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Compressed Geopolymer Mud Blocks Testing and Production - A Review

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***Abstract:** The rapid growth in civil construction field has resulted in a substantial scarcity in availability of conventional building materials. Due to the combustion of coal in industries/thermal plants, there are large quantities of wastes obtained such as fly ash, GGBFS, silica fume etc. Wastage disposal issues and environmental issues has become prime concern in the society. These issues have encouraged and necessitated to develop new building materials and construction technologies. The purpose of building mud blocks is to renovate stable natural soil into an engineered block. Mixing geopolymers along with mud generate significant strength in the characteristics of block. Geopolymer technology has resulted in lowering carbon-di-oxide emissions in the eco-system. This article presents the procedure for manufacturing and testing compressed geopolymer mud block masonry specimens. The compressed geopolymer mud blocks has proven to be a sustainable alternative material compared to Portland cement concrete blocks. The article focusses on choosing the right mix proportion of the block and to determine the basic properties of masonry units, masonry strength of the prisms/wallettes and walls.*
***Keywords:** Building material, Geopolymer, Masonry, Mix Proportion, Mud Blocks, Strength.*

I. INTRODUCTION

We have noticed in the nature that natural architects, like ants build their houses (ant-hills) composing of mud which is an engineering marvel. These ant-hills sustains for ages overcoming all types of temperatures, rain impact, wind pressure and other natural calamities including floods without total destruction. These heaps also help enrich the nutritional value of soil nearby, which makes us wonder, why, we human beings should not try to adopt and do something similar to this, survive and go along with nature and preserve nature for future mankind, this makes a strong case for the study.

Earlier conventional construction bricks were composed of sand and clay. Sand and clay were mixed along with other additives and cast by various methods then dried and burned to get conventional burnt bricks. Recent decade inclusion is cement blocks produced by mixing Portland cement and stone powder in water, moulded, dried and cured to get cement blocks. Engineers have employed and adopted several other methods to produce the building blocks using cement, lime-fly ash, lime-slag bindings, etc.

Large scale consumption of the above said type of bricks and blocks are in use for the constructions of walls and partitions in residences, commercial and industrial structures. Enormous quantity of fuel and materials are used in making these bricks. The process involves continuous removal top soil and the burning process. The removal of top fertile soil and burning methods for conventional bricks has also become a major concern of environment. Pollution and conservation issues have propped up even for using stone powder in making of cement blocks. Inevitably this has given way to study the use alternate building materials. Nowadays lot of efforts is put upon developing economically sustainable, durable, eco-friendly and re-utilizable technologies by using easily available and abundant local materials.

Mud is a mixture of water and some combinations of soil, silt, grit and clay. Sand is a naturally occurring granular material composed of finely divided rock and mineral particle. Mud can be made into mud bricks, also called adobe, by mixing mud with water, placing the mixture into moulds and then allowing it to dry in open air. A binder used within the bricks, makes it composite. Binder will redistribute the force throughout the brick and thus decreases the chance of breakage of the brick.

The process of obtaining mud bricks/blocks depends on several factors. One common method is the fired or burnt brick. These burnt bricks are durable but consume more energy to produce. Improper firing results in wastage, deformation of brick and material cannot be reutilized.

One more method is stabilized mud. Stabilized mud (soil) has an added binder along with mud such as cement or bitumen. Few examples are soil cement, landcrete and mudcrete. Stabilization is a procedure to improve the properties of bricks or blocks. This process yields good compressive strength and water resistance. Commonly used stabilisers in are lime, cement and bituminous emulsions. Latest technology is the use of geopolymers as an alternative binder to produce blocks. When compared to burnt bricks, material loss and production loss is negligible in these geopolymer blocks.

The term, Geopolymer was phrased by Professor Joseph Davidovits in the year 1978 for a family of high alkali binders formed in a reaction called as geopolymerization. Geopolymers are the family of binders obtained by using alkaline solutions (activators) and alumino silicates (binders) like fly ash, ground granulated blast furnace slag, metakaolin, silica fume, etc. to produce three dimension alumino-silicate polymeric gel which are environmental friendly since they are made by use of industrial byproducts and eliminate use of traditional cement. It is essential that these binder materials are in amorphous form for good activation.

