Strength and durability features of fiber reinforced geo-polymer earth bricks.

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**ABSTRACT**

Merely 30% of the world and 50% of developing countries have buildings made of earth. More related to the soil are probably the most critical problem for both strength and long-term durability. An attempt tried to solve, Geo-Polymer Earth Bricks are made to improve strength, durability, and modernize earthen architecture. Seventy-two specimens in which the proportion of Fly Ash, Ground Granulated Blast-Furnace Slag, soil, and Quarry Dust (0.5:0.5:1.75:0.25) are prepared and tested after 7 and 28 days. The dosages of coir fiber are selected as 1% of the brick weight and alkaline solution of 10 Molarities. The mix gives enhancement of compressive and flexural strength of 5.93 MPa and 3.43 MPa. The mixed formulations give better resistance against acidic and sulfate attack and enhanced compressive strength up to 40%. The standard deviation and coefficient of variation of brick specimen test results for the mix met less than ±2% and 10% found true value and very good. This research confirms the mix enhancing the strength and durability of the brick and also suggests alternate to burnt clay brick, acid, and sulphate resistant brick and stabilized mud blocks.

**1. Introduction**

Concrete production is raised at a pace of 10% each year in the world. This augmentation is directed to an expansion in CO₂ in the environment. About one ton of concrete creation radiates roughly about one ton of CO₂ (Mahaesenan et al. 2003). Cement production ventures transmit about 7% or 1.5 billion tons of Green House Gases every year which contaminates the earth’s atmosphere. Major opportunities to diminish CO₂ discharge from the concrete are alluded by the investigations of Hendricks et al. India’s commitment for CO₂ outflow from concrete ventures is around 2,000 million metric tons in the year of 2010 among the worldwide concrete businesses (Ernest Worrell and Lynn Price et al.; Worrell et al. 2001).

There is enormous amount of increases in CO₂ emaciation which made a significant issue in the environment. Due to that there is desire and ideal need to approach and to use the industrial by-products rather than concrete. Low pozzolanic and cementitious materials like FA (Oswal and Manojkumar 2014) from thermal plant and slag from steel businesses are being used on the other hand to ensure the ecological conditions.

A binder material created from highly alkaline fluids is called Alumino-silicate (Ivana and Radomir 2013). It has responded with GGBS and FA, and shaped an inorganic geo-polymer binder framework. The framework has been used as a substitute component for cement mortar and concrete (Davidovits 1991; Hardjitto and Rangan 2005; Aleem and Arumairaj 2012). It is likewise used in the creation of ecologically well-disposed building products. High Molarity arrangement is coordinated in the higher quality of geo-polymer (up to certain limits) (Reddy, Varaprasad, and Reddy 2010). Because of ecological issues, it is safe to discover the elective materials rather than the normal waterway sand. Soil and Quarry Dust are used as an alternative for sand in this present study. Soil is gathered from the local site having a range of sandy portion of (4.75 mm to 0.075 mm) over 65% (FAO Corporate Document Repository 2010). Sandy soil containing lesser than 65% sieve must be suitably modified (Bahoria, Parbat, and Nagannak 2013; Madheswaran and Gnanasundar 2013; Jin-Soo and Myung 2013) by blending the soil with coarser material like quarry residue or elective material for sand. Geo-polymer concrete/mortar is used as the best substitute rather than conventional concrete/mortar which is arrived at high compressive strength for higher Molarity inside specific cutoff points (Palanisamy and Suresh Kumar 2018) and observed a setback in the creation of traditional bricks which is recognized by the ongoing examinations (TIFAC) (Technology information Forecasting and Assessment Council 2000). In order to defeat the deficit, the GPEB creation is presented by this study which includes to keep up the sustainability in building materials particularly in the creation of the GPEB. Materials like fly ash, steel slag, rice husk ash, Limestone residue, welding flux slag,
marble dust, granite sawing powder, and other waste items are considered to make un-burnt bricks which will be improving the sustainability (Ahmari and Zhang 2012; Bennet, Sudakar, and Natarajan 2013).

1.1. Significance of the study

Soil-based construction methods have a history of more than 400 years soil is a natural abundantly available raw material for building construction. But its potential in block making is not yet satisfactorily explored. The International scene in stabilized earth construction is also encouraging. The parameters related to soil are probably the most critical for both strength and long-term durability. On the other side, the waste supplementary cementitious materials from industries are of enormous quantity causing pollution to the nearby areas. Hence the soil with industrial wastes and byproducts are stabilized and made block maybe one of the solutions to this problem. The experimental values obtained here proved more however compare well with most current and previous Stabilized Mud Block standards.

