earth blocks, especially when stabilizing agent is used in preparation of the blocks. Curing would aid the hydration process of the stabilizing agent during the different ageing periods up to 1 month for stabilized blocks and thus giving strength to the block. Curing would also prove to essential for internal movement of stabilizing agents such as lime, liquid based stabilizing agents. Curing would enable effective movement of stabilizers within the block. In order to achieve good results, the newly produced blocks are allowed to air dry for the required curing period under a shade.

The specimens were numbered as per the nomenclature using Indian ink before being placed for Air curing. The moulds were immediately cleaned and assembled for future use. The dates of casting of specimens were marked for identified. The following fig 4.3 shows the air curing in dry shade.

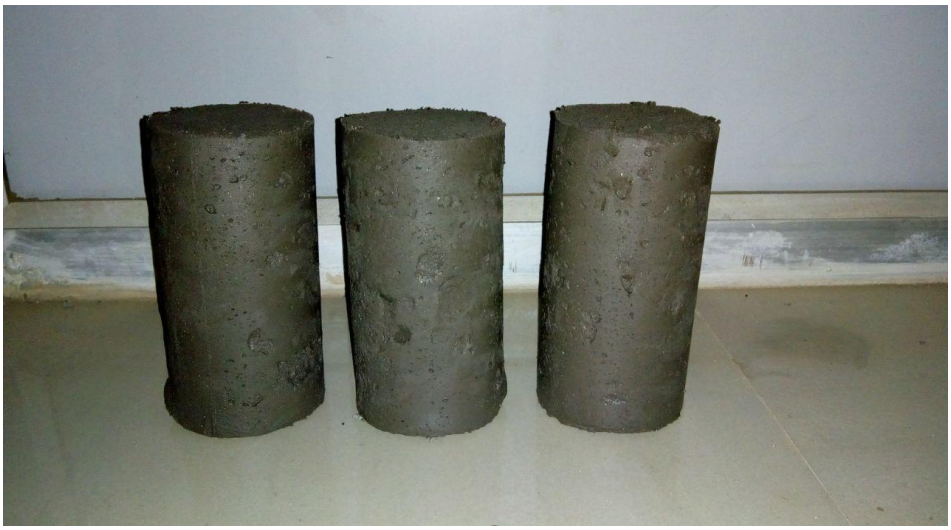

Fig 4.3 Air dry curing under shade

TEST ON EARTH BLOCK

The Classical Method By crushing specimens in the compressive testing machine is to obtain the compressive strength as the test result. Therefore, it is a direct test method which is globally standardized. By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test.

COMPRESSIVE STRENGTH TEST

The cylinder specimens were tested for compressive strength at the end of 28 days of air curing. The surface was wiped of the specimen and any projecting finds were removed. The dimensions of the specimens and their weight were recorded before testing.

The bearing surfaces of the testing machine was wiped clean and again the surface of the specimen was cleaned from sand and other materials which may come in contact with the compression plates. While placing the specimen in the machine care was taken such that the load was applied to opposite sides of the specimen as cast and not to the top and bottom. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated plate. As the spherically seated block is brought to bear on the specimen, movable portion was rotated gently by hand so that uniform seating was obtained. The load was applied without shock and increased continuously until the resistance of the specimen to the increasing load broke and no greater load could be borne. The maximum load applied to the specimen was recorded and any usual appearance in the type of failure was noted. A total of 72 blocks were prepared and crushed at curing age of 28 days.

The measured compressive strength of the specimen was calculated by the following equation.

Compressive strength = (P / A)

Where,

P – Ultimate load in N.

A – Area of specimen in mm^2.

The following fig 4.4 shows the compressive strength test conducted on specimens.

Fig 4.4 Compression test on specimens

V. RESULTS AND DISCUSSION

The various tests conducted on materials and specimen to determine the properties. The results were discussed in this chapter obtained from the experimental investigation.

TESTING RESULTS - COMPRESSION TEST

The compressive strength test on the earth blocks are made by using Universal Testing Machine. The blocks are loaded, crushed and the corresponding maximum or failure load for each sample block was recorded. Then, the compressive strength of the blocks is calculated by dividing the maximum or failure load by loading area of the sample blocks. Test for compressive strength is carried out on cylindrical moulds of size 83mm in diameter and 165mm in height are used. The compressive strength of the specimen at 28 days of air curing is provided in table 7.1 given below.

Table 7.1 Result of Compressive strength of specimens

S.NO	SPECIMEN	STABILIZING AGENT VARIATION (%)	WATER CONTENT VARIATION (%)	LOAD (kN)	COMPRESSIVE STRENGTH (N/mm^2)
1.	S1	2.5	90	144	**2.65**
			95	165	3.05
			100	182	3.35
			110	160	2.96
2.	S2	4	90	183	3.38
			95	209	3.86
			100	214	3.95
			110	196	3.62
3.	S3	5	90	221	4.09
			95	225	4.15
			100	228	**4.22**
			110	222	4.11

DISCUSSIONS

Being clayey soil, to be qualified as a good soil for making compressed earth blocks, there is a real need to improve the granularity of natural soil used. To do so, sand has good properties of reducing shrinkage and cracking. The addition of sand has highly improved the grading properties of the clay.

- In this phase I the properties of the materials used for the project is evaluated by conducting different types of test.
- The newly produced blocks are allowed to air dry for the required curing period under a shade and unburnt.
- There are several bulk properties that are believed to influence the strength and durability of earth blocks. In this study, the strength of each block is investigated by making dry compressive strength tests.
- Finally the compressive strength test for the different levels of cement stabilization at the optimum w/c ratio at 28 days curing ages for the specimens was undertaken.
- After breaking the Stabilized Earth blocks strengths for various SEBs were determined as shown on the Table 7.1 above.
- The maximum strength obtained was 4.22 N/mm^2 for specimen S3 (5% stabilizing agent and 100% of water content).
- The minimum strength obtained was 2.65 N/mm^2 for specimen S1 (2.5% stabilizing agent and 90% of water content).

VI. CONCLUSION

The following conclusions were drawn from the results of this experimental study.

- Different research workers have contributions on the Compressed Stabilized Earth Blocks in terms of different parameters. CSEBs were eco-friendly and as these blocks were un-burnt products, during production no coal or burning material is needed. So, it does not produce any harmful gases during production.
- The specimen with 5% of stabilizing agent content and 100% of water content shows good results in mechanical properties such as compressive strength when compared to the specimens with 2.5% and 4.0% of stabilizing agent.
- Increase in stabilizing agent results in an increase in the compressive strength value of blocks. For instance, by increasing the stabilizing agent content from 2.5% to 5% yields 59.24% of increment in compressive strength of the block.
- The strength of samples increased with increasing stabilization level from 0% to 5% with an average value of 0.35 N/mm^2.

Considering a minimum dry compressive strength value of 3.5MPa recommended by building standard codes, the earth blocks manufactured from natural black cotton soil with 5% of stabilizing agent content (4.22 MPa) fulfills the requirements and hence may be conveniently used in building construction.

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