Though there is considerable research reported on brick and concrete block masonry units, there is need to develop alternative masonry units, one of which can be geopolymer masonry unit. When compared to conventional bricks and concrete blocks, geopolymer mud blocks manufacturing consumes less energy and low cost in terms of production. The main raw material-mud/grit/silt is available everywhere. Casting near site of construction is an added advantage. Fly ash is another raw material. Fly ash geopolymer bricks adopting wet stabilization process is already in production, it is very economical to acquire geopolymer blocks in the nearby areas where fly ash is generated. The evolution of geopolymer mud block is a vital step towards production of building material with improved performance and eco-friendly properties.

This paper reviews the insights from the literature, properties characterization techniques of all the raw materials used, process of compressed stabilised geopolymer blocks production and potential application of this material in the construction industry

II. LITERATURE REVIEW

A. On Soil or Mud Blocks

Venu Madhava Rao et al [1] have reported that when soil or lime was added into the mortar mix, there was improvement in masonry flexural bond strength. The moisture content of the masonry unit (at the time of casting) had a significant influence on the flexural bond strength. Optimum moisture content resulted in maximum bond strength. When masonry units with deep and wide frogs were used, the masonry flexural bond strength was more when compared to units without frogs.

B. V. Venkatarama Reddy and A. Gupta [2] have reported that compressive strength of the block greatly depends on the cement content and it increases with increase in cement content. As the cement content of the blocks is doubled from 6%, the compressive strength increases by 2.3 times. Soil-cement block modulus varies between 2000 and 6000 MPa. Elastic modulus increased by 2.5 times when the cement content increased from 6 to 8%, whereas the increase in modulus was marginal when cement content went from 8 to 12%. B. V. Venkatarama Reddy and A. Gupta [3] reported that SMB masonry strength is sensitive to block strength and increases with increase in block strength, strength of SMB masonry using cement-soil mortars is more sensitive to the cement content of the mortar than to the clay fraction of the mortar mix; Masonry modulus increases as the block strength increases.The prisms failed by developing vertical splitting cracks parallel to the loading direction.

B. On Geopolymer Concrete Blocks

Antonella Petrilloa et al. [5] article results revealed that the geopolymer brick making process consumes less energy and involves low cost in terms of raw materials. The production of geopolymer concrete paving blocks had a slightly lower CO2 footprint than OPC concrete ones. However they also revealed that the production of geopolymer concrete cause a higher environmental impact regarding heavy effects of the production of the sodium silicate solution.

Chameera Udawattha and Rangika Halwatura [6] show that the most suitable combination of Sodium hydroxide and Sodium chloride to alkaline activate fly ash is Sodium hydroxide 5% of the dry weight and Sodium chloride 2% of the dry weight. The most suitable mix proportion range was between 60% and 35% gravel and 5% fine and 70% and 25% gravel and 5% fine. The self-compacting nature study revealed that at the range of (15%–20%) water content, it could gain the suitable strength without compaction. Self-compacting can be achieved with 15s vibration at the moisture range below 10%.

C.D Udawattha et al [7] reported that mud blocks having composition of 20% Fly ash, 5% NaOH, 2% NaCl, and soil, build satisfied minimum strength requirement of load-bearing construction.

C. Geopolymer Soil/Mud Blocks Masonry

Nassif Nazeer et al [11] concluded that the strength of masonry prisms was influenced by the volume fraction of masonry unit, volume ratio of bed joint to mortar and height-to thickness (h/t) ratio of the specimen in addition to the masonry unit strength and mortar strength. Unit strength, mortar strength, volume fraction of masonry unit and volume ratio of bed joint to mortar are directly proportional to the prism strength and height-to-thickness ratio has an inverse relationship with the prism strength. Rui A. Silva et al [12] reported that mechanical tests carried on single CEB units showed that the percentage of geopolymer binders directly proportional to the strength parameters. The shear parameters obtained were comparatively high. And finally, the alkaline activation of fly ash was shown to promote excellent mechanical performance of CEB units.

Emerson O. Gapuz, et al [13] concluded that for attaining 2.50MPa strength, the cement and geopolymer content of 10% or more can be used as proportion and also highly improved hydrological properties of blocks specimens can be obtained.

III.EXPERIMENTAL PROGRAM

The first phase is the production of compressed geopolymer blocks.