1.2. Previous studies

Previous studies found a positive relationship among GGBS, red mud and Geo-Polymer Concrete (Alwis Deva Kirupa and Saktieswaran, 2015). Earlier studies on the inclusion of coconut and sisal fibers in soil blocks with a fiber content of 4% by weight showed a reduction in the occurrence of visible cracks and gave highly ductile blocks (Khosrow, Filho, and Barbosa 1999). For stabilization of soil, it should have a sandy fraction of more than 65%. Unless it should be modified by mixing with coarse materials like sand or Quarry Dust (Harsha, Radhakrishna, and Devanand 2015). Previous studies are indicated that combination of FA and GGBS can be used for development of Geo-Polymer Concrete (Madheswaran and Gnanasundar 2013). Latest studies are conducted by the same author about the effect of molarity in GPEB reinforced with fibrous coir wastes using sandy soil and quarry dust as fine aggregate (P alanisamy and Suresh Kumar 2018).

The resistance of brick to sulfate attack can be improved by using adding supplementary cementitious materials (SCMs) such as fly ash and slag. Many studies have been conducted to evaluate the properties of brick with SCMs from mechanical, chemical, durable perspectives (Nie et al. 2014). A total survey of the existing writing shows that, very negligible investigations were just attempted to use materials like FA, GGBS, Soil, QD, Coir Fiber, and Alkali Activator for creation of the GPEB. Guiding with all previous studies a new composite material is produced using the concepts. Waste materials from thermal power plants, steel industry, coir industry, and quarry affect the general public and make a danger to the land, water, and air which leads to contamination. This proposed research is centered on not just the feasible removal of all the materials for making the GPEB to be additionally fulfilled with more quality and better sturdiness even in an aggressive environment.

2. Objective

The principal objective of the research was to focus on the study of strength and durability features of GPEB with combinations of (FA, GGBS, soil, QD) (0.5:0.5:1.75:0.25) 1% of fibrous coir waste, and 10 Molarity of alkaline solution.

3. Materials and methodology

3.1. Materials

FA, GGBS, QD, Excavated Earth (Soil), and Alkaline Activator Solution were used to produce GPEB specimens.

3.1.1. Fly ash

The “C” classification FA was gathered from nearby and had both pozzolanic and cementitious properties around 10 percentages and affirming to ASTM C 618–1993 class C (ASTM-C 618-1993 class C 1993). The properties are recorded in Tables 1 and 2. The microstructure of FA was dissected by a Scanning Electron Microscope (SEM). It looked like thin-walled hollow circles, which are very smooth and dense to exceptionally permeable surface structure as appeared in Figure 1(a).

### Table 1. Physical properties of supplementary cementing materials.

| Physical Property | OPC | FA | GGBS |
|-------------------|-----|----|------|
| Specific gravity  | 3.15| 2.4| 2.9  |
| Fineness m2/kg    | 410 | 1134| 415  |
| LOI (%)           | 2.06| 0.9| 0.19 |
| Bulk density Kg/m³ | 1440| 750| 1200 |
| Surface area m2/kg | 320–400| 300–500| 350  |
| Grain size        | 45 µm| 45 µm| 40 µm |

### Table 2. Chemical properties of supplementary cementing materials.

| Chemical Property | SiO₂ | Al₂O₃ | CaO | Fe₂O₃ | Glass | MgO | Sulphide | Sulphite | K₂O+ | MgO | SO₃ | Clorides | Na₂O+ | TiO₂ |
|-------------------|------|-------|-----|-------|-------|-----|----------|----------|-------|-----|-----|----------|------|------|
| OPC               | 22.48| 6.43  | 58.9| 3.82  | -    | 1.88| -        | -        | -     | -   | 2.45| -        | 0.53 | 0.05 |
| FA                | 61.12| 31.23 | 3.2 | 1.5   | -    | 2.19| -        | -        | -     | -   | 0.75| 0.53     | -    | 1.35 |
| GGBS              | 34.07| 12.42 | 38.53| 0.38  | 0.90 | 0.76| 0.54     | 0.23     | 0.75  | 0.53| 0.05| 1.35     | -    | -    |
3.1.2. GGBS
GGBS obtained from nearby and affirming to IS 12089:1987 was used (Indian Standards: 12089-1987 (R2008) 1987). The physical and chemical properties are organized in Tables 1 and 2. The microstructure of GGBS was analyzed utilizing a Scanning Electron Microscope (SEM). It looked like predominantly in anomalous shape with clear edges and angles as appeared in Figure 1(b).

3.1.3. Soil
Soil was taken from the building site for this test. Primary examination and rough assessment were done through simple sensitive tests like color, smell, touch, pressure tests, plasticity, and cohesion of soil. Generally dark shades of grey, brown, and black show natural soils while more splendid colors are found as an inorganic soils. Natural soils usually have a distinctive smell. The individual particles of soil and sediment are not noticeable to naked, but rather daintily compacted by hand to testing. Additionally soil, sediment, and shale are distinguished from cohesion and plasticity of soils. Natural soil, mud, silt, and shale were confined by a prior examination.

The top soil was expelled out because of the fact that it contained natural matter. The soil underneath 0.45 m ground level was exhumed and used. This soil was examined between 4.75 mm sieve and 75 micron strainer and it was used. Fundamental physical properties of soil were shown up according to IS: 2720 Part 5 standards and confirmed IS: 383 principles for its appropriateness (I to IV zones) for planning concrete (Indian Standards: 2720-1985(R 2006) 1985, Indian Standards:383-1970(R 2002) 1970) and it is recorded as in Tables 3 and 4.

The soil was characterized as well-graded and under zone IV, since it contained a decent depiction of particles of all sizes considered and recorded. The soil is

![Figure 1. (a) Microstructure of FA/GGBS/GPEB. (b) Microstructure of GGBS. (c) Microstructure of GPEB.](image)

### Table 3. Physical properties of sample soil.

| S.No. | Characteristics                  | Value  | S.No. | Characteristics               | Value  |
|-------|----------------------------------|--------|-------|--------------------------------|--------|
| 1     | Specific gravity                 | 2.43   | 5     | Sand fraction (4.75 mm to 75µ) | 70     |
|       |                                  |        |       | (Wet sieve analysis) %        |        |
| 2     | Bulk density                     | -      | 6     | Fineness Modulus              | 2.76   |
| 3     | Loose soil density, Kg/m³        | 1520   | 7     | Plastic limit %               | 27     |
| 4     | Compacted soil density, Kg/m³    | 1670   | 8     | Liquid limit %                | 34     |

### Table 4. Sieve analysis of soil compared with fine aggregate of natural sand.

| Sieve size (mm) | Weight retained (gm) | Cumulative Weight retained (gm) | Cumulative % retained (gm) | Percentage passing | Grading for zone – IV as per IS:383(1970) |
|-----------------|----------------------|---------------------------------|---------------------------|--------------------|----------------------------------------|
| 4.75            | 0                    | 0                               | 0                         | 100                | 90–100                                 |
| 2.36            | 90                   | 90                              | 9                         | 91                 | 75–100                                 |
| 1.18            | 200                  | 290                             | 29                        | 71                 | 55–90                                  |
| 0.6             | 340                  | 630                             | 63                        | 37                 | 35–59                                  |
| 0.3             | 150                  | 780                             | 78                        | 22                 | 12–40                                  |
| 0.15            | 90                   | 870                             | 87                        | 13                 | 0–15                                   |
further recommended even for concrete also according to the standards. These soils were used as fine aggregate and the soil finer than 75 microns was dismissed. The coarser part of soil was only considered for this research. Waterway sand had been succeeded by soil and stabilized with Geo-polymer for making bricks (Olaniyan et al. 2011; Kabiraj and Mandal 2012). Later these bricks were compared with the river sand at the same time and it was selected for production of GPEB specimen.

3.2.4. Quarry dust
Sieve analysis of Quarry Dust was carried out and tested as per IS 2386 (Part. III) (Indian Standards 2386 (Part. III) 1963). Fineness modulus of GGBS was found out to be 3.3. The bulk density of quarry dust both loose and compacted was recorded as 1540 kg/m$^3$ for loose and 1751 kg/m$^3$ for compact. The specific gravity of GGBS was found out to be 2.4.

3.1.5. Fibrous coir waste additives
Coir fiber wastes (CF) were collected from nearby coir industries for this research. In this study, the fiber length between 25 and 50 mm was used. The physical and chemical properties of the waste fiber are listed in Table 5.