A. Test On Raw Materials

1) Cement: Ordinary Portland cement conforming to IS: 12269 – 1987 to be used. The physical properties of the cement is found by conducting appropriate tests like Standard Consistency, Setting time, Specific Gravity and Compressive Strength as per IS: 269/4831 and the requirements as per IS: 12269 – 1987 .
2) *Sand:* Natural river sand can be used for the mortars. IS: 2116 – 1980 gives the specification for sand for masonry mortars. IS: 383 – 1970 gives the specifications for grading zones for fine aggregates. Grading. Specific Gravity and Fineness Modulus of Sand are determined. The particle size distribution, as per IS: 2386 (Part 1) -1963 for sand should be carried out.
3) *Mud:* Locally available excavated mud can be used. IS 1725 -1982, standard covers the requirements and test for soil based blocks for use in general building construction. Tests conducted as per IS 2720 – 1985, includes Grain Size Analysis, Specific Gravity, Plastic limit and Liquid limit. SP 36 is also referred. There are two methods for finding the distribution of grain size larger than 75 micron IS Sieve; the first method wet sieving shall be applicable only to soils which do not have an appreciable amount of clay. For the determination of distribution of grain sizes smaller than 75 microns, the pipette method is given as the standard method. This method shall be not applicable if less than 10 percent of material passes the 75 micron IS sieve. Wet sieve analysis is carried out by either Pipette Method or Hydrometer Method. The methods are not applicable if less than 10 percent material passes the 75 micron sieve.
4) *Geopolymer Stabilizer:* The binding materials used for preparation of geopolymer block shall comprise of any one or more of the following: Pulverized fuel ash conforming to IS 3812(part 1), Ground Granulated Blast Furnace Slag conforming to IS 16714, Rice husk ash, Groundnut shell ash, Sugarcane bagasse ash, Metakaolin conforming to IS 16354, Calcined clay conforming to IS 1344, Silica fume conforming to IS 15388, Reactive alumina. Fly ash is chosen as stabilizer in this paper. Samples are to be analyzed to understand the use of the full chemical, physical and particle size distribution property of fly ash. Its typical properties should satisfy the requirements of IS: 3812: 2003.
5) *Geopolymer Activator:* The activators used for preparation of geopolymer block shall include any one or more of the following: Sodium Hydroxide, Potassium hydroxide, Sodium silicate, Potassium silicate, Sodium carbonate, Potassium Carbonate. The admixtures to be employed for usage in making geopolymer block can include the following Naphtha and lignin based chemical admixtures, Glucose or any other admixture. In this study, Sodium hydroxide (NaOH) is used as the activator. To improve the swift movement of Sodium chloride (NaCl) common salt can be used.
6) *Geopolymer Mud Block Mix Proportion:* The first step is to study the binder content that is, ideal fly ash content and the curing method. Fly ash content (0%–60%) is varied and mixed with mud/soil and studied alongside the strength and development. Then the finest fly ash content will be chosen. After that, the optimized mix is subjected to three different curing techniques such as sun drying, heating, and water curing. The second step involves study of the activator content. First, Sodium hydroxide content is augmented by using altered composition of Sodium hydroxide like 0%, 2%, 4%, etc. Then Sodium Chloride content is adjusted in the similar manner after studying different values of sodium chloride content like 0%, 1%, etc. The third step, the mud/soil mix developed to gain the best strength. Because, the soil originates in different particle sizes such as gravel, sand, and fine. A few different soil compositions are tested considering their sieve size composition. And the fourth step to finish, is to optimize the manufacturing technology for the stabilised geopolymer mud block, the moisture content and ease of workability.
7) *Method of Casting:* The stabilized mud/soil mix can be compressed at high pressures to produce blocks. With regards to the literature survey, approximately 21 MPa (3,000 psi) is applied in compression, and the soil volume is condensed to almost half its original volume. There are several equipments and technologies to produce these compressed blocks. It may be a manual press machine or an electric machine or hydraulic press machine. The CINVA Ram/MARDINI press is a single-block, manual-press that uses a long hand-operated lever to drive a piston, generating high compression. Industrial manufacturers produce much larger machines that run with electric, diesel or gasoline engines and hydraulic presses that receive the mixture through a hopper. This is fed into a chamber to create a block that is then ejected onto a conveyor.