3.1.6. Alkaline liquid
Sodium silicate fluid was bought in mass locally. NaOH pieces with 97% to 98% purity and were dissolved with water to make the liquid solution. The concentration was estimated in terms of Molarity of Sodium hydroxide-based solution and had been kept at (10 M × 40 = 400 grams of NaOH) in lab. Sodium-based solution was economical in comparison to calcium-based solution. Both Na$_2$SiO$_3$ liquid and NaOH solution had reacted and gave antacid fluid for polymerization process.

3.2. Methodology

3.2.1. Solution preparation
Ten Molarity of NaOH was mixed with distilled water at least before 24 hours to make solution. Na$_2$SiO$_3$ liquid was prior mixed with the dry materials. Both NaOH solution and Na$_2$SiO$_3$ were kept to mix in the next process.

3.2.2. Dry mixing
FA and GGBS (binders) were mixed in a dry condition in the ratio of 0.5:0.5 initially. Then soil and QD (fine aggregate) were taken in the ratio of 1.75:0.25. Both binders and fine aggregate were mixed together for three minutes until a uniform color appeared.

3.2.3. Wet mixing
The activator solution quantity was determined from the predefined liquid to binder proportion of (F/B) = 0.3 and divided by both NaOH and Na$_2$SiO$_3$ in the proportion of 1:2. Water was included according to the limit of Optimum dampness content of soil to get a fine mortar. The wet blending was being proceeded for four minutes to prepare the concrete mortar. A bit of mortar was framed in the shape of a ball during blending. These were broken by gloved hands press or pounding in the middle of hands with scouring until the uniform blend was acquired.

This mix proportion was picked by the encounters of past examines and attempted through progressive number of preliminaries. The mortar was filled half in the mold of size 23 cm×10 cm×7 cm and hand compacted once. The remaining half was filled and compacted. The specimens were deformed after hand compaction had been done. The de-formed specimens were cured in the outdoors at the research facility until it was tested (Manjunath, Radhakrishnan, and Giridhar 2011). For each arrangement of parameters, 72 bricks were casted and tested every nine for 7 days and 28 days in each direction. The SEM micrographs of paste and mortar with (F/B) of 0.3 were shown in Figure 1(c). It was revealed that the paste and mortar have been formed generally as dense reacted products. The ambient cured specimens as appeared in Figure 2 were tested for compressive strength at the time period of 7 days and 28 days. The average compressive strength of the GPEB is expressed in MPa.

4. Test results

4.1. Compressive strength
Compressive strength is indicated as a fundamental mechanical property of the material. It depends upon the curing time, temperature, and different factors. In

Table 5. Physical and chemical properties of coir wastes.

| Physical   | Chemical   |
|------------|------------|
| Diameter   | 0.31 mm    |
| Density    | 1.35 g/cc  |
| Tenacity   | 14.9       |
| Breaking elongation | 25.53%   |
| Swelling in water | 87.35%     |

| Physical   | Chemical   |
|------------|------------|
| Diameter   | Lignin     |
| Density    | Cellulose  |
| Tenacity   | Ash        |
| Breaking elongation | Pectin   |
| Swelling in water | 3%        |

Figure 2. Wooden mold and specimen of GPEB.
present study, 72 samples were taken and ambient cured with no uncommon curing system (just cured in open in the lab at room temperature). The most extreme load that the GPEB can withstand was resolved using the compressive strength test according to IS 3495 (Part I and II): 1976. The bricks were tested along three axes both in wet/dry conditions and recorded the most extreme load at failure. Thirty-six bricks were tested for each dry and wet compressive strength test at 7 and 28 days (Indian Standards – 3495 1976). The average dry and wet compressive strength of GPEB is given in tabular form in Table 6. The tested wet specimen results at 28 days were separated in Table 7 for finding coefficient of variation and analyzed the test results.

### 4.2. Numerical analysis test

Considering 3-D solid – 45 steel plates were used for load dissemination on the prism. The end conditions at base of the prism were viewed as all degrees of freedom and at top the load was applied over the steel plate under compression load. In full-scale modeling the brick was thought to be made of a solitary sort of material possessing isotropic properties rather than non-homogeneous as appeared in Figure 3.

![Figure 3. Numerical analysis using ANSYS for GPEB compression test.](image)

### 4.3. Flexure strength

The flexural strength of the brick was obtained experimentally based on IS 4860 (section l):1968. The sample was put in UTM and load was being increased continuously. The load at failure point was recorded as N. The flexural strength of brick specimen with breadth (B) and depth (D) was determined utilizing the formula, flexural strength = 3PL/2BD2 in kg/cm2.

### Table 6. Average dry/wet compressive strength of GPEB.

| Mix Id/Axis of testing | Molar ratio | Fiber content in % | Mix proportion Binder: Soil: Quarry dust | Liquid to binder ratio | Compressive strength (7 days) MPa | Compressive strength (28 days) MPa |
|------------------------|-------------|--------------------|------------------------------------------|-----------------------|----------------------------------|----------------------------------|
| GPEB-X                 | 10 M (400)  | 1                  | 0.50:0.5:1.75:0.25                       | 0.3                   | 5.80                             | 5.18                             |
| GPEB-Y                 | 10 M (400)  | 1                  | 0.50:0.5:1.75:0.25                       | 0.3                   | 4.16                             | 3.62                             |
| GPEB-Z                 | 10 M (400)  | 1                  | 0.50:0.5:1.75:0.25                       | 0.3                   | 3.24                             | 2.76                             |

### Table 7. Wet compressive strength of GPEB @ 28 days.

| Samples Tested along X/Y/Z directions | Crushing strength (x) in MPa | Average strength in MPa | Deviation (x-|\(\bar{x}\)) | Deviation square of (x-\(\bar{x}\))^2 | Standard deviation (\(\sigma\)) | Co-efficient of variation (\(\mu\)) |
|----------------------------------------|------------------------------|-------------------------|---------------|----------------------------------------|---------------------------------|----------------------------------|
| X1                                     | 6.0                          | 0.07                    | 0.0049        |                                        |                                 | 0.84%                            |
| X2                                     | 5.9                          | -0.03                   | 0.0009        |                                        |                                 |                                  |
| X3                                     | 5.9                          | -0.03                   | 0.0009        |                                        |                                 |                                  |
| X4                                     | 5.9                          | 0.93                    | -0.03         | 0.0009                                 | 0.0144                          |                                  |
| X5                                     | 6.0                          | 0.07                    | 0.0049        |                                        |                                 |                                  |
| X6                                     | 5.9                          | -0.03                   | 0.0009        |                                        |                                 |                                  |
| Total                                  | 0.0134                       |                         |               | 0.05                                  | 0.84%                           |                                  |
| Y1                                     | 4.1                          | -0.02                   | 0.0004        |                                        |                                 |                                  |
| Y2                                     | 4.1                          | -0.02                   | 0.0004        |                                        |                                 |                                  |
| Y3                                     | 4.2                          | 0.08                    | 0.0064        |                                        |                                 |                                  |
| Y4                                     | 3.9                          | 4.12                    | -0.12         | 0.0144                                 | 0.0046                          |                                  |
| Y5                                     | 4.2                          | 0.08                    | 0.0064        |                                        |                                 |                                  |
| Y6                                     | 4.2                          | 0.08                    | 0.0064        |                                        |                                 |                                  |
| Total                                  | 0.0344                       |                         | 0.08          | 1.94%                                 |                                  |                                  |
| Z1                                     | 4.0                          | 0.04                    | 0.0016        |                                        |                                 |                                  |
| Z2                                     | 3.9                          | -0.06                   | 0.0036        |                                        |                                 |                                  |
| Z3                                     | 3.9                          | -0.06                   | 0.0036        |                                        |                                 |                                  |
| Z4                                     | 3.9                          | 3.96                    | -0.06         | 0.0036                                 | 0.0036                          |                                  |
| Z5                                     | 4.0                          | 0.04                    | 0.0016        |                                        |                                 |                                  |
| Z6                                     | 4.1                          | 0.14                    | 0.0196        |                                        |                                 |                                  |
| Total                                  | 0.0336                       | 0.07                    | 1.77%         |                                        |                                 |                                  |
Table 8. Flexural strength of GPEB.

| Mix designation | Mix proportion by weight (%) | Load in (KN) | Flexural Strength (MPa) |
|-----------------|-------------------------------|--------------|-------------------------|
| GPEB-1          | (0.50:0.5):(1.75:0.25): 1%    | 34           | 4.198                   |
| GPEB-2          | (0.50:0.5):(1.75:0.25): 1%    | 35           | 4.321                   |
| GPEB-3          | (0.50:0.5):(1.75:0.25): 1%    | 32           | 3.951                   |

Where, “L” is the length of intermediate span between the supports. Three specimens were tested (Indian Standards –4860 1968) after 28 days and average estimation of flexural strength of GPEB recorded is given in Table 8.