B. Test on Masonry

The second phase is the testing of the masonry. The focus of this paper is to study the masonry in detail. The structural parameters of masonry units/prism/wallettes/walls are to be tested before and during construction to guarantee their true characteristic strengths. Prisms are small assemblages of masonry units having thickness of one to three units. Masonry wallettes are short wall specimens of several courses having width of three or more units.

Masonry wall specimens are comparable to actual walls and have heights greater than prisms and wallettes. However, as per literature testing of masonry wall specimens is quite expensive and hence it is desirable to test prisms/wallettes to evaluate the strength of masonry.

Prisms are a better representation of the real masonry construction as it encompasses the effects of the characteristics of the constituents of the masonry and the quality of workmanship.

1) *Compressed Stabilised Geopolymer Mud Block (Masonry Unit):* Using block pressing equipment, casting blocks of the optimum base proportions. Compressed Stabilized Geopolymer Mud Block of required size are cast in the moulds, cured and dried. Studies on mechanical and physical properties are carried out on blocks on 7, 14 and 28 days. These blocks are tested for:
   a) Dimensionality as per IS: 1077-1992.
   b) Initial rate of absorption test conducted as per the guidance given in ASTM C67.
   c) Density Test done as per IS 2185:2008 (Part 4).
   d) Water absorption test is performed as per IS: 3495(Part 2).
   e) Compressive strength test conducted as per the guidance given in IS 3495 (Part 1).
   f) Tensile Strength test conducted as per ASTM C1006-07.
2) *Mortar:* Cement-sand mortar of standard proportion will be prepared using OPC and sand. The compressive strength of mortar is determined by testing cubes of 50cm2 face area as per IS: 2250–1981.
3) *Stabilised Geopolymer Block Masonry Prism/ Wall:* IS: 1905 recommends a height-to-thickness (h/t) ratio between 2 and 5 for the prism specimens and a minimum height of 40cm. The American standard ASTM E447 suggests that the minimum height of the specimen should be fifteen inches. SP 20–1991 (S&T), Handbook on Masonry Design and Construction is referred. Prisms are constructed using cement mortar of standard bed mortar joint thickness of 10mm and tested for:
   a) Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. Compressive strength resists compression (being pushed together). Compressive Strength of Masonry Prisms is tested as per IS 1905 (BIS 1987) and ASTM C1314-12 (ASTM 2012). This code covers the test procedures for masonry prism construction and testing, and procedures for determining the compressive strength of masonry.
   b) The Tensile strength is the capacity of a material or structure to withstand loads tending to elongate. Tensile strength resists tension (being pulled apart). Ultimate tensile strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking.
      Tensile Bond Strength: required for masonry walls subjected to wind, eccentric gravity loads, and so on. Indian code remains silent. Tensile Strength Tests include the bond wrench test, direct tension test, and crossed couplet test.
   c) Flexural strength of such alternative materials is important to evaluate the performance when subjected to lateral loads due to wind, floods or any other load that can cause out-of-plane bending in a wall. Flexural bond strength is crucial in normal as well as parallel directions to the bed-joint. ASTM E518 / E518M – 10 gives Standard Test Methods for Flexural Bond Strength of Masonry and ASTM C1072-13e1 gives Standard Test Methods for Measurement of Masonry Flexural Bond Strength.
   d) Current masonry design codes [MSJC (2011)] duly consider the flexural tensile strength in the design of masonry in both directions. BS EN 1052-2 describes the methods of test for masonry, Determination of Flexural Strength.
   e) Shear strength is the strength of a material or component against the type of yield or structural failure when the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. Shear Strength test: gives us the Shear Strength and Friction Factor. This is an important parameter for the design of masonry under lateral load. Shear strength of masonry can be determined from Diagonal Tension Test of masonry wallettes in accordance with ASTM E519/E519M-10 (ASTM 2010). Also, Diagonal Compression Test to determine the shear strength of masonry panel by loading them in compression along one diagonal conducted on the masonry wall conducted as per ASTM E519/E519M.
   f) And determine the strength and load-deflection characteristics of masonry wall elements as per ASTM C1717.
   g) The modes of failure/crack pattern on specimens are observed and examined.

IV. CONCLUSION

Geopolymer technology proposes the use of industrialised end product (unwanted derivatives). Hence, it holds a conservative perception on the development of new, effective and sustainable building material in the construction industry. There has been extensive research from quite a long period on different manufacturing and production methods of geopolymer (concrete/soil) masonry models.