4.4. Acid attack test

GPEB was placed into water containing 5% of H₂SO₄ for 28 days of ambient curing and then tested. The level of attack had been assessed by estimating the development of bricks, compressive strength, and weight reduction of bricks. The weight reduction is determined as % of weight lost = (W₂ – W₁)/W₁

Where

W₂ = Weight of sample before attack.
W₁ = Weight of sample after attack.

The test consequences of three samples average under corrosive attack were recorded in Table 9.

4.5. Sulphate attack test

GPEB was cured in water containing 5% of Na₂SO₄ for 28 days of ambient temperature and then tested. The sulphate solution ought to have been replaced where the pH exceeded 9.5 however for this situation it was under 8.5. The test consequences of samples under sulphate attack are recorded in Table 9 above. The degree of attack was assessed by estimating the expansion in bricks, compressive strength, and weight reduction of blocks as like acid resistance case.

4.6. Alkalinity measurement test

The messed up bits of tested samples were broken into little pieces utilizing hammer and powdered. The powdered samples of 20 grams were placed into 100 ml of refined water. The aqueous solution was being allowed to sit for 72 hours and disintegrated in water. The pH of the aqueous solution was tested after 72 hours was noted.

4.7. Microstructure analysis

The microstructure of FA seemed polished, hollow, circular which is cenosphere. Surface seemed smooth and dense to profoundly permeable. The microstructure of GGBS shape relies upon various crushing methods and strange shape with clear edges and angles whereas alkaline solution was loose and less dense. Both FA paste and alkaline solution exhibited a large part of partially reactive FA particles implanted in a ceaseless matrix and shaped marginally denser than alkaline solution.

FA with GGBS blend has less number of non-responded FA particles and denser matrix. Contrasted with alkaline solution both FA and GGBS pastes are denser behind polymerization. The response of FA and GGBS with soluble solution produced extra CSH. This prompted the general with overall CSH modified CSH the microstructure. At long last Geo-polymer mortar and paste have been formed as dense reactive products and progressively homogeneous which invigorated increasingly compressive strength. The holding surface was comparatively thick with just a little gap at the interface. This prompted the general flexural strength.

5. Discussions

In this section, the increase in strength of cured bricks was discussed and experimental outcomes are clarified in Figure 4 for encouraging the discussions without any problem. Information was given demonstrating compressive strength versus the age of the sample. Totally 72 brick specimens, six bricks at each phase along each direction were tested on 7th and 28th day for Dry and Wet compressive strength. The average result of six dry blocks each at 7th and 28th day was recorded as 5.80 &
6.51 MPa and an average of 6 wet blocks each on 7th and 28th day was recorded as 5.18 and 5.93 MPa in the X-axis direction. Likewise, the specimen was tested and recorded 4.16 & 4.53 MPa and 3.62 & 4.12 MPa in Y-axis direction and ultimately got 3.24 & 3.96 MPa and 2.76 & 3.97 MPa in Z-axis direction.

It was seen that the quality of GPEB had an increment with age. Even 7 days' quality of GPEB obtained reached the minimum requirement of 3 MPa. It is seen that the expansion in compressive strength of GPEB following 7 days to 28 days was only less than 1 MPa which was a lot more prominent than normally consumed mud brick. Results had been proclaimed that the compressive strength was significantly more noteworthy than a typical customary brick agreeing to IS 1077–2007 both in x and y direction (Indian Standards 1077, 2007). In both x and y direction (full brick and partition wall) the bricks will be developed.

The minimum and maximum compressive strength values for burnt clay structure bricks have been suggested by the code as 3 MPa and 35 MPa. Harsha, Radhakrishna, and Devanand (2015) have concluded that the Coal ash and cement stabilized mud block had a wet compressive strength of 3.8 MPa. The experimental values obtained here however compare well with most current Compressed Stabilized Earth Block standards. Some recommended minimum values for SMB are referred 1.2 MPa, 1.4 MPa, and 2.8 MPa by Ugwuishiwu et al. (2013). Sreekumar and Nair (2013) have also concluded that coir fiber of 0.5% induced to improve compressive strength from 3.6 MPa to 4.28 MPa (19%) in cement stabilized lateritic block (Sreekumar and Nair 2013).

The average compressive strength of the wet specimen at 28 days was 5.93 MPa, Standard Deviation (SD), and Coefficient of Variation (CV) of the result as 0.05% and 0.84% along X-direction respectively. Similarly, compressive strength was 4.12 MPa, SD, and CV of the result as 0.08% and 1.94% along the Y direction. Likewise, compressive strength was 3.96 MPa, standard deviation and coefficient of variation of the result as 0.07% and 1.77% along the Z direction. The SD and CV of the brick specimen test results for the given mix along X, Y, and Z directions showed 0.05 to 0.08 and 0.84% to 1.94% and SD and CV, less than ±2%, and 10% was very closely true value and very good.

The quality of GPEB will be expanded by utilizing high Molarity of alkaline solution however it is to be uneconomical. From numerical analysis test, both displaying the compressive strength and the test strategies were safe and this examination is just used for cross-checking whether the outcome is safe or unsafe.

The normal flexural strength of GPEB was determined to be 4.15 MPa. It was higher than the one indicated in codebook as a minimum 1 MPa for class I bricks and 0.7 for class II bricks. This strength improvement over typical brick had been acquired due to GPEB strengthened with 1% of coir fibers. Sreekumar and Nair (2013) have observed that coir fiber of 0.5% induced the improvement of the tensile strength of 9% in cement stabilized lateritic block and also the strength was also found decreasing with further increase in fiber content (Sreekumar and Nair 2013).

It relied upon the arrangement and bonding of fiber-soil matrix. For the most part bonding strength is influenced by level of fiber introduced, measurement, and surface states of the brick. The expanded fiber content also influences the bonding quality and a flexural strength. Limited studies were included distinctly to enhance the usage of coir fiber waste as reinforcing element in fiber-soil matrix as for strength and durability highlights. This research was also centered mainly on increased use of coir fiber waste in soil matrix and ensured the earth against slow pace of organic degradation and tremendous amount of coir waste removal.

The pH estimation of the acid solution which was estimated after 28 days was discovered less than 7. The brick had no noteworthy loss in weight and no change in expansion. The code (IS 4860 – R2001) referred by weight reduction for class I bricks not surpassing 1.5% and for class II blocks as 4% and the minimum Compressive strength for class I block as 7 MPa and for class II as 5 MPa. The outcomes were reached underclass I. An improvement of 23% compressive strength in acid attack resistance due to the addition of GGBS and red mud-based GPC incorporated with hybrid fibers was reported by Alwis deva kirupa J. P. et al. Geo-polymer is a kind of inorganic polymer composite which is produced and solidified even at ambient temperature under exceptional alkaline conditions, in presence of alkali hydroxide and silicate solution. Polymerization happens when receptive Alumino-silicates are quickly broken up and free SiO₂ and Al₂O₃ tetrahedral units are discharged in solution. The tetrahedral units are then again connected to polymeric precursors by sharing oxygen atoms thus forming indistinct Geo-polymers. Positive particles Na⁺ and Fe⁺ that were introduced in framework cavities, balanced the negative charge. This compound response has reinforced the materials when exposed to aggressive conditions.

The pH estimation of the sulphate solution which was estimated after 28 days was discovered less than 8.5. The brick had no loss in weight and no change in extension due to sulphate attack. Even though standard codes are not availed for sulphate attack resistance it can be converted in terms of the acid attack. The outcomes were reached also underclass I in terms of acid attack. An increment of 17% compressive strength in sulphate attack resistance due to the addition of GGBS and red mud-based GPC incorporated
with hybrid fibers was concluded by Alwis deva kirupa J.P. et al.

For the alkalinity measurement test, the pH of the aqueous solution was tested after 72 hours and was found not less than 9. So usage of FA, GGBS, Soil, QD, reduces the risk of damages caused by alkali-silica reaction and provides higher resistance to environmental impacts. Limited investigations were taken care of to optimize the use of industrial waste as principle constituents in the fiber-soil matrix. This research was centered on using wastage of industrial waste used for making un-burnt bricks rather than regular bricks.