From this article, we conclude that by considering proper criteria like optimum quantities of raw and geopolymer materials, casting and curing of blocks, excellent compressive strength can be achieved under various loading conditions, along with tensile strength, flexural strength and shear strength.

Therefore, compressed stabilised geopolymer mud blocks can be obtained to meet standards of strength, toughness and durability, they can be a versatile, affordable and environmentally appropriate building material for the housing sectors in both developed and developing regions.

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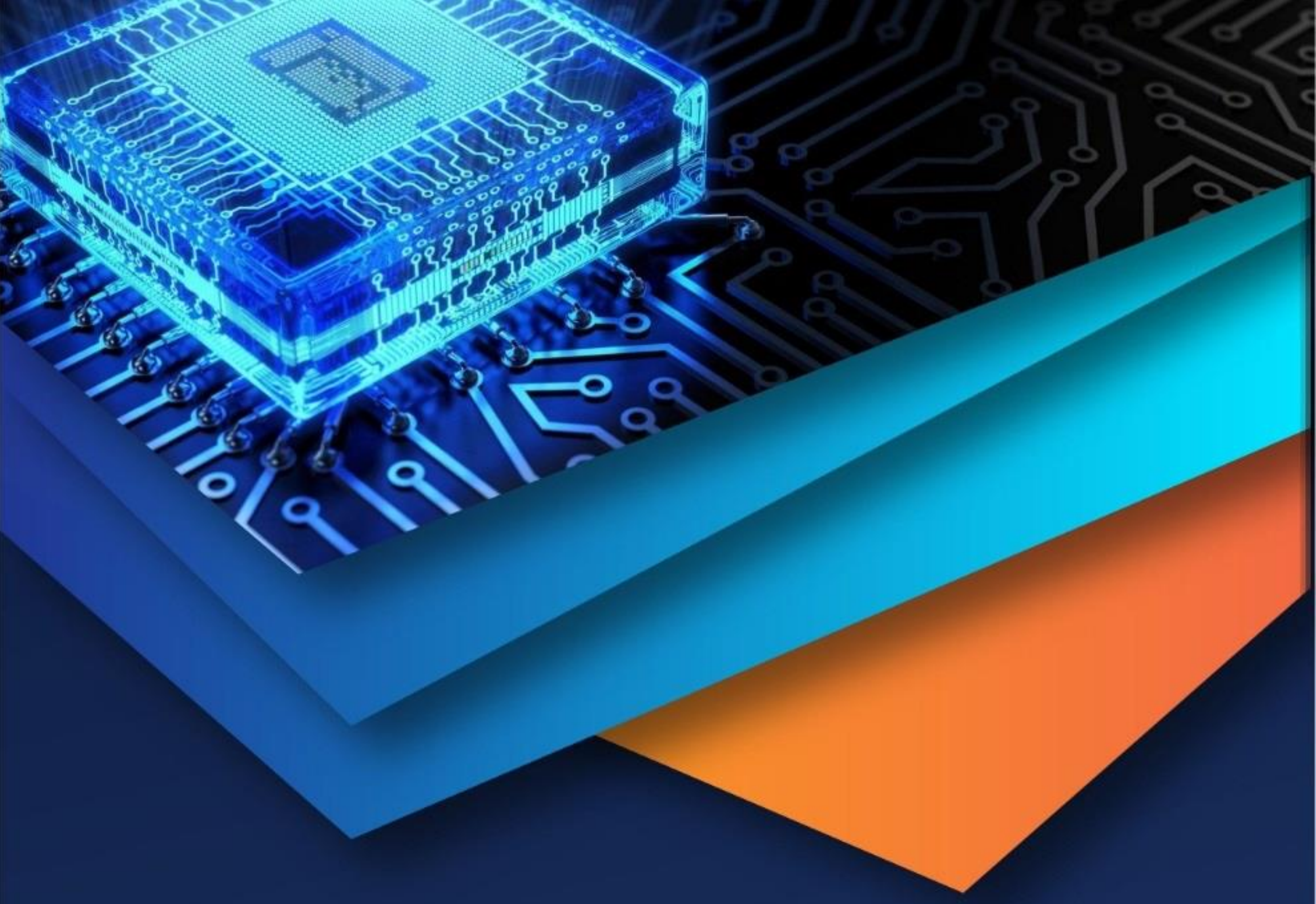

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