6. Economic features of GPEB

The quantity of material was estimated for preparing a single brick of size 0.00161 m$^3$. The cost was calculated and listed in Table 10. The cost of a single unit of brick was estimated at merely 40 Rupees. Cost-wise contribution of NaOH and Na$_2$SO$_3$ was calculated as 85% of the total cost of the brick. Further study has to be taken to reducing the cost of NaOH, and Na$_2$SO$_3$ with cost-effective methods.

Table 10. Cost of a GPEB (or) 0.00161 m$^3$

| Material          | Cost per kg in Rs. | Material required for one GPB(Kg) | Total cost for one GPB in Rs. |
|-------------------|--------------------|----------------------------------|-----------------------------|
| Fly ash           | 2.00               | 1.37                             | 2.75                        |
| GGBS              | 1.90               | 1.37                             | 2.60                        |
| Soil              | Free of cost       | 0.00                             | 0.00                        |
| Coir fiber        | Free of cost       | 0.00                             | 0.00                        |
| Quarry dust       | 0.5                | 0.75                             | 0.40                        |
| NaOH (10 M)       | 80.00              | 0.26                             | 20.80                       |
| Na$_2$SO$_3$      | 25.00              | 0.52                             | 13.00                       |
| Total cost        | Size of GPEB (23 cm×10 cm×7 cm) | 39.55                           |

reduces the cost of making un-burnt brick with more resistant against acid, sulphate, and alkalinity attack.

- The average of alumina and silica in FA and GGBS is 70%. Hence it is suitable to use as natural supplemental cementing materials.
- The inclusion of FA and GGBS in equal proportions does not affect the bulk density. The bulk density increases with an increase in GGBS content and the bulk density reduces with increases in the percentage of CFW.
- The proportion of supplementary cementing material and filler materials in brick production is 1:2. It is suitable to use as a conventional mortar.
- The higher molarity of sodium hydroxide more than 10 M increases the strength up to a certain limit and increases the cost and decreases the workability.
- The proportion of Sodium Hydroxide to Sodium Silicate in brick production is 1:2 makes a good binder. It is stabilized the earth’s composites well. While increase the proportions of Sodium Silicate gives more strength and adversely uneconomical.
- The optimum strength of the GPEB had been accomplished from the materials like FA, GGBS, soil, Quarry Dust (0.5:0.5:1.75:0.25), Coir fiber Waste of 1%, and 10 M alkaline solution was found 50.67% higher than the minimum compressive strength and 415% times more than the minimum flexural strength of burnt clay brick prescribed by the standard codes.
- The standard deviation and coefficient of variation of the brick specimen test results for the mix met true value and very good.
- The optimum compressive strength of the GPEB mix against aggressive environment conditions especially acid attack was found 1.8 times more than the minimum compressive strength of acid-resistant brick prescribed by the standard codes. Also, the sulphate attack found 1.6 times higher than the minimum strength in terms of acid resistance.
- Supporting this, both SEM analysis and numerical investigations have demonstrated that the compacted structure of mortar showed better compressive and flexural strength. Both qualities can be expanded with higher Molarity of soluble solution. Simultaneously, the workability is diminished with higher concentration of soluble solution. Expanding workability with more admixtures was found to be uneconomical.
- The GPEB demonstrated more strength compared to clay burnt bricks, SMB, CSEB, acid attack, and sulphate attack resistance, and also generally safe to harms against alkali-silica response. Indeed, even the GPEB were uneconomical compared to

7. Conclusion

The present study investigated the effectiveness of using supplemental cementing materials and filler materials incorporated with CFW stabilized with Alkaline Activator for the production of new un-burnt bricks with long-term durability. When such waste materials are used in brick production it is necessary to study the strength and durability properties of conventional bricks. Test results indicate that the use of supplementary cementing materials, filling materials, and CFW in brick is a beneficial and Eco-friendly option. Based on the investigations the following conclusions were drawn.

- Non-Portland concrete and stabilized mud block were made by a mix of soil with industrial waste supplement cementing materials in this study.
- The utilization of waste materials in un-burnt brick production provides additional environmental as well as technical benefits to all related industries. Alkali activated binder with supplemental cementing materials, filling materials
burnt clay brick yet profoundly desirable to meet all aggressive conditions.

- Experimental studies have been reasoned that GPEB is viewed as suitable, eco-accommodating as compared to traditional bricks. At last, this research has indicated that the GPEB can be effectively proposed for load-bearing structures and partition wall development.